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Syllabus

Paper: Science and Technology in Ancient India
Paper code: AIH - DSE 4

Unit- I Importance of the Study of History of Science

Unit- II History of Mathematics and Astronomy in Ancient India

Unit- III History of Metallurgy, Glass and Ceramics

Unit- IV History of Agriculture in Ancient India

Science in Ancient India

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November 15, 2005

In *Ananya: A portrait of India*, S.R. Sridhar and N.K. Mattoo (eds.). AIA: New York, 1997, pages 399-420

1

'Veda' means knowledge. Since we call our earliest period Vedic, this is suggestive of the importance of knowledge and science, as a means of acquiring that knowledge, to that period of Indian history. For quite some time scholars believed that this knowledge amounted to no more than speculations regarding the self; this is what we are still told in some schoolbook accounts. New insights in archaeology, astronomy, history of science and Vedic scholarship have shown that such a view is wrong. We now know that Vedic knowledge embraced physics, mathematics, astronomy, logic, cognition and other disciplines. We find that Vedic science is the earliest science that has come down to us. This has significant implications in our understanding of the history of ideas and the evolution of early civilizations.

The reconstructions of our earliest science are based not only on the Vedas but also on their appendicies called the Vedangas. The six Vedangas deal with: *kalpa*, performance of ritual with its basis of geometry, mathematics and calendrics; *shiksha*, phonetics; *chhandas*, metrical structures; *nirukta*, etymology; *vyakarana*, grammar; and *jyotisha*, astronomy and other cyclical phenomena. Then there are naturalistic descriptions in the various Vedic books that tell us a lot about scientific ideas of those times.

Briefly, the Vedic texts present a tripartite and recursive world view. The universe is viewed as three regions of earth, space, and sky with the corresponding entities of Agni, Indra, and Vishve Devah (all gods). Counting separately the joining regions leads to a total of five categories where, as we see in Figure 1, water separates earth and fire, and air separates fire and ether.

In Vedic ritual the three regions are assigned different fire altars. Furthermore, the five categories are represented in terms of altars of five layers. The great altars were built of a thousand bricks to a variety of dimensions. The discovery that the details of the altar constructions code astronomical knowledge is a fascinating chapter in the history of astronomy (Kak 1994a; 1995a,b).

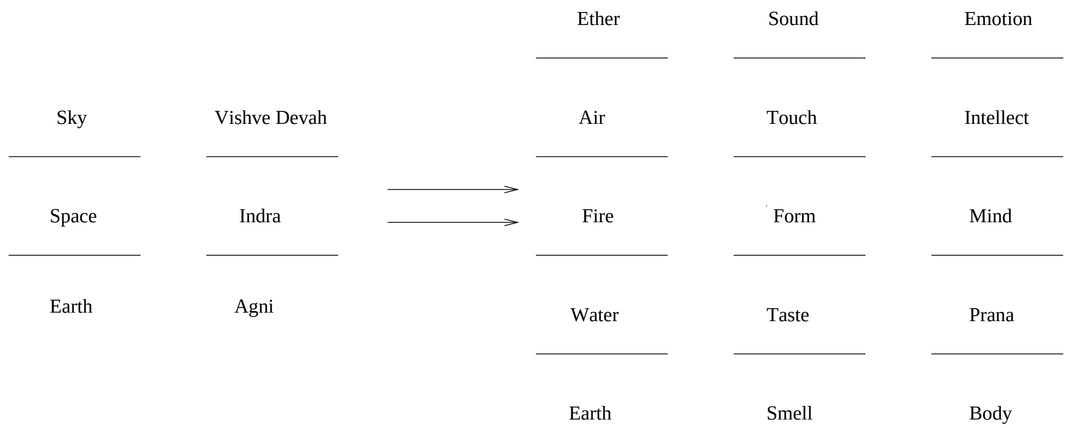

Figure 1: From the tripartite model to five categories of analysis

In the Vedic world view, the processes in the sky, on earth, and within the mind are taken to be connected. The Vedic rishis were aware that all descriptions of the universe lead to logical paradox. The one category transcending all oppositions was termed *brahman*. Understanding the nature of consciousness was of paramount importance in this view but this did not mean that other sciences were ignored. Vedic ritual was a symbolic retelling of this world view.

Chronology

To place Vedic science in context it is necessary to have a proper understanding of the chronology of the Vedic literature. There are astronomical references in the Vedas which recall events in the third or the fourth millennium B.C.E. and earlier. The recent discovery (e.g. Feuerstein 1995) that Sarasvati, the preeminent river of the Rigvedic times, went dry around 1900 B.C.E. due to tectonic upheavels implies that the Rigveda is to be dated prior to this epoch, perhaps prior to 2000 B.C.E. since the literature that immediately followed the Rigveda does not speak of any geological catastrophe. But we cannot be very precise about our estimates. There exist traditional accounts in the Puranas that assign greater antiquity to the Rigveda: for example, the Kaliyuga tradition speaks of 3100 B.C.E. and the Varāhamihira tradition mentions 2400 B.C.E. According to Henri-Paul Francfort (1992) of the Indo-French team that surveyed this area, the Sarasvati river had ceased to be a perennial river by the third millennium B.C.E.; this supports those who argue for the older dates. But in the absence of conclusive evidence, it is prudent to take the most conservative of these dates, namely 2000 B.C.E. as the latest period to be associated with the Rigveda.

The textbook accounts of the past century or so were based on the now disproven supposition that the Rigveda is to be dated to about 1500-1000 B.C.E. and, therefore, the question of the dates assigned to the Brahmanas, Sutras and other literature remains open. The detailed chronology of the literature that followed Rigveda has not yet been worked out. A chronology of this literature was attempted based solely on the internal astronomical evidence in the important book "Ancient Indian Chronology" by the historian of science P.C. Sengupta in 1947. Although Sengupta's dates have the virtue of inner consistency, they have neither been examined carefully by other scholars nor checked against archaeological evidence.

This means that we can only speak in the most generalities regarding the chronology of the texts: assign Rigveda to the third millennium B.C.E. and earlier and the Brahmanas to the second millennium. This also implies that the archaeological finds of the Indus-Sarasvati period, which are coeval with Rigveda literature, can be used to cross-check textual evidence.

No comprehensive studies of ancient Indian science exist. The textbook accounts like the one to be found in Basham's "The Wonder that was India" are hopelessly out of date. But there are some excellent surveys of selected material. The task of putting it all together into a comprehensive whole will be a major task for historians of science.

This essay presents an assortment of topics from ancient Indian science. We begin with an outline of the models used in the Vedic cognitive science; these models parallel those used in ancient Indian physics. We also review mathematics, astronomy, grammar, logic and medicine.

1 Vedic cognitive science

The Rigveda speaks of cosmic order. It is assumed that there exist equivalences of various kinds between the outer and the inner worlds. It is these connections that make it possible for our minds to comprehend the universe. It is noteworthy that the analytical methods are used both in the examination of the outer world as well as the inner world. This allowed the Vedic rishis to place in sharp focus paradoxical aspects of analytical knowledge. Such paradoxes have become only too familiar to the contemporary scientist in all branches of inquiry (Kak 1986).

In the Vedic view, the complementary nature of the mind and the outer world, is of fundamental significance. Knowledge is classified in two ways: the lower or dual; and the higher or unified. What this means is that knowledge is superficially dual and paradoxical but at a deeper level it has a unity. The Vedic view claims that the material and the conscious are aspects of the same transcendental reality.

The idea of complementarity was at the basis of the systematization of Indian philosophic traditions as well, so that complementary approaches were paired together. We have the groups of: logic (nyaya) and physics (vaisheshika), cosmology (sankhya) and psychology (yoga), and language (mimamsa) and reality (vedanta). Although these philosophical schools were formalized in the post-Vedic age, we find an echo of these ideas in the Vedic texts.

In the Rigveda there is reference to the yoking of the horses to the chariot of Indra, Ashvins, or Agni; and we are told elsewhere that these gods represent the essential mind. The same metaphor of the chariot for a person is encountered in Katha Upanishad and the Bhagavad Gita; this chariot is pulled in different directions by the horses, representing senses, which are yoked to it. The mind is the driver who holds the reins to these horses; but next to the mind sits the true observer, the self, who represents a universal unity. Without this self no coherent behaviour is possible.

The Five Levels

In the Taittiriya Upanishad, the individual is represented in terms of five different sheaths or levels that enclose the individual's self. These levels, shown in an ascending order, are:

- The physical body (annamaya kosha)
- Energy sheath (pranamaya kosha)
- Mental sheath (manomaya kosha)
- Intellect sheath (vijnanamaya kosha)
- Emotion sheath (anandamaya kosha)

These sheaths are defined at increasingly finer levels. At the highest level, above the emotion sheath, is the self. It is significant that emotion is placed higher than the intellect. This is a recognition of the fact that eventually meaning is communicated by associations which are influenced by the emotional state.

The energy that underlies physical and mental processes is called prana. One may look at an individual in three different levels. At the lowest level is the physical body, at the next higher level is the energy systems at work, and at the next higher level are the thoughts. Since the three levels are interrelated, the energy situation may be changed by inputs either at the physical level or at the mental level. When the energy state is agitated and restless, it is characterized by *rajas*; when it is dull and lethargic, it is characterized by *tamas*; the state of equilibrium and balance is termed *sattva*.

The key notion is that each higher level represents characteristics that are emergent on the ground of the previous level. In this theory mind is an emergent entity, but this emergence requires the presence of the self.

The Structure of the Mind

The Sankhya system takes the mind as consisting of five components: manas, ahankara, chitta, buddhi, and atman. Again these categories parallel those of Figure 1.

Manas is the lower mind which collects sense impressions. Its perceptions shift from moment to moment. This sensory-motor mind obtains its inputs from the senses of hearing, touch, sight, taste, and smell. Each of these senses may be taken to be governed by a separate agent.

Ahankara is the sense of I-ness that associates some perceptions to a subjective and personal experience.

Once sensory impressions have been related to I-ness by ahankara, their evaluation and resulting decisions are arrived at by buddhi, the intellect. Manas, ahankara, and buddhi are collectively called the internal instruments of the mind.

Next we come to chitta, which is the memory bank of the mind. These memories constitute the foundation on which the rest of the mind operates. But chitta is not merely a passive instrument. The organization of the new impressions throws up instinctual or primitive urges which creates different emotional states.

This mental complex surrounds the innermost aspect of consciousness which is called atman, the self, brahman, or jiva. Atman is considered to be beyond a finite enumeration of categories.

All this amounts to a brilliant analysis of the individual. The traditions of yoga and tantra have been based on such analysis. No wonder, this model has continued to inspire people around the world to this day.

2 Mathematical and physical sciences

Here we review some new findings related to the early period of Indian science which show that the outer world was not ignored at the expense of the inner.

Geometry and mathematics

Seidenberg, by examining the evidence in the Shatapatha Brahmana, showed that Indian geometry predates Greek geometry by centuries. Seidenberg argues that the birth of geometry and mathematics had a ritual origin. For example, the earth was represented by a circular altar and the heavens were represented by a square altar and the ritual consisted of converting the circle into a square of an identical area. There we see the beginnings of geometry!

In his famous paper on the origin of mathematics, Seidenberg (1978) concluded: "Old-Babylonia [1700 BC] got the theorem of Pythagoras from India or that both Old-Babylonia and India got it from a third source. Now the Sanskrit scholars do not give me a date so far back as 1700 B.C. Therefore I *postulate* a pre-Old-Babylonian (i.e., pre-1700 B.C.) source of the kind of geometric rituals we see preserved in the Sulvasutras, or at least for the *mathematics* involved in these rituals." That was before archaeological finds disproved the earlier assumption of a break in Indian civilization in the second millennium B.C.E.; it was this assumption of the Sanskritists that led Seidenberg to postulate a third earlier source. Now with our new knowledge, Seidenberg's conclusion of India being the source of the geometric and mathematical knowledge of the ancient world fits in with the new chronology of the texts.

Astronomy

Using hitherto neglected texts related to ritual and the Vedic indices, an astronomy of the third millennium B.C.E. has been discovered (Kak 1994a; 1995a,b). Here the altars symbolized different parts of the year. In one ritual, pebbles were placed around the altars for the earth, the atmosphere, and the sky. The number of these pebbles were 21, 78, and 261, respectively. These numbers add up to the 360 days of the year. There were other features related to the design of the altars which suggested that the ritualists were aware that the length of the year was between 365 and 366 days.

The organization of the Vedic books was also according to an astronomical code. To give just one simple example, the total number of verses in all the Vedas is 20,358 which

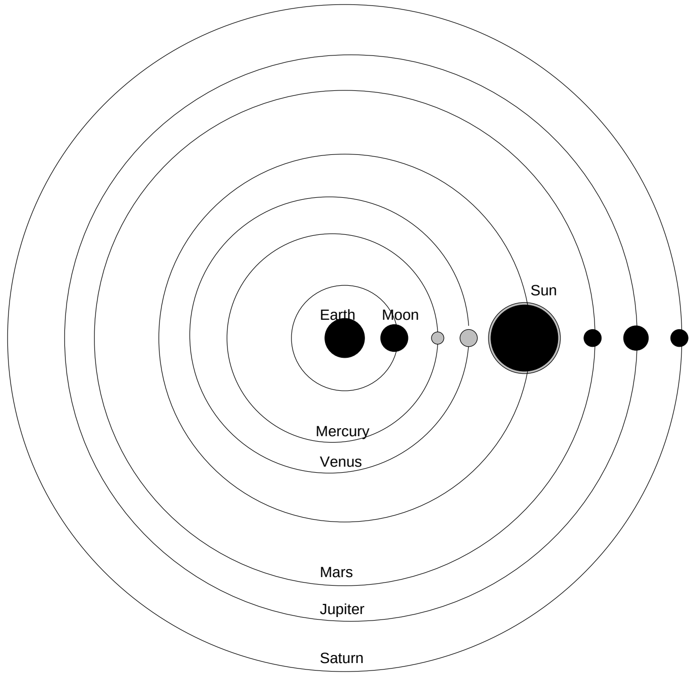

Figure 2: The Vedic planetary model

equals 261 $\times$ 78, a product of the sky and atmosphere numbers! The Vedic ritual followed the seasons hence the importance of astronomy.

The second millennium text Vedanga Jyotisha went beyond the earlier calendrical astronomy to develop a theory for the mean motions of the sun and the moon. This marked the beginnings of the application of mathematics to the motions of the heavenly bodies.

Planetary knowledge

The Vedic planetary model is given in Figure 2. The sun was taken to be midway in the skies. A considerable amount of Vedic mythology regarding the struggle between the demons and the gods is a metaphorical retelling of the motions of Venus and Mars (Frawley 1994).

The famous myth of Vishnu's three strides measuring the universe becomes intelligible when we note that early texts equate Vishnu and Mercury. The myth appears to celebrate the first measurement of the period of Mercury (Kak 1996a) since three periods equals the number assigned in altar ritual to the heavens. Other arguments suggest that the Vedic people knew the periods of the five classical planets.

Writing

Cryptological analysis has revealed that the Brahmi script of the Mauryan times evolved out of the third millennium Sarasvati (Indus) script. The Sarasvati script was perhaps the first true alphabetic script. The worship of Sarasvati as the goddess of learning remembers the development of writing on the banks of the Sarasvati river. It also appears that the symbol for zero was derived from the fish sign that stood for “ten” in Brahmi and this occurred around 50 B.C.E.-50 C.E. (Kak 1994b).

Binary numbers

Barend van Nooten (1993) has shown that binary numbers were known at the time of Pingala's *Chhandahshastra*. Pingala, who lived around the early first century B.C.E., used binary numbers to classify Vedic meters. The knowledge of binary numbers indicates a deep understanding of arithmetic. A binary representation requires the use of only two symbols, rather than the ten required in the usual decimal representation, and it has now become the basis of information storage in terms of sequences of 0s and 1s in modern-day computers.

Music

Ernest McClain (1978) has described the tonal basis of early myth. McClain argues that the connections between music and myth are even deeper than astronomy and myth. The invariances at the basis of tones could very well have served as the ideal for the development of the earliest astronomy. The tonal invariances of music may have suggested the search of similar invariances in the heavenly phenomena.

The Samaveda, where the hymns were supposed to be sung, was compared to the sky. Apparently, this comparison was to emphasize the musical basis of astronomy. The Vedic hymns are according to a variety of meters; but what purpose, if any, lay behind a specific choice is unknown.

Grammar

Panini's grammar (6th century B.C.E. or earlier) provides 4,000 rules that describe the Sanskrit of his day completely. This grammar is acknowledged to be one of the greatest intellectual achievements of all time. The great variety of language mirrors, in many ways, the complexity of nature. What is remarkable is that Panini set out to describe the entire grammar in terms of a *finite* number of rules. Frits Staal (1988) has shown that the grammar of Panini represents a universal grammatical and computing system. From this perspective it anticipates the logical framework of modern computers (Kak 1987).

Medicine

There is a close parallel between Indian and Greek medicine. For example, the idea of breath (*prana* in Sanskrit, and *pneuma* in Greek) is central to both. Jean Filliozat (1970) has argued that the idea of the correct association between the three elements of the wind, the gall, and the phlegm, which was described first by Plato in Greek medicine, appears to be derived from the earlier *tridosha* theory of Ayurveda. Filliozat suggests that the transmission occurred via the Persian empire.

These discoveries not only call for a revision of the textbook accounts of Indian science but also call for new research to assess the impact on other civilizations of these ideas.

3 Rhythms of life

We have spoken before of how the Vedas speak of the connections between the external and the internal worlds. The hymns speak often of the stars and the planets. These are sometimes the luminaries in the sky, or those in the firmament of our inner landscapes or both.

To the question on how can the motions of an object, millions of miles away, have any influence on the life of a human being one can only say that the universe is interconnected. In this ecological perspective the physical planets do not influence the individual directly. Rather, the intricate clockwork of the universe runs on forces that are reflected in the periodicities of the astral bodies as also the cycles of behaviors of all terrestrial beings and plants.

It is not the gravitational pull of the planet that causes a certain response, but an internal clock governed by the genes. We know this because in some mutant organisms the internal clock works according to periods that have no apparent astronomical basis. So these cycles can be considered to be a manifestation of the motions of the body's inner "planets." In the language of evolution theory one would argue that these periods get reflected in the genetic inheritance of the biological system as a result of the advantage over millions of years that they must have provided for survival.

The most fundamental rhythms are matched to the periods of the sun or the moon. It is reasonable to assume that with their emphasis on time bound rituals and the calendar, the ancients had discovered many of the biological periods. This would include the 24-hour-50-minute circadian rhythm, the connection of the menstrual cycle with the motions of the moon, the life cycles of various plants, and the semimonthly estrus cycle of sheep, the three-week cycles of cattle and pigs, and the six-month cycle of dogs.

The moon (Soma) is called the "lord of speech" (Vachaspati) in the Rigveda. It is also taken to awaken eager thoughts. Other many references suggest that in the Rigvedic times the moon was taken to be connected with the mind.

This is stated most directly in the the famous Purushasukta, the Cosmic Man hymn, of the Rigveda where it is stated that the mind is born of the moon and in Shatapatha Brahmana where we have: "the mind is the moon." Considering the fact that the relationships between the astronomical and the terrestrial were taken in terms of periodicities, doubtless, this slogan indicates that the mind is governed by the period of the moon.

Fire, having become speech, entered the mouth
Air, becoming scent, entered the nostrils
The sun, becoming sight, entered the eyes
The regions becoming hearing, entered the ears
The plants, becoming hairs, entered the skin
The moon, having become mind, entered the heart.
—Aitreya Aranyaka 2.4.2.4

This verse from the Upanishadic period speaks at many levels. At the literal level there is an association of the elements with various cognitive centers. At another level, the verse connects the time evolution of the external object to the cognitive center.

Fire represents consciousness and this ebbs and flows with a daily rhythm. Air represents seasons so here the rhythm is longer. The sun and sight have a 24-hour cycle. The regions denote other motions in the skies so hearing manifests cycles that are connected to the planets. The plants have daily and annual periods; the hairs of the body have an annual period. The mind has a period of 24 hours and 50 minutes like that of the moon.

What are the seats of these cycles? According to tantra the chakras of the body are the centers of the different elements as well as cognitive capacities and rhythms related to "internal planets." The knowledge of these rhythms appears to have led to astrology.

4 Cosmology

We have seen how the logical apparatus that was brought to bear on the outer world was applied to the analysis of the mind. But the question remains: How does inanimate matter come to have awareness? This metaphysical question was answered by postulating entities for smell, taste, form, touch, and sound as in Figure 1. In the Sankhya system, a total of twenty-four such categories are assumed. These categories are supposed to emerge at the end of a long chain of evolution and they may be considered to be material. The breath of life into the instruments of sight, touch, hearing and so on is provided by the twenty-fifth category, which is *purusha*, the soul.

The recursive Vedic world-view requires that the universe itself go through cycles of creation and destruction. This view became a part of the astronomical framework and ultimately very long cycles of billions of years were assumed. The Sankhya evolution takes the life forms to evolve into an increasingly complex system until the end of the cycle.

The categories of Sankhya operate at the level of the individual as well. Life mirrors the entire creation cycle and cognition mirrors a life-history. Surprisingly similar are the modern slogan: ontogeny is phylogeny, and microgeny (the cognitive process) is a speeded-up ontogeny (Brown 1994).

5 Concluding Remarks

We are in the midst of a paradigm shift in our understanding of Vedic science and cosmology. We now know that measurement astronomy is to be dated to at least the third millennium B.C.E. which is more than a thousand years earlier than was believed only a decade ago; and mathematics and geometry date to at least the beginning of the second millennium B.C.E. Indian mythology is being interpreted in terms of its underlying astronomy or/and cognitive science. We find that many Indians dates are much earlier than the corresponding dates elsewhere. What does it all mean for our understanding of the Indian civilization and its interactions with Mesopotamia, Egypt, China and Greece? Was Indian knowledge carried to the other nations or do we have a case here for independent discovery in different places?

Contemporary science has begun to examine Vedic theories on the nature of the "self" and see if they might be of value in the search for a science of consciousness (e.g. Kak 1996b). Man has mastered the outer world and Vedic science formed the basis for that enterprise; it is now possible that the exploration of the inner world, which is the heart of modern science, will also be along paths long heralded by Vedic rishis.

2

In the earliest period of Indian science, it is exceptional when we know the authorship of a text or an idea. For example, although Lagadha (c. 1400 B.C.E.) is the author of Vedanga Jyotisha we do not know if its astronomy was developed by him or if he merely summarized what was then well known. Likewise we are not sure of the individual contributions in the Shulba Sutras, of Baudhayana, Apastamba, and other authors, which describe geometry, or Pingala's Chhandahsutra which shows how to count in a binary manner. The major exception to the anonymous nature of early Indian science is the grammatical tradition starting with Panini. This tradition is a wonderful application of the scientific method where the infinite variety of linguistic data is generated by means of a limited number of rules.

With Aryabhata of Kusumapura (born 476), we enter a new phase in which it becomes easier to trace the authorship of specific ideas. But even here there remain other aspects which are not so well understood. For example, the evolution of Indian medicine is not as well documented as that of Indian mathematics. Neither do we understand well the manner in which the philosophical basis underlying Indian science evolved.

Thus many texts speak of the relativity of time and space—abstract concepts that developed in the scientific context just a hundred years ago. The Puranas speak of countless universes, time flowing at different rates for different observers and so on.

The Mahabharata speaks of an embryo being divided into one hundred parts each becoming, after maturation in a separate pot, a healthy baby; this is how the Kaurava brothers are born. There is also mention of an embryo, conceived in one womb, being transferred to the womb of another woman from where it is born; the transferred embryo is Balarama and this is how he is a brother to Krishna although he was born to Rohini and not to Devaki.

There is an ancient mention of space travellers wearing airtight suits in the epic Mahabharata which may be classified as an early form of science fiction. According to the well-known Sanskritist J.A.B. van Buitenen, in the accounts in Book 3 called "The Razing of Saubha" and "The War of the Yakshas":

> the aerial city is nothing but an armed camp with flame-throwers and thundering cannon, no doubt a spaceship. The name of the demons is also revealing: they were Nivātakavacas, "clad in airtight armor," which can hardly be anything but space suits. (van Buitenen, 1975, page 202)

Universes defined recursively are described in the famous episode of Indra and the ants in Brahmavaivarta Purana. Here Vishnu, in the guise of a boy, explains to Indra that the ants he sees walking on the ground have all been Indras in their own solar systems in different times! These flights of imagination are to be traced to more than a straightforward generalization of the motions of the planets into a cyclic universe. They must be viewed in the background of an amazingly sophisticated tradition of cognitive and analytical thought (see e.g. Staal 1988; Kak 1994).

The context of modern science fiction books is clear: it is the liberation of the earlier modes of thought by the revolutionary developments of the 20th century science and technology. But how was science fiction integrated into the mainstream of Indian literary tradition two thousand years ago? What was the intellectual ferment in which such sophisticated ideas arose?

I do not answer these questions directly. My goal is to provide a survey so that the reader can form his or her own conclusions. I begin with an account of Indian mathematics and astronomy from the time of Aryabhata until the period of the Kerala school of astronomy. Then I consider material from one randomly chosen early text, Yoga-Vasishtha, to convey basic Indian notions about time, space, and matter. Yoga-Vasishtha has been dated variously as early as the sixth century and as late as the 14th century. It claims to be book regarding consciousness but it has many fascinating passages on time, space, matter and the nature of experience. We present a random selection that has parallels with some recent speculations in physics. Lastly, I take up the question of the conceptions behind the Shri Yantra, whose origins, some scholars believe, go back to the age of Atharvaveda.

6 Mathematics and astronomy

One would expect that the development of early Indian mathematics and astronomy went through several phases but we don't have sufficient data to reconstruct these phases. A certain astronomy has been inferred from the Vedic books, but there existed additional sources which have not survived. For example, there were early astronomical siddhantas of which we know now only from late commentaries written during the Gupta period (320-600); this period provided a long period of stability and prosperity that saw a great flowering of art, literature, and the sciences.

Of the eighteen early siddhantas the summaries of only five are available now. Perhaps one reason that the earlier texts were lost is because their theories were superseded by the more accurate later works. In addition to these siddhantas, practical manuals, astronomical tables, description of instruments, and other miscellaneous writings have also come down to us (Sarma 1985). The Puranas also have some material on astronomy.

Aryabhata

Aryabhata is the author of the first of the later siddhantas called Aryabhatiyam which sketches his mathematical, planetary, and cosmic theories. This book is divided into four chapters: (i) the astronomical constants and the sine table, (ii) mathematics required for computations, (iii) division of time and rules for computing the longitudes of planets using eccentrics and epicycles, (iv) the armillary sphere, rules relating to problems of trigonometry and the computation of eclipses.

The parameters of Aryabhatiyam have, as their origin, the commencement of Kaliyuga on Friday, 18th February, 3102 B.C.E. He wrote another book where the epoch is a bit different.

Aryabhata took the earth to spin on its axis; this idea appears to have been his innovation. He also considered the heavenly motions to go through a cycle of 4.32 billion years; here he went with an older tradition, but he introduced a new scheme of subdivisions within this great cycle. According to the historian Hugh Thurston, “Not only did Aryabhata believe that the earth rotates, but there are glimmerings in his system (and other similar systems) of a possible underlying theory in which the earth (and the planets) orbits the sun, rather than the sun orbiting the earth. The evidence is that the basic planetary periods are relative to the sun.”

That Aryabhata was aware of the relativity of motion is clear from this passage in his book,“Just as a man in a boat sees the trees on the bank move in the opposite direction, so an observer on the equator sees the stationary stars as moving precisely toward the west.”

Varahamihira

Varahamihira (died 587) lived in Ujjain and he wrote three important books: Panchasiddhantika, Brihat Samhita, and Brihat Jataka. The first is a summary of five early astronomical systems including the Surya Siddhanta. (Incidently, the modern Surya Siddhanta is different in many details from this ancient one.) Another system described by him, the Paitamaha Siddhanta, appears to have many similarities with the ancient Vedanga Jyotisha of Lagadha.

Brihat Samhita is a compilataion of an assortment of topics that provides interesting details of the beliefs of those times. Brihat Jataka is a book on astrology which appears to be considerably influenced by Greek astrology.

Brahmagupta

Brahmagupta of Bhilamala in Rajasthan, who was born in 598, wrote his masterpiece, Brahmasphuta Siddhanta, in 628. His school, which was a rival to that of Aryabhata, has been very influential in western and northern India. Brahmagupta’s work was translated into Arabic in 771 or 773 at Baghdad and it became famous in the Arabic world as Sindhind.

One of Brahmagupta’s chief contributions is the solution of a certain second order indeterminate equation which is of great significance in number theory.

Another of his books, the Khandakhadyaka, remained a popular handbook for astronomical computations for centuries.

Bhaskara

Bhaskara (born 1114), who was from the Karnataka region, was an outstanding mathematician and astronomer. Amongst his mathematical contributions is the concept of differentials. He was the author of Siddhanta Shiromani, a book in four parts: (i) Lilavati on arithmetic, (ii) Bijaganita on algebra, (iii) Ganitadhyaya, (iv) Goladhyaya on astronomy. He epicyclic-eccentric theories of planetary motions are more developed than in the earlier siddhantas.

Subsequent to Bhaskara we see a flourishing tradition of mathematics and astronomy in Kerala which saw itself as a successor to the school of Aryabhata. We know of the contributions of very many scholars in this tradition, of whom we will speak only of two below.

Madhava

Madhava (c. 1340-1425) developed a procedure to determine the positions of the moon every 36 minutes. He also provided methods to estimate the motions of the planets. He gave power series expansions for trigonometric functions, and for pi correct to eleven decimal places.

Nilakantha Somayaji

Nilakantha (c. 1444-1545) was a very prolific scholar who wrote several works on astronomy. It appears that Nilakantha found the correct formulation for the equation of the center of the planets and his model must be considered a true heliocentric model of the solar system. He also improved upon the power series techniques of Madhava.

The methods developed by the Kerala mathematicians were far ahead of the European mathematics of the day.

7 Concepts of space, time, and matter

Yoga-Vasishtha (YV) is an ancient Indian text, over 29,000 verses long, traditionally attributed to Valmiki, author of the epic Ramayana which is over two thousand years old. But the internal evidence of the text indicates that it was authored or compiled later. It has been dated variously as early as the sixth century AD or as late as the 13th or the 14th century (Chapple 1984). Dasgupta (1975) dated it about the sixth century AD on the basis that one of its verses appears to be copied from one of Kalidasa's plays considering Kalidasa to have lived around the fifth century. The traditional date of of Kalidasa is 50 BC and new arguments (Kak 1990) support this earlier date so that the estimates regarding the age of YV are further muddled.

YV may be viewed as a book of philosophy or as a philosophical novel. It describes the instruction given by Vasishtha to Rama, the hero of the epic Ramayana. Its premise may be termed radical idealism and it is couched in a fashion that has many parallels with the notion of a participatory universe argued by modern philosophers. Its most interesting passages from the scientific point of view relate to the description of the nature of space, time, matter, and consciousness. It should be emphasized that the YV ideas do not stand in isolation. Similar ideas are to be found in the Vedic texts. At its deepest level the Vedic conception is to view reality in a monist manner; at the next level one may speak of the dichotomy of mind and matter. Ideas similar to those found in YV are also encountered in Puranas and Tantric literature.

We provide a random selection of these passages taken from the abridged translation of the book done by Venkatesananda (1984).

Time

- Time cannot be analyzed... Time uses two balls known as the sun and the moon for its pastime. [16]

- The world is like a potter's wheel: the wheel looks as if it stands still, though it revolves at a terrific speed. [18]

- Just as space does not have a fixed span, time does not have a fixed span either. Just as the world and its creation are mere appearances, a moment and an epoch are also imaginary. [55]

- Infinite consciousness held in itself the notion of a unit of time equal to one-millionth of the twinkling of an eye: and from this evolved the time-scale right upto an epoch consisting of several revolutions of the four ages, which is the life-span of one cosmic creation. Infinite consciousness itself is uninvolved in these, for it is devoid of rising and setting (which are essential to all time-scales), and it devoid of a beginning, middle and end. [72]

Space

- There are three types of space—the psychological space, the physical space and the infinite space of consciousness. [52]

  The infinite space of individed consciousness is that which exists in all, inside and outside... The finite space of divided consciousness is that which created divisions of time, which pervades all beings... The physical space is that in which the elements exist. The latter two are not independent of the first. [96]

- *Other universes.* On the slopes of a far-distant mountain range there is a solid rock within which I dwell. The world within this rock is just like yours: it has its own inhabitants, ...the sun and the moon and all the rest of it. I have been in it for countless aeons. [402]

- The entire universe is contained in a subatomic partice, and the three worlds exist within one strand of hair. [404]

Matter

- In every atom there are worlds within worlds. [55]

- (There are) countless universes, diverse in composition and space-time structure... In every one of them there are continents and mountains, villages and cities inhabited by people who have their time-space and life-span. [401-2]

Experience

- Direct experience alone is the basis for all proofs... That substratum is the experiencing intelligence which itself becomes the experiencer, the act of experiencing, and the experience. [36]

- Everyone has two bodies, the one physical and the other mental. The physical body is insentient and seeks its own destruction; the mind is finite but orderly. [124]

- I have carefully investigated, I have observed everything from the tips of my toes to the top of my head, and I have not found anything of which I could say, 'This I am.' Who is 'I'? I am the all-pervading consciousness which is itself not an object of knowledge or knowing and is free from self-hood. I am that which is indivisible, which has no name, which does not undergo change, which is beyond all concepts of unity and diversity, which is beyond measure. [214]

- I remember that once upon a time there was nothing on this earth, neither trees and plants, nor even mountains. For a period of eleven thousand years the earth was covered by lava. In those days there was neither day nor night below the polar region: for in the rest of the earth neither the sun nor the moon shone. Only one half of the polar region was illumined.

  Then demons ruled the earth. They were deluded, powerful and prosperous, and the earth was their playground.

  Apart from the polar region the rest of the earth was covered with water. And then for a very long time the whole earth was covered with forests, except the polar region. Then there arose great mountains, but without any human inhabitants. For a period of ten thousand years the earth was covered with the corpses of the demons. [280]

Mind

- The same infinite self conceives within itself the duality of oneself and the other. [39]

- Thought is mind, there is no distinction between the two. [41]

- The body can neither enjoy nor suffer. It is the mind alone that experiences. [109-110]

- The mind has no body, no support and no form; yet by this mind is everything consumed in this world. This is indeed a great mystery. He who says that he is destroyed by the mind which has no substantiality at all, says in effect that his head was smashed by the lotus petal... The hero who is able to destroy a real enemy standing in front of him is himself destroyed by this mind which is [non-material].

- The intelligence which is other than self-knowledge is what constitutes the mind. [175]

Complementarity

- The absolute alone exists now and for ever. When one thinks of it as a void, it is because of the feeling one has that it is not void; when one thinks of it as not-void, it is because there is a feeling that it is void. [46]
- All fundamental elements continued to act on one another—as experiencer and experience—and the entire creation came into being like ripples on the surface of the ocean. And, they are interwoven and mixed up so effectively that they cannot be extricated from one another till the cosmic dissolution. [48]

Consciousness

- The entire universe is forever the same as the consciousness that dwells in every atom. [41]
- The five elements are the seed fo which the world is the tree; and the eternal consciousness if the seed of the elements. [48]
- Cosmic consciousness alone exists now and ever; in it are no worlds, no created beings. That consciousness reflected in itself appears to be creation. [49]
- This consciousness is not knowable: when it wishes to become the knowable, it is known as the universe. Mind, intellect, egotism, the five great elements, and the world—all these innumerable names and forms are all consciousness alone. [50]
- The world exists because consciousness is, and the world is the body of consciousness. There is no division, no difference, no distinction. *Hence the universe can be said to be both real and unreal: real because of the reality of consciousness which is its own reality, and unreal because the universe does not exist as universe, independent of consciousness.* [50]
- Consciousness is pure, eternal and infinite: it does not arise nor cease to be. It is ever there in the moving and unmoving creatures, in the sky, on the mountain and in fire and air. [67]
- Millions of universes appear in the infinite consciousness like specks of dust in a beam of light. In one small atom all the three worlds appear to be, with all their components like space, time, action, substance, day and night. [120]
- The universe exists in infinte consciousness. Infinite consciousness is unmanifest, though omnipresent, even as space, though existing everywhere, is manifest. [141]
- The manifestation of the omnipotence of infinite consciousness enters into an alliance with time, space and causation. Thence arise infinite names and forms. [145]
- The Lord who is infinite consciousness is the silent but alert witness of this cosmic dance. He is not different from the dancer (the cosmic natural order) and the dance (the happenings). [296]

The YV model of knowledge

YV is not written as a systematic text. But the above descriptions may be used to reconstruct its system of knowledge.

YV appears to accept the idea that laws are intrinsic to the universe. In other words, the laws of nature in an unfolding universe will also evolve. According to YV, new information does not emerge out the inanimate world but it is a result of the exchange between mind and matter.

It also appears to accept consciousness as a kind of fundamental field that pervades the whole universe.

One might speculate that the parallels between YV and some recent ideas of physics are a result of the inherent structure of the mind.

8 The Shri Yantra

Although our immediate information on the Shri Yantra (SY) comes from medieval sources, some scholars have seen the antecedents of the yantra in Book 10 of the Atharvaveda. The Shri Yantra consists of nine triangles inscribed within a circle which leads to the formation of 43 little triangles (Figure 1) (Kulaichev 1984). Whatever the antiquity of the idea of this design, it is certain that the yantra was made both on flat and curved surfaces during the middle ages. The drawing of the triangles on the curved surface implies the knowledge that sum of the angles of such triangles exceeds 180 degrees.

The question that the physicist and historian of science John Barrow (1992) has asked is whether these shapes intimate a knowledge of non-Euclidean geometry in India centuries before its systematic study in Europe.

It is possible that the yantras were made by craftsmen who had no appreciation of its mathematical properties. But scholars have argued that the intricacies of the construction of this yantra requires mathematica knowledge.

9 Concluding Remarks

This has been a survey of some topics that have interested me in the past decade. If the revisions in our understanding required for these topics are indicative of other subjects also then we are in for a most radical rewriting of the history of science in India.

Our survey of these topics did not stress enough one aspect of Indian thought that sets it apart from that of most other nations, viz. the belief that thought by itself can lead to objective knowledge. Being counter to the reductionist program of mainstream science, this aspect of Indian thought has been bitterly condemned by most historians of science as being irrational and mystical. Now that reductionism is in retreat in mainstream science itself one would expect a less emotional assessment of Indian ideas. We can hope to address issues such as how do some ideas in India happen to be ages ahead of their times.

Students of scientific creativity increasingly accept that conceptual advances do not appear in any rational manner. Might then one accept the claim of Srinivasa Ramanujan that his theorems were revealed to him in his dreams by the goddess Namagiri? This claim, so persistently made by Ramanujan, has generally been dismissed by his biographers (see, for example, Kanigel, 1991). Were Ramanujan's astonishing discoveries instrumented by the autonomously creative potential of consciousness, represented by him by the image of Namagiri? If that be the case then the marvellous imagination shown in Yoga-Vasishtha and other Indian texts becomes easier to comprehend.

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Technology in Ancient India

Introduction:

Technology is today defined as applied science, but early humans developed technologies such as stone-working, agriculture, animal husbandry, pottery, metallurgy, textile manufacture, bead-making, wood-carving, cart-making, sailing, etc. with hardly any science to back them up. If we define technology as a human way of altering the surrounding material world, we find that the first stone tools in the Indian subcontinent go back more than two million years! (That was long before the advent of modern man in India, which is thought to have occurred some 70,000 years ago.) Jumping across ages, the "Neolithic revolution" of some 9,000 years ago saw the development in agriculture in parts of the Indus and the Ganges valleys, which in turn triggered the need for pots, water management, metal tools, transport, etc.

The Indus or Harappan civilization (2600–1900 BCE for its urban or "Mature" phase), which flourished in the northwest of the subcontinent, saw the rapid growth of an efficient agriculture that adapted itself to very diverse climates and conditions, from the water-rich Indus valley to semi-arid areas of today's Rajasthan. The Harappans grew wheat, barley and millets, and practised not only plough-based agriculture but also intercropping in places. Their wheel-turned pots came in various shapes and sizes, and some were glazed and painted in addition. Metal smiths extracted copper from ore available in the Aravalli hills, Ambaji (Gujarat) or Oman, and, alloying with tin, produced bronze. Mixing (deliberately or accidentally) various impurities into it, such as nickel or arsenic, hardened it to the point where bronze tools could be used to dress stones. Harappans invented the true saw, with teeth and the adjoining part of the blade set alternatively from side to side, a type of saw unknown elsewhere until Roman times. They left us a few bronze figurines, which were cast by the "lost-wax" process.

The Harappans also developed advanced grid-based town-planning, sanitation that collected used waters from individual bathrooms into municipal drains that were regularly inspected and cleaned. They realized that bricks of proportions 1 : 2 : 4 (width equals two heights; length equals two widths) permitted alternating courses and therefore stronger walls — the so-called "English bond" of masonry, which should properly be called the "Harappan bond"! Baked or mud bricks were not the only building material: at Dholavira (in the Rann of Kachchh), stone was also used on a huge scale. Harappan craftsmen used a number of minerals for ornamental, cosmetic and medicinal purposes; they excelled at bead-making, and their long beads of carnelian (a semiprecious stone), in particular, were highly prized in royal families of Mesopotamia. India's love for bangles is traceable to the Harappans' manufacture of large numbers of gold, bronze, conchshell, glazed faience or humble terracotta bangles. Weavers used wheel-spun thread and, besides the widely-used cotton, evidence of silk has recently come to light at two sites. Other crafts included stone and ivory carving, carpet-making, or inlaid woodwork.

Later Pottery

After the Harappan age, innovations in pottery shifted to the Ganges valley. The Painted Grey Ware (PGW), late in the second millennium BCE, is associated with iron-based cultures. A few centuries later, from around 700 BCE onward, the Northern Black-Polished Ware (NBPW) was first found in today's Uttar Pradesh and Bihar and is associated with the emerging cities of the Ganges valley. Both pottery types were produced on fast-spinning wheels using fine clay and fired to a high temperature in kilns under controlled conditions. Other regions of India eventually developed many other types and styles of pottery, and pottery sherds remain a major source of information for archaeologists, who have meticulously documented all those types and worked out their chronologies and regional spreads.

Metallurgy after the Harappans

As we have seen, the Indus civilization was essentially bronze-based, while the later Ganges civilization was iron-based. But it is now known that iron was produced in central parts of the Ganges valley right from 1800 BCE. Its use became widespread by about 1000 BCE, and we find in late Vedic texts mentions of a "dark metal" (*krishnāyas*), while the earliest texts, such as the Rig-Veda, only spoke of *ayas*, which, it is now accepted, referred to copper or bronze.

Whether other parts of India learned iron technology from the Gangetic region or came up with it independently is not easy to figure out. What matters is that the dates for copper, bronze and iron in India correspond broadly with those in Asia Minor (modern Turkey) and Caucasus. Let us note that an old theory according to which India learned iron metallurgy from those regions is now discredited.

Moreover, Indians invented two highly advanced types of iron. The "wootz steel", produced first in south India from about 500 BCE, was iron carburized under controlled conditions. Exported from the Deccan all the way to Damascus, it was shaped there into swords renowned for their sharpness and toughness; later, the Arabs fashioned it into swords and other weapons. A Roman historian, Quintius Curtius, recorded that among the gifts which Alexander the Great received from Porus of Taxila (in 326 BCE), there was some two-and-ahalf tons of wootz steel — clearly it was as highly prized as gold or jewels. From the 18th century onward, savants in England (Pearson, Stodart and Faraday), France and Italy tried to master the secrets of wootz; their researches led to the understanding of the role of carbon in steel and to new techniques in steel-making.

The second advanced iron is the one used in the famous 1,500-year-old Delhi Iron Pillar, consisting of six tons of wrought iron (there are a few other such pillars in other parts of India). Its rust-resistant properties were only recently understood, and are due to the presence of phosphorus in the iron: together with iron and oxygen from the air, phosphorus forms a thin protective coating at the surface, which gets reconstituted if damaged by scratching. Indian iron-smiths would not have known the chemistry at play here, but it goes to their credit that through patient trial and error they were able to locate and process the right type of iron ore for such monumental pillars. The same technology was used to manufacture huge iron beams used in some temples of Odisha, such as Jagannath of Puri.

It is interesting to note that most of India's production of iron was controlled by specific communities, most of them from the lower rungs of Indian society. For instance, the Agarias of U.P. and M.P. are reputed metal workers, and there are other communities scattered across Jharkhand, Bihar, West-Bengal, Kerala and Tamil Nadu.

In the late 1600s, shipments of tens of thousands of wootz ingots would leave the Coromandel coast for Persia every year. India's iron and steel industry was intensive till the 18th century and declined only with the British selling their own products into India while imposing high duties on Indian products.

Iron technology did not put an end to the earlier bronze metallurgy, however. The two were used for different purposes. An eloquent testimony of the further growth of bronze metallurgy is found in a huge bronze statue of the Buddha made in Sultanganj (Bhagalpur district, Bihar), between 500 and 700 CE; at 2.3m high, 1m wide, and weighing over 500 kg, it is the largest bronze figure of its kind in the world, and was made by the same lost-wax technique that Harappans used three millenniums earlier (it is now at the Birmingham Museum). So were thousands of bronze statues made later in Tamil Nadu, such as the beautiful Natarāja statues. Similarly, highly polished bronze mirrors are still made in Kerala today, just as they were in Harappan times.

Chemistry and Alchemy

Although chemical practices were in use much earlier, a theory of chemistry took shape in the first centuries CE, especially during the Gupta Empire. The discipline was variously called *rasashāstra, rasavidyā* or *dhātuvāda*. Its foundations were basically esoteric: *rasa* or mercury, one of the most important elements, was identified with the male principle (Shiva), while sulphur was associated with the female principle (Shakti). Transmuting base metals into gold and the pursuit of the "elixir of life" would today be categorized as "alchemy" more than chemistry.

his connection with concepts from Tantrism was not, however, devoid of practical applications, since Indian chemistry evolved practical methods to refine and produce medicines and other substances. The *rasashāstra* texts discuss many chemical substances categorized as *mahārasas*, *uparasas*, *navaratnas*, *dhātus*, poisons and plants, and also describe various types of apparatus, which were ingeniously developed and used for processing these substances. A detailed study of these texts reveals how skilled the *rasavādins* (chemists) were at performing purificatory processes in order to remove the toxic effects of metals and minerals and make them fit for internal use. For instance, although mercury compounds are regarded as poisonous, cinnabar (mercuric sulphide) went through eighteen complex processes called *samskāras*, including rubbing with various medicinally efficacious plant juices and extracts, incorporation of sulphur, mica, certain alkaline substances, etc. The resulting mercury compound was then declared fit for consumption and believed to lead to the body's rejuvenation. Similar processes existed in Tamil alchemy and the Siddha system of medicine, which developed special techniques in connection with various naturally occurring salts.

Other technologies
The first appearance of glass in India goes back to the second half of the 2nd millennium BCE. At Taxila (ancient Takshashila, now in northern Pakistan), the Bhir mound yielded numerous glass beads of several shapes and colours dated to the 5th century BCE or so. Glass objects and ornaments have also come to light at places like Kopia, Ujjain, Nasik, Ahicchatra, Sravasti, Kolhapur, Kaundinya, Brahmagiri, and at several sites of Tamil Nadu (such as Arikamedu, Kodumanal and Porunthal). The early Indian glass-makers were skilled at controlling the temperature of fusion, moulding, annealing, blotching and gold-foiling, the last done in an exquisite manner.

From antiquity this land has been renowned for the quality and dazzling variety of its production of textiles with fine skills in weaving and dyeing. The art of paper-makingwas introduced into India probably in the 11th century CE, perhaps from China through Nepal. Before the introduction of paper, the ancient literature was preserved on palm-leaves in south India and birch-bark in the north. By the latter half of the 15th century, Kashmir was producing paper of attractive quality from the pulps of rags and hemp, with lime and soda added to whiten the pulp. Sialkot, Zafarabad, Patna, Murshidabad, Ahmedabad, Aurangabad and Mysore were among the well-known centres of paper production.

Pyrotechnic Practices (or fireworks) appear to have been current in India in the 13th or 14th century. Gunpowder was an article of warfare at the beginning of the 16th century: the Indian craftsmen were quick to learn the technique from the Mughals and to evolve suitable explosive compositions. A 16th- or 17th-century Sanskrit treatise contains a description of how gunpowder can be prepared using saltpetre, sulphur and charcoal in different ratios for use in different types of guns.

From the 16th century, rockets began being used in wars waged in India, as testified by military annals of the period. The Mahrattas are reported to have fired rockets at the 1761 Battle of Panipat which they lost to the Afghans. Hyder Ali, the 18th-century ruler of Mysore, and his son and successor, Tipu Sultan, used rockets to great effect in the Anglo-Mysore Wars against the British East India Company, with a “rocket corps” of thousands of men. The rockets consisted of a tube of soft hammered iron about 20 cm long and 4 to 8 cm in diameter, closed at one end and strapped to a shaft of bamboo about 1 m long, with a sword often fitted at the other end. The iron tube contained well-packed black powder propellant. Though not very accurate, when fired en masse they could cause damage as well as panic among the troops. The British lost no time in taking a few rockets to England for closer study, which ended up boosting rocket technology in European warfare.

Cosmetics and Perfumes were an article of trade with the Romans (along with textiles, spices and timber) and are described at some length in Varāhamihira’s *Brihat Samhitā*: scented water for bathing, scented hair oil, perfume for cloths, for the mouth, scented tooth sticks are among the described items. This art became increasingly popular and some new compositions catered to the needs of the royal baths and religious ceremonies, particularly during the Mughal period. The *Āin-i-Akbarī* speaks of the “Regulations of the Perfume Office of Akbar”; the *āttar* of roses was a popular perfume, the discovery of which is attributed to the mother of Nurjehan.

In many fields, especially metallurgy, India perfected advanced technologies centuries before Europe, which occasionally practised “reverse engineering”, as in the case of wootz steel, zinc distillation, Sushruta’s rhinoplasty and Tipu Sultan’s rockets. Some of the ancient technologies remain useful even today: metallurgical techniques, ecological and agricultural traditions, Ayurveda and various local health traditions, water management (see Module on Water Management), among others. They are part of what has been called India’s traditional knowledge systems. Even the technologies that have lost their relevance today remain interesting from a historical point of view. And there remains considerable scope for documenting, testing, assessing, and sometimes streamlining India’s enormous traditional technological wealth.

Chapter 1
A Study of Glass and Beads

> Bead research is not just a sub-division of archaeology. Rather it is a related inter disciplinary field with aims and methods of its own (Francis 1987: 24).

1.1 Introduction

Archaeologically, there are four main problems in the study of ancient Indian glass beads; they are related to context, chronology, inadequate emphasis on manufacturing methods and symbolic value. For the first two there is no alternative but to rely on the reported material, but for the last two problems there does exist enough ethnographic evidence in India. Glass beads are continued to be widely used by numerous tribal populations like that of Juang, Bondo and Nagas of India, and they are produced in large scale mainly at Papanaidupet, Varanasi and Purdalpur. Study of such ethnographic materials constitutes the core of this research.

Trade, exchange of commodities and skills, ethnoarchaeology, and scientific interpretation have emerged as leading areas of research in bead archaeology. There have been a few studies on trade and a few on scientific analysis of ancient Indian glass beads but none on ethnoarchaeology till date. In fact, India is perhaps the only country where both traditional producers and users of glass beads have retained their traditional skills and practice through time. This work aims at reconstructing the ancient Indian technology involved in the production of glass beads and their subsequent through ethnographic investigations and archaeological record.

1.2 Glass

Glass is an amorphous substance made primarily of silica fused at high temperatures. In technical terms, glass is called as a 'super cooled liquid', in which molecular units share disordered arrangement but sufficient cohesion to produce mechanical rigidity. Molten glass can be cooled to this rigid state and can be brought to the liquid form by application of heat. Glass can be transparent, translucent, or opaque; it can also be coloured to any desired shade with minimal ingredients. Molten glass can be shaped by means of several techniques. This flexibility has made glass an important and integral part of day-to-day requirements for human beings for more than 3000 years and a valuable trade item. Production of glass and its by-products is perhaps among the earliest achievements of the handicrafts of men (Singh 1989: 11). Manufacture of glass required a high degree of advancement in technology and knowledge of controlling appropriate temperatures.

1.3 History of glass

Early glassmaking was slow and costly, and it required hard work. Glass blowing and glass pressing were unknown, furnaces were small, the clay pots were of poor quality, and the heat was hardly sufficient for melting. But glassmakers eventually learned how to make coloured glass jewellery, cosmetics cases, and tiny jugs and jars. People who could afford them—the priests and the ruling classes—considered glass objects to be as valuable as jewels.

1.3.1 Early Times

Before people learned to make glass, they had found two forms of natural glass. These are 1) desert glass/fulgurites: this is essentially fused silica, produced when lightning strikes sand, the heat sometimes fuses the sand into long, slender glass tubes called fulgurites, which are commonly called petrified lightning and 2) obsidian: the terrific heat of a volcanic eruption also sometimes fuses rocks and sand into a glass called obsidian. In early times, people shaped obsidian into knives, arrowheads, jewellery and money.

The exact place and the period in which glass and glass beads were first manipulated are not known. There are different opinions regarding its inventions; among these, the two prominent ones are: 1) that glass was first fabricated either in Syria or Palestine (Harden 1933: 413); and 2) that simultaneous development of glass took place at different centres, presumably in Syria, Mesopotamia and Egypt. Most of the scholars agree that glass was developed in the late 3rd millennium B.C. possibly from a development in the production of faience. Glass became common from the mid 2nd millennium B.C. in the Levant and then Egypt, where manufacture of glass received a great impetus. But the most remarkable finds are those from the city of Tell el Amerna (Petrie 1874: 25; 1909: 119) established by Akhenaton (1450-1400 B.C.), where the extensive remains of a glass house and glass in various stages of manufacture have been recorded. This forms the chief source of knowledge regarding the fabrication of glass in Ancient times.

The earliest sample of glass has been noticed at Tell Asmar in Mesopotamia from a stratum dated *c.* 2700-2600 B.C. The first glass vessels were produced about 1500 B.C. in Egypt and Mesopotamia. The glass industry was extremely successful for the next 300 years, and then declined. It was revived in Mesopotamia around 700 B.C. and in Egypt around 500 B.C. For the next 500 years, Egypt, Syria, and other countries along the eastern shore of the Mediterranean Sea were glassmaking centres. Beads and bangles were also made in abundance but are less often illustrated and displayed in museums.

The use of blowpipe in glass making was invented about 1st century B.C. on the Phoenician coast and rapidly spread all around. This invention made glass production easier, faster, and cheaper. As a result, glass became available to the common people for the first time. Glass manufacture became important in all countries under Roman rule. In fact, the first four centuries of the Christian era may justly be called the First Golden Age of Glass. The glassmakers of this time knew how to make transparent glass, and engaged in offhand glass blowing, painting, and gilding (application of gold leaf). They knew how to build up layers of glass of different colours and then cut out designs in high relief. The celebrated Portland vase, which was made in Rome during the beginning of the Christian era, is an excellent example of this art. This vase is considered to be one of the most valuable glass art objects in the world.

1.3.2 The Middle Ages

The manufacture of household glass suffered a decline in the West with the fall of the Roman Empire. Little is known about the glass industry between the decline of the Roman Empire and the 1200's. The Medieval period produced mosaic glass in Mediterranean Europe and stained glass windows in the north. Glass windows in churches are mentioned in documents as early as the 6th century A.D., but the earliest examples existing today date from the 11th century (Martin: World Book Online).

Although glassmaking was practiced in Venice from the 10th century onwards, the earliest known Venetian glassware dates from the 15th century. Glass manufacture had developed in Venice by the time of the Crusades (A.D. 1096-1270), and by the 1290's an elaborate guild system of glassworkers had been set up. Equipment was transferred to the Venetian island of Murano, and the Second Golden Age of Glass began. Venetian glass blowers created some of the most delicate and graceful glass the world has ever seen. They perfected cristallo glass, a nearly colourless, transparent glass, which could be blown to extreme thinness in almost any shape. It is a highly refined and hard-soda glass. From cristallo, they made intricate lacework patterns in goblets, jars, bowls, cups, and vases. In the 1100's and 1200's, the art of making stained-glass windows reached its height throughout Europe. The Venetian industry dominated the European market until 1700; its major contribution being cristallo. Glass manufacturers throughout Europe tried to copy the Venetians, and each country developed its own variation on the Venetian model.

By the late 1400's and early 1500's, glassmaking had become important in Germany and other northern European countries. Manufacturers there chiefly produced containers and drinking vessels. Northern forms were heavier, sturdier, and less clear than Venice's cristallo. During the late 1500's, many Venetians went to northern Europe, hoping to earn a better living. They established factories there and made glass in the Venetian fashion. A new type of glass that worked well for copper-wheel engraving was perfected in Bohemia (now part of the Czech Republic) and Germany in the mid 1600's, and a flourishing industry developed. In the 17th century Germany's potash-lime glass was thicker and harder than Cristallo. German glasscutters and engravers became famous for skilfully executed glass designs in the baroque manner.

Glassmaking became important in England during 1500's. By 1575, English glassmakers were producing Venetian-style glass. In 1674, an English glassmaker named George Ravenscroft patented a new type of glass in which he had changed the usual ingredients. This glass, called lead glass, contains a large amount of lead oxide. This is especially suitable for optical instruments, and caused English glassmaking to prosper. Lead glass reached its full potential in the neoclassical pieces of the Anglo-Irish period (1780-1830). Glassmaking was the first manufacture undertaken in America, with a glasshouse built at Jamestown, Virginia, in 1608.

1.3.3 Modern Glassmaking

After 1890, the development, manufacture, and use of glass increased rapidly. The science and engineering of glass as a material are now so much better understood that glass can be tailored to meet exact needs. Any one of its thousands of compositions may be used. Machinery has been developed for precise, continuous manufacture of sheet glass, tubing, containers, bulbs, and a host of other products. Mechanical pressing, introduced in the United States, was a cheap, fast means of production that greatly expanded the role of glass both within the home and the industry. Chemical advancements led to new opaque coloured glass that resembled semiprecious stones. Transparent enamels and stains were applied to vessels, paralleling the revival of stained-glass windows. By 1880 glassmakers were creating new styles of hand worked glass, generally called art glass. Between 1890 and 1910, styles reflected the international art nouveau movement. Louis Comfort Tiffany in the United States was one of the leading proponents of the art nouveau style. After World War I (1914-1918) the designs of French glassmakers René Lalique and Maurice Marinot were popular. A new era in glassmaking began in the early 1960s with the studio glass movement.

Changes in the fuel used by the glass industry affected the location of glass factories. In the early days when wood was used as fuel, glassworks were built near forests. By 1880, coal had become the most widely used fuel for glassmaking, and glassmaking operations were near large coal deposits. After 1880, natural gas became accepted as the perfect fuel for melting glass. Today, most glass manufacturing plants are near the major sales markets.

1.3.4 Non-Western Glass

The history of glass from the 8th century through the 14th century is focused on the Islamic world of the Middle East. Muslim artisans made high-relief cut vessels, many with animal subjects. Quality colourless glass, fired-on enamel colours, and gilding techniques were developed. Egypt introduced lustrous metallic effects on both pottery and glass. Chinese-made glassware from the Zhou dynasty (1027-256 B.C.) has been excavated. Early glass objects were small and carved in close imitation of gemstones. No evidence exists of glass made in Japan before 200 B.C. Some glass Buddhist relic bottles and urns are believed to have date from the Asuka and Nara periods (A.D. 552-784). Glass was made in India as early as in Painted Gray Ware (PGW) period, but the industry was not established until the early historic period and gathered momentum only in the Mughal period. Indian glass was often gilded or enamelled in floral patterns.

1.4 Composition of Glass

Glass can be generally divided into two groups: oxide glass and non-oxide glass. The ingredients of oxide glasses include oxides (chemical compounds that include oxygen). Non-oxide glasses are made from compounds that contain no oxides, and which often instead contain sulfides or metals. Oxide glasses are much more widely used commercially. The common types of glass discussed below are all oxide glasses.

1.4.1 Soda-lime glass is the kind of glass used for flat glass, most containers and electric light bulbs, and many other industrial and art objects. More than 90 percent of all glass is soda-lime glass. It has been made of almost the same materials for hundreds of years. The composition is about 72 percent silica (from sand), about 13 percent sodium oxide (from soda ash), about 11 percent calcium oxide (from limestone), and about 4 percent minor ingredients. Soda-lime glass is inexpensive, easy to melt and shape, and reasonably strong.

All glass container manufacturers use the same basic soda-lime composition, making the containers easy to recycle. Manufacturers sort the glass by colour and then later reuse it in the production of new containers.

1.4.2 Soda-lead glass, commonly called crystal or lead glass, is made by substituting lead oxide for calcium oxide and often for part of the silica used in soda-lime glass. Soda-lead glass is easy to melt and is much more expensive than soda-lime glass. Soda-lead glass has such beautiful optical properties that it is widely used for the finest tableware and art objects. In addition, lead oxide improves the electrical properties of glass.

1.4.3 Borosilicate glass is heat-shock resistant and better known by such trade names as Pyrex and Kimax. It contains about 80 percent silica, 4 percent sodium oxide, 2 percent alumina, and 13 percent boric oxide. Such glass is about three times as heat-shock resistant as soda-lime glass and is excellent for chemical and electrical uses. This glass makes possible such products as ovenware and beakers, test tubes, and other laboratory equipment.

1.4.4 Fused silica glass is a highly heat-shock resistant glass that consists entirely of silica. It can be heated to extremely high temperatures and then plunged into ice-cold water without cracking. Fused silica is expensive because exceptionally high temperatures must be maintained during production. It is used in laboratory glassware and optical fibers.

1.4.5 96 percent silica glass resists heat almost as well as fused silica, but it is less expensive to produce. It consists of a special borosilicate composition that has been made porous by chemical treatment. The pores shrink when the glass is heated, leaving a smooth, transparent surface. The glass is sold under the trade name Vycor.

1.4.6 Coloured glass gets it's colouring from certain oxides that are added to the glass. For example, 1 part of nickel oxide in 50,000 produces a tint that may range from yellow to purple, depending on the base glass. One part of cobalt oxide in 10,000 gives an intense blue. Red glasses are made with gold, copper, or selenium oxides. Other colours can be produced in glass with other chemicals.

The higher the proportion of silica, alumina and lime, the harder is the glass, high alkali content reducing its hardness. Soda-lime glasses are generally harder than potash glasses of the same composition. However the hardness of the glass also depends on the heat treatment to which the glass is subjected after working. Poor annealing and uncontrolled cooling at high rate increase the hardness of glass (Lal 1958: 140-41).

Soda-lime glass has been the trademark of Indian glass from ancient times and is still in use in all the bead production centres.

1.5 Development of Glass in India

Pliny in his Natural History commented that Indian glass was of high quality because the basic raw material used was not sand but pounded crystal. It has long been suggested that this may have been the reason behind the high silica content in ancient Indian glass (Stern 1987a: 28). In Gudur (Andhra Pradesh), the government glass factory till recently used to produce glass from crystal. Dr. Brill of Corning Museum, USA believes that even pebbles were being routinely used, instead of sand, as the source of silica, by glassmakers throughout Iran, Mesopotamia, and Central Asia in ancient times (cited in Stern 1987a: 28). In fact, in the Heart (Afghanistan) factory in

1977, the glassmakers still used pebbles collected in the riverbed as their source of silica.

Although glass was commonly made in the West Asian Bronze Age, there is some controversy concerning its manufacture in the Indus Valley Civilization (Glover and Henderson 1994). Some scholars have tried to trace back the origin of Indian glass to the Harappan Civilization on the basis of the finding of glazed pottery and quartz beads. It is evident that Harappans made glazed pottery which is nothing but a ceramic with a thin layer of glass on the surface (Tite *et al.* 1983). Though no true glass has been found in India during the Protohistoric periods at Mohenjo-daro and Harappa, the second millennium B.C. saw its people able to mould and fuse excellent articles of faience, glazing their quartz beads with frit, a material similar to glass. All the three materials, glass, glaze, and faience consist customarily of silica and lime, although special modern glasses need have neither. Glass and glazes always contain soda or some or the other alkali, whereas faience generally contains only very small quantities of soda. In the evolution of glass, frit, faience and glaze might have signified certain stages of development (Beck 1934; Brill 1963: 120; Forbes 1957: 223; Biek and Bayley 1979).

Glass is a state rather than a material (Biek and Bayley 1979: 1). There is little doubt that glass was an outcome of glaze. Glass and glazes are chemically identical but they are worked and used differently (Forbes 1957; Tite *et al.* 1983). The glazing technique marks the emergence of the first glass or synthetic material (Barthelemy and Bouquillon 1994). However, a glaze is a glassy layer applied to a core or base of some other material. This is in some cases mixed with the material before firing and in many cases applied to the body after firing. In the 4th millennium B.C. glaze was used extensively within the context of Badarian civilization in Egypt, the Jemdet Nasr period in Mesopotamia and in the 3rd millennium B.C., the Indus valley civilization. The method of grinding quartz and mixing it with a little alkali before firing and producing faience occurred somewhat later in Egypt in Early Predynastic period (Lucas 1926; Forbes 1957). Marshall (1931: 578, 582, 692) states that, the glazing of pottery is an Indian invention and a craft which appears to have been practised for the first time on the bank of Indus. No example of it has come to light in Mesopotamia before 1000 B.C., nor in Egypt before Roman period, though in Nubia there is said to be evidence of glazed ware as early as XII dynasty (1991-1928 B.C.). On the strength of the available material at Mohenjo-daro and Harappa, Marshall (1931) went on to say that they are so closely allied to glass that it hardly seems possible that glass could have long been delayed. Bhardwaj (1979: 31) opined on the four pieces of glazed pottery found at Mohenjo-daro to be the handiwork of a potter who was well acquainted with the process of glazing and able to carry it to a high degree of perfection.

Faience is nearer to glass in the process of evolution. It is reported from many ancient sites and is likely to have been the predecessor of glass (Brill 1963: 120). In the archaeological sense it is generally agreed that faience consist of a lightly sintered core of crushed quartz grains coated with a translucent blue-to-green glaze, both fluxing due to soda. Such material needs a firing temperature of some 1,000°C and a certain amount of sophistication in making it (Biek and Bayley 1979: 3). Crystalline quartz grains with a small amount of glassy material predominates in the case of faience. A few simple variations, whether accidental or deliberate, would have resulted in true glass (Basa 1991). Stone and Thomas (1956: 37) proposed that glass could be produced by heating faience too much or for too long, while adding a little surplus of alkali. They further suggested that it is most probable, then, that the faience-makers found this out by simple observation and so became the first makers of real glass. Forbes (1957) and Bhardwaj (1979) have proposed to call most of ancient objects dubbed faience to be glazed siliceous ware, as they have a body consisting of powdered quartz covered with a layer of glaze. This material has been reported from most of the ancient civilizations including those of Egypt, Mesopotamia and India (Lucas 1926; Safianopoulas 1952). Faience was certainly made in India and fashioned into a variety of objects such as amulets, bangles and inlay, segmented beads, spindle-whorls, fluted disc beads, seals, animal figurines, and pots. High temperature stoneware bangles and some glazed pottery have also been recorded. Such materials have also been reported from Lothal, Bhagwanpura, Sanghol, Banavali, Bara, Ropar, Chanhudaro, Hulas, Mithathal, etc. (Dayton 1989). In Indus Valley itself the people of Mohenjo-daro and Harappa are known to have made extensive use of articles from faience, a composition resulting from powdered quartz grains fused at low temperature with the addition of lime. Some of the articles like beads and inlays were found treated with a glaze or frit which does not materially differ from glass. Marshall (1931: 683) and Mackay (1931: 576, 578 and 582) are of the opinion that though no true glass has been recovered from Mohenjo-daro and Harappa, the authors of these cultures had perfected a composition which very nearly approached glass. Experiments conducted by McCarthy and Vandiver (1991) have revealed that the Harappan faience has a quite dense body with a continuous glassy phase and a relatively thin skin of glaze. Intentional addition of glass frit and clay are postulated. The Harappan faience bodies are particularly strong, compared with contemporary faience from West Asia and Egypt. A similar technology is not found in Egypt until much later during the New Kingdom about 1450 B.C.

Brill (1987: 2) gives two reasons in support of the belief that glassmaking grew out of faience manufacture, viz., 1) both processes involve the pyrotechnology of the same materials (silica and alkali) and 2) faience was made for some fifteen centuries before glass was made. In this regard the data gathered at Mehrgarh and Nausharo are of great interest since they allow the study of the local evolution of the glazing techniques through time, from the Chalcolithic to the Mature Indus period (Barthelemy and Bouquillon 1997: 63).

Bhardwaj (1987) and Singh (1989), on the basis of glazed pottery from Mohenjo-daro, have argued that the Harappans were aware of glass making. Bhardwaj (1987) regards a number of vitreous materials unearthed from Mohenjo-daro as weathered unworked glass, but more finds from well-dated contexts are needed before we can be sure that the Harappans had truly mastered the secrets of glassmaking (Singh 1989), and that it is probable that glass could have decomposed to the point where it looked like faience.

Singh (1989) cautioned about the possibility that some glass beads might have been classified wrongly as stone beads and hence the Harappan Civilization did not get the credit for manufacturing glass. Even if they had this knowledge it seems to have been lost with the collapse of the urban Bronze Age civilization and the subsequent finds of glass from the subcontinent come only with the Harappan-PGW overlap phase at Bhagwanpura in Haryana, datable to about 1450-1200 B.C. (Joshi 1976). From this time onwards glass beads and bangles were regularly made in many parts of the subcontinent (Lal 1987). However, here thorough investigation of faience objects from Chalcolithic sites is required as they are reported to have yielded an enormous quantity of burnt steatite and paste, some time glazed too. Here it is important to mention that some of the beads that had been interpreted as shell beads (Wheeler *et. al.* 1946; Casal 1949) have now been identified as corroded glass (Francis: n.d.). Too much soda will yield a kind of glass that will be easily corroded by water, though ancient glasses often have a large percentage of soda to achieve a low melting point (Forbes 1957). In some cases faience is also wrongly identified as glass; for example faience excavated in Baoji and Fufeng Country of China dated to 11^{th}-10^{th} c.B.C. was for a long time considered to be earliest glass finding of China (Brill 1995: 270).

From the analysis of 38 specimens found at Alamgirpur (undated), Brahmagiri (Megalithic and Andhra culture), Hastinapur (Period V and III), Sar Dheri, Arikamedu (*c*. 200 A.D.), Kausambi (200 B.C.-200 A.D. and 100-200 A.D.), Bihar (1-2^{nd} c.A.D.), Orissa (200 A.D.), Rupar (1000-700 B.C. and 200 B.C.-600 A.D.), Vankali (Sri Lanka 1200-1250 A.D.), Brill (1987) comments that if a glass found in India has a high alumina content ($Al_2 O_3$) i.e., 3.5-4.0% or greater, it probably was made in India and that a low lime content (CaO) can also be considered as evidence of local manufacture. Francis opines that both imported and indigenous glasses were used for bead production. This was supported on the basis of scientific analysis of some of the early glass samples. In Egypt and the Roman Empire glass consisted of sodium oxide as alkali, whereas in India and Vietnam, as evident from Arikamedu (India) and Oc-Eo (Vietnam), both sodium and potassium oxide were utilized

(Francis 1990a). Lead as a colouring agent or opacifier in glass is found more in the West than in India. Glasses from Khairadih, dated between 700 B.C. to 2nd century A.D. (Singh and Abdurajakov 1988), Nevasa (Varshney *et al.* 1988) and Arikamedu (Glover and Henderson 1994) are found to have low lime content.

Glass is made chiefly from silica sand (silica, also called silicon dioxide), soda ash (sodium carbonate), and limestone (calcium carbonate). And in antiquity, there was no dearth of raw materials for glass making in various regions of India. Silica can be obtained from sand, quartz and sandstone; soda from *reh* soil in Uttar Pradesh and Bihar and from salt lakes of Didwana and Lonar in Rajasthan; potash from various plant ashes and from saltpetre in the Gangetic valley and Amritsar in North India, in the districts of Anantapur, Guntur, Kurnool, Coimbatore, Madurai and Nellore in south India and in Ahmedabad in Gujarat (Sen and Chaudhuri 1985). Craftsmen of India used copper, manganese, tin, antimony and iron combinations for colouring (Abdurazakov 1987: 38).

Glass production in antiquity required at least 3 major steps (Biek and Bayley 1979: 1):

1. The first was to bring the two main components silica and alkali together at a moderate heat for some time and allow them to react in the solid state. Because the melting point of silica was too high for ancient furnaces to achieve, a flux, generally an alkali (usually soda [Na_2O] or potash [K_2O]) was (and still is) added to lower the melting point. Lime (CaO) or some other stabilizer must also be added. The ancients may not have known this; the lime was nearly always present as an impurity in the sand (Turner 1956: 45T-46T). These ingredients are heated for several days, forming a dark, hard substance called “frit”. Melting at this stage had to be avoided at all costs as it prevented proper contact. It was also uneven, and did not allow for any through mixing. All ancient recipes are very careful to emphasize this vital point.

2. The second step was to break up the resultant 'frit' and grind it up as finely as possible to get the most intimate mixture.

3. Finally the powder was thoroughly melted and could then be cast, moulded or blown into objects, which were finished by annealing (gentler heating to relieve stresses), polishing, cutting, etc.

Traditionally, beadmakers in India break the frit, and then heat the mixture again before producing any objects.

In ancient India fragments of glass slag and other debris of glass production have been noticed at Kopia (Roy and Varshney 1953; Dikshit 1969: 39; Sen and Chaudhuri 1985: 64-65; Lal 1987: 45; Abdurazakov 1987), Taxila (Marshall 1951), Rajghat (Narain and Ray 1976; Singh 1989) and Khairadih, period II (IAR 1981-82: 68, Sing and Abdurazakov 1990) in the North; Brahmapuri (Kolhapur) (Sankalia and Dikshit 1952), Nevasa (Sankalia *et al.* 1960: 355, 383-85), Bhokardan (Deo and Gupte 1974: 197), Paunar (Deo and Dhavalikar 1968: 82-83), and Ahmednagar (Chaudhuri 1986: 97) in the Deccan; Tripuri and Sirpur in Central India; Hulas Khera (Tewari 1983); Nagra (Mehta and Shah 1968: 132-37) and Maheswar (Sankalia *et al.* 1958) in the West; and Arikamedu and Karaikadu in the South. Thus, it is evident that ancient India was not only manufacturing glass beads but was also making glass for its use.

Regarding the glass furnace in ancient India, our information is however meager. A solitary reference comes from Nevasa, where a glassmaking kiln dated to the period *c.* 3-4th c.A.D. was unearthed. It is a circular oven 2'-6" in diameter with 1′-7″ depth and is made of burnt clay. Around it was found an abundance of bichrome glass, slag lime, cow-dung, etc. (Sankalia *et al.*1960). At one of the points near the periphery was a channelled projection evidently to insert the pipe for the bellows (Deo 2000: 11). Chaudhuri (1986: 99) remarked that most of glass furnaces in ancient India are open-fired type, using solid fuel, and the melting was carried out in a clay pot (Fig. 1).

Many substances, chiefly metallic oxides, are added to impart various properties to glass. The most common additives are the colorants. With only iron or copper and the proper handling of the furnace (blowing air into it, muffling it, or leaving it open) nearly every colour maybe achieved. Special colorants, notably cobalt (Co) and manganese (Mn), have been used since antiquity. Even tiny amounts of cobalt yield a pleasing dark blue. Manganese in small quantity produces pink, which cancels out "bottle green" and clarifies the glass, earning it the name "glassmaker's soap". Larger amounts produce violet. Antimony tin, and arsenic were employed as opacifier. Black glass is usually deep green or violet, made with large amounts of iron or manganese; an organic black glass also exists. Many colorants have been experimented with in recent centuries as the science of chemistry had developed (Francis 2002).

In the absence of archaeological evidence for the glass industry, it is necessary to explore more sites and ethnographic reports/records of the British period. Out of many (Halifax 1892; Dobbs 1895; Mukherjee 1895; anonymous 1895) investigations about the glass industry in India carried out during 1885-90 by the British Government, Dobbs' account of the region of north-western Provinces and the Oudh (Modern Uttar Pradesh) is probably the best and most authentic ethnographic observation in the 19th century. Dikshit (1069: chapter VI) and Basa (1991) summarize Dobbs work as:

> The chief ingredients of glass in north-western Province was *Reh*, a carbonate of soda, and not powdered flint rock as it was in the Punjab. *Reh* was gathered by collecting water in small plots of land, close to canals, and then allowing water to evaporate. Thus soda from the soil was gathered, after four-to-six days, in the form of an encrustation, called *Papri* collected as flakes and balls – which were further dehydrated, and put in to the furnace

> along with other ingredients (silica and colouring agents). It took about 18 days to melt and 10 days to cool. Crude glass was thus formed, which was mostly greenish white or black in colour which was sold in bulk. Greenish white glass was considered superior to black glass. Black glass was made either by adding 1-4% iron oxide and a little saltpetre to the scorched *Reh* or by adding 20% of *Senda* – a red ferrous stone. About 400 *maunds* of *Reh* was required for one smelting, which produced about 300 *maunds* of glass. The lack of toughness in Uttar Pradesh glass was apparently due to deficiency of lime (about 1.22%).

Francis (1870) gives the details of the construction process of furnace and the working of glass at Chenapatnam near Mysore, in 1800 A.D. (cited in Dikshit 1969: 127-28):

> The furnaces are generally constructed in the yard of a building against a wall. There are three or four vaults, about 6 ft. high, 12 ft. broad and twenty-six feet deep. Each furnace is domed and at the top of each is a round opening, about 2 ft. in diameter, over which a holed stone is kept like a lid. There is a sort of a platform in the centre of each vault, the lower portion of which is used for the feeding of the fuel through an opening at the bottom. Firewood is supplied from the other end of the wall to each vault through this opening. Crucibles are kept in the furnace through the aperture at the top, arranged in a circle, about 42 crucibles in each vault. When the materials are ready to be fused, the top of the aperture is closed completely by means of moist clay but a small hole is left for the gases to escape. The lower portion of the vault is then stuffed with fuel. On the first day only ten bundles of firewood are burnt. Next day all air is excluded from the furnace by closing all apertures. Firewood is again supplied for eight days, there being no supply of fuel by night. Afterwards the furnace is kept burning until all the glass in crucibles is melted into required consistency. The testing is

done by means of a long iron rod inserted through the aperture in the dome and to see if the materials have vitrified.

By devitrifying the material in the furnace for eight to nine days it is possible to produce about 44 ½ lbs of glass worth 4 ½ fanams or a little more than three shillings. In other cases each crucible produces 41 lbs of green or red glass worth 7 Sultani Fanams i.e. worth about 4 s. 8 ½ d.

Table 1: Dikshit (1969: 131) gives the colouring agent used by the craftsmen from Uttar Pradesh as follows:

1	Transparent dark green	Di-oxide of copper	1 tola
2	Opaque light green	Di-oxide of copper Lead Tin Yellow shale	2 tolas 1 chhatak 1 chhatak 1 chhatak
3	Light blue	Sulphate of copper	1 chhatak
4	Sky blue	White Firozabad glass Chep, a white stone Patra, a stone	1 ser 2 chhataks ½ tola
5	Indigo violet	Chep	2 chhataks
6	Opaque lemon yellow	Pilli, a powder of lead, tin and yellow shale	3 chhataks
7	Opaque brown	Black glass	4 chhataks
8	Opaque ochre	Tin Lead Goramba, a red stone	1 chhatak 1 chhatak 1 ½ chhatak
9	Dark red	Lead Zinc	1 chhatak 1 chhatak
10	Light red	Copper oxide Black glass	1 tola 4 chhataks or 1 seer
11	Uda (purple)	Anjani	10 chhataks or one maund

Though the account by Dobbs and Francis gave many useful and interesting details regarding the manufacture of glass, very little has been said regarding the main centres of the glass industries. Dikshit (1969: 139) mentions some of the glass industries at many different places of India and cites the reports of D. Narayana Rao on indigenous glass industry of those days to the Madras Government in 1927-29. According to Rao the Chittor district had 15 centres viz., 1) Maddiledu, 2) Somapalaiem, 3) Kalahasti, 4) Jangarapalli, 5) Chintayapalle, 6) Upparapalle, 7) Bhimavaram, 8) Pillemedu, 9) Seetharampet, 10) Merelapaka, 11) Parapalle, 12) Kothapalayam, 13) Kanjiniputtur, 14) Kurukkamputtur and 15) Gundipedu, where glass was being worked. The industry was said to be flourishing in these at one time or the other. The method of preparing glass is practically identical with that in the North. It was made by lixiviating the alkaline earth, allowing the salts to crystallize out in the sun and by heating them in a mud crucible for several hours with bits of broken bangles. The vitreous mass produced is solidified into block glass which is removed by breaking the receptacle. Occasionally flint stones called Kanikiroy are used as an additional material.

The most extensive remains were at Somapalaiem where twelve huge furnaces, some of them large enough as to accommodate 320 pots have been noticed; the production stopped due to competition by the year 1929. The only place where the industry was still flourishing was at Maddiledu. For black and white glass only green shrubs were used as a fuel, the batch being continuously heated for about 2 ½ days. Gradual heating was resorted to, which would otherwise turn the glass black. The industry was worked on co-operative basis, most of the capital being borrowed from the local financiers. The finished articles were sold at Adoni, Gulbarga, Raichur, Annavaram, Hamasavaram, Ragampeta and Papanaidupet. At Papanaidupet, in the last place glass was worked into minute beads [details see in chapter III][1].

Though this gave the description of the production process as being the same as North India about which we have references Dobbs' (1895) work, all those refer to the nineteenth century and at most eighteenth century glass industries. South India has been the cradle of Indo-Pacific beads, which travelled to far off places from Africa to Japan both in quantity of material and its technological skill (with man power) at least for 2000 years (Francis 1990b, 1991a, 1991b, 1996, 2002, n.d.; Gupta 1999; Katsuhiko and Gupta 2000; Kanungo 2000-01). It is highly likely that Indo-Pacific bead producers were producing their own glass.

However, it is unfortunate that we know nothing about the place and technology of glass production at these places as the archaeological evidence at sites like Arikamedu and Karaikadu have been limited to slags and waste pieces rather than concrete evidence like that of furnace and crucibles. Thus, it was intended to look for a site of early glass manufacture in the southeast. Here came the suggestion of Prof. Jayaraj Jacob of Sri Venketeswara University, Tirupati, who had located one such site, near Karkambadi tank, 15 km from Tirupati, which was to be developed by estate agents. A quick survey around the site not only yielded evidence of glass making but also evidences of this being of the late early historic period. Thus a small exposure of the site became more imminent. As the land was to be sold within a week, the owner, rather the watchman reluctantly permitted me to work there only for three days, out of which one day was used up in surveying the area. This made matters worse, but whatever little I could record is given below.

1.6 Karakambadi

The site is 15 km south of Tirupati near the Karakambadi tank. It is in the form of a bund about 150 m long and 3 to 4 m wide. Its height is 1½ m. adjoining to which the farmers have made their field boundaries. This bund is about 700 m north of the Karakambadi tank and 300 m east of a rail track (Map 2). There is littering evidence of glass manufacture in the form of numerous broken crucibles, slags and glass pieces all around the bund and in the nearby cultivated lands (Fig. 2). What is unusual about the find was that crucibles were unusually small, indicating the

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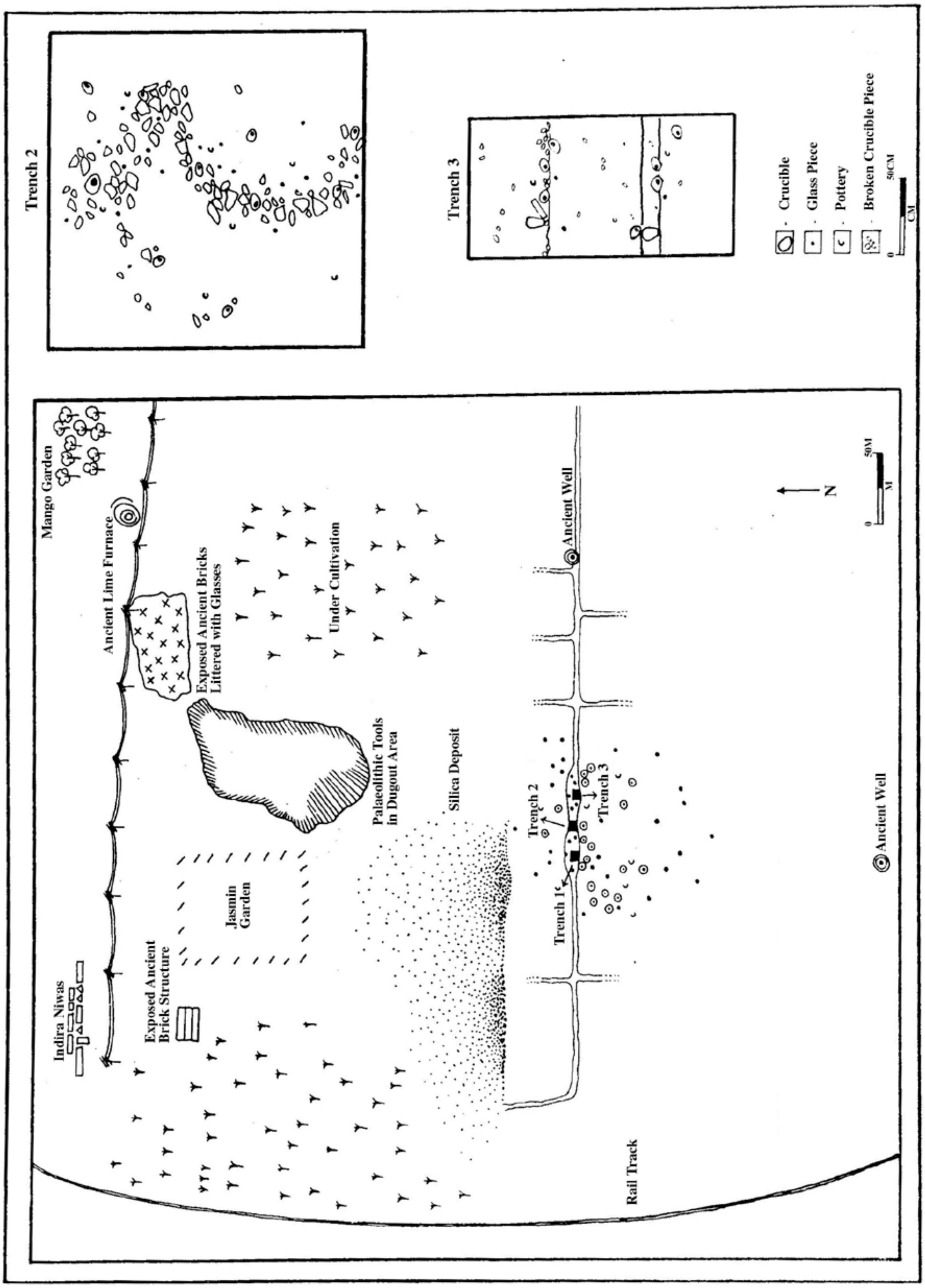
[1] [ ] insertion is mine



Map. 2: Ancient Glass Furnace Area, Tirupati, Andhra Pradesh

quantity of glass produced and number of crucibles put in the furnace. This size of the crucibles is not that surprising while considering that Somapalaiem glass furnace used to accommodate as many as 320 pots (crucibles) (Narayan Rao 1929, cited in Dikshit 1969). Enquiry revealed that the remains of this site and its by-products were spread over a large area towards Karakambadi tank. They must have been washed off with water, which comes next to the bund and stays there for months during the rainy season.

For verifying the existence of any furnace one trial trench of 2x2 at the centre of the bund and 2 small scraping sections of about one metre width with step trenches were carried out at two of the most wide and raised points of the bund. They are numbered as trench 1, 2 and 3 (Map 2).

1.6.1 Trench 2

The area was selected for the trial trench because of the occurrence of a large concentration of crucibles and slags. At the centre of the bund four pegs were placed at the four corners and a grid of 2x2 m was made with the help of threads (Fig. 3). One peg was placed at the highest point on the western side of the trench as datum point. Cleaning the area inside the grid gave a number of broken crucibles, burnt clay and bricks, glass pieces and a few potsherds. Uppermost 5 cm soil was removed from surface while retaining crucible pieces in situ to see the alignment. Crucible pieces were found to be haphazardly scattered (Fig. 4). A dig of 10 cm was then called as the layer 1. From this layer, a number of broken crucibles, comparatively more glass pieces (mostly green in colour), slags, and some pottery pieces were noticed (Fig. 5). Their concentration was less towards the northern side. This area looked more like the piling of debitage rather than (anything to do with) furnace area as most of the crucible pieces were of broken tops and body parts (probably broken intentionally to remove the frit/ glass), without any alignment. The soils were loose, not hard as it should be in a furnace. Besides this, potsherds were found inside. For confirmation another dig of 10 cm (layer 2) was taken and the evidence consists of only few pieces of broken crucibles

Fig. 1: A crucible from Early Historic Nevasa

Fig. 2: The site of Karkambadi

Fig. 3: Trench 2 before opening

Fig. 4: Alignment of broken crucibles in Trench 2

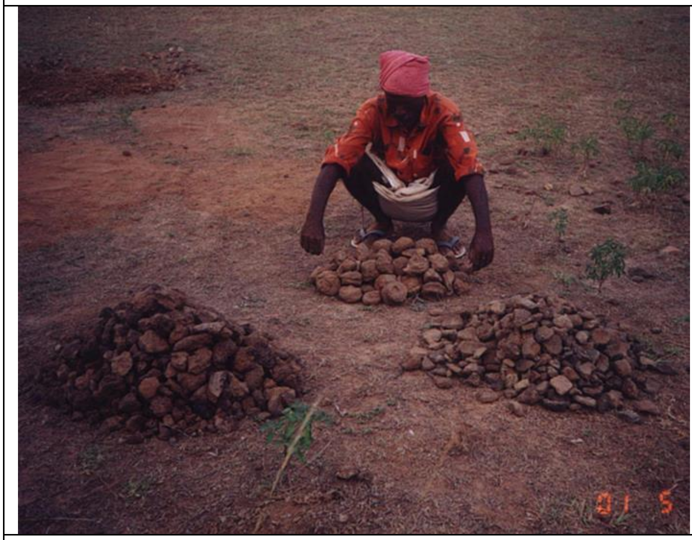


Fig. 5: Broken crucible pieces and glass slags from Trench 2

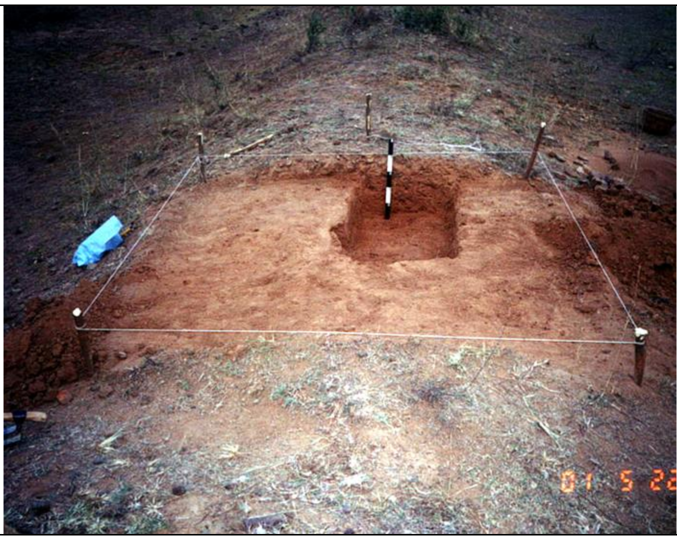


Fig. 6: Trench 2 with a test pit in one corner

in the centre in north-south direction. A test pit of 25 cm depth was then dug at the one corner. It revealed only loose soils which confirmed that it was not a furnace area (Fig. 6).

1.6.2 Trench 1 and 3

Due to constraints of time, two section scrapping of 1 m width from the top were attempted at the two most bulging and raised point of the bund. Debitage at these points was less but concentration of the crucible pieces was fairly high. However, at both places after scraping of about 5-8 cm, the soil was so hard that it was difficult to scrape (Fig. 7). It gave evidence of the furnace of glass making. As neither time nor resources at hand would have permitted to expose the full furnace, it was decided to expose the section fully. It confirmed the existence of furnace at both places with the exposure of a thick layer of slag along with in situ crucibles and bellow pipes (Fig. 8).

As the scraping progressed, the soil become more and more hard and after scraping of about 30 cm of hard soil at both the places, an arrangement of crucibles was located. At trench 3, the crucibles were found arranged in two layers and a cluster of slags below them. At the lower portion on both sides, a thick hard burnt clay section was visible and it was harder than any other soil. Perhaps that was a part of the furnace wall. The upper parts were evidently broken. The evidence of a bellow pipe attached to the wall confirmed that this was in fact part of the furnace wall. Also blowpipe was found in the upper level of trench 1, which indicated that the bellow pipes were not always fixed at the lowest level (Map 2). The inclination of wall indicates that the furnace was of conical shape and also of smaller size.

1.6.3 Crucible

There were hundreds of broken crucibles scattered on the surface and in the trenches, and in situ findings of crucibles with silica and pieces of flint stones inside them (Fig. 9). One crucible in trench 1 has given the evidence of frits in it.

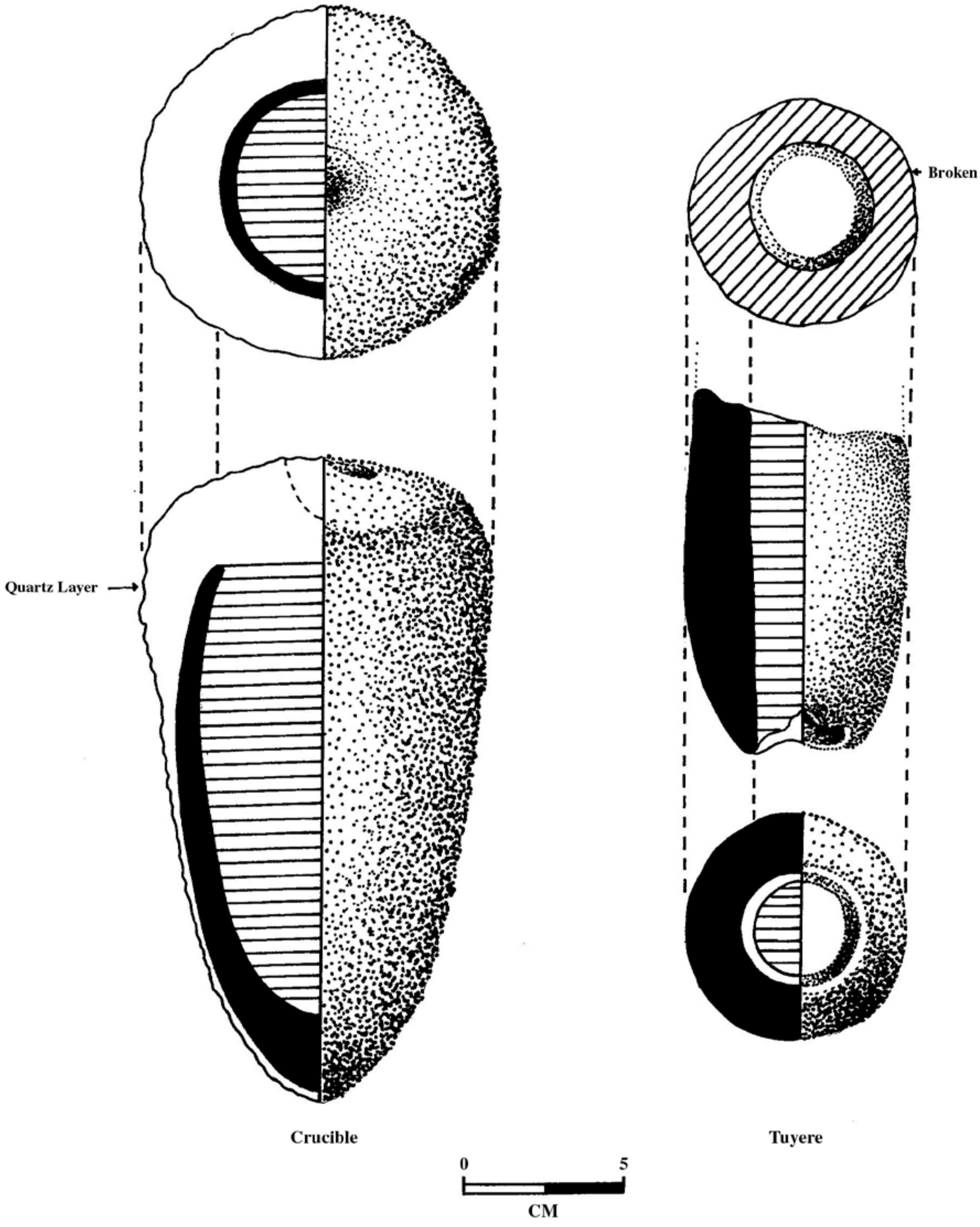


Fig. 10: Crucible and Tuyere

Both the crucibles and the bellow pipes were made of clay. Crucibles were of pointed U shape (Fig. 10). The pointed base shows that the crucibles were kept in a small tripod over fire. From the appearance of the crucibles it appears that they were coated with quartz, which would have served to keep them hot for longer periods. There was an opening at the top of the crucible. There is a possibility that the glassmaker might be closing the opening of the crucible with a layer of quartz after inserting the raw materials into it. After the frit/glass was made it was removed by breaking the upper portion of crucible; this resulted in a debitage of plenty of crucible rims with quartz incrustation and smaller body parts. After taking out the frit/glass from the crucible, they were flaked from all sides of the soils and impurity. One such piece of green coloured frit piece was found from Trench 1 (Fig. 11).

<u>Size of the crucible</u>

Length:	17 cm
Diameter of the opening:	21 cm

1.6.4 Pottery and Probable Date

Most of the associated pottery from the trench was simple coarse red ware. It appears to belong to the later part of the early historic period i.e., *c.* 4^{th}-5^{th} A.D. (personal communication Dr. Vasant Shinde, Deccan College). There are four potsherds with rims, with a thin layer of glass inside the potsherds indicating their association with glass making rather than deliberate glazing (Fig. 12 and 13). These layer of glass was uneven in its thickness and in no case were they found on the outer side. However, one piece of potsherd, was covered with a layer of glass all around, even on the broken borders. This confirmed that this pottery was associated with glass making.

Out of these glassy layered potsherds, three are globular pots with beaded rim (Fig. 14.A) and one is a small basin with internally thicken and undercut rim from inside

Fig. 7: Scraping at trench 3

Fig. 8: In-situ crucibles

Fig. 9: Broken crucibles, frit and tuyere

Fig. 11: In-situ frit

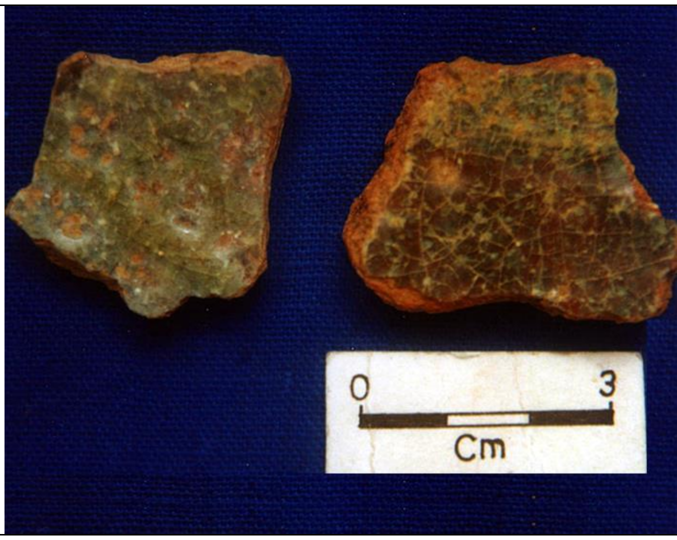


Fig. 12: Potsherds found in the trenches

Fig. 14: Rim Sections

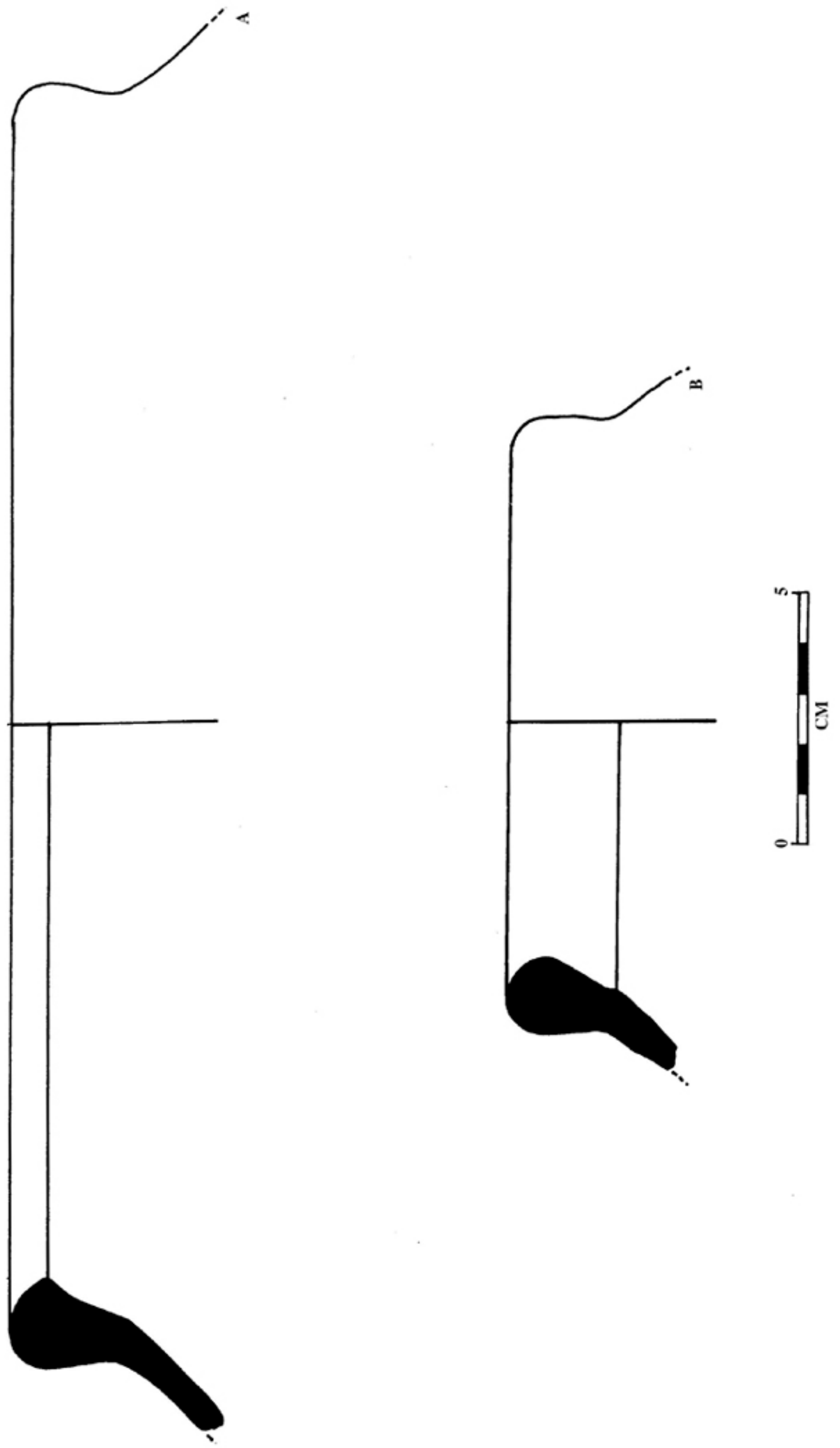


Fig. 14: Rim Sections

(Fig. 14.B). Rests all are nondescript. Some give an impression of a bluish colour but that is due only to a thick layer of glass.

Some potsherds without any glassy layer are also noticed with one exception that has a rim (globular pot with beaded rim). All of them are nondescript.

1.6.5 Raw Materials

50 meter northwest of the bund there lay a silica deposit forming a bund of about 300 m spilling towards the north. It is evident that this silica was transported to this area from some nearby source.

The area is rich in Palaeolithic deposits, one can see a number of Palaeolithic tools (hand-axe, cleavers, scrapers etc.) in the dugout area 200 m north from the bund. And at both the west and east corners of the dug out area there was exposure of ancient brick structures and floors. A few pieces of glass were also seen on these floors. There are two old wells with brick lining, one towards the east of the bund and another towards the south.

Mukharji (1888: 294-96) gives the following description of nineteenth century Indian glass and its products:

> The manufacture of glass in India is still in its most primitive state, the indigenous production being a coarse blue or green glass full of flaws and air bubbles. This is produced by melting *Reh* [soda] soil over a strong fire. Or, where *Reh* is not procurable, quartzose pebbles ground and mixed with an equal quantity of an alkaline ash is the material commonly used…. The glass thus obtained is chiefly used in the manufacture of bangles, beads, and crackle ware for perfumes. White glass was obtained by melting broken pieces of European ware, of which small vessels are sometime made. But glassware is now almost entirely imported from Europe. However glass vessels of Patna in Bengal have been highly admired and are of graceful

shapes and beautiful colours. In the north-western Provinces crackle ware is largely made in the Bijnor district. These mostly consist of bottles or flagons, for pilgrims to store and carry water of Ganges to far off places. Small flasks and glasses are made at Deoband, a town in the district of Saharanpur. Walking sticks of glass are made at Lucknow. Bangles and lamp chimneys are made at Delhi and Lahore in the Punjab, globes and pear-shaped carboys at Karnal, and small wares at Hushiarpur. Bottles and beads, both white and of various colours, are made at Jaipur chiefly in the School of Art. One or two private men in the bazaar also do the work. The colour produced is cobalt blue, Indian red, marbled and dark green. Bangles of various colours are made both in the town of Jaipur as well as in many other places in the State. Plaques of frosted glass are made at Gwalior, the pattern being chiselled on the glass. Bangles of various colours and designs are made in Indore and in Madras Presidency. Small quantities of glassware are made at Salem, Trichinopoly, and Anantpur. The colour of the glass is usually various shades of green and claret. In Mysore bangles, rings, and phials for scents are made in large quantities at Matood and Chinnapatna. In the Bombay presidency glassware is manufactured in very small quantities.

1.7 Present Day Production of Glass

A glass factory has its own uniqueness. Huge bins called silos hold the raw materials for glassmaking. These materials are powders that look very much alike but can produce greatly different results. Giant roof ventilators and huge stacks release the terrific heat required to melt these powders to a white-hot liquid. At the hot end of the plant are the furnaces.

1.7.1 Mixing: the principal raw materials are weighed and mixed in the proper proportions. This mix is called the batch. The manufacturer then adds cullet to the batch. Cullet is either recycled glass or waste glass from a previous melt of the same kind of glass. Adding cullet to the batch eventually reduces the amount of heat needed to melt the new batch of raw materials. Besides, materials that otherwise would be wasted get used in this manner. Sometimes, glassmakers produce a new batch entirely from cullet. After mixing, the batch goes to the furnaces.

1.7.2 Melting: the mixture melts at 2600 to 2900 °F (1425 to 1600 °C), depending on its composition. In the past, the batch was melted in refractory pots (small clay pots), heated in wood or coal burning furnaces, which still are used for hand working. In modern glass plants, most glass is melted in large tank furnaces. They are special refractory pots and hold up to 3,000 pounds (1,400 kilograms) of glass. They are heated by gas or oil, and a single furnace may contain 6 to 12 pots. Small quantities of optical glass, art glass, and specialty glass are still made in refractory pots.

Larger quantities of glass are made in furnaces that are called day tanks because the process that goes on in them takes about 24 hours. These tanks can hold 1 to 4 tons (0.9 to 3.6 metric tons) of glass.

1.8 Shaping and Finishing of Glass

When working molten glass, five basic methods are employed to produce an almost limitless variety of shapes: casting, blowing, pressing, drawing, and rolling. After the shaping process, annealing is used to increase the strength of the glass. Tempering and other finishing techniques may also be used to further strengthen the glass. For traditional glass bead production also the same procedure is followed but manually.

1.8.1 Blowing: introduction of the blowing process in about 1st century B.C. on the Phoenician coast, and its rapid diffusion to other places, made large-scale glass production of glass possible. This changed the status of glassware from an elite item to an everyday material. Thus blowing became the standard way of shaping glass vessels from the 1st century B.C. to the present day (Fig. 15). Using a hollow iron pipe about 4 to 5 feet (1.2 to 1.5 meters) long with a mouthpiece at one end, the glassblower, or gaffer, collects a small amount of molten glass on the end of the pipe and rolls it against a paddle or metal plate to shape its exterior and cool it slightly. The gaffer then blows into the pipe, expanding the glass into a bubble (Fig. 16). By constantly reheating it at the furnace opening, blowing, and rolling, the gaffer controls the form and thickness of the glass. The bulb can be squeezed, stretched, twirled, and cut. From time to time, the worker reheats the glass to keep it soft. When the red-hot glass has been given its final shape, it is removed from the pipe. Glass can also be blown into iron-moulds.

Stretching the hot hollow bulb while blowing produces the glass pipe and cutting them into pieces to make beads is the most ancient of bead production techniques. This produces its own typical debitage.

1.8.2 Pressing: This is accomplished by dropping a hot gob of glass into a mould, then pressing it with a plunger until it spreads and fills the inside of the mould. To be pressed, an article must be of such a shape that the plunger can be withdrawn. Baking dishes, glass blocks, and lenses are often pressed.

1.8.3 Drawing: Molten glass also can be drawn directly from the furnace to make tubing, sheets, fibers, and rods of glass. Almost all flat glass produced today is float glass. It is shaped by drawing a wide sheet of molten glass into a furnace containing a bath of molten tin. This furnace is called a float bath because the glass "floats" in an even layer on the perfectly smooth surface of the molten tin.

Drawing a stream of molten glass out of the furnace makes a glass rod. Drawing the molten glass around a rotating cylinder or cone called a mandrel makes tubing. Air blowing through the mandrel causes the glass to form a continuous tube. Indo-Pacific beads at Papanaidupet are produced more or less in the same manner, the only exception being that instead of machines highly skilled craftsmanship is used to produce them (see chapter III). However in recent times this is also being done mechanically and in India Prasant Beads Industry of Varanasi produces such mechanized Indo-Pacific beads (Fig. 17). Fiberglass is also made by drawing the molten glass through tiny holes in the bottom of the furnace.

1.8.4 Rolling: Plate glass was originally made by rolling molten glass on a flat surface; later, it was made by continuous rolling between double rollers.

1.8.5 Casting: This is an ancient process. Molten glass is poured into a mould and allowed to solidify (Fig. 18). The glass may be poured either from ladles or directly from the furnace, or drained from the bottom of the furnace. Casting is used in the production of architectural glass pieces, art glass, laser glass, and telescope mirrors.

1.8.6 Lampworking: This is a method of reshaping solid glass into new forms by reheating it. Lampworkers reheat various kinds and sizes of glass tubing and rod over a blowtorch fired by gas, oxygen or oil. They can then bend, twist, stretch, and seal the softened glass into a variety of objects. In this way, lampworkers make a variety of beads and sometimes moulds are used to give them different shapes (see chapter III). Besides, miniature animals, vases, sail ships, scientific equipment, and parts for incandescent lamps and various kinds of industrial equipment are made using this technique.

1.8.7 Annealing: Reheating the glass and gradually cooling it according to a planned time-and-temperature schedule is called annealing (Fig. 19). It is a process that removes the stresses and strains remaining in glass after shaping. Most glassware is annealed just after it has been formed. If it is not annealed, glass may shatter from tension caused by uneven cooling. Almost all glass beads produced either with traditional technologies or with modern are annealed after production to avoid cracking.

1.8.8 Tempering: This is a process in which a glass article that is already formed is reheated until almost soft. Then, under carefully controlled conditions, it is chilled

Fig. 13: Potsherd with rims found in the trenches

Fig. 15: Painting of a melting furnace by John Mandeville: 15th century (*After* A. Kottmann 2002)

Fig. 16: Expanding the bubble

Fig. 17: Drawing ports of mechanical Indo-Pacific bead producing furnace at Prashant Bead Industry

Fig. 18: Casting of glass

Fig. 19: Annealing chambers at a glass industry in Firozabad

suddenly by blasts of cold air or by plunging it in oil or certain chemicals in a liquid state. This tempering treatment makes the glass much stronger than ordinary glass. Glass articles can also be tempered with chemicals.

Glass may be decorated in a number of ways, including cutting, using facets, grooves, and depressions: engraving is done using a diamond point, metal needle, or rotating wheels; etching is done using acid; sandblasting is done using sand, flint, or powdered iron; in cold painting, paint is applied to glass but not affixed by firing; in enamel painting, enamel colours are painted and then affixed through firing; and in gilding gold leaf, gold paint, or gold dust is applied.

1.9 Firozabad: the Glass Capital of India

Firozabad is a small town in the Indian State of Uttar Pradesh, 40 kilometres from Agra and the Taj Mahal. The town has a natural cluster of labour-intensive small-scale glass manufacturers and secondary producers of decorated ware, bangles, beads, handmade tumblers and tableware. There are also a few medium scale units using semi-automatic equipment to manufacture industrial glass products such as automobile headlight lenses, glass bulbs, shells and consumer products such as bowls and ashtrays. The glass industry over here accounts for almost 70 per cent of the country's glass production in the small-scale sector and is also critical to the livelihood of the town's population.

Most importantly, it has the monopoly over the glass and glass rod supply to the bead producers in India. There were/are instances of both local glass production at bead production places and at various other places but most could not stand the stiff competition given by Firozabad in the recent past.

The furnaces used by the industry are modified forms of a Japanese design, which has been acquired many decades ago, without understanding the basic design. This results in decreased furnace life and fuel efficiency.

The different types of furnaces employed in the cluster are: (i) tank furnace (coal fired), (ii) tank furnace (oil fired), (iii) open pot furnace, (iv) closed pot furnace, and (v) muffle furnace, used for the finishing of bangles. In addition, there are a few, partially automated units employing oil-fired furnaces. The primary form of energy used in the cluster has been coal, followed by residual fuel oil (RFO). Being located within the Taj Trapezium Zone, the industry now also faces the consequences of the Supreme Court mandate banning the use of fuels other than natural gas within the area.

1.10 Beads

Beads are small, colourful, frequently standardized, inexpensive and often quite beautiful. They can be arranged in almost endless configurations. Beads are universal, and are one of the oldest forms of human expression. They can and have been made from virtually any solid material (Francis 1982a). They have been worn in strings or necklaces, which was the common mode of ornamentation known from very ancient times. What interest more is the variety of their shapes, mode of decoration and the different material employed in their manufacture (Margabandhu 1971: 764). Inorganic beads become very important in archaeological findings due to its durability and are generally protected from weathering or corrosion by some constituent in the soil in which they lie, preserves shape and colour and decoration.

During the early phase of bead research, Eisen (1916: 2) defined a bead as “a unit of necklace and perforated by one or several bores”. Horace Beck, who introduced a systematic approach for studying beads for the first time, mentioned “to describe a bead fully, it is necessary to state its form, perforation, colour, material and decoration” (Beck 1928: 1). Later Sleen (1973: 16) added the importance of manufacturing methods in the study of beads. Going beyond the mere descriptive classification of beads Kenoyer (1986: 16) argued for their symbolic value. Dubin (1987: 17) elaborated by saying that “beads so often mirror the culture of which they are a part that they tell us a great deal about the social, political, economic, and religious lives of the people who have made and worn them”. Francis (1990a, 1990b, 1991b, 1996, 2002; Basa *et al.* 1991; Glover and Henderson 1994; Basa 1991, 1994-95) emphasized beads as an important item of trade in Asia. Deo (2000: viii) writing about Indian beads mentioned, "Indian Beads represent the culture and technology of the period to which they belong". This echoed Margabandhu (1971: 1203) generalized comment on ancient technology as "technological development is closely linked to the various industrial and technical arts and other developments during a particular period". Francis (2002) summed everything about beads in the following words, "they [beads][2] function in the economic, social, identical, and aesthetic realms of culture. They encode human behaviours, including those difficult to assess archaeologically. The ancients held them in awe. They [beads] were magical as well as valuable. They incorporate powers and were both stores and evidence of wealth".

Beads, amulets and pendants help to interpret certain aspects of social life in the past. Though this is true for most of the societies in India, such an interpretation gains enhanced tempo owing to the corroborative evidence met with in ancient literature and ethnographical evidences. Beads have been used in many instances to escape the evil eye, and it naturally takes the form of the "eye" on the body of the beads and other allied forms. Certain beads are invested with medicinal properties which are supposed to cure some ailments. Sometimes they are used as charms. The religious significance of certain beads and pendants is evident in many cases. Beads may also indicate the social status of the user. Certain bead materials, if non-indigenous (as for instance, lapis lazuli) have their origin in distant lands which indicate regional or commercial contacts or/and cultural migrations. Beads and pendants are thus capable of providing very useful data in building up the cultural history of a society (Deo 2000: 1). Combinations of these qualities make beads especially interesting artifacts to study. However this also adds to the limitation of bead study in dating any associated materials as rightly pointed out by Mackay (1944) in the following words:

[2] [ ] insertion is mine.

> Possession of magical properties – so often ascribed to beads in early days – such as protection from the evil eye or from disease, sentimental and aesthetic reasons also may cause beads to be preserved from generation to generation; and being small and mostly rounded in one plane at least, they are likely to roll down or be washed away by rain from their original level. Besides remarking in his introduction that the large amount of wear on some of the beads found in relic caskets at the Dharmarajika stupa and elsewhere at Taxila that they were already old and valued at the date when they were buried.

The study of ancient Indian glass beads has received very scanty attention because accurately dated specimens are comparatively few and are inadequately published. The subject has four main aspects (i) archaeological data; (ii) ethnographic investigation; (iii) scientific and technological study of dated specimens; and (iv) literary references to glass beads in Indian literature. Unless these all are marshalled fully no accurate picture of the glass beads of ancient India can be obtained.

1.10.1 Early Beads

Beads first appear with the advent of modern man, Homo sapiens, at least forty thousand years ago, and probably have been made and used by every culture in the world since then. However, use of organic material beads could be much earlier. They have always been treated as important personal possessions and are well represented in the archaeological records.

The earliest known beads are associated with Neanderthal man. They were discovered at La Quina, an archaeological site in France, and have been dated to approximately 38,000 B.C. They are made from grooved animal teeth and bones and were worn as pendants. They are unique to the Neanderthal period. Recently, shell beads of about 40,000 B.C. have been found in Ucagizli Cave in Turkey (Powell 2002: 12) (Fig. 20).

More sophisticated bead craftsmanship developed during the Gravettian and Aurignacian periods (30,000-18,000 B.C.). Grooving ornaments gave way to perforation; pieces of bone and ivory were ground into definite bead shapes and decorated with incisions. Important bead discoveries from this period have been made at the sites of Dolni Vestonice and Pavlov in Czechoslovakia. Some of the beads were carved in the shape of female breasts and torsos and were probably associated with rituals for increasing fertility (Dubin 1987: 22).

It is only in the Upper Palaeolithic period in western Europe, known as the Chatelperronian period (*c*. 31,000 B.C.), that beads appear in quantity and as creations of modern man (Dubin 1987: 21). That this period witnessed an elaborate development both in the design of individual beads, and in the ways in which beads and pendants were combined and used is universally recognized (Francis 1981, 1982b). Upper Palaeolithic beads have been found at several localities in India, China, and Korea; however the date of this period in this region is about 17,000-10,000 B.C.

With the invention of the technology of storing surplus food, the Neolithic man probably got more time for development of the crafts. Further with the introduction of irrigation systems, river valley societies in Mesopotamia (present-day northern Syria and Iraq), India, and Egypt evolved into sophisticated, complex city-states.

By 3500 B.C. metal weapons and tools came into use alongside traditional stone implements. Of great significance for the study of beads was the expansion of long-distance trade between the rapidly evolving, agriculturally intensive civilizations of the Mediterranean and the mountain cultures of western Asia. In the earliest civilizations, one way in which social differences were reflected was the display of ornaments, including beads.

The uneven distribution of the regions' resources created networks of commercial relations that united these societies and encouraged the exchange of cultural artifacts.

For example, Lapis lazuli was mined in the ancient Afghan region of Badakhshan, fifteen hundred miles away from the Sumerians and a thousand miles away from the Indus people, who exercised no political control over Afghanistan's production centers or the trade routes traversing the rugged plateaus; yet they were the major users of Lapis lazuli. Mesopotamian and Egyptian priests and kings employed full-time jewellers, and through their patronage beadmaking technology developed rapidly. Indus people were not far behind with their sophisticated and large scale production and use of beads.

Both beads and their raw materials to make them have been important trade items for Millennia. However, throughout antiquity, raw materials were traded more often than finished beads (Dubin 1987: 30). Finished beads were traded usually by more technically advanced cultures to less advanced ones. The early Greeks and Mycenae, who established trading contacts with the Bronze Age cultures in the Baltic, exchanged copper and bronze implements for rare amber, with which they made beads. In effect, they extended their technical expertise to the less developed European regions while absorbing new materials and forms of adornment. Eventually, large quantities of glass beads would be carried thousands of miles by the ancient Phoenician and Roman seafaring civilizations.

Towards the beginning of the 1^{st} millennium B.C. and in subsequent centuries a full-fledged urban revolution took place. Beads are not an exception to this development. This is evident from the beads found at Hastinapura, Ujjain, Pataliputra, Rajghat, Rajagriha, Vaisali, Kausambi, Paithan and many other sites, which includes a large number of glass beads.

Although glass beads are known by the Seventh and Eighth Dynasties (*c.* 2181-2160 B.C.) in Egypt, they were first manufactured for a large commercial market beginning with 1400 B.C. The new Kingdom, especially the later phases of the Eighteenth Dynasty (*c.* 1350 B.C.), is generally considered to be the world's first great glassmaking epoch. The proximity of Egyptian glass factories to the palaces at

Thebes, Amarna, and Shurak attest to the royal patronage of glassmaking. Soon glass was manipulated to make beads. Once practical techniques had been discovered to transform beads and its secret was known to the local craftsman, glass gradually replaced all other materials to a considerable extent: first as expensive specimens which served the elite; later, the common folk could use the glass on account of the easy manipulation and mass production at low cost. Since then it has been the most important material for bead manufacture. This is because of its beauty, durability, versatility and pliability. This is evident from the finding of most ancient glass in the form of beads. However, in the early period and still among the tribes the preferred choice of colour remained the same as that of stone; for example, the Egyptians favoured deeply coloured opaque glass, since it closely resembled lapis lazuli and turquoise, and Nagas prefer dark red or bluish-green coloured opaque glass, which resembles the colour of carnelian and agate.

A decline in glassmaking skills occurred in Egypt after the end of the Nineteenth Dynasty (*c.* 1200 B.C.), and glass virtually disappeared after the fall of the New Kingdom (1085 B.C.). It was revived in Ptolemaic times, during the fourth century B.C., when Alexander the Great founded Alexandria, a cosmopolitan centre with international trading links. The term “Roman” and “Roman-period” glass are used to describe glass production from 100 B.C. to A.D. 400 within the boundaries of the Roman Empire, including the factories at Syria, Egypt, Italy, Switzerland, Rhineland, France, and England. Everywhere the Romans went, they took glass beads to trade. Produced in a large range of colours, patterns, and frequently complex techniques, Roman-made glass beads were widely coveted (Dubin 1987: 55). More glass was made in the first century A.D. than in the previous fifteen hundred years. Because the material was widely obtainable, relatively inexpensive, and no longer reserved for the elite, everyone could now afford to wear beads.

1.10.2 Early Beads from India

In undivided India beadmaking was one of the most ancient arts since in most places the requisite materials were ready to hand (Basa 2002: 4); this was not the case in

Mesopotamia, where even the commonest stone was difficult to procure (Marshall 1931: 510).

Some of the oldest beads in the world have been found in India. Disk beads of ostrich eggshell and an olivia shell bead from Patne in Maharashtra date to about 23, 000 B.C., and a bone bead and several cattle incisor teeth grooved for stringing, found at the Kurnool Cave, date to 17,000 B.C.

Evidence of beads in Mesolithic sites are found at Langhnaj (Sankalia 1965), where objects like dentalium shell, perforated vertebrate of birds and perforated pieces of bone have been recorded as decorative ornaments, and the site of Mahadaha (Sharma et al. 1980) in Uttar Pradesh has yielded perforated bone ornaments along with evidence of the stages of their manufacture (Fig. 21).

By the early Neolithic period (7000-5500 B.C.), beadmaking technology was sufficiently developed for beads to be shaped and not just simply grooved or pierced. Beads of softer stones, such as steatite, turquoise, lapis lazuli, and alabaster, were produced and traded in the early Indus valley site of Mehargarh (Kenoyer 1986: 19; Dubin 1987; Vidale 1995; Basa 2002: 3). The Mehargarh excavations also revealed that pump or bow drills with chert bit were used to perforate stone beads. Besides these, we also have similar evidence from Hallur, Tekkalkota in south India and in the burials at Nagarjunakonda. Evidence of beads and pendants, well made and neatly perforated, has come to light from Mahagara in Uttar Pradesh (Sharma *et al*. 1980); Hallur in Karnataka reported perforated terracotta discs, whereas Chirand in Bihar has given beads of steatite and faience and Pusalpadu have reported steatite disc beads in a Neolithic context (*IAR* 1962-63: 6).

It is, however, with the Harappan and Chalcolithic urban complexes that one comes across the spectacular evidence of stone and shell beads indicative of an established local industry. Niharika (1993) reports more than thirty varieties of stones used by the Harappans and more than nineteen by the Chalcolithic people to make beads.

However, there are some exceptions, like the absence of beads in Chalcolithic sites of Jorwe, Maheshwar and Nasik. It is quite likely that this has to do with insufficiently excavated area than the culture. Beadmakers of Harappa, which alongside Mohenjo-daro was one of the twin capitals of the Indus civilization, mastered stone bead cutting by 2600 B.C., and they probably traded carnelian and agate beads to Sumer, 1600 miles to the west. There were also beads of bone, shell, pottery, faience, steatite (including glazed steatite), onyx, amethyst, feldspar, turquoise, lapis lazuli, copper, bronze, silver, and gold. Beadmakers in the Chalcolithic period were also not far behind in employing longer cylinder stone drills made of chert and jasper. There is evidence of the use of even copper drilling at Inamgaon (personal observation).

With the fall of Indus civilizations about 1600 B.C., long-distance trade in Indian beads diminished for the next thousand years. Although beads appear to have been made in quantity, they were primarily for local use.

From the day of the Indus Valley civilization to the present, Indian craftsman have produced exquisite beaded jewellery. Quantities of beads from archaeological sites, as well as early icons, reliefs on friezes, and literary texts, affirm that beaded jewellery has always been important to all classes of Indian society; rich and poor, sacred and secular. Ancient terracotta figurines, often representing the gods of the common people, were depicted in typical daily dress wearing beaded necklaces, earrings, girdles, and bracelets. Typical examples are from sites like Chandraketugarh and Tamluk (Fig. 22). Sculptures of Buddha are not far behind in these characteristics.

1.10.3 Ancient Literature

Mention of glass (*kāca*) beads occurs in early Sanskrit and Buddhist literature. Mukharji (1888), Ghosh (1924), Chaudhuri (1986), Dikshit (1964-65, 1969) and Deo (1987, 2000) lists a few of them; for instance in the *Yajurveda* (*c*. 1200 B.C.)

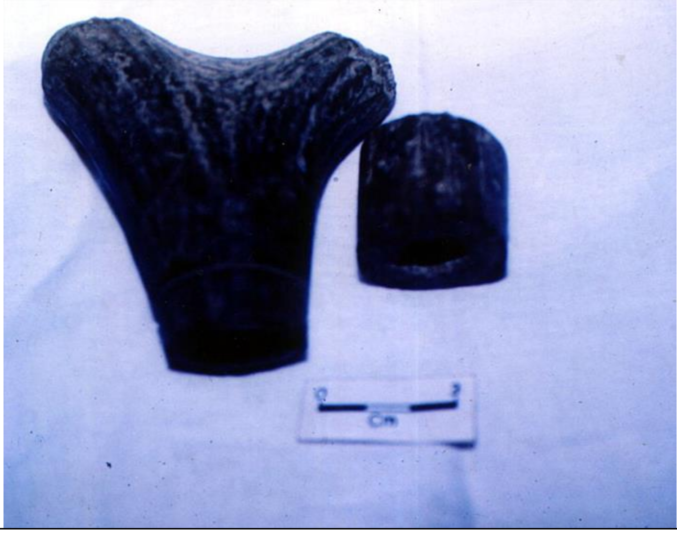


Fig. 20: 40, 000 years old shell beads from Ucagizli Cave, Turkey (*After* E.A. Powell 2002)

Fig. 21: Bone beads with evidence of manufacture, Mahadaha

Fig. 22: Mother Goddess from Tamluk (*After* M. Postel 1989)

kāca is mentioned as one of the articles of which female ornaments were made by means of stringing with gold thread. In *Śatapatha Brahmana* (*c*. 1000 B.C.), the word *kāca* refers to glass beads which were used for decoration of horses in the *Aśvamedha* sacrifice. Besides, there are references to women wearing glass beads and to the wearing of or threading of one hundred and one beads of glass. The *Taittiriya Brahmana* also refers to the wearing of glass (beads). Coming to the Sutra period, one comes across references to glass beads in the *Baudhayana Srauta Sutra* and in *Manava Srauta Sutra*. Glass is also mentioned in the *Mahabharata*, and in *Yuktikarata* the effects on the human system of drinking water out of a glass tumbler are stated to be the same as those of drinking out of a crystal cup. *Ramayana* refers to the makers of glass, the '*kachakara*'. Kautilya's *Arthaśāstra* (3rd century B.C.) alludes to the making of glass at two places: 1) *Adhikarana* 14, *Adhyaya* 1, *Sutra* 12, lays down that in order to punish the enemy, obstacles like the smoke of Puti, Karanja leaves….as in manufacture of glass, by burning cowdung etc., should deliberately be created; 2) another passage *Adhikarana* 2, *Adhyaya* 14, *Sutra* 45 though somewhat currupt but interpreted to be the process of making gold-foiled glass beads. It describes about the piercing of glass beads in a molten stage for the purpose of setting ornaments and the setting of glass-fragments (*kśepana*) in gold ornaments for the preparation of the so-called glass-gems. Amongst the various punishment inflicted for stealing, it is ordained that a person stealing articles made of copper, bronze, tin, glass and ivory was to be fined 46-96 panas; thus glass objects were classified among the miscellaneous objects. The *Māhavagga* section of *Vinayapitaka* (Buddhist period) alludes to the use of shoes ornamented with glass as being forbidden to the Buddhist *bhiksus*. The *Chullavagga* similarly forbids the use of glass bowls. In Puranas (*c.* 4-14th A.D.), some texts like the Matsya, the Vishnu, the Bhagawata, etc. assigned to Gupta period refers to *kāca* (beads). Apart from these, references to glass-vessels for preserving medicines can be seen in texts like *Charaka* and *Śusruta Samhita*. In the *Amarakosa* (7th c.A.D.) mention of glass-vessel, glass cup and glass dish are made. *Brihatsamhita* (6th c.A.D.) also mentions glass and there is mention of spectacles in *Vyasoyogi Carita* by Somnath Kavi (*c*. 1446-1539 A.D.).

One of the earliest literary references to glass or quartz is a Tamil word *palingu* used in the *Manimekalai* (3, 64), possibly a curruption of the Sanskrit word *sphatika* though the prakrit *phalika* (quartz), occurs in the Bhattiproru inscription of the 2nd c. B.C. (Srinivasan and Banerjee 1953: 113).

Foreign travel accounts of Pliny (translated by Bostock and Riley), Periplus (translated by Schoff 1912) and Strabo (Majumdar 1960: 279, 394) consider Indian glass to be of high quality as they were made of pounded quartz rather than silica.

1.10.4 Ethnography

Unlike the clay tablets in west Asia, we have little information about the method of glass making in ancient India, nor do we know how raw materials for glass were quarried. There are 19th century British Government accounts of glass industries in India by Halifax 1892; Dobbs 1895; Mukherjee 1895; and anonymous 1895. In the 20th century there has not been any study on the Indian glass as a whole, and except for the solitary work *History of Indian Glass* by M.G. Dikshit (1969), nothing noteworthy has been done. Since then not only have fifty years of discovery and new technologies to study them passed, but Dikshit's study also lacks any ethnographic work and discussions on production technologies of glass and glass beads. However, in India, glass beads are commonly used even today and particularly with traditional values by the tribal world. More particularly, they are produced using more or less the same techniques that have been used for thousands of years in several places in India. Of course, the modern technologies have also emerged in the meantime. However, both co-exist together perhaps due to the fact that tradition in India is a closed-door system. Traditionally glass beads are produced in India in a major way in at least three different locations, using altogether different techniques. These are at: 1) Papanaidupet, Andhra Pradesh (drawing method); 2) Purdalpur, Uttar Pradesh (furnace winding and manual pulling/drawing method); and 3) Varanasi, Uttar Pradesh (lamp winding method) (see chapter III). Each production process leaves behind debitage unique to its individual manufacturing process. Archaeologically, it is imperative to identify and record these production techniques of glasswork and to identify the various specific waste products to formulate certain criteria that can be used to draw better inferences about archaeological sites from which glass debitage has been found. These production places have not only been producing beads for the local need but for export throughout the world since early historic time (2nd C.B.C) (Kanungo 2000-01, 2001a, n.d.b.; Francis 2002).

India has not only been the cradle of ancient civilization but also shows a continuity in age-old traditions, both in the general belief system that pervades the whole of India, and in the culture of numerous primitive communities located in pockets across the country. Some of them are large-scale users of glass beads since long. To understand the procurement-to-dispersal mechanism of beads and their use by the present day primitive communities like Bondos and Juangs of Orissa and Nagas of Nagaland, ethnographic studies have been carried out (see chapter IV) (Map 1).

CHAPTER – II

HISTORY OF INDIAN AGRICULTURE

2.1 INTRODUCTION

Indian agriculture has long, old and beyond memory history which begins the Indus valley civilization. One of the most old water regulating structure in the world is Grand Anicut dam on river Kaveri (1st-2nd Century CE)[1].

Indian agriculture began by 9000 BCE as a result of early cultivation of plants, and domestication of crops and animals. Settled life soon followed with implements and techniques being developed for agriculture. Double monsoons led to two harvests being reaped in one year. Indian products soon reached the world via existing trading networks and foreign crops were introduced to India. Plants and animals—considered essential to their survival by the Indians—came to be worshiped and venerated.

The middle ages saw irrigation channels reach a new level of sophistication in India and Indian crops affecting the economies of other regions of the world under Islamic patronage. Land and water management systems were developed with an aim of providing uniform growth. Despite some stagnation during the later modern era the independent Republic of India was able to develop a comprehensive agricultural program.

Reference 1: Stein, Burton (1998), ***A History of India*****, Blackwell Publishing, ISBN 0-631-20546-2**

2.2 HISTORY OF INDIAN AGRICULTURE

2.2.1 Early History

Wheat, barley and jujube were domesticated in the Indian subcontinent by 9000 BCE. Domestication of sheep and goat soon followed. This period also saw the first domestication of the elephant. Barley and wheat cultivation—along with the domestication of cattle, primarily sheep and goat—was visible in Mehrgarh by 8000-6000 BCE. Agro pastoralism in India included threshing, planting crops in rows—either of two or of six—and storing grain in granaries. By the 5th millennium BCE agricultural communities became widespread in Kashmir. Zaheer Baber (1996)[1] writes that 'the first evidence of cultivation of cotton had already developed'. Cotton was cultivated by the 5th millennium BCE-4th millennium BCE. The Indus cotton industry was well developed and some methods used in cotton spinning and fabrication continued to be practiced till the modern Industrialization of India. A variety of tropical fruit such as mango and muskmelon are native to the Indian subcontinent. The Indians also domesticated hemp, which they used for a number of applications including making narcotics, fiber, and oil. The farmers of the Indus Valley grew peas, sesame, and dates. Sugarcane was originally from tropical South Asia and Southeast Asia. Different species likely originated in different locations with *S. barberi* originating in India and *S. edule* and *S. officinarum* coming from New Guinea. Wild Oryza rice appeared in the Belan and Ganges valley regions of northern India as early as 4530 BCE and 5440 BCE respectively. Rice was cultivated in the Indus Valley Civilization. Agricultural activity during the second millennium BC included rice cultivation in the Kashmir and Harrappan regions. Mixed farming was the basis of the Indus valley economy. Denis J. Murphy (2007)[2] details the spread of cultivated rice from India into South-east Asia:

References 1 : Baber, Zaheer (1996), The Science of Empire: Scientific Knowledge, Civilization, and Colonial Rule in India, State University of New York Press, ISBN 0-7914-2919-9.

Reference 2: Murphy, Denis J. (2007), People, Plants and Genes: The Story of Crops and Humanity, Oxford University Press, ISBN 0-19-920713-5.

Several wild cereals, including rice, grew in the Vindhyan Hills, and rice cultivation, at sites such as Chopani-Mando and Mahagara, may have been underway as early as 7000 BP. The relative isolation of this area and the early development of rice farming imply that it was developed indigenously....Chopani-Mando and Mahagara are located on the upper reaches of the Ganges drainage system and it is likely that migrants from this area spread rice farming down the Ganges valley into the fertile plains of Bengal, and beyond into south-east Asia.

Irrigation was developed in the Indus Valley Civilization by around 4500 BCE. The size and prosperity of the Indus civilization grew as a result of this innovation, which eventually led to more planned settlements making use of drainage and sewers. Sophisticated irrigation and water storage systems were developed by the Indus Valley Civilization, including artificial reservoirs at Girnar dated to 3000 BCE, and an early canal irrigation system from circa 2600 BCE. Archeological evidence of an animal-drawn plough dates back to 2500 BC in the Indus Valley Civilization.

2.2.2 Vedic period – Post Maha Janapadas period (1500 BCE – 200 CE)

Accoridng to Gupta (2004) [1] the summer monsoons may have been longer and may have contained moisture in excess than required for normal food production. One effect of this excessive moisture would have been to aid the winter monsoon rainfall required for winter crops. In India, both wheat and barley are held to be *Rabi* (winter) crops and—like other parts of the world—would have largely depended on winter monsoons before the irrigation became widespread. The growth of the *Kharif* crops would have probably suffered as a result of excessive moisture. Jute was first cultivated in India, where it was used to make ropes and cordage. Some animals—thought by the Indians as being vital to their survival—came to be worshiped.

Reference 1: Gupta, Anil K. (2004), "Origin of agriculture and domestication of plants and animals linked to early Holocene climate amelioration", *Current Science*, 87 (1), Indian Academy of Sciences.

Trees were also domesticated, worshiped, and venerated—*Pipal* and *Banyan* in particular. Others came to be known for their medicinal uses and found mention in the holistic medical system *Ayurveda*.

In the later Vedic texts (c. 1000–500 BC), there are repeated references to iron. Cultivation of a wide range of cereals, vegetables, and fruits is described. Meat and milk products were part of the diet; animal husbandry was important. The soil was plowed several times. Seeds were broadcast. Fallowing and a certain sequence of cropping were recommended. Cow dung provided the manure. Irrigation was practiced.

The Mauryan Empire (322–185 BCE) categorized soils and made meteorological observations for agricultural use. Other Mauryan facilitation included construction and maintenance of dams, and provision of horse-drawn chariots—quicker than traditional bullock carts. The Greek diplomat Megasthenes (c. 300 BC)—in his book *Indika*—provides a secular eyewitness account of Indian agriculture:

2.2.3 Early Common Era – High Middle Ages (200–1200 CE)

The Tamil people cultivated a wide range of crops such as rice, sugarcane, millets, black pepper, various grains, coconuts, beans, cotton, plantain, tamarind and sandalwood. Jackfruit, coconut, palm, areca and plantain trees were also known. Systematic ploughing, manuring, weeding, irrigation and crop protection was practiced for sustained agriculture. Water storage systems were designed during this period. Kallanai (1st-2nd century CE), a dam built on river Kaveri during this period, is considered the as one of the oldest water-regulation structures in the world still in use.

Spice trade involving spices native to India—including cinnamon and black pepper—gained momentum as India starts shipping spices to the Mediterranean. Roman trade with India followed as detailed by the archaeological record and the *Periplus of the Erythraean Sea*. Chinese sericulture attracted Indian sailors during the early centuries of the common era. Crystallized sugar was discovered by the time of the Guptas (320-

550 CE), and the earliest reference of candied sugar come from India. The process was soon transmitted to China with traveling Buddhist monks. Chinese documents confirm at least two missions to India, initiated in 647 CE, for obtaining technology for sugar-refining. Each mission returned with results on refining sugar. Indian spice exports find mention in the works of Ibn Khurdadhbeh (850), al-Ghafiqi (1150), Ishak bin Imaran (907) and Al Kalkashandi (fourteenth century).

Noboru Karashima's research of the agrarian society in South India during the Chola Empire (875-1279) reveals that during the Chola rule land was transferred and collective holding of land by a group of people slowly gave way to individual plots of land, each with their own irrigation system. The growth of individual disposition of farming property may have led to a decrease in areas of dry cultivation. The Cholas also had bureaucrats which oversaw the distribution of water—particularly the distribution of water by tank-and-channel networks to the drier areas.

2.2.4 Late Middle Ages – Early Modern Era (1200–1757 CE)

The construction of water works and aspects of water technology in India is described in Arabic and Persian works. The diffusion of Indian and Persian irrigation technologies gave rise to an irrigation system which bought about economic growth and growth of material culture. Agricultural 'zones' were broadly divided into those producing rice, wheat or millets. Rice production continued to dominate Gujarat and wheat dominated north and central India. The Encyclopedia Britannica details the many crops introduced to India during this period of extensive global discourse:

> Introduced by the Portuguese, cultivation of tobacco spread rapidly. The Malabār Coast was the home of spices, especially black pepper, that had stimulated the first European adventures in the East. Coffee had been imported from Abyssinia and became a popular beverage in aristocratic circles by the end of the century. Tea, which was to become the common man's drink and a major export, was yet undiscovered, though it was growing wild in the hills of Assam. Vegetables were

cultivated mainly in the vicinity of towns. New species of fruit, such as the pineapple, papaya, and cashew nut, also were introduced by the Portuguese. The quality of mango and citrus fruits was greatly improved.

Land management was particularly strong during the regime of Akbar the Great (reign: 1556-1605), under whom scholar-bureaucrat Todarmal formulated and implemented elaborated methods for agricultural management on a rational basis. Indian crops—such as cotton, sugar, and citric fruits—spread visibly throughout North Africa, Islamic Spain, and the Middle East. Though they may have been in cultivation prior to the solidification of Islam in India, their production was further improved as a result of this recent wave, which led to far-reaching economic outcomes for the regions involved.

2.2.5 Colonial British Era (1757–1947 CE)

In 1857 a Rampur canal on river Sutlej was constructed and a number of irrigation canals are located on the Sutlej river. Few Indian commercial crops—such as Cotton, indigo, opium, and rice—made it to the global market under the British Raj in India. The second half of the 19th century saw some increase in land under cultivation and agricultural production expanded at an average rate of about 1 percent per year by the later 19th century. Due to extensive irrigation by canal networks Punjab, Narmada valley, and Andhra Pradesh became centers of agrarian reforms. There was influence of the world wars on the Indian agricultural system [1].

Reference 1:

Roy, T. (2006), "Agricultural Prices and Production, 1757–1947", ***Encyclopedia of India (vol. 1)*** **edited by Stanley Wolpert, pp. 20–22, Thomson Gale, ISBN 0-684-31350-2.**

Agricultural performance in the interwar period (1918–1939) was dismal. From 1891 to 1946, the annual growth rate of all crop output was 0.4 percent, and food-grain output was practically stagnant. There were significant regional and intercrop differences, however, nonfood crops doing better than food crops. Among food crops, by far the most important source of stagnation was rice. Bengal had below-average growth rates in both food and nonfood crop output, whereas Punjab and Madras were the least stagnant regions. In the interwar period, population growth accelerated while food output decelerated, leading to declining availability of food per head. The crisis was most acute in Bengal, where food output declined at an annual rate of about 0.7 percent from 1921 to 1946, when population grew at an annual rate of about 1 percent.

The British regime in India did supply the irrigation works but rarely on the scale required. Community effort and private investment soared as market for irrigation developed. Agricultural prices of some commodities rose to about three times between 1870-1920.

A rich source of the state of Indian agriculture in the early British era is a report prepared by a British engineer, Thomas Barnard, and his Indian guide, Raja Chengalvaraya Mudaliar, around 1774. This report contains data of agricultural production in about 800 villages in the area around Chennai in the years 1762 to 1766. This report is available in Tamil in the form of palm leaf manuscripts at Thanjavur Tamil University, and in English in the Tamil Nadu State Archives. A series of articles in The Hindu newspaper in the early 1990s authored by researchers at The Center for Policy Studies led by Shri Dharampal Dharampal highlight the impressive production statistics of Indian farmers of that era.

2.2.6 Republic of India (1947 CE onwards)

Bhakra Dam (completed 1963) is the largest dam in India. Special programs were undertaken to improve food and cash crops supply. The Grow More Food Campaign (1940s) and the Integrated Production Programme (1950s) focused on food and cash crops supply respectively. Five-year plans of India—oriented towards agricultural development—soon followed. Land reclamation, land development, mechanization, electrification, use of chemicals—fertilizers in particular, and development of agriculture oriented 'package approach' of taking a set of actions instead of promoting single aspect soon followed under government supervision. The many 'production revolutions' initiated from 1960s onwards included Green Revolution in India, Yellow Revolution (oilseed: 1986-1990), Operation Flood (dairy: 1970-1996), and Blue Revolution (fishing: 1973-2002) etc. Following the economic reforms of 1991, significant growth was registered in the agricultural sector, which was by now benefiting from the earlier reforms and the newer innovations of Agro-processing and Biotechnology.

Due to the growth and prosperity that followed India's economic reforms a strong middle class emerged as the main consumer of fruits, dairy, fish, meat and vegetables—a marked shift from the earlier staple based consumption. Since 1991, changing consumption patterns led to a 'revolution' in 'high value' agriculture while the need for cereals is experienced a decline. The per capita consumption of cereals declined from 192 to 152 kilograms from 1977 to 1999 while the consumption of fruits increased by 553%, vegetables by 167%, dairy products by 105%, and non-vegetarian products by 85% in India's rural areas alone. Urban areas experienced a similar increase.

Agricultural exports continued to grow at well over 10.1% annually through the 1990s. Contract farming—which requires the farmers to produce crops for a company under contract—and high value agricultural product increased. Contract farming led to a decrease in transaction costs while the contract farmers made more profit compared to the non-contract workforce. However, small landholding continued to create problems for India's farmers as the limited land resulted in limited produce and limited profits.

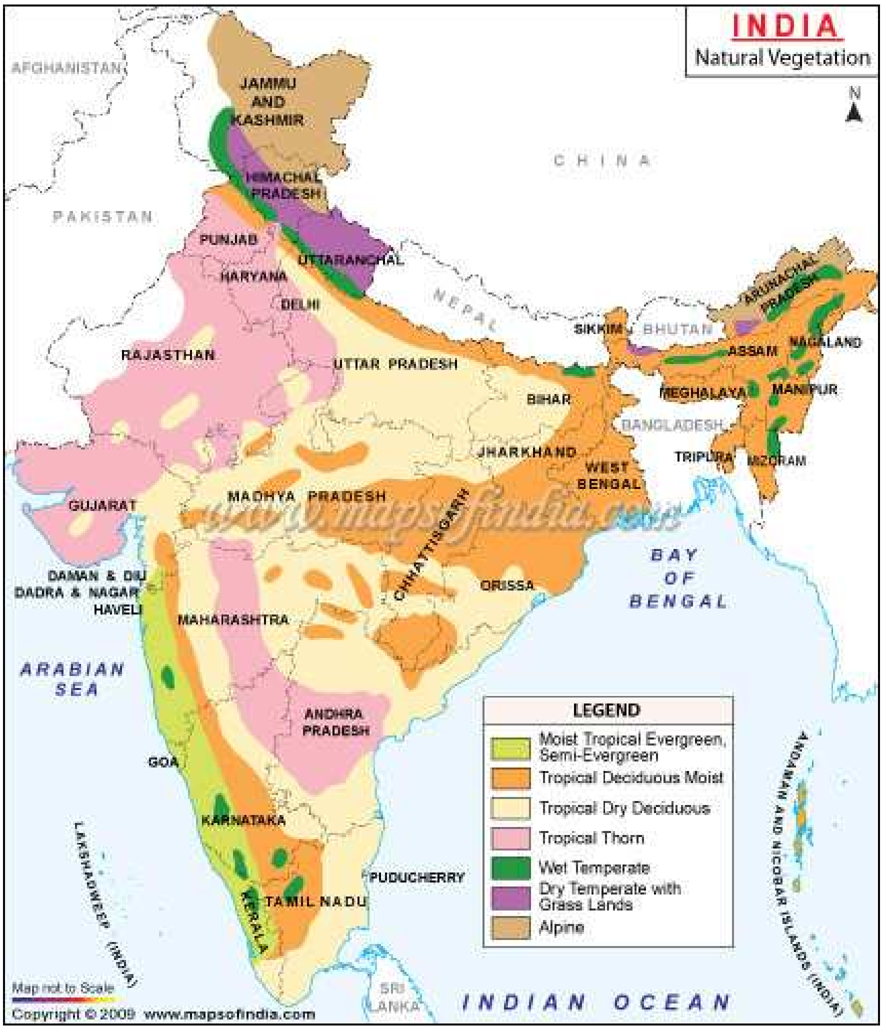
Since independence, India has become one of the largest producers of wheat, edible oil, potato, spices, rubber, tea, fishing, fruits, and vegetables in the world. The Ministry of Agriculture oversees activities relating to agriculture in India. Various institutions for agriculture related research in India were organized under the Indian Council of Agricultural Research (est. 1929). Other organizations such as the National Dairy Development Board (est. 1965), and National Bank for Agriculture and Rural Development (est. 1982) aided the formation of cooperatives and improved financing.

The contribution of agriculture in employing India's male workforce declined from 75.9% in 1961 to 60% in 1999–2000. Dev (2006)[1] holds that 'there were about 45 million agricultural labor households in the country in 1999–2000.' These households recorded the highest incidence of poverty in India from 1993 to 2000. The green revolution introduced high yielding varieties of crops which also increased the usage of fertilizers and pesticides. About 90% of the pesticide usage in India is accounted for by DDT and Lindane (BHC/HCH). There has been a shift to organic agriculture particularly for exported commodities.

- **Reference 1 :Dev, S. M. (2006), "Agricultural Labor and Wages since 1950", *Encyclopedia of India (vol. 1)* edited by Stanley Wolpert, pp. 17–20, Thomson Gale, ISBN 0-684-31350-2.**

Figure 2.1

India's Natural vegetation



Source: ICAR report 2006-2007

2.3 Indian Agriculture under Five Year Plans

On the eve of first plan (1951-1956) agriculture was in a hopeless and deplorable condition. Our farmers were heavy debt to the village money-lenders. They were having small and scattered holdings. They had neither the money nor the knowledge to use proper equipment, good seeds and chemical manures. Except in certain areas, they were dependent upon rainfall and upon the vagaries of the monsoons. Productivity of land as well as of labour had been declining and was generally the lowest in the world. In spite of the fact that nearly 70% of our working population was engaged in cultivation, the country was not self-sufficient in food grains but had come to depend on imports of food grains. Besides, the partition of the country in 1946 worsened the agricultural situation as India was allotted more people but less land to support.

2.3 (A) Objectives of Economic Planning for the Agricultural Sector

While planning to develop the agricultural sector, the Planning Commission has kept four broad objectives[1]:

(a) Increase Agricultural Production - The aim has always been

i) To bring more land under cultivation,

ii) Raise the per hectare yield through intensive application of such agricultural inputs as irrigation, improved seeds fertilizers, etc. and thus

iii) Bring about increased agricultural production.

(b) Increase Employment Opportunities – Apart from increase in production, the agricultural sector has to generate additional employment opportunities and provide scope for increasing the incomes of the poorer sections in our villages.

© **Reduce the Pressure of Population on Land -** Another basic objective of planning in the agricultural sector has been to reduce the number of people working on land, on the assumption that there are too many people working on land. The surplus labour on land should be shifted to secondary and tertiary sectors, preferably in rural land semi-urban areas.

Reference 1 : Indian Economy, Ruddar Datta, K.P.M Sundaram, S. Chand & Co.53rd Edition, ISBN : 81-219-2045-0

(d) Reduce Inequality of Incomes in the Rural Sector - The Government should remove the exploitation of tenants, and should distribute surplus land among small and marginal farmers in such a way that there would be some degree of equality and justice in the rural areas.

All these four objectives are generally followed in all our five year plans but in practice, agricultural planning in India has come to mean increase in agricultural production, viz., the achievement of the first objective; all other objectives have either been ignored or given lower priority.

2.4 Strategy Used in Agricultural Sector under Five Year Plans

To bring about increase in agricultural production and also increase in rural employment such as; setting up of community development programmes and agricultural extension services throughout the country, expansion of irrigation facilities, fertilizers, pesticides, agricultural machinery, high-yielding varieties of seeds and expansion of transportation, power, marketing, and of institutional credit. To reduce the pressure of population on land, the strategy used was to set up agro-based industries and handicrafts in rural areas, to promote rural transport and communications and to encourage the movement of people from agriculture to industries and service sectors. Finally, to bring about equality and justice in rural India, the strategy used was land reforms which included the removal of intermediaries, like the Zamindars, the protection of tenants through tenancy legislation, ceiling of land holding and distribution of surplus land among landless labourers and small and marginal farmers.

2.4.1 Pattern of Investment in the Agricultural Sector - The pattern of investment in the different five year plans is summarized in table 2.1 :

Table 2.1 Pattern of Government Outlay on Agriculture in the Plans (in Rs.)

Five Year Plan	**Year**	**Total Plan Outlay**	**Outlay on Agriculture & Irrigation**	**% of Total Outlay**
First Plan	1951-56	1,960	600	31
Second Plan	1956-61	4,600	950	20
Third Plan	1961-66	8,600	1,750	21
Fourth Plan	1969-74	15,780	3,670	23
Fifth Plan	1974-79	39,430	8,740	22
Sixth Plan	1980-85	1,09,290	26,130	24
Seventh Plan	1985-90	2,18,730	48,100	22
Eighth Plan	1992-97	4,85,460	1,02,730	20
Ninth Plan	1997-2002	8,59,200	1,70,230	20
Tenth Plan	2002-07	15,25,640	3,05,060	20

Source: Various Five Year Plan documents

It would be clear that the total outlay in each Plan had increased and, correspondingly, the outlay on agriculture and irrigation had also increased. However. The percentage of outlay on agriculture and irrigation to total plan outlay was the highest in the First Plan, viz, 31% but ranged between 20 to 24% in all other plans.

The Indian Planning Commission specified the various programmes for increasing agricultural production such as irrigation, soil conservation, dry farming and land reclamation, supply of fertilizers and manures, better ploughs and improved agricultural implements, adoption of scientific practices, etc. The Government gave considerable attention to institutional changes such as the setting up of community development programmes and agricultural expansion of transportation, power, marketing and other basic facilities, improvement of the system of co-operative credit, etc. From the Third Plan onwards, the greatest emphasis was laid on irrigation, fertilizer, seed technology which led to green revolution.

2.4.2 Agricultural Progress under the Five Year Plans

We shall describe the progress made by India in the field of agriculture under the first nine plans. In the next section, we shall take up the progress of agriculture under the Ninth Plan separately.

a) First two Plans (1951-61)

The First Plan aimed at solving the food crisis India was facing at that time and ease the critical agricultural raw material situation, particularly the acute shortage pf raw cotton and raw jute. Accordingly, it gave highest priority to agriculture, specially food production by allotting 31% of the total public sector outlay on agriculture, but it fixed rather modest targets of production. **(See the above table).** As a result of favourable weather conditions and the production targets in the agricultural sector were exceeded for instance, as against the target of about 62 million tones, actual production of food grains came to nearly 67 million tones. The targets fixed for other crops were not fulfilled.

The Planning Commission wanted the Second Plan to lay the foundations of industrialization and secure equal opportunities for all, particularly for the weaker sections of the people in the country. Out of total outlay of Rs. 4,600 crores during the Second Plan, a sum of Rs. 950 crores or about 20% was spent on agriculture. Despite the percentage reduction in Plan outlay on agriculture, the progress on the agricultural front was significant. For example, food grains production recorded nearly 80 million tonnes in 1960-61, as against the target of 81 million tonnes. Likewise the production of oilseeds, sugarcane, and cotton was much more in 1960-61. There was, however, a shortfall in the production of all groups of commodities, as against the target fixed, except in the case of sugarcane in which there was remarkable progress.

b) Third to Fifth Plans (1961-79)

Experience in the Second Plan had shown clearly that the rate of growth in agricultural production was a major limiting factor in the progress of the India economy. As the Government felt that the success of the agricultural sector was an essential condition for the agricultural sector was an essential condition for the success of entire plan, the Third Plan fixed ambitious targets of production for all agricultural crops.

It was during the Third Plan that the Government introduced the new agricultural technology known as Intensive Agricultural District Programme of using improved seeds, viz., High Yielding Varieties Programme (HYVP). The new agricultural technology was expected to usher in the green revolution. However, as a result of the extensive and serious drought conditions in 1965-66, agricultural production was adversely affected.

a) None of the agricultural targets except sugarcane was chieved during the third plan period; and

b) The actual output at the end of the Third Plan in the case of food grains, oilseeds and raw cotton was lower than the output at the end of the Second Plan, indicating that the Third Plan was a wash-out, as far as agriculture was concerned.

As the consequence of the shortfall in food production and serious famine conditions in many parts of the country, the Government was forced to import food grains extensively during the last of the third plan. Besides, for the first time, the public lost interest in the planning process and the Government adopted “plan holiday” for three years.

The experience of the Third Plan made the Planning Commission realize the bitter fact that economic Planning would be a failure unless agricultural production was increased rapidly. Accordingly, the Planning Commission assigned high priority to agriculture in the successive plans.

Table 2.2: Achievements in the Agricultural Sector in the Various Plans

Five Year Plans	Food grains		Oilseeds		Sugarcane		Cotton		Jute	
	Target	Achiev-ement	Target	Achiev-ement	Target	Achiev-Ement	Target	Achiev-ement	Target	Achiev-ement
First Plan	62	67	5.5	5.6	63	60	4.2	4.0	5.4	4.2
Second Plan	81	80	7.6	6.5	78	104	6.5	5.4	6.5	4.0
Third Plan	100	72	9.8	6.4	100	127	7.0	4.6	6.2	4.5
Fourth Plan	129	104	10.5	8.7	150	140	8.0	5.8	7.4	6.2
Fifth Plan	125	126	12.0	8.9	165	165	8.0	7.1	7.7	7.1
Sixth Plan	154	146	11.1	13.0	215	170	9.2	8.5	9.1	7.8
Seventh Plan	180	172	18.0	17.0	217	210	9.5	10.5	9.5	7.9
Eighth Plan	210	191	23.0	25.0	275	277	14.0	14.3	9.5	11.0
Ninth Plan	234	211	30.0	20.7	336	300	15.7	10.1	-----	11.6

Note: 1. Production of food grains, oilseeds and sugar cane in million tones
2: Production of cotton in millions of bales of 180 kgs each
3: Production of jute in millions of bales of 170 kgs each

Source: Plan documents and Economic Surveys

The approach to the Fourth Plan, for instance, emphasized the necessity to create favourable economic conditions for the promotion of agriculture and a systematic effort to extend the application of science and technology to improve agricultural practices.

Table above, however, reveals clearly that none of the targets fixed in agriculture in Fourth Plan was realized. For example, the target for food grains was 129 million tonnes for 1973-74 but the actual production in that year was only 104 million tones the highest level of production was 108 million in 1970-71.

The Fifth Plan (1974-79) was prepared with great care, with total plan outlay at Rs. 39,430 crores out of which outlay on agriculture would be Rs. 8,740 crores (which was 22% of the total Plan outlay). The targets for production of various crops and necessary inputs to achieve these targets were also clearly set. Unfortunately, all the financial calculations went wrong because of the serious inflationary situation during 1973-74. The Fifth Plan period also witnessed the declaration of emergency (1975). Even though agricultural progress was steady and plan targets were being realized, the Janata Party which came to power at the Center suspended the Fifth Plan mid way and started preparing the Sixth Plan. (Refer to Table 2.1 for V Plan targets and actual achievements in the agricultural sector).

(D) Progress since the Sixth Plan

Of all the Plans, the Sixth Plan (1980-85) was hailed as a great success, particularly because of the success on the agricultural front. As against the annual growth rate of 3.8 for agriculture, the actual growth rate was 4.3%. The production of food grains in 1983-84 was 154 million tonnes (against the target of 154 million tonnes) and was hailed by the Indian Government as the *second green revolution*. While the First Green Revolution from 1967-68 arose from the introduction of new high yielding varieties of Mexican Wheat and dwarf rice varieties, the Second Green Revolution from 1983-84 was said to be from expansion in supplies of inputs and services to farmers, agricultural extension and better management.

While the First Green Revolution was confined mainly to Punjab, Haryana and Western U.P., the Second Green Revolution had spread to eastern and central states including West Bengal, Bihar, Orissa, Madhya Pradesh and Eastern U.P. These states had made tremendous progress in recent years.

However, it is important to emphasize the fact that, despite all the great claim of the Government, none of the targets (except in oilseeds) of agricultural production was achieved during Sixth Plan (Refer Table).

The Seventh Plan (1985-90) and the Eighth Plan (1992-97) laid emphasis on specific projects in the field of agriculture They included a special rice production programme for rain fed agriculture, national oilseeds development project, social forestry, etc.

The Seventh Plan was not successful in the sense that the targets fixed for various sectors (except cotton) were not achieved. However, the level of production at the end of the Seventh Plan was much higher than the beginning of the Seventh Plan.

The Eighth Plan (1992-97) was basically sound in its approach in the strategy of development and in the targets of agricultural crops. Fortunately, weather and climate conditions were favourable and broadly many of the targets could be fulfilled. For instance, the actual outputs in1996-97 of oil seeds, of sugarcane, of cotton and of jute were higher than the targets for these crops in the Eighth Plan. The only exception was food grains the Eighth Plan target was 210 million tones but the actual production was 199 million tonnes. In fact, the production of food Grains at 199 million tonnes was the highest output registered by India till the date.

The Ninth Plan (1997-2002) treated more elaborately in the next section was not much of a success, as far as the agricultural targets were concerned. For instance, the Ninth Plan fixed the target of food grains production at 234 million tonnes in 2001-02; but the actual production was only 212 million tones. The same story of under – achievement was to be noted in other sectors of agriculture also. One is inclined to ask the question: why should the planners fix unrealistic and unrealizable targets?

2.5 India's Rainbow Revolution

Rainbow revolution concept is a combination of Green Revolution, White Revolution, Blue Revolution, Yellow Revolution and Brown Revolution. It was after these revolutions, the Indian agriculture slowly shifted from traditional behaviour to scientific behaviour. So, it is necessary to understand these revolutions in brief. The following chart shows various revolutions related to various produces of Indian agriculture. Here we are discussing mainly Green Revolution, White Revolution, Blue Revolution and Yellow Revolution in brief

Revolution	**Production**
Black Revolution	Petroleum production
Blue Revolution	Fish production
Brown Revolution	Leather/non-conventional(India)/Cocoa production
Golden Revolution	Overall Horticulture development/Honey Production
Golden Fiber Revolution	Jute Production
Green Revolution	Food grain (Cereals, Wheat &Leguminous plant) production
Grey Revolution	Fertilizer production
Pink Revolution	Onion production/Pharmaceutical (India)/Prawn production
Red Revolution	Meat & Tomato production
Round Revolution	Potato production
Silver Fiber Revolution	Cotton production
Silver Revolution	Egg/Poultry production
White Revolution	Milk/Dairy production (In India - Operation Flood)
Yellow Revolution	Oil Seeds production

2.5.1 Green Revolution

The introduction of high-yielding varieties of seeds after 1965 and the increased use of fertilizers and irrigation are known collectively as the Green Revolution, which provided the increase in production needed to make India self-sufficient in food grains, thus improving agriculture in India. Famine in India, once accepted as inevitable, has not returned since the introduction of Green Revolution crops.

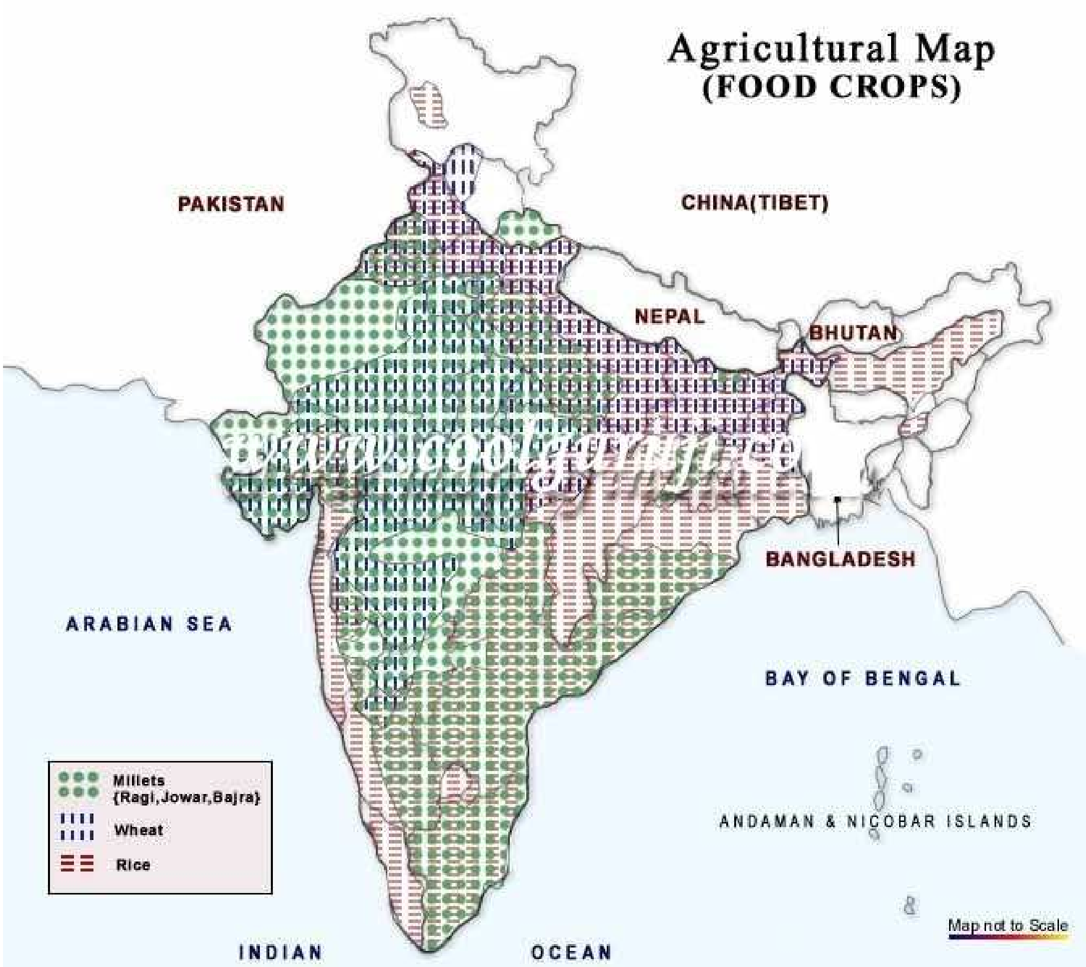
Of the high-yielding seeds, wheat produced the best results. All India Radio (AIR) played a vital role in creating awareness for these methods. Along with high yielding seeds and irrigation facilities, the enthusiasm of farmers mobilized the idea of agricultural revolution and is also credited to All India Radio.

The major benefits of the Green Revolution were experienced mainly in northern and northwestern India between 1965 and the early 1980s; the program resulted in a substantial increase in the production of food grains, mainly wheat and rice Food-grain yields continued to increase throughout the 1980s, but the dramatic changes in the years between 1965 and 1980 were not duplicated. By FY 1980, almost 75 percent of the total cropped area under wheat was sown with high-yielding varieties. For rice the comparable figure was 45 percent. In the 1980s, the area under high-yielding varieties continued to increase, but the rate of growth overall was slower. The eighth plan aimed at making high-yielding varieties available to the whole country and developing more productive strains of other crops

The map no.2 shows the total food grain cultivation in India. From the map we see that the foodgrains such as wheat and rice are majorly cultivated in Punjab, Haryana, Himachal Pradesh, Uttaranchal, Jharkhand, Uttar Pradesh for wheat and Andhra Pradesh, Tamilnadu, Karnatak and Kerala for rice. We see a crowded foodgrain cultivation of Bajra, Jowar and Maize in the states of Maharashtra and Karnataka.

Figure no. 2.2

Agricultural Map of India (Food crops)



Source :-Indian Economy,Agriculture report 2007-2008

From the above map we see that rice is majorly cultivated on the western coastal line completely, in some parts of Andhra Pradesh, Tamilnadu, Orissa, West Bengal and North-Eastern states. Wheat is densely cultivated in the states of Punjab, Haryana, Jharkhand and in some parts of Maharashtra, Madhya Pradesh and Gujarat. Millets which constitute foodgrains such as Ragi, Jowar, Bajra is densely cultivated in the states of Tamilnadu, Andhra Pradesh, Karnataka and in some parts of Rajasthan, Gujarat and Himachal Pradesh.

The environmental impact of excessive use to chemical fertilizers and pesticides was only revealed as years passed by. In 2009, under a Greenpeace Research Laboratories investigation, Dr Reyes Tirado, from the University of Exeter, UK, conducted a study in 50 villages in Muktsar, Bathinda and Ludhiana districts that revealed chemical, radiation and biological toxicity was rampant in Punjab. 20% of the sampled wells showed nitrate levels above the safety limit of 50 mg/l, established by WHO. The study connected this finding with high use of synthetic nitrogen fertilizers. With increasing poisoning of the soil, the region once hailed as the home to the Green Revolution, now due to excessive use of chemical fertilizer, is being termed by one columnist as the "Other Bhopal". For example, Buddha Nullah, a rivulet which run through Malwa region of Punjab, India, and after passing through highly populated Ludhiana district, before draining into Sutlej River, a tributary of the Indus river, is today an important case point in the recent studies, which suggest this as another Bhopal in making. A joint study by PGIMER and Punjab Pollution Control Board in 2008, revealed that in villages along the Nullah, calcium, magnesium, fluoride, mercury, beta-endosulphan and heptachlor pesticide were more than permissible limit (MPL) in ground and tap waters. Plus the water had high concentration of COD and BOD (chemical and biochemical oxygen demand), ammonia, phosphate, chloride, chromium, arsenic and chlorpyrifos pesticide. The ground water also contains nickel and selenium, while the tap water has high concentration of lead, nickel and cadmium.

In addition to large inputs of fertilizers and pesticides, the Green Revolution in India was made possible in large part by a dramatic increase in irrigation, particularly from deep groundwater sources. The exploitation of groundwater resources allowed farmers to double-crop (grow crops even during the dry season) and to grow water-intensive crops such as rice in areas that were traditionally unsuited for rice production.

This growth in irrigation has led to an alarming drop in the water table in a number of key agricultural Indian states, such as Punjab, where the water table is reportedly falling by about 1 meter per year. In other states, the problem is worse; in Gujarat, the water table is falling by as much as 3-5 meters per year.

What this means is that without a dramatic change in agricultural practice, groundwater resources could be depleted within a few years. In the case of Gujarat and other coastal areas, intrusion of seawater could render underground aquifers useless for human consumption or agriculture.

2.5.2 White Revolution

White Revolution was a rural development programme started by India's National Dairy Development Board (NDDB) in 1970. One of the largest of its kind, the programme objective was to create a nationwide milk grid.

It resulted in making India the largest producer of milk and milk products, and hence is also called the White Revolution of India. It also helped reduce malpractices by milk traders and merchants. This revolution followed the Indian Green Revolution and helped in alleviating poverty and famine levels from their dangerous proportions in India during the era.

Operation Flood has helped dairy farmers, direct their own development, placing control of the resources they create in their own hands. A 'National Milk Grid', links milk producers throughout India with consumers in over 700 towns and cities, reducing seasonal and regional price variations while ensuring that the producer gets a major share of the price consumers pay.

The bedrock of Operation Flood has been village milk producers' cooperatives, which procure milk and provide inputs and services, making modern management and technology available to members. Operation Flood's objectives included :

- Increase milk production ("a flood of milk")
- Augment rural incomes
- Fair prices for consumers
- Based co-operation "Anand Milk Union Limited", often called Amul, was the engine behind the success of the programme, and in turn became a mega company based on the cooperative approach. Tribhuvandas Patel was the founder Chairman of Amul, while Verghese Kurien was the chairman of NDDB at the time when the programme was implemented. Verghese Kurien, who was then 33, gave the professional management skills and necessary thrust to the cooperative, and is considered the architect of India's 'White Revolution' (Operation Flood). His work has been recognised by the award of a Padma Bhushan, the Ramon Magsaysay Award for Community Leadership, the Carnegie-Wateler World Peace Prize, and the World Food Prize.
- Operation Flood was implemented in three phases.

Phase I of White Revolution

- Phase I (1970–1980) was financed by the sale of skimmed milk powder and butter oil donated by the European Union (then the European Economic Community) through the World Food Programme. NDDB planned the programme and negotiated the details of EEC assistance.
- During its first phase, Operation Flood linked 18 of India's premier milksheds with consumers in India's major metropolitan cities: Delhi, Mumbai, Kolkata and Chennai. Thus establishing mother dairies in four metros.
- Operation flood, also referred to as “White Revolution” is a gigantic project propounded by Government of India for developing dairy industry in the country. The Operation Flood – 1 originally meant to be completed in 1975, actually spanned the period of about nine years from 1970–79, at a total cost of Rs.116 crores.

- At start of operation Flood-1 in 1970 certain set of aims were kept in view for the implementation of the programmes. Improvement by milk marketing the organized dairy sector in the metropolitan cities Mumbai(then Bombay), Kolkata(then Calcutta), Chennai(then Madras), Delhi. The objectives of commanding share of milk market and speed up development of dairy animals respectively hinter lands of rural areas with a view to increase both production and procurement.

Phase II of White Revolution

- Operation Flood Phase II (1981–1985) increased the milksheds from 18 to 136; 290 urban markets expanded the outlets for milk. By the end of 1985, a self-sustaining system of 43,000 village cooperatives with 4,250,000 milk producers were covered. Domestic milk powder production increased from 22,000 tons in the pre-project year to 140,000 tons by 1989, all of the increase coming from dairies set up under Operation Flood. In this way EEC gifts and World Bank loan helped promote self-reliance. Direct marketing of milk by producers' cooperatives increased by several million litres a day.

Phase III of White Revolution

- Phase III (1985–1996) enabled dairy cooperatives to expand and strengthen the infrastructure required to procure and market increasing volumes of milk. Veterinary first-aid health care services, feed and artificial insemination services for cooperative members were extended, along with intensified member education.
- Operation Flood's Phase III consolidated India's dairy cooperative movement, adding 30,000 new dairy cooperatives to the 42,000 existing societies organized during Phase II. Milksheds peaked to 173 in 1988-89 with the numbers of women members and Women's Dairy Cooperative Societies increasing significantly.
- Phase III gave increased emphasis to research and development in animal health and animal nutrition. Innovations like vaccine for Theileriosis, bypassing protein feed and urea-molasses mineral blocks, all contributed to the enhanced productivity of milch animals.

2.5.3 Blue Revolution

The fisheries-based blue revolution can become real and sustainable if the production potential of available water resources can be efficiently managed. But there are several areas of concern that need to be addressed to realize this goal. The marine fish production, which at one stage constituted the bulk of the total fish output, is showing practically no growth for nearly a decade. Much of the growth in the fisheries sector is coming chiefly from the inland fisheries, which is also beset with some formidable problems, including the environmental degradation of inland waters and the paucity of fish seed. Indeed, at present, hardly 40 per cent of the country's fresh water resources are being used for fisheries. The output of the inland fisheries sector could, therefore, be stepped up by two-and-half times just by utilizing all the available water bodies. Similarly, most of the fisheries potential of deep sea waters is going abegging for want of suitable fishing vessels and curbs on joint ventures for deep sea fishing. The fish stocks of these waters are being either clandestinely harvested by ships belonging to countries or are remaining unexploited. On the other hand, the coastal waters, predominantly drawn upon by the traditional fishing communities, are being over-exploited, leading to the fast depletion of fisheries resources of this zone. This is also reflected in gradual shrinking of fish catches in the coastal waters. Even shrimps-based aquaculture, which has till recently been witnessing a fast, largely exports-driven, growth, has now begun flagging due to the imposition of various kinds of non-tariff trade barriers by the importing countries. Besides, the vulnerability of shrimps to diseases is causing problems for the shrimp industry.

Equally worrisome is the poor post-harvest handling of fish, which is resulting in huge wastage of this nutritious food. While these losses are reckoned at a huge 25 per cent in the marine sector, these are around 8 per cent in inland fisheries. The total value of the losses is assessed at a colossal Rs 1,000 crore annually.

2.5.4 Brown Revolution

Brown revolution means turn garbage which is brown into gold and fertilizer which is totally organic or bio or worm compost.

A ***`Brown Revolution'*** is happening in the tribal areas of Visakhapatnam district. The tribal people are taught and encouraged to grow "socially responsible and environment friendly" coffee to cater to the demand from developed countries.

The Coffee Board has embarked upon the challenging campaign of promoting the coffee grown in these remote areas as niche coffee for markets in the West. Niche coffee, determined by consistent quality and the socio-economic well-being of the local people, is a $55-billion market world-wide.

Although the tribal people of Visakhapatnam district have been growing coffee since the 1970s, it is only recently, particularly after eyeing the organic market, that it is being given a thrust. Some 30,000 tribal people of Andhra Pradesh, who once practised slash-and-burn `Podu' (shifting) cultivation, are now growing coffee as a shade crop under the canopy of silver oak.

What the tribal people of Visakhapatnam are cultivating may be a minuscule part of India's annual coffee production of around three lakh tonnes. But, according to the Coffee Board, what is significant is that apart from regenerating the forest cover in those parts of the Eastern Ghats where it is cultivated, coffee has helped at the micro level by boosting the income of the tribal people. Their per hectare income from coffee is estimated at Rs.15,000 compared to Rs.10,000 for pineapple, Rs.1,500 for niger seeds and Rs.1,000 for maize.

The Coffee Board cites the instance of 50-year-old Linganna Padal who owns a demonstration coffee plot, which has generated enough income for him to own a house and educate his children. His success is now sought to be replicated throughout the Integrated Tribal Development Agency areas of the district.

However, it is not just a case of the good intentions of the Coffee Board and the ITDA of Paderu to help the tribal people. Some argue that there could even be a sound marketing base to all this. World over, there is a burgeoning demand for organic coffee. In those areas of Karnataka, Tamil Nadu and Kerala where over 90 per cent of India's coffee is grown, any shift to organic coffee cultivation would necessitate a break in cultivation as the soil has to be left fallow for a few years to wash out traces of chemicals. But the tribal areas of Visakhapatnam can cultivate organic coffee as no chemical fertilizers or pesticides are used, as much owing to financial constraints as the lack of exposure to modern methods of cultivation.

Trying to turn this into an advantage, the Coffee Board and the ITDA launched the programme to grow coffee in the Araku Valley. Coffee Board officials, however, say that it seems far-fetched for Araku Valley coffee to sell in London or New York. But the process is moving in that direction. The Coffee Board has even created a logo for the "Araku Valley Coffee" brand.

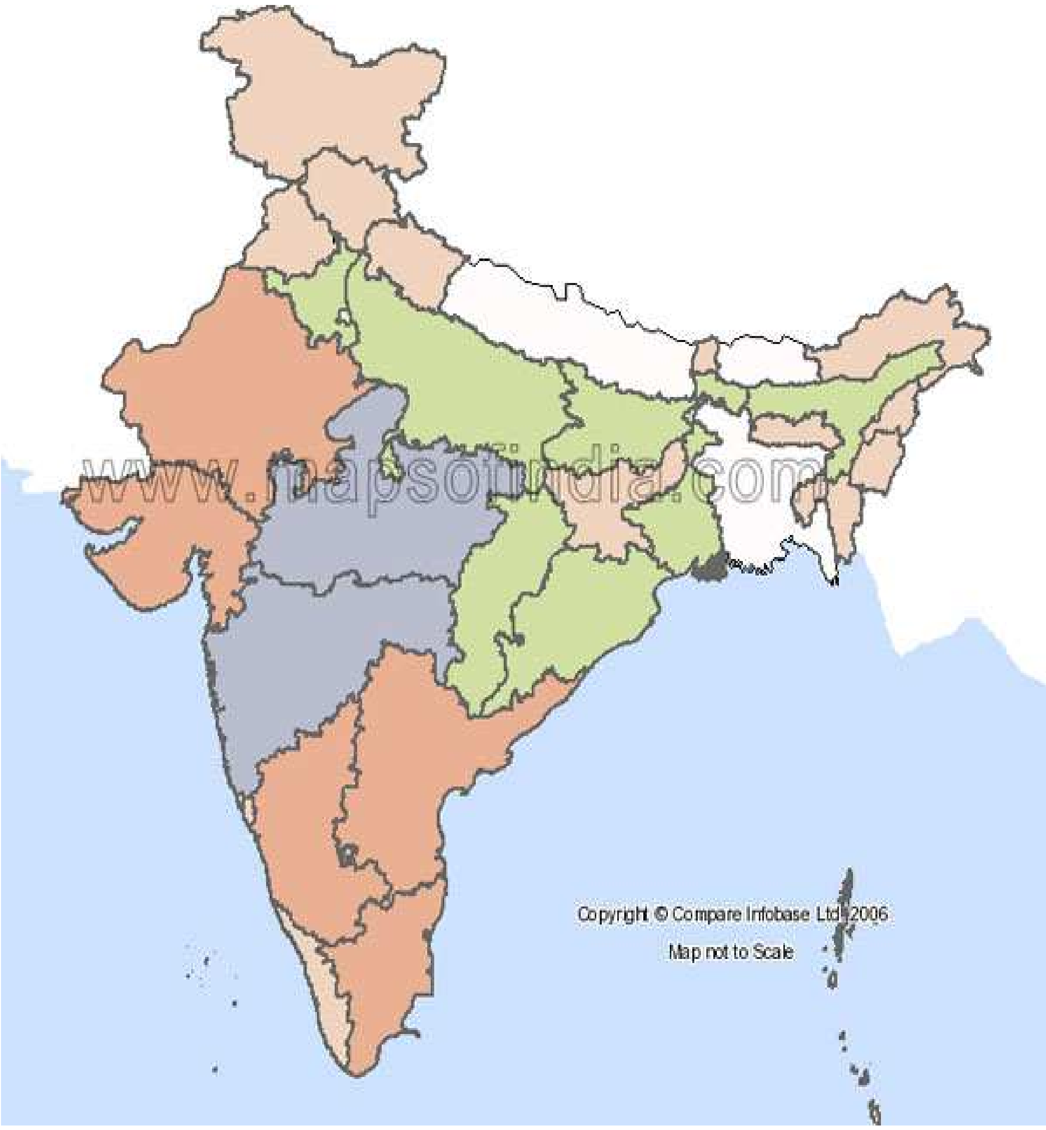
According to the Coffee Board, the quality of Araku Valley coffee will be improved through systematic development of on- and off-farm processing facilities. Self-help groups of tribal farmers are to be strengthened to facilitate pooling of coffee so as to offer consistent and larger quantities. A physical platform for auctioning is expected to give a fillip to marketing and the prospects of exporting coffee to Japanese, Australian and American markets through Visakhapatnam port are to be pursued. Araku coffee is turning out to be a potent brew indeed.

2.5.5 Yellow Revolution

Yellow revolution means the cultivation of mustard as a part of crop rotation. It prevents the soil from getting eroded and at the same time gives a rich crop of oil seeds. The use of mustards is to build soil organic matter and to eliminate the need for chemical soil fumigants. The yellow revolution man of Vaishali is Bindeshwar Prasad Singh (67), a farmer owning just 2.5 acre of land but still making gold. No matter he was not chosen for last year's Kisan Samman by Bihar government, the Indian Vegetable Research Institute at Varanasi gave him silver medal The growth, development and adoption of new varieties of oilseeds and complementary technologies nearly doubled oilseeds production from 12.6 mt in 1987-88 to 24.4 mt in 1996-97, catalyzed by the Technology Mission on Oilseeds, brought about the Yellow Revolution.

Figure 2.3

Map shows production of Oil seeds in India



Source : ICAR Report 2007-2008

	>100'000 tonnes		**100'000-1000'000 tonnes**		**1000'000-2000'000 tonnes**
	2000'000tonnes >				

The map no.3 shows the amount of production of Oilseeds in India. From the map it is clear that the states of Himachal Pradesh, Jammu & Kashmir, Uttarkhand, Haryana, North-Eastern states, Jharkhand and Kerala have a production of less than 1 lakh tones. The states of Uttar Pradesh, Bihar, Chattisgarh, Orissa and West Bengal produce oilseeds upto 10 lakh tones, while the states of Rajasthan, Gujarat, Karnataka, Andhra Pradesh and Tamilnadu have production of oilseeds in the range of 10 lakh to 20 lakh tones. The highest oilseed production of above 20 lakh tonnes is seen in the states of Maharashtra and Madhya Pradesh.

The growth, development and adoption of new varieties of oilseeds and complementary technologies nearly doubled oilseeds production from 12.6 mt in 1987-88 to 24.4 mt in 1996-97, catalyzed by the Technology Mission on Oilseeds, brought about the Yellow Revolution. The term also stands for the People Power Revolution in Phillipines in 1986 against then President Ferdinand Marcos. It was a series non-violent protests where demonstrators used yellow ribbons during the arrival of Ninoy Aquino. Around this time of the year, bright yellow flowers carpet the fields in scores of villages in Bihar's Vaishali district. They are not mustard crops waiting to burst into full bloom but cauliflower seeds that have ushered in a revolution of sorts — locals term it ‘Yellow Revolution’ — in the region. These seeds — which fetch high prices as they are completely organic — are sold across Bihar, Rajasthan, Madhya Pradesh and Maharashtra under an exclusive brand called Vaishali under various names like satya beej, green seeds and jawahar seeds. While over three dozen villages under Hajipur, Mahnar and Lalganj blocks in Vaishali cultivate cauliflower seeds along with other crops, the entire Chakbara village near Hajipur is devoted to cauliflower seed cultivation. The cumulative earning of around 50 farmers from the sale of seeds last year was about Rs 50 lakh.

2.5.6 Results of Rainbow Revolution

After effective implementation of Green Revolution, White Revolution, Blue Revolution, Yellow Revolution and a combined concept of Rainbow Revolution has certain programmes such as

1. To increase the annual growth rate in agriculture over 4%
2. To give greater private sector participation through contract farming
3. To enable price protection for farmers
4. To launch National Agriculture Insurance Scheme for all farmers and for all crops
5. To dismantle the restrictions on movement of agricultural commodities throughout the country

The new agriculture policy which was presented in 2000 aimed to achieve the above said objectives through Rainbow Revolution. Today, India ranks second worldwide in farm output. Agriculture and allied sectors like forestry and logging accounted for 16.6% of the GDP in 2007, employed 52% of the total workforce[1] and despite a steady decline of its share in the GDP, is still the largest economic sector and plays a significant role in the overall socio-economic development of India.

Today India is the largest producer in the world of fresh fruit, anise, fennel, badian, coriander, tropical fresh fruit, jute, pigeon peas, pulses, spices, millets, castor oil seed, sesame seeds, safflower seeds, lemons, limes, cow's milk, dry chillies and peppers, chick peas, cashew nuts, okra, ginger, turmeric guavas, mangoes, goat milk and buffalo milk and meat. Coffee.It also has the world's largest cattle population (281 million). It is the second largest producer of cashews, cabbages, cotton seed and lint, fresh vegetables, garlic, egg plant, goat meat, silk, nutmeg. mace, cardamom, onions, wheat, rice, sugarcane, lentil, dry beans, groundnut, tea, green peas, cauliflowers, potatoes, pumpkins, squashes, gourds and inland fish. It is the third largest producer of tobacco, sorghum, rapeseed, coconuts, hen's eggs and tomatoes. India accounts for 10% of the world fruit production with first rank in the production of mangoes, papaya, banana and sapota. India's population is growing faster than its ability to produce rice and wheat.

2.6 Scenario of Agriculture in 2008-09

The performance of the agricultural sector influences the growth of the Indian economy. Agriculture (including allied activities) accounted for 17.8 per cent of the Gross Domestic Product (GDP-at constant prices) in 2007-08 as compared to 21.7 per cent in 2003-04. Notwithstanding the fact that the share of this sector in GDP has been declining over the years, its role remains critical as it accounts for about 52 per cent of the employment in the country. Apart from being the provider of food and fodder, its importance also stems from the raw materials that it provides to industry. The prosperity of the rural economy is also closely linked to agriculture and allied activities. Agricultural sector contributed 12.2 per cent of national exports in 2007-08. The rural sector (including agriculture) is being increasingly seen as a potential source of domestic demand; a recognition, that is shaping the marketing strategies of entrepreneurs wishing to widen the demand for goods and services.

In terms of composition, out of the total share of 17.8 per cent in GDP in 2007-08 for the agriculture and allied activities sector, agriculture alone accounted for 16.3 per cent of GDP followed by fishing at 0.8 per cent and forestry and logging at 0.7 per cent of GDP (Table 2.3).

Table 2.3: Agriculture sector - Key indicators

S.No	Item	2007-08	2008-09
1.	**GDP - share and growth** (per cent at 1999-00 prices)		
	Growth in GDP in agriculture & allied sectors	4.9	1.6
	Share in GDP - Agriculture and allied sectors	17.8	17.1
	Agriculture	16.3	
	Forestry and logging	0.7	
	Fishing	0.8	
2.	**Share in total gross capital formation in the country** (per cent at 1999-00 prices)		
	Share of agriculture & allied sectors in total gross capital	6.7	
	Agriculture	5.7	
	Forestry and logging	0.1	
	Fishing	0.9	
3.	**Agricultural imports & exports** (per cent at current prices)		
	Agricultural imports to national imports	3.1	
	Agricultural exports to national exports	12.2	
4.	**Employment** in the agriculture sector as share of total		52.1
	employment in 2004-05 as per Current Daily Status (per cent)		

Source: Central Statistical Organization & Dept of Agriculture and Cooperation

Gross capital formation in agriculture and allied sector

The Gross Capital Formation (GCF) in agriculture as a proportion to the total GDP has shown a decline from 2.9 per cent in 2001-02 to 2.5 per cent in 2007-08. However, the GCF in agriculture relative to GDP in this sector has shown an improvement from 11.23 per cent in 1999-2000 to 14.24 per cent in 2007-2008 (Table 2.3).

Table 2.4: Gross capital formation in agriculture (Figures in Rs. crore at 1999-2000 prices)

Year	GDP	Agriculture & allied activities		GCF/GDP in Agriculture & allied (%)	GCF in agriculture as % of total GDP
		GCF	GDP		
2004-05	2388768	57849	482446	12.0	2.4
2005-06	2616101	66065	511013	12.9	2.5
2006-07	2871120	73285	531315	13.8	2.6
2007-08	3129717	79328	557122	14.2	2.5

Source: Central Statistical Organization & Dept of Agriculture and Cooperation

The share of agriculture & allied sector in total GCF after showing a marginal increase during 1999-2000 to 2001-02 has been continuously declining. It stood at 10.2 per cent in 1999-2000, increased to 11.7 per cent in 2001-02 and thereafter declined to 7 per cent in 2006-07. The decline was mainly attributed to decline in the private sector despite increase in the share of public sector (Table 2.4).

Table 2.5: Share of agriculture & allied sector in total GCF (%) (at 1999-2000 prices)

Year	Public sector	Private sector	Total
1999-2000	6.0	11.9	10.2
2000-01	5.8	11.3	9.7
2001-02	6.7	13.7	11.7
2002-03	6.5	11.5	10.3
2003-04	7.4	9.2	8.8
2004-05	7.8	7.7	7.7
2005-06	7.9	7.1	7.2
2006-07	8.2	6.6	7.0

Source: Agricultural Statistics at a Glance 2008, Directorate of Economics & Statistics

Apart from production, the demand and distributional aspects of the agricultural sector, especially of food availability and food management, are of importance to the economy. The production performance of different segments of agriculture and allied activities covering, inter alia, horticulture, animal husbandry and fisheries as also the developments in the area of food management during the year 2008-09 is shown in the above tables

2.7 Indian Agri Export Scenario

Export of agricultural produces has taken a large leap after 1990-91, when Indian government went for economic reforms in all sectors. After the beginning of WTO and globalization of markets the Indian Agricultural Produces specially fruits, vegetables, spices and cash crops like cotton, jute, tea, coffee and rubber have exceeded the expectations and proved to be a great economical support for the country.

2.7.1 Exports of fruits since 1990

India is the second largest producer of Fruits after China, with a production of 44.04 million tonnes of fruits from an area of 3.72 million hectares (Table 2.6). A large variety of fruits are grown in India, of which mango, banana, citrus, guava, grape, pineapple and apple are the major ones. Apart from these, fruits like papaya, sapota, annona, phalsa, jackfruit, ber, pomegranate in tropical and sub-tropical group and peach, pear, almond, walnut, apricot and strawberry in the temperate group are also grown in a sizeable area. Although fruit is grown throughout of the country, the major fruit growing states are Maharashtra, Tamil Nadu, Karnataka, Andhra Pradesh, Bihar, Uttar Pradesh and Gujarat. It is seen that mango fruit is highly cultivated with large area of land cultivated under it. After mango, banana and citrus fruits are cultivated largely. Grapes are cultivated mainly in the district of Nasik of Maharashtra state. Area under grape cultivation is comparatively less as seen from the table. 2.6

Table 2.6

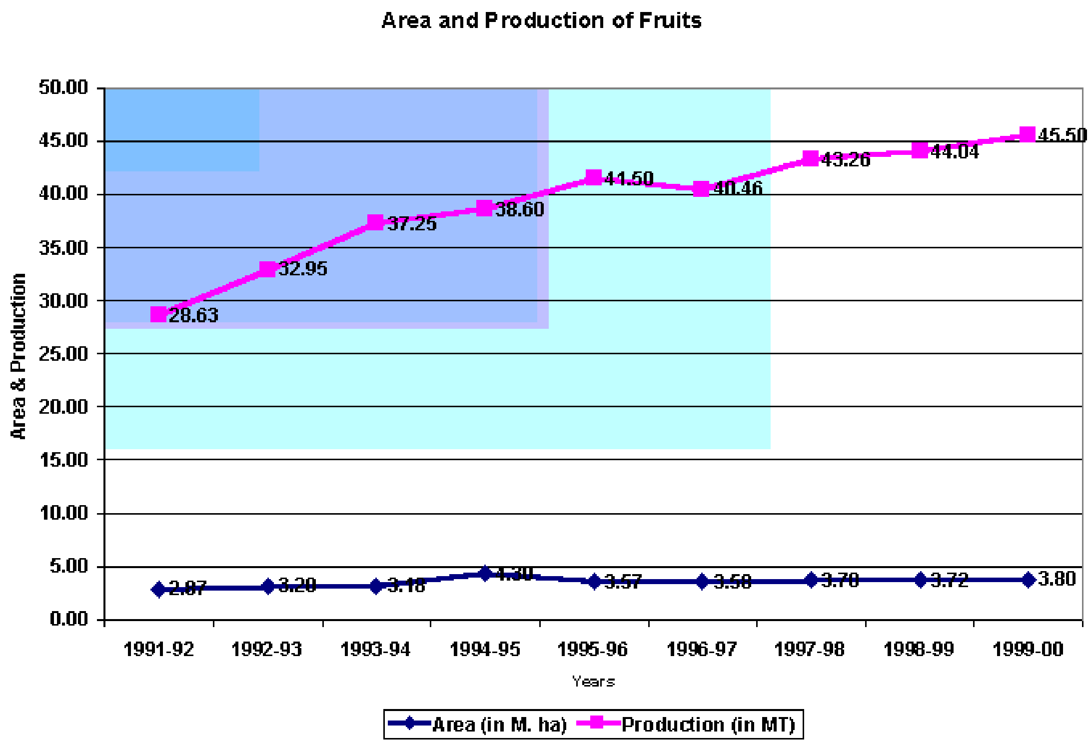
AREA, PRODUCTION AND EXPORT OF FRUITS IN INDIA AFTER 1990

S.No	**Fruits**	**Area (000 ha.)**	**Production (000 MT)**	**Exports (in million tones)**
1	Apple	238.3	1047.4	**375**
2	Banana	490.7	16813.5	436
3	Citrus	526.9	4650.6	**865**
4	Grapes	44.3	1137.8	646
5	Guava	150.9	1710.5	**230**
6	Litchi	56.4	433.2	185
7	Mango	1486.9	10503.5	**2634**
8	Papaya	60.5	1666.2	346
9	Pineapple	75.5	1025.4	**292**
10	Sapota	64.4	800.3	76.3
11	Others	601.2	5707.6	**932**
	Total	**3796.8**	**45496.0**	**7017.3**

Source: Directorate General of Commercial Intelligence and Statistics, Kolkatta

The graph 2.1 shows the area, production of fruits from 1990 to 2000. From the graph we see that the area under cultivation of fruits has shown a constant area ranging between 2.5 million hectares to 3.5 million hectares. But by 2008-09 the area under fruit cultivation has increased slightly to 4.2 million hectares. Whereas the production of fruits has shown a steady growth from 28.63 million tonnes in 1992-93 to 45.50 million tonnes in 1999-2000. As per the agricultural report the growth in the production of fruits had increased to 96.36 million tonnes by the end of 2009-10. The table also shows export of fruits in the 2008-09 in metric million tones.

Figure 2.1: Area and Production of fruits from 1991-92 to 1999-2000



Source: Central Statistical Organization & Dept of Agriculture and Cooperation

2.7.2 Export of Vegetables:

In vegetables production, India is next only to China with an annual production of 87.53 million tonnes from 5.86 million hectares having a share of 14.4 per cent to the world production. Adoption of high yielding cultivars and FI hybrids and suitable production technologies has largely contributed for higher production and productivity. Per capital consumption has also increased from 95 gram to 175 gram per day. More than 40 kinds of vegetables belonging to different groups, namely cucurbits, cole crops, solanaceous, root and leafy vegetables,are grown in different agro-climatic situations of the country. Except a few, namely brinjal (egg plant), colocasia, cucumber, ridge gourd, sponge gourd, pointed gourd etc., most of the other vegetables have been introduced from abroad.

Potato is most widely grown vegetable crop in the country with a share of 25.7 per cent. The area under potato cultivation is 1.28 Million ha with total production of 22.49 MT. The main varieties of potato grown in the country are Kufri Chandramukhi, Kufri Jyoti, Kufri Badshah, Kufri Himalani, Kufri Sindhuri, Kufri Lalima etc. Uttar Pradesh is the leading potato growing state in the country with a production of 9.53 million tonnes followed by West Bengal and Bihar. **Tomato** occupies second position amongst the vegetable crops in terms of production. The total production of tomato in the country in 1998-99 was 8.27 MT from an area of 0.46 M. ha. The main varieties of tomato grown in the country are Pusa Ruby, Pusa Early Dwarf, Arka Abha, Arka Alok, Pant Bahar, Pusa hybrid-1, Pusa hybrid-2, MTH-6, Arka Vardan etc. Andhra Pradesh is the largest grower of tomato with a production of 2.05 MT. The other main tomato growing states are Bihar, Karnataka, Maharashtra and Orissa. **Brinjal** occupies the third position amongst vegetable crops. The production of brinjal in the year 1998-99 was 7.88 MT from an area 0.49 M.ha. The varieties of brinjal popular in the country are Arka Navneet, Pusa Ankur, Hybrid-6, Pusa hybrid-5, ARBH-1, ABH-1, Pusa Purple Long, Pusa Purple Cluster, Ritu Raj etc. West Bengal is the largest producer of brinjal followed by Maharashtra and Bihar. The other main state growing brinjal Karnataka, Maharashtra, Gujarat, Andhra Pradesh, Assam and Madhya Pradesh. **Cabbage** is the fourth most widely grown vegetable crop of our country. India is the leading country producing Cabbage. The area under Cabbage cultivation is 0.23 M.ha producing 5.62 MT. The main varieties of cabbage are Pusa Drum Head, Golden Acre, Pride of India, Pusa Mukta, Pusa Synthetic etc. West Bengal produces 1.84 MT and is the largest grower of the cabbage. Orissa and Bihar occupies second and third position respectively. The other major growers of cabbage are Assam, Karnataka, Maharashtra and Gujarat. The other important vegetable crops grown in the country are onion, chillies, peas, beans, okra, cabbage, cauliflower, pumpkin, bottlegourd, cucumber, watermelon, palak, methi, carrot and radish.

India, known as “Land of Spices”, is the largest producer, consumer and exporter of variety of spices in the world. The area covered under various spices in the country is estimated to be 25.17 lakhs ha with an annual production of 29.10 lakhs tonnes (Fig-8). More than 90% of the spices produced in the country is used for domestic consumption and the rest exported as raw as well as value added products. The important spices produced in the country are: Black pepper, ginger, turmeric, garlic, chillies, coriander, cumin, fennel, fenugreek, celery, clove, cassia, nutmeg, mace, cardamom, saffron, vanilla and a group of herbal spices. Chillies occupies the top position amongst spices with a share of 30 per cent. Total production of Chillies in the year 1998-99 was The share of spices in the total agricultural export during 1998-99 was about 6% with an export of 2.31 lakh tonnes earning foreign exchange worth Rs. 1758 crores. The exports of spices and spice products during 1999-2000 was 2.09 lakh tonnes valuing Rs. 1861 crores. Pepper was the leader in export earning with 46% share followed by Oil & Oleoresins (15%), chillies (13%) and turmeric (6%).

2.8 Initiatives to Improve Agriculture sector

The required level of investment for the development of marketing, storage and cold storage infrastructure is estimated to be huge. The government has not been able to implement various schemes to raise investment in marketing infrastructure. Among these schemes are Construction of Rural Go downs, Market Research and Information Network, and Development / Strengthening of Agricultural Marketing Infrastructure, Grading and Standardization.

The Indian Agricultural Research Institute (IARI), established in 1905, was responsible for the research leading to the "Indian Green Revolution" of the 1970s. The Indian Council of Agricultural Research (ICAR) is the apex body in agriculture and related allied fields, including research and education. The Union Minister of Agriculture is the President of the ICAR. The Indian Agricultural Statistics Research Institute develops new techniques for the design of agricultural experiments, analyses data in agriculture, and specializes in statistical techniques for animal and plant breeding.

Recently Government of India has set up Farmers Commission to completely evaluate the agriculture program. However the recommendations have had a mixed reception.

2.8.1 Problems

There are many problems in Indian agriculture for example cotton flower in India. This is the main cash crop in Vidarbha region. Slow agricultural growth is a concern for policymakers as some two-thirds of India's people depend on rural employment for a living. Current agricultural practices are neither economically nor environmentally sustainable and India's yields for many agricultural commodities are low. Poorly maintained irrigation systems and almost universal lack of good extension services are among the factors responsible. Farmers' access to markets is hampered by poor roads, rudimentary market infrastructure, and excessive regulation.

According to World Bank Report 'India countryOverview 2007-08' The low productivity in India is a result of the following factors:

- According to World Bank, Indian Branch: Priorities for Agriculture and Rural Development", India's large agricultural subsidies are hampering productivity-enhancing investment. Overregulation of agriculture has increased costs, price risks and uncertainty. Government intervenes in labour, land, and credit markets. India has inadequate infrastructure and services. World Bank also says that the allocation of water is inefficient, unsustainable and inequitable. The irrigation infrastructure is deteriorating. The overuse of water is currently being covered by over pumping aquifers, but as these are falling by foot of groundwater each year, this is a limited resource.
- Illiteracy, general socio-economic backwardness, slow progress in implementing land reforms and inadequate or inefficient finance and marketing services for farm produce.
- Inconsistent government policy. Agricultural subsidies and taxes often changed without notice for short term political ends.
- The average size of land holdings is very small (less than 20,000 m^2) and is subject to fragmentation due to land ceiling acts, and in some cases, family disputes.

Such small holdings are often over-manned, resulting in disguised unemployment and low productivity of labour.

- Adoption of modern agricultural practices and use of technology is inadequate, hampered by ignorance of such practices, high costs and impracticality in the case of small land holdings.
- Irrigation facilities are inadequate, as revealed by the fact that only 52.6% of the land was irrigated in 2003–04, which result in farmers still being dependent on rainfall, specifically the Monsoon season. A good monsoon results in a robust growth for the economy as a whole, while a poor monsoon leads to a sluggish growth. Farm credit is regulated by NABARD, which is the statutory apex agent for rural development in the subcontinent. At the same time over pumping made possible by subsidized electric power is leading to an alarming drop in aquifer levels.

2.8.2 India needs to improve food product standards

India needs to improve the standards of its food products to acquire a competitive edge in the global market, says Sanjay Dave[1], the first Indian vice-chair of the Rome-based Codex Alimentarius Commission (CAC), an international organization that aims at promoting food safety globally. Dave, also the director of India's Agricultural and Processed Food Products Export Development Authority (APEDA), feels that his tenure as CAC vice-chair would see continuous deliberations to meet emerging challenges at home and abroad.

"There is no scope for any complacency when it comes to dealing with the issue of food product standards. International and domestic consumers are quite quality conscious. India and other developing nations need to improve standards of food products," Dave told IANS in an interview.

India's farm and processed food products' exports have grown from Rs.6.47 billion in 1999-2000 to Rs.24.12 billion in 2006-07.

Major importers of Indian products like pomegranates, mangoes, onions and basmati rice are the United Arab Emirates, Saudi Arabia, Russia, Bangladesh, Turkey, Kuwait, Sri Lanka, Italy, Germany, Australia, Jordan, Bahrain, and Malaysia.

As capacity building is the key to ensuring food standards, the CAC intends to provide technical assistance to the developing nations so that the quality aspect is addressed right from the field. “From proper monitoring of pesticide residue to the processing units, there is a need to be vigilant at all levels so that the end product is healthy and well received by consumers,” Dave maintained.

Dave said he would act aggressively to implement Codex Plan-2008-13, a vision document that speaks of consensus building and understanding food safety needs. “For me, the vice-chair of CAC does not mean just holding a few meetings. I am committed to holding meeting and deliberating with all stakeholders throughout the year,” he said. The Food and Agriculture Organisation (FAO) and the World Health Organisation (WHO) created the Codex Alimentarius (Latin for food law or code) in 1963. The CAC aims at developing food standards, guidelines and related texts such as codes of practice under the food standards programme of FAO and WHO, two bodies under the aegis of the United Nations. His new position, however, does not mean that he will have less time for APEDA, the organization he has headed for long.

Reference 1: Article by Rajeev Ranjan Roy July 12th, 2008 ICT by IANS

"APEDA stands to benefit a lot from CAC and vice versa. Our great work at APEDA in managing quality of processed foods and agricultural products played a decisive role in my election," he said. APEDA is an autonomous body under India's ministry of commerce and industry dealing with quality management of agricultural and processed foods, and promoting their export.

2.9 CONCLUSIONS

Indian agriculture forms the back bone of Indian economy and despite concerted industrialization in the last six decades, agriculture occupies a place of pride. Being the largest industry in the country it provides employments to around 65% of the total workforce in the country. But in the recent year, its share in the GDP has declined to 18% in 2008-09. There is lot of scope for improvement in this sector. Summarizing the important points we can conclude that

1. Indian agriculture needs shift itself from traditional approach to scientific approach.
2. Indian agriculture should focus on market oriented produces rather than self sufficiency of food grains.
3. Indian agriculture needs to adapt technological and research oriented environment instead of struggling in traditional and superstitious environment.
4. Indian government should provide modern technology access to the rural farmers along with knowledge of markets and export potential.
5. Indian agriculture should aim to be free from trades and middle men dominant market and establish market access directly to farmers.
6. Indian agriculture shows a lot of potential because it has the largest diversity in physiography and climate and has highest amount of resources such as man power.
7. Indian agriculture should utilize these resources and develop the agriculture sector into one of the fastest growing, largest contributing sector of our economy.

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Science in Ancient India

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November 15, 2005

In *Ananya: A portrait of India*, S.R. Sridhar and N.K. Mattoo (eds.). AIA: New York, 1997, pages 399-420

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'Veda' means knowledge. Since we call our earliest period Vedic, this is suggestive of the importance of knowledge and science, as a means of acquiring that knowledge, to that period of Indian history. For quite some time scholars believed that this knowledge amounted to no more than speculations regarding the self; this is what we are still told in some schoolbook accounts. New insights in archaeology, astronomy, history of science and Vedic scholarship have shown that such a view is wrong. We now know that Vedic knowledge embraced physics, mathematics, astronomy, logic, cognition and other disciplines. We find that Vedic science is the earliest science that has come down to us. This has significant implications in our understanding of the history of ideas and the evolution of early civilizations.

The reconstructions of our earliest science are based not only on the Vedas but also on their appendicies called the Vedangas. The six Vedangas deal with: *kalpa*, performance of ritual with its basis of geometry, mathematics and calendrics; *shiksha*, phonetics; *chhandas*, metrical structures; *nirukta*, etymology; *vyakarana*, grammar; and *jyotisha*, astronomy and other cyclical phenomena. Then there are naturalistic descriptions in the various Vedic books that tell us a lot about scientific ideas of those times.

Briefly, the Vedic texts present a tripartite and recursive world view. The universe is viewed as three regions of earth, space, and sky with the corresponding entities of Agni, Indra, and Vishve Devah (all gods). Counting separately the joining regions leads to a total of five categories where, as we see in Figure 1, water separates earth and fire, and air separates fire and ether.

In Vedic ritual the three regions are assigned different fire altars. Furthermore, the five categories are represented in terms of altars of five layers. The great altars were built of a thousand bricks to a variety of dimensions. The discovery that the details of the altar constructions code astronomical knowledge is a fascinating chapter in the history of astronomy (Kak 1994a; 1995a,b).

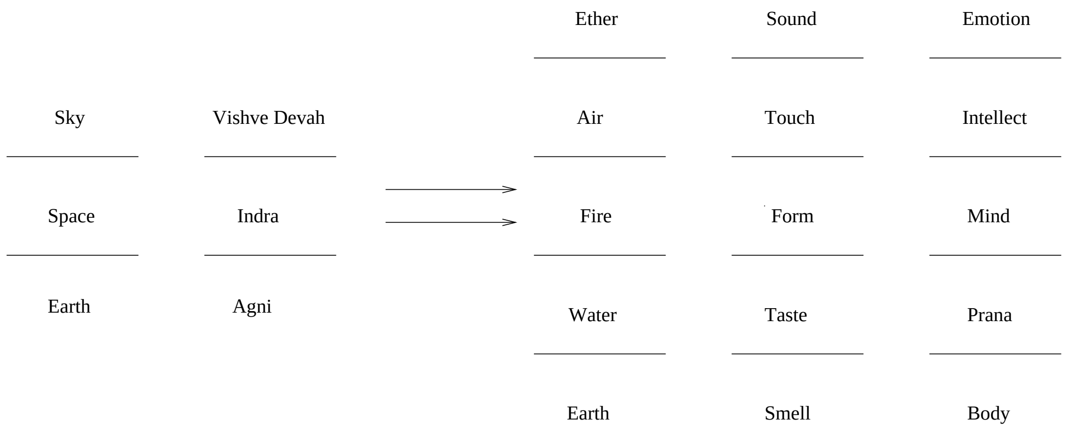

Figure 1: From the tripartite model to five categories of analysis

In the Vedic world view, the processes in the sky, on earth, and within the mind are taken to be connected. The Vedic rishis were aware that all descriptions of the universe lead to logical paradox. The one category transcending all oppositions was termed *brahman*. Understanding the nature of consciousness was of paramount importance in this view but this did not mean that other sciences were ignored. Vedic ritual was a symbolic retelling of this world view.

Chronology

To place Vedic science in context it is necessary to have a proper understanding of the chronology of the Vedic literature. There are astronomical references in the Vedas which recall events in the third or the fourth millennium B.C.E. and earlier. The recent discovery (e.g. Feuerstein 1995) that Sarasvati, the preeminent river of the Rigvedic times, went dry around 1900 B.C.E. due to tectonic upheavels implies that the Rigveda is to be dated prior to this epoch, perhaps prior to 2000 B.C.E. since the literature that immediately followed the Rigveda does not speak of any geological catastrophe. But we cannot be very precise about our estimates. There exist traditional accounts in the Puranas that assign greater antiquity to the Rigveda: for example, the Kaliyuga tradition speaks of 3100 B.C.E. and the Varāhamihira tradition mentions 2400 B.C.E. According to Henri-Paul Francfort (1992) of the Indo-French team that surveyed this area, the Sarasvati river had ceased to be a perennial river by the third millennium B.C.E.; this supports those who argue for the older dates. But in the absence of conclusive evidence, it is prudent to take the most conservative of these dates, namely 2000 B.C.E. as the latest period to be associated with the Rigveda.

The textbook accounts of the past century or so were based on the now disproven supposition that the Rigveda is to be dated to about 1500-1000 B.C.E. and, therefore, the question of the dates assigned to the Brahmanas, Sutras and other literature remains open. The detailed chronology of the literature that followed Rigveda has not yet been worked out. A chronology of this literature was attempted based solely on the internal astronomical evidence in the important book "Ancient Indian Chronology" by the historian of science P.C. Sengupta in 1947. Although Sengupta's dates have the virtue of inner consistency, they have neither been examined carefully by other scholars nor checked against archaeological evidence.

This means that we can only speak in the most generalities regarding the chronology of the texts: assign Rigveda to the third millennium B.C.E. and earlier and the Brahmanas to the second millennium. This also implies that the archaeological finds of the Indus-Sarasvati period, which are coeval with Rigveda literature, can be used to cross-check textual evidence.

No comprehensive studies of ancient Indian science exist. The textbook accounts like the one to be found in Basham's "The Wonder that was India" are hopelessly out of date. But there are some excellent surveys of selected material. The task of putting it all together into a comprehensive whole will be a major task for historians of science.

This essay presents an assortment of topics from ancient Indian science. We begin with an outline of the models used in the Vedic cognitive science; these models parallel those used in ancient Indian physics. We also review mathematics, astronomy, grammar, logic and medicine.

1 Vedic cognitive science

The Rigveda speaks of cosmic order. It is assumed that there exist equivalences of various kinds between the outer and the inner worlds. It is these connections that make it possible for our minds to comprehend the universe. It is noteworthy that the analytical methods are used both in the examination of the outer world as well as the inner world. This allowed the Vedic rishis to place in sharp focus paradoxical aspects of analytical knowledge. Such paradoxes have become only too familiar to the contemporary scientist in all branches of inquiry (Kak 1986).

In the Vedic view, the complementary nature of the mind and the outer world, is of fundamental significance. Knowledge is classified in two ways: the lower or dual; and the higher or unified. What this means is that knowledge is superficially dual and paradoxical but at a deeper level it has a unity. The Vedic view claims that the material and the conscious are aspects of the same transcendental reality.

The idea of complementarity was at the basis of the systematization of Indian philosophic traditions as well, so that complementary approaches were paired together. We have the groups of: logic (nyaya) and physics (vaisheshika), cosmology (sankhya) and psychology (yoga), and language (mimamsa) and reality (vedanta). Although these philosophical schools were formalized in the post-Vedic age, we find an echo of these ideas in the Vedic texts.

In the Rigveda there is reference to the yoking of the horses to the chariot of Indra, Ashvins, or Agni; and we are told elsewhere that these gods represent the essential mind. The same metaphor of the chariot for a person is encountered in Katha Upanishad and the Bhagavad Gita; this chariot is pulled in different directions by the horses, representing senses, which are yoked to it. The mind is the driver who holds the reins to these horses; but next to the mind sits the true observer, the self, who represents a universal unity. Without this self no coherent behaviour is possible.

The Five Levels

In the Taittiriya Upanishad, the individual is represented in terms of five different sheaths or levels that enclose the individual's self. These levels, shown in an ascending order, are:

- The physical body (annamaya kosha)
- Energy sheath (pranamaya kosha)
- Mental sheath (manomaya kosha)
- Intellect sheath (vijnanamaya kosha)
- Emotion sheath (anandamaya kosha)

These sheaths are defined at increasingly finer levels. At the highest level, above the emotion sheath, is the self. It is significant that emotion is placed higher than the intellect. This is a recognition of the fact that eventually meaning is communicated by associations which are influenced by the emotional state.

The energy that underlies physical and mental processes is called prana. One may look at an individual in three different levels. At the lowest level is the physical body, at the next higher level is the energy systems at work, and at the next higher level are the thoughts. Since the three levels are interrelated, the energy situation may be changed by inputs either at the physical level or at the mental level. When the energy state is agitated and restless, it is characterized by *rajas*; when it is dull and lethargic, it is characterized by *tamas*; the state of equilibrium and balance is termed *sattva*.

The key notion is that each higher level represents characteristics that are emergent on the ground of the previous level. In this theory mind is an emergent entity, but this emergence requires the presence of the self.

The Structure of the Mind

The Sankhya system takes the mind as consisting of five components: manas, ahankara, chitta, buddhi, and atman. Again these categories parallel those of Figure 1.

Manas is the lower mind which collects sense impressions. Its perceptions shift from moment to moment. This sensory-motor mind obtains its inputs from the senses of hearing, touch, sight, taste, and smell. Each of these senses may be taken to be governed by a separate agent.

Ahankara is the sense of I-ness that associates some perceptions to a subjective and personal experience.

Once sensory impressions have been related to I-ness by ahankara, their evaluation and resulting decisions are arrived at by buddhi, the intellect. Manas, ahankara, and buddhi are collectively called the internal instruments of the mind.

Next we come to chitta, which is the memory bank of the mind. These memories constitute the foundation on which the rest of the mind operates. But chitta is not merely a passive instrument. The organization of the new impressions throws up instinctual or primitive urges which creates different emotional states.

This mental complex surrounds the innermost aspect of consciousness which is called atman, the self, brahman, or jiva. Atman is considered to be beyond a finite enumeration of categories.

All this amounts to a brilliant analysis of the individual. The traditions of yoga and tantra have been based on such analysis. No wonder, this model has continued to inspire people around the world to this day.

2 Mathematical and physical sciences

Here we review some new findings related to the early period of Indian science which show that the outer world was not ignored at the expense of the inner.

Geometry and mathematics

Seidenberg, by examining the evidence in the Shatapatha Brahmana, showed that Indian geometry predates Greek geometry by centuries. Seidenberg argues that the birth of geometry and mathematics had a ritual origin. For example, the earth was represented by a circular altar and the heavens were represented by a square altar and the ritual consisted of converting the circle into a square of an identical area. There we see the beginnings of geometry!

In his famous paper on the origin of mathematics, Seidenberg (1978) concluded: "Old-Babylonia [1700 BC] got the theorem of Pythagoras from India or that both Old-Babylonia and India got it from a third source. Now the Sanskrit scholars do not give me a date so far back as 1700 B.C. Therefore I *postulate* a pre-Old-Babylonian (i.e., pre-1700 B.C.) source of the kind of geometric rituals we see preserved in the Sulvasutras, or at least for the *mathematics* involved in these rituals." That was before archaeological finds disproved the earlier assumption of a break in Indian civilization in the second millennium B.C.E.; it was this assumption of the Sanskritists that led Seidenberg to postulate a third earlier source. Now with our new knowledge, Seidenberg's conclusion of India being the source of the geometric and mathematical knowledge of the ancient world fits in with the new chronology of the texts.

Astronomy

Using hitherto neglected texts related to ritual and the Vedic indices, an astronomy of the third millennium B.C.E. has been discovered (Kak 1994a; 1995a,b). Here the altars symbolized different parts of the year. In one ritual, pebbles were placed around the altars for the earth, the atmosphere, and the sky. The number of these pebbles were 21, 78, and 261, respectively. These numbers add up to the 360 days of the year. There were other features related to the design of the altars which suggested that the ritualists were aware that the length of the year was between 365 and 366 days.

The organization of the Vedic books was also according to an astronomical code. To give just one simple example, the total number of verses in all the Vedas is 20,358 which

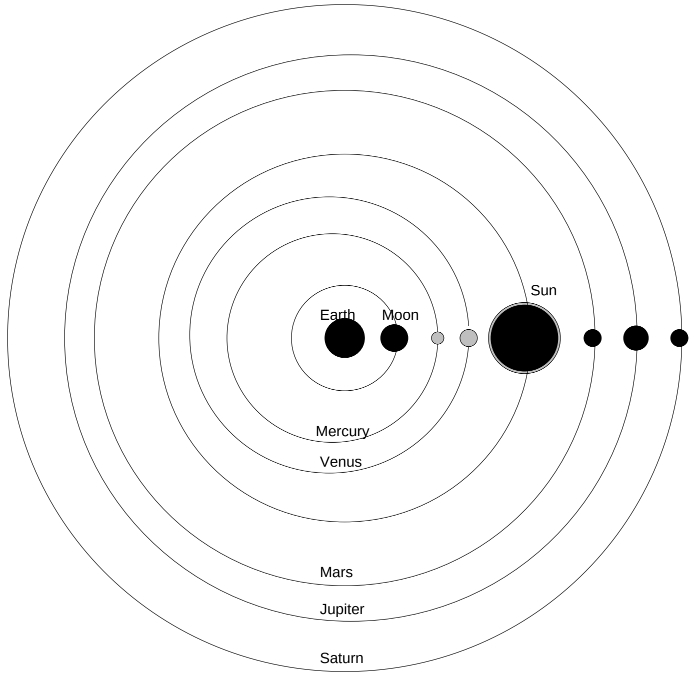

Figure 2: The Vedic planetary model

equals 261×78, a product of the sky and atmosphere numbers! The Vedic ritual followed the seasons hence the importance of astronomy.

The second millennium text Vedanga Jyotisha went beyond the earlier calendrical astronomy to develop a theory for the mean motions of the sun and the moon. This marked the beginnings of the application of mathematics to the motions of the heavenly bodies.

Planetary knowledge

The Vedic planetary model is given in Figure 2. The sun was taken to be midway in the skies. A considerable amount of Vedic mythology regarding the struggle between the demons and the gods is a metaphorical retelling of the motions of Venus and Mars (Frawley 1994).

The famous myth of Vishnu's three strides measuring the universe becomes intelligible when we note that early texts equate Vishnu and Mercury. The myth appears to celebrate the first measurement of the period of Mercury (Kak 1996a) since three periods equals the number assigned in altar ritual to the heavens. Other arguments suggest that the Vedic people knew the periods of the five classical planets.

Writing

Cryptological analysis has revealed that the Brahmi script of the Mauryan times evolved out of the third millennium Sarasvati (Indus) script. The Sarasvati script was perhaps the first true alphabetic script. The worship of Sarasvati as the goddess of learning remembers the development of writing on the banks of the Sarasvati river. It also appears that the symbol for zero was derived from the fish sign that stood for "ten" in Brahmi and this occurred around 50 B.C.E.-50 C.E. (Kak 1994b).

Binary numbers

Barend van Nooten (1993) has shown that binary numbers were known at the time of Pingala's *Chhandahshastra*. Pingala, who lived around the early first century B.C.E., used binary numbers to classify Vedic meters. The knowledge of binary numbers indicates a deep understanding of arithmetic. A binary representation requires the use of only two symbols, rather than the ten required in the usual decimal representation, and it has now become the basis of information storage in terms of sequences of 0s and 1s in modern-day computers.

Music

Ernest McClain (1978) has described the tonal basis of early myth. McClain argues that the connections between music and myth are even deeper than astronomy and myth. The invariances at the basis of tones could very well have served as the ideal for the development of the earliest astronomy. The tonal invariances of music may have suggested the search of similar invariances in the heavenly phenomena.

The Samaveda, where the hymns were supposed to be sung, was compared to the sky. Apparently, this comparison was to emphasize the musical basis of astronomy. The Vedic hymns are according to a variety of meters; but what purpose, if any, lay behind a specific choice is unknown.

Grammar

Panini's grammar (6th century B.C.E. or earlier) provides 4,000 rules that describe the Sanskrit of his day completely. This grammar is acknowledged to be one of the greatest intellectual achievements of all time. The great variety of language mirrors, in many ways, the complexity of nature. What is remarkable is that Panini set out to describe the entire grammar in terms of a *finite* number of rules. Frits Staal (1988) has shown that the grammar of Panini represents a universal grammatical and computing system. From this perspective it anticipates the logical framework of modern computers (Kak 1987).

Medicine

There is a close parallel between Indian and Greek medicine. For example, the idea of breath (*prana* in Sanskrit, and *pneuma* in Greek) is central to both. Jean Filliozat (1970) has argued that the idea of the correct association between the three elements of the wind, the gall, and the phlegm, which was described first by Plato in Greek medicine, appears to be derived from the earlier *tridosha* theory of Ayurveda. Filliozat suggests that the transmission occurred via the Persian empire.

These discoveries not only call for a revision of the textbook accounts of Indian science but also call for new research to assess the impact on other civilizations of these ideas.

3 Rhythms of life

We have spoken before of how the Vedas speak of the connections between the external and the internal worlds. The hymns speak often of the stars and the planets. These are sometimes the luminaries in the sky, or those in the firmament of our inner landscapes or both.

To the question on how can the motions of an object, millions of miles away, have any influence on the life of a human being one can only say that the universe is interconnected. In this ecological perspective the physical planets do not influence the individual directly. Rather, the intricate clockwork of the universe runs on forces that are reflected in the periodicities of the astral bodies as also the cycles of behaviors of all terrestrial beings and plants.

It is not the gravitational pull of the planet that causes a certain response, but an internal clock governed by the genes. We know this because in some mutant organisms the internal clock works according to periods that have no apparent astronomical basis. So these cycles can be considered to be a manifestation of the motions of the body's inner "planets." In the language of evolution theory one would argue that these periods get reflected in the genetic inheritance of the biological system as a result of the advantage over millions of years that they must have provided for survival.

The most fundamental rhythms are matched to the periods of the sun or the moon. It is reasonable to assume that with their emphasis on time bound rituals and the calendar, the ancients had discovered many of the biological periods. This would include the 24-hour-50-minute circadian rhythm, the connection of the menstrual cycle with the motions of the moon, the life cycles of various plants, and the semimonthly estrus cycle of sheep, the three-week cycles of cattle and pigs, and the six-month cycle of dogs.

The moon (Soma) is called the "lord of speech" (Vachaspati) in the Rigveda. It is also taken to awaken eager thoughts. Other many references suggest that in the Rigvedic times the moon was taken to be connected with the mind.

This is stated most directly in the the famous Purushasukta, the Cosmic Man hymn, of the Rigveda where it is stated that the mind is born of the moon and in Shatapatha Brahmana where we have: "the mind is the moon." Considering the fact that the relationships between the astronomical and the terrestrial were taken in terms of periodicities, doubtless, this slogan indicates that the mind is governed by the period of the moon.

Fire, having become speech, entered the mouth
Air, becoming scent, entered the nostrils
The sun, becoming sight, entered the eyes
The regions becoming hearing, entered the ears
The plants, becoming hairs, entered the skin
The moon, having become mind, entered the heart.
—Aitreya Aranyaka 2.4.2.4

This verse from the Upanishadic period speaks at many levels. At the literal level there is an association of the elements with various cognitive centers. At another level, the verse connects the time evolution of the external object to the cognitive center.

Fire represents consciousness and this ebbs and flows with a daily rhythm. Air represents seasons so here the rhythm is longer. The sun and sight have a 24-hour cycle. The regions denote other motions in the skies so hearing manifests cycles that are connected to the planets. The plants have daily and annual periods; the hairs of the body have an annual period. The mind has a period of 24 hours and 50 minutes like that of the moon.

What are the seats of these cycles? According to tantra the chakras of the body are the centers of the different elements as well as cognitive capacities and rhythms related to "internal planets." The knowledge of these rhythms appears to have led to astrology.

4 Cosmology

We have seen how the logical apparatus that was brought to bear on the outer world was applied to the analysis of the mind. But the question remains: How does inanimate matter come to have awareness? This metaphysical question was answered by postulating entities for smell, taste, form, touch, and sound as in Figure 1. In the Sankhya system, a total of twenty-four such categories are assumed. These categories are supposed to emerge at the end of a long chain of evolution and they may be considered to be material. The breath of life into the instruments of sight, touch, hearing and so on is provided by the twenty-fifth category, which is *purusha*, the soul.

The recursive Vedic world-view requires that the universe itself go through cycles of creation and destruction. This view became a part of the astronomical framework and ultimately very long cycles of billions of years were assumed. The Sankhya evolution takes the life forms to evolve into an increasingly complex system until the end of the cycle.

The categories of Sankhya operate at the level of the individual as well. Life mirrors the entire creation cycle and cognition mirrors a life-history. Surprisingly similar are the modern slogan: ontogeny is phylogeny, and microgeny (the cognitive process) is a speeded-up ontogeny (Brown 1994).

5 Concluding Remarks

We are in the midst of a paradigm shift in our understanding of Vedic science and cosmology. We now know that measurement astronomy is to be dated to at least the third millennium B.C.E. which is more than a thousand years earlier than was believed only a decade ago; and mathematics and geometry date to at least the beginning of the second millennium B.C.E. Indian mythology is being interpreted in terms of its underlying astronomy or/and cognitive science. We find that many Indians dates are much earlier than the corresponding dates elsewhere. What does it all mean for our understanding of the Indian civilization and its interactions with Mesopotamia, Egypt, China and Greece? Was Indian knowledge carried to the other nations or do we have a case here for independent discovery in different places?

Contemporary science has begun to examine Vedic theories on the nature of the "self" and see if they might be of value in the search for a science of consciousness (e.g. Kak 1996b). Man has mastered the outer world and Vedic science formed the basis for that enterprise; it is now possible that the exploration of the inner world, which is the heart of modern science, will also be along paths long heralded by Vedic rishis.

2

In the earliest period of Indian science, it is exceptional when we know the authorship of a text or an idea. For example, although Lagadha (c. 1400 B.C.E.) is the author of Vedanga Jyotisha we do not know if its astronomy was developed by him or if he merely summarized what was then well known. Likewise we are not sure of the individual contributions in the Shulba Sutras, of Baudhayana, Apastamba, and other authors, which describe geometry, or Pingala's Chhandahsutra which shows how to count in a binary manner. The major exception to the anonymous nature of early Indian science is the grammatical tradition starting with Panini. This tradition is a wonderful application of the scientific method where the infinite variety of linguistic data is generated by means of a limited number of rules.

With Aryabhata of Kusumapura (born 476), we enter a new phase in which it becomes easier to trace the authorship of specific ideas. But even here there remain other aspects which are not so well understood. For example, the evolution of Indian medicine is not as well documented as that of Indian mathematics. Neither do we understand well the manner in which the philosophical basis underlying Indian science evolved.

Thus many texts speak of the relativity of time and space—abstract concepts that developed in the scientific context just a hundred years ago. The Puranas speak of countless universes, time flowing at different rates for different observers and so on.

The Mahabharata speaks of an embryo being divided into one hundred parts each becoming, after maturation in a separate pot, a healthy baby; this is how the Kaurava brothers are born. There is also mention of an embryo, conceived in one womb, being transferred to the womb of another woman from where it is born; the transferred embryo is Balarama and this is how he is a brother to Krishna although he was born to Rohini and not to Devaki.

There is an ancient mention of space travellers wearing airtight suits in the epic Mahabharata which may be classified as an early form of science fiction. According to the well-known Sanskritist J.A.B. van Buitenen, in the accounts in Book 3 called "The Razing of Saubha" and "The War of the Yakshas":

> the aerial city is nothing but an armed camp with flame-throwers and thundering cannon, no doubt a spaceship. The name of the demons is also revealing: they were Nivātakavacas, "clad in airtight armor," which can hardly be anything but space suits. (van Buitenen, 1975, page 202)

Universes defined recursively are described in the famous episode of Indra and the ants in Brahmavaivarta Purana. Here Vishnu, in the guise of a boy, explains to Indra that the ants he sees walking on the ground have all been Indras in their own solar systems in different times! These flights of imagination are to be traced to more than a straightforward generalization of the motions of the planets into a cyclic universe. They must be viewed in the background of an amazingly sophisticated tradition of cognitive and analytical thought (see e.g. Staal 1988; Kak 1994).

The context of modern science fiction books is clear: it is the liberation of the earlier modes of thought by the revolutionary developments of the 20th century science and technology. But how was science fiction integrated into the mainstream of Indian literary tradition two thousand years ago? What was the intellectual ferment in which such sophisticated ideas arose?

I do not answer these questions directly. My goal is to provide a survey so that the reader can form his or her own conclusions. I begin with an account of Indian mathematics and astronomy from the time of Aryabhata until the period of the Kerala school of astronomy. Then I consider material from one randomly chosen early text, Yoga-Vasishtha, to convey basic Indian notions about time, space, and matter. Yoga-Vasishtha has been dated variously as early as the sixth century and as late as the 14th century. It claims to be book regarding consciousness but it has many fascinating passages on time, space, matter and the nature of experience. We present a random selection that has parallels with some recent speculations in physics. Lastly, I take up the question of the conceptions behind the Shri Yantra, whose origins, some scholars believe, go back to the age of Atharvaveda.

6 Mathematics and astronomy

One would expect that the development of early Indian mathematics and astronomy went through several phases but we don't have sufficient data to reconstruct these phases. A certain astronomy has been inferred from the Vedic books, but there existed additional sources which have not survived. For example, there were early astronomical siddhantas of which we know now only from late commentaries written during the Gupta period (320-600); this period provided a long period of stability and prosperity that saw a great flowering of art, literature, and the sciences.

Of the eighteen early siddhantas the summaries of only five are available now. Perhaps one reason that the earlier texts were lost is because their theories were superseded by the more accurate later works. In addition to these siddhantas, practical manuals, astronomical tables, description of instruments, and other miscellaneous writings have also come down to us (Sarma 1985). The Puranas also have some material on astronomy.

Aryabhata

Aryabhata is the author of the first of the later siddhantas called Aryabhatiyam which sketches his mathematical, planetary, and cosmic theories. This book is divided into four chapters: (i) the astronomical constants and the sine table, (ii) mathematics required for computations, (iii) division of time and rules for computing the longitudes of planets using eccentrics and epicycles, (iv) the armillary sphere, rules relating to problems of trigonometry and the computation of eclipses.

The parameters of Aryabhatiyam have, as their origin, the commencement of Kaliyuga on Friday, 18th February, 3102 B.C.E. He wrote another book where the epoch is a bit different.

Aryabhata took the earth to spin on its axis; this idea appears to have been his innovation. He also considered the heavenly motions to go through a cycle of 4.32 billion years; here he went with an older tradition, but he introduced a new scheme of subdivisions within this great cycle. According to the historian Hugh Thurston, “Not only did Aryabhata believe that the earth rotates, but there are glimmerings in his system (and other similar systems) of a possible underlying theory in which the earth (and the planets) orbits the sun, rather than the sun orbiting the earth. The evidence is that the basic planetary periods are relative to the sun.”

That Aryabhata was aware of the relativity of motion is clear from this passage in his book,“Just as a man in a boat sees the trees on the bank move in the opposite direction, so an observer on the equator sees the stationary stars as moving precisely toward the west.”

Varahamihira

Varahamihira (died 587) lived in Ujjain and he wrote three important books: Panchasiddhantika, Brihat Samhita, and Brihat Jataka. The first is a summary of five early astronomical systems including the Surya Siddhanta. (Incidently, the modern Surya Siddhanta is different in many details from this ancient one.) Another system described by him, the Paitamaha Siddhanta, appears to have many similarities with the ancient Vedanga Jyotisha of Lagadha.

Brihat Samhita is a compilataion of an assortment of topics that provides interesting details of the beliefs of those times. Brihat Jataka is a book on astrology which appears to be considerably influenced by Greek astrology.

Brahmagupta

Brahmagupta of Bhilamala in Rajasthan, who was born in 598, wrote his masterpiece, Brahmasphuta Siddhanta, in 628. His school, which was a rival to that of Aryabhata, has been very influential in western and northern India. Brahmagupta’s work was translated into Arabic in 771 or 773 at Baghdad and it became famous in the Arabic world as Sindhind.

One of Brahmagupta’s chief contributions is the solution of a certain second order indeterminate equation which is of great significance in number theory.

Another of his books, the Khandakhadyaka, remained a popular handbook for astronomical computations for centuries.

Bhaskara

Bhaskara (born 1114), who was from the Karnataka region, was an outstanding mathematician and astronomer. Amongst his mathematical contributions is the concept of differentials. He was the author of Siddhanta Shiromani, a book in four parts: (i) Lilavati on arithmetic, (ii) Bijaganita on algebra, (iii) Ganitadhyaya, (iv) Goladhyaya on astronomy. He epicyclic-eccentric theories of planetary motions are more developed than in the earlier siddhantas.

Subsequent to Bhaskara we see a flourishing tradition of mathematics and astronomy in Kerala which saw itself as a successor to the school of Aryabhata. We know of the contributions of very many scholars in this tradition, of whom we will speak only of two below.

Madhava

Madhava (c. 1340-1425) developed a procedure to determine the positions of the moon every 36 minutes. He also provided methods to estimate the motions of the planets. He gave power series expansions for trigonometric functions, and for pi correct to eleven decimal places.

Nilakantha Somayaji

Nilakantha (c. 1444-1545) was a very prolific scholar who wrote several works on astronomy. It appears that Nilakantha found the correct formulation for the equation of the center of the planets and his model must be considered a true heliocentric model of the solar system. He also improved upon the power series techniques of Madhava.

The methods developed by the Kerala mathematicians were far ahead of the European mathematics of the day.

7 Concepts of space, time, and matter

Yoga-Vasishtha (YV) is an ancient Indian text, over 29,000 verses long, traditionally attributed to Valmiki, author of the epic Ramayana which is over two thousand years old. But the internal evidence of the text indicates that it was authored or compiled later. It has been dated variously as early as the sixth century AD or as late as the 13th or the 14th century (Chapple 1984). Dasgupta (1975) dated it about the sixth century AD on the basis that one of its verses appears to be copied from one of Kalidasa's plays considering Kalidasa to have lived around the fifth century. The traditional date of of Kalidasa is 50 BC and new arguments (Kak 1990) support this earlier date so that the estimates regarding the age of YV are further muddled.

YV may be viewed as a book of philosophy or as a philosophical novel. It describes the instruction given by Vasishtha to Rama, the hero of the epic Ramayana. Its premise may be termed radical idealism and it is couched in a fashion that has many parallels with the notion of a participatory universe argued by modern philosophers. Its most interesting passages from the scientific point of view relate to the description of the nature of space, time, matter, and consciousness. It should be emphasized that the YV ideas do not stand in isolation. Similar ideas are to be found in the Vedic texts. At its deepest level the Vedic conception is to view reality in a monist manner; at the next level one may speak of the dichotomy of mind and matter. Ideas similar to those found in YV are also encountered in Puranas and Tantric literature.

We provide a random selection of these passages taken from the abridged translation of the book done by Venkatesananda (1984).

Time

- Time cannot be analyzed... Time uses two balls known as the sun and the moon for its pastime. [16]

- The world is like a potter's wheel: the wheel looks as if it stands still, though it revolves at a terrific speed. [18]

- Just as space does not have a fixed span, time does not have a fixed span either. Just as the world and its creation are mere appearances, a moment and an epoch are also imaginary. [55]

- Infinite consciousness held in itself the notion of a unit of time equal to one-millionth of the twinkling of an eye: and from this evolved the time-scale right upto an epoch consisting of several revolutions of the four ages, which is the life-span of one cosmic creation. Infinite consciousness itself is uninvolved in these, for it is devoid of rising and setting (which are essential to all time-scales), and it devoid of a beginning, middle and end. [72]

Space

- There are three types of space—the psychological space, the physical space and the infinite space of consciousness. [52]

  The infinite space of individed consciousness is that which exists in all, inside and outside... The finite space of divided consciousness is that which created divisions of time, which pervades all beings... The physical space is that in which the elements exist. The latter two are not independent of the first. [96]

- *Other universes.* On the slopes of a far-distant mountain range there is a solid rock within which I dwell. The world within this rock is just like yours: it has its own inhabitants, ...the sun and the moon and all the rest of it. I have been in it for countless aeons. [402]

- The entire universe is contained in a subatomic partice, and the three worlds exist within one strand of hair. [404]

Matter

- In every atom there are worlds within worlds. [55]

- (There are) countless universes, diverse in composition and space-time structure... In every one of them there are continents and mountains, villages and cities inhabited by people who have their time-space and life-span. [401-2]

Experience

- Direct experience alone is the basis for all proofs... That substratum is the experiencing intelligence which itself becomes the experiencer, the act of experiencing, and the experience. [36]

- Everyone has two bodies, the one physical and the other mental. The physical body is insentient and seeks its own destruction; the mind is finite but orderly. [124]

- I have carefully investigated, I have observed everything from the tips of my toes to the top of my head, and I have not found anything of which I could say, 'This I am.' Who is 'I'? I am the all-pervading consciousness which is itself not an object of knowledge or knowing and is free from self-hood. I am that which is indivisible, which has no name, which does not undergo change, which is beyond all concepts of unity and diversity, which is beyond measure. [214]

- I remember that once upon a time there was nothing on this earth, neither trees and plants, nor even mountains. For a period of eleven thousand years the earth was covered by lava. In those days there was neither day nor night below the polar region: for in the rest of the earth neither the sun nor the moon shone. Only one half of the polar region was illumined.

  Then demons ruled the earth. They were deluded, powerful and prosperous, and the earth was their playground.

  Apart from the polar region the rest of the earth was covered with water. And then for a very long time the whole earth was covered with forests, except the polar region. Then there arose great mountains, but without any human inhabitants. For a period of ten thousand years the earth was covered with the corpses of the demons. [280]

Mind

- The same infinite self conceives within itself the duality of oneself and the other. [39]

- Thought is mind, there is no distinction between the two. [41]

- The body can neither enjoy nor suffer. It is the mind alone that experiences. [109-110]

- The mind has no body, no support and no form; yet by this mind is everything consumed in this world. This is indeed a great mystery. He who says that he is destroyed by the mind which has no substantiality at all, says in effect that his head was smashed by the lotus petal... The hero who is able to destroy a real enemy standing in front of him is himself destroyed by this mind which is [non-material].

- The intelligence which is other than self-knowledge is what constitutes the mind. [175]

Complementarity

- The absolute alone exists now and for ever. When one thinks of it as a void, it is because of the feeling one has that it is not void; when one thinks of it as not-void, it is because there is a feeling that it is void. [46]
- All fundamental elements continued to act on one another—as experiencer and experience—and the entire creation came into being like ripples on the surface of the ocean. And, they are interwoven and mixed up so effectively that they cannot be extricated from one another till the cosmic dissolution. [48]

Consciousness

- The entire universe is forever the same as the consciousness that dwells in every atom. [41]
- The five elements are the seed fo which the world is the tree; and the eternal consciousness if the seed of the elements. [48]
- Cosmic consciousness alone exists now and ever; in it are no worlds, no created beings. That consciousness reflected in itself appears to be creation. [49]
- This consciousness is not knowable: when it wishes to become the knowable, it is known as the universe. Mind, intellect, egotism, the five great elements, and the world—all these innumerable names and forms are all consciousness alone. [50]
- The world exists because consciousness is, and the world is the body of consciousness. There is no division, no difference, no distinction. *Hence the universe can be said to be both real and unreal: real because of the reality of consciousness which is its own reality, and unreal because the universe does not exist as universe, independent of consciousness.* [50]
- Consciousness is pure, eternal and infinite: it does not arise nor cease to be. It is ever there in the moving and unmoving creatures, in the sky, on the mountain and in fire and air. [67]
- Millions of universes appear in the infinite consciousness like specks of dust in a beam of light. In one small atom all the three worlds appear to be, with all their components like space, time, action, substance, day and night. [120]
- The universe exists in infinte consciousness. Infinite consciousness is unmanifest, though omnipresent, even as space, though existing everywhere, is manifest. [141]
- The manifestation of the omnipotence of infinite consciousness enters into an alliance with time, space and causation. Thence arise infinite names and forms. [145]
- The Lord who is infinite consciousness is the silent but alert witness of this cosmic dance. He is not different from the dancer (the cosmic natural order) and the dance (the happenings). [296]

The YV model of knowledge

YV is not written as a systematic text. But the above descriptions may be used to reconstruct its system of knowledge.

YV appears to accept the idea that laws are intrinsic to the universe. In other words, the laws of nature in an unfolding universe will also evolve. According to YV, new information does not emerge out the inanimate world but it is a result of the exchange between mind and matter.

It also appears to accept consciousness as a kind of fundamental field that pervades the whole universe.

One might speculate that the parallels between YV and some recent ideas of physics are a result of the inherent structure of the mind.

8 The Shri Yantra

Although our immediate information on the Shri Yantra (SY) comes from medieval sources, some scholars have seen the antecedents of the yantra in Book 10 of the Atharvaveda. The Shri Yantra consists of nine triangles inscribed within a circle which leads to the formation of 43 little triangles (Figure 1) (Kulaichev 1984). Whatever the antiquity of the idea of this design, it is certain that the yantra was made both on flat and curved surfaces during the middle ages. The drawing of the triangles on the curved surface implies the knowledge that sum of the angles of such triangles exceeds 180 degrees.

The question that the physicist and historian of science John Barrow (1992) has asked is whether these shapes intimate a knowledge of non-Euclidean geometry in India centuries before its systematic study in Europe.

It is possible that the yantras were made by craftsmen who had no appreciation of its mathematical properties. But scholars have argued that the intricacies of the construction of this yantra requires mathematica knowledge.

9 Concluding Remarks

This has been a survey of some topics that have interested me in the past decade. If the revisions in our understanding required for these topics are indicative of other subjects also then we are in for a most radical rewriting of the history of science in India.

Our survey of these topics did not stress enough one aspect of Indian thought that sets it apart from that of most other nations, viz. the belief that thought by itself can lead to objective knowledge. Being counter to the reductionist program of mainstream science, this aspect of Indian thought has been bitterly condemned by most historians of science as being irrational and mystical. Now that reductionism is in retreat in mainstream science itself one would expect a less emotional assessment of Indian ideas. We can hope to address issues such as how do some ideas in India happen to be ages ahead of their times.

Students of scientific creativity increasingly accept that conceptual advances do not appear in any rational manner. Might then one accept the claim of Srinivasa Ramanujan that his theorems were revealed to him in his dreams by the goddess Namagiri? This claim, so persistently made by Ramanujan, has generally been dismissed by his biographers (see, for example, Kanigel, 1991). Were Ramanujan's astonishing discoveries instrumented by the autonomously creative potential of consciousness, represented by him by the image of Namagiri? If that be the case then the marvellous imagination shown in Yoga-Vasishtha and other Indian texts becomes easier to comprehend.

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History of Mathematics & Astrology in Ancient India

Science and Mathematics were highly developed during the ancient period in India. Ancient Indians contributed immensely to the knowledge in Mathematics as well as various branches of Science. In this section, we will read about the developments in Mathematics and the scholars who contributed to it. You will be surprised to know that many theories of modern day mathematics were actually known to ancient Indians. However, since ancient Indian mathematicians were not as good in documentation and dissemination as their counterparts in the modern western world, their contributions did not find the place they deserved. Moreover, the western world ruled over most of the world for a long time, which empowered them to claim superiority in every way, including in the field of knowledge. Let us now take a look at some of these contributions of ancient Indian mathematicians.

Baudhayan

Baudhayan was the first one ever to arrive at several concepts in Mathematics, which were later rediscovered by the western world. The value of pi was first calculated by him. As you know, pi is useful in calculating the area and circumference of a circle. What is known as Pythagoras theorem today is already found in Baudhayan's Sulva Sutra, which was written several years before the age of Pythagoras.

Aryabhatta

Aryabhatta was a fifth century mathematician, astronomer, astrologer and physicist. He was a pioneer in the field of mathematics. At the age of 23, he wrote Aryabhattiya, which is a summary of mathematics of his time. There are four sections in this scholarly work.

In the first section he describes the method of denoting big decimal numbers by alphabets. In the second section, we find difficult questions from topics of modern day Mathematics such as number theory, geometry, trigonometry and Beejganita (algebra). The remaining two sections are on astronomy.

Aryabhatta showed that zero was not a numeral only but also a symbol and a concept. Discovery of zero enabled Aryabhatta to find out the exact distance between the earth and the moon. The discovery of zero also opened up a new dimension of negative numerals.

As we have seen, the last two sections of Aryabhattiya were on Astronomy. Evidently, Aryabhatta contributed greatly to the field of science, too, particularly Astronomy.

In ancient India, the science of astronomy was well advanced. It was called Khagolshastra. Khagol was the famous astronomical observatory at Nalanda, where Aryabhatta studied. In fact science of astronomy was highly advanced and our ancestors were proud of it. The aim behind the development of the science of astronomy was the need to have accurate calendars, a better understanding of climate and rainfall patterns for timely sowing and choice of crops, fixing the dates of seasons and festivals, navigation, calculation of time and casting of horoscopes for use in astrology. Knowledge of astronomy, particularly knowledge of the tides and the stars, was of great importance in trade, because of the requirement of crossing the oceans and deserts during night time.

Disregarding the popular view that our planet earth is 'Achala' (immovable), Aryabhatta stated his theory that 'earth is round and rotates on its own axis' He explained that the appearance of the sun moving from east to west is false by giving examples. One such example was: When a person travels in a boat, the trees on the shore appear to move in the opposite direction. He also correctly stated that the moon and the planets shined by reflected sunlight. He also gave a scientific explanation for solar and lunar eclipse clarifying that the eclipse were not because of Rahhu and/or Ketu or some other rakshasa (demon,). Do you realize now, why the first satellite sent into orbit by India has been named after Aryabhatta?

Brahmgupta

In 7th century, Brahmgupta took mathematics to heights far beyond others. In his methods of multiplication, he used place value in almost the same way as it is used today. He introduced negative numbers and operations on zero into mathematics. He wrote Brahm Sputa Siddantika through which the Arabs came to know our mathematical system.

Bhaskaracharya

Bhaskaracharya was the leading light of 12th Century. He was born at Bijapur, Karnataka. He is famous for his book Siddanta Shiromani. It is divided into four sections: Lilavati (Arithmetic), Beejaganit (Algebra), Goladhyaya (Sphere) and Grahaganit (mathematics of planets). Bhaskara introduced Chakrawat Method or the Cyclic Method to solve algebraic equations. This method was rediscovered six centuries later by European mathematicians, who called it inverse cycle. In the nineteenth century, an English man, James Taylor, translated Lilavati and made this great work known to the world.

Mahaviracharya

There is an elaborate description of mathematics in Jain literature (500 B.C -100 B.C). Jain gurus knew how to solve quadratic equations. They have also described fractions, algebraic equations, series, set theory, logarithms and exponents in a very interesting manner. Jain Guru Mahaviracharya wrote Ganit Sara Sangraha in 850A.D., which is the first textbook on arithmetic in present day form. The current method of solving Least common Multiple

(LCM) of given numbers was also described by him. Thus, long before John Napier introduced it to the world, it was already known to Indians.

SCIENCE

As in Mathematics, ancient Indians contributed to the knowledge in Science, too. Let us now learn about the contributions of some scientists of ancient India.

Kanad

Kanad was a sixth century scientist of Vaisheshika School, one of the six systems of Indian philosophy. His original name was Aulukya. He got the name Kanad, because even as a child, he was interested in very minute particles called "kana". His atomic theory can be a match to any modern atomic theory. According to Kanad, material universe is made up of kanas, (anu/atom) which cannot be seen through any human organ. These cannot be further subdivided. Thus, they are indivisible and indestructible. This is, of course, as you may be knowing, what the modern atomic theory also says.

Varahamihira

Varahamihira was another well known scientist of the ancient period in India. He lived in the Gupta period. Varahamihira made great contributions in the fields of hydrology, geology and ecology. He was one of the first scientists to claim that termites and plants could be the indicators of the presence of underground water. He gave a list of six animals and thirty plants, which could indicate the presence of water. He gave very important information regarding termites (Deemak or insects that destroy wood), that they go very deep to the surface of water level to bring water to keep their houses (bambis) wet. Another theory, which has attracted the world of science is the earthquake cloud theory given by Varahmihira in his Brhat Samhita. The thirty second chapter of this samhita is devoted to signs of earthquakes. He has tried to relate earthquakes to the influence of planets, undersea activities, underground water, unusual cloud formation and abnormal behaviour of animals.

Another field where Varahamihira's contribution is worth mentioning is Jyotish or Astrology. Astrology was given a very high place in ancient India and it has continued even today. Jyotish, which means science of light, originated with the Vedas. It was presented scientifically in a systematic form by Aryabhatta and Varahmihira. You have already seen that Aryabhatta devoted two out of the four sections of his work Aryabhattiyam to astronomy, which is the basis for Astrology. Astrology is the science of predicting the future. Varahamihira was one of the nine gems, who were scholars, in the court of Vikramaditya.

Varahamihira’s predictions were so accurate that king Vikramaditya gave him the title of ‘Varaha’.

Nagarjuna

Nagarjuna was a tenth century scientist. The main aim of his experiments was to transform base elements into gold, like the alchemists in the western world. Even though he was not successful in his goal, he succeeded in making an element with gold-like shine. Till date, this technology is used in making imitation jewelry. In his treatise, Rasaratnakara, he has discussed methods for the extraction of metals like gold, silver, tin and copper.

MEDICAL SCIENCE IN ANCIENT INDIA (AYURVEDA & YOGA)

As you have read, scientific knowledge was in a highly advanced stage in ancient India. In keeping with the times, Medical Science was also highly developed. Ayurveda is the indigenous system of medicine that was developed in Ancient India. The word Ayurveda literally means the science of good health and longevity of life. This ancient Indian system of medicine not only helps in treatment of diseases but also in finding the causes and symptoms of diseases. It is a guide for the healthy as well as the sick. It defines health as an equilibrium in three doshas, and diseases as disturbance in these three doshas. While treating a disease with the help of herbal medicines, it aims at removing the cause of disease by striking at the roots. The main aim of ayurveda has been health and longevity. It is the oldest medical system of our planet. A treatise on Ayurveda, Atreya Samhita, is the oldest medical book of the world. Charak is called the father of ayurvedic medicine and Susruta the father of surgery. Susruta, Charak, Madhava, Vagbhatta and Jeevak were noted ayurvedic practitioners. Do you know that Ayurveda has lately become very popular in the western world? This is because of its many advantages over the modern system of medicine called Allopathy, which is of western origin.

Susruta

Susruta was a pioneer in the field of surgery. He considered surgery as “the highest division of the healing arts and least liable to fallacy”. He studied human anatomy with the help of a dead body. In Susruta Samhita, over 1100 diseases are mentioned including fevers of twenty-six kinds, jaundice of eight kinds and urinary complaints of twenty kinds. Over 760 plants are described. All parts, roots, bark, juice, resin, flowers etc. were used. Cinnamon, sesame, peppers, cardamom, ginger are household remedies even today.

In Susruta Samhita, the method of selecting and preserving a dead body for the purpose of its detailed study has also been described. The dead body of an old man or a person who died of a severe disease was generally not considered for studies. The body needed to be perfectly cleaned and then preserved in the bark of a tree. It was then kept in a cage and hidden carefully in a spot in the river. There the current of the river softened it. After seven days it was removed from the river. It was then cleaned with a brush made of grass roots, hair and bamboo. When this was done, every inner or outer part of the body could be seen clearly.

Susruta's greatest contribution was in the fields of Rhinoplasty (plastic surgery) and Ophthalmic surgery (removal of cataracts). In those days, cutting of nose and/or ears was a common punishment. Restoration of these or limbs lost in wars was a great blessing. In Susruta Samhita, there is a very accurate step-by-step description of these operations. Surprisingly, the steps followed by Susruta are strikingly similar to those followed by modern surgeons while doing plastic surgery. Susruta Samhita also gives a description of 101 instruments used in surgery. Some serious operations performed included taking foetus out of the womb, repairing the damaged rectum, removing stone from the bladder, etc. Does it not sound interesting and wonderful?

Charak

Charak is considered the father of ancient Indian science of medicine. He was the Raj Vaidya (royal doctor) in the court of Kanishka. His Charak Samhita is a remarkable book on medicine. It has the description of a large number of diseases and gives methods of identifying their causes as well as the method of their treatment. He was the first to talk about digestion, metabolism and immunity as important for health and so medical scienc. In Charak Samhita, more stress has been laid on removing the cause of disease rather than simply treating the illness. Charak also knew the fundamentals of Genetics. Don't you find it fascinating that thousands of years back, medical science was at such an advanced stage in India.

Yoga & Patanjali

The science of Yoga was developed in ancient India as an allied science of Ayurveda for healing without medicine at the physical and mental level. The term Yoga has been derived from the Sanskrit work Yoktra. Its literal meaning is "yoking the mind to the inner self after detaching it from the outer subjects of senses". Like all other sciences, it has its roots in the Vedas. It defines chitta i.e. dissolving thoughts, emotions and desires of a person's consciousness and achieving a state of equilibrium. It sets in to motion the force that purifies and uplifts the consciousness to divine realization. Yoga is physical as well as mental. Physical yoga is called Hathyoga. Generally, it aims at removing a disease and restoring healthy condition to the body. Rajayoga is mental yoga. Its goal is self realization and liberation from bondage by achieving physical mental, emotional and spritiual balance.

Yoga was passed on by word of mouth from one sage to another. The credit of systematically presenting this great science goes to Patanjali. In the Yoga Sutras of Patanjali, Aum is spoken of as the symbol of God. He refers to Aum as a cosmic sound, continuously flowing through the ether, fully known only to the illuminated. Besides Yoga Sutras, Patanjali also wrote a work on medicine and worked on Panini’s grammar known as Mahabhasaya.