EVERYMAN'S SCIENCE

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COVER PHOTOGRAPHS

Past General Presidents of ISCA

1. **Sir U. N. Brahmachari (1936)**
2. **R.B.T.S. Venkatraman (1937)**
3. **Prof. Rt. Hon. Lord Rutherford of Nelson *(1938)**
4. **Sir James H. Jeans (1938)**
5. **Prof. J. C. Ghosh (1939)**
6. **Prof. B. Sahani (1940)**
7. **Sir Ardeshir Dalal (1941)**

* Lord Rutherford unfortunately passed away before the Science Congress and Sir James H. Jeans presided over the Congress in his place.

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EDITORIAL

IS THE OIL CRISIS A BLESSING IN DISGUISE?

"The Stone Age came to an end not because of lack of stones and the Oil Age will come to an end not because of lack of oil."

Recently when Shane Warne announced his retirement, compliments poured in from everywhere about his career. One of the best came from Sachin Tendulkar who said that Warne kept him awake and on toes. Similarly, challenge posed by the so-called oil crisis is keeping a whole lot of people on their toes–geologists, explorers, scientists and technologists concerned with oil, oil companies, economists and governments. If really there is a crisis, then it may be a blessing in disguise.

It is said that the Chinese write the word "crisis" using two characters one of which means "danger" and the other "opportunity". Thus fear about oil supply opens up search for alternatives. Some experts believe that there may not be any crisis at all and the oil scene is a cyclic phenomenon–supply perception oscillating between fears of doom and anticipation of boom. The subject has been well discussed in a recent special issue of Newsweek (December 2006) and much of the present article is inspired by it. The write-ups in the magazines quote several experts who claim that there will be enough oil at least till the end of this century and there is no cause for panic. It also presents a view held by a minority that oil may be actually almost a renewable source of energy. One can be sceptical about such a suggestion, but one should also note that many of today's almost universally accepted theories were, after all, nucleated by a minority at one time.

The biggest exports of oil today are from Russia, followed by Saudi Arabia. These as well as several other oil producing countries are now minting money because of the current price rise. The price boom has helped almost triple their revenues over the last four or five years (OPEC countries from about $ 200 fillion to about $ 600 billion ; Iran $ 19 to 60 billion, Venezuela $ 21 to about 50 billion). Today the world economy consumes about 30 billion barrels of oil per year and it is expected to grow at around 2 per cent. The price rise makes everybody uncomfortable—the countries that consume as well as those who produce.

Oil producing countries are in a tricky position. Very high oil prices are likely to change the political and economic tie-ups and, in extreme situations, can lead to serious conflicts–even worse. If there is widespread drive for technological innovations to reduce dependence on oil, then the energy scene itself can change its character. Those who amass wealth by selling oil will certainly not like that.

What happens to the oil wealth ? Shaik Ahmed Zaki Yamani, the former Saudi Oil Minister said in the seventies "We in the middle east are wealthy but we are not rich". The countries lacked development in terms of health, education and infrastructure–the oil revenues stayed invested in financial institutions in the U. S. and European countries who actually were the beneficiaries. The scene, of course, has changed and countries in the Mid-East are ploughing much of the wealth in their own development and also investing in China and India. There is construction boom for buildings, hotels, roads, facilities for health care, education and sports. Yet, they lack of developments in science and technology, and therefore, western countries remain dominant partners. They need to keep the prices in check to ensure dependence of the world economy on oil supply. Shaik Yamani had also observed that the Stone Age came to an end not for lack of stones and the Oil Age may end but not for lack of oil. Dependence on oil will surely decrease if prices exceed reasonable limits. There is evidence that major economies are becoming less oil intensive. Many had believed that economies will collapse if the price exceeded $ 40 a barrel but nothing happened when the price exceeded $ 70. India imports more than two thirds of its total requirement and yet, inspite of hike in oil price, the economy continues to thrive. It is said that the price rise is more in response to demands made by countries, like China and India with high growth rates and because of supply constraints. It is a case of "demand shock" rather than "supply shock" as was the case in the seventies.

It is not often realized that demand for oil is not restricted to the energy sector. Hundreds of chemicals and various kinds of plastics came from the oil industry and scientists have started developing substitutes.

THE SUPPLY SCENE

There are 250 medium and large oild fields that produce nearly 85 per cent of global oil supplies. Since field by field data are not available, it is not possible to accurately make supply forecasts. It should also be noted with the present level of technology, it is not possible to recover more than 35 per cent of oil available in any field. Thus, when supply is exhausted some 65 per cent still remains unrecovered. In the future, newer technologies will be surely developed to resurrect abandoned/ exhausted wells. Moreover, only 30 per cent of the sedimentary rock basins that may hold oil has been adequately explored. With continuing exploration, estimates get upgraded from time to time and prophecies to doom have been routinely proved false.

There are attempts now to make oil from unconventional sources such as tar sands, shale oil, biofuels and liquefied gas and coal. Qatar is developing massive gas reserves to produce liquefied gas LNG that is going to the U. S., France, South Korea and other countries. China and India will surely use this in massive amounts soon. During the second World War, Germany fuelled its war machine mostly by using oil produced from coal. Successful pilot plants were operated in India in the fifties and the sixties in IIT Kharagpur and Central Fuel Research Institute, Dhanbad, but they were discontinued because oil was available in abundance and the price was very low. The interest in liquefied coal is sure to be revived in many countries if oil prices rise too much.

ABOUT NEW FINDS

A commonly held view is that there may not be major findings of new sources in the near future. The average size of new findings is said to be declining steadily. The large findings in Northern Alaska, Western Siberia and North Sea happened nearly 40 years ago and then there was one in Mexico thirty years ago. Yet this is also true that there have been many more explorations in the U. S. and Canada, which do not produce much oil, than in the Middle East (apparently there is no need). Nobody, however, can rule out major discoveries. The Bay of Bengal is a potential candidate now that more advanced technologies for undersea explorations have become available.

To summarise, the oil market will remain cyclical, characterized by boom and bust periods for decades irrespective of the uncertainites. The world is not running out of oil and today even the most advanced technology can not tell how much crude oil the earth holds. It may be a bottomless well. The oil price, however, will remain somewhat unpredictable.

POSSIBLE EFFECTS OF PRICE FLUCTUATION

One can speculate about the scenario if oil price rise becomes too high and if prices fall dramatically. If there is an upward trend then the following corrective actions will follow. Energy supply mix will begin to change with solar and wind energy drawing increasing investments. R & D efforts in the areas of bio-fuels and bio-plastics will be strengthened. Automobiles will be modified to consume less oil and the goal will be to produce units which will go 200 km. per litre if not more. In windy regions there will be house top wind mills. In isolated areas, roof tops of buildings will be covered by solar panels. Transport by canals and rivers will be more common. Newer technologies will be developed for extreme explorations going upto 12 km. depth in land (at present the limit is 4-5 km.) and thousands of meters in sea bed and, at the same time, recovering from the 65 per cent of oil remaining in previously abandoned wells. Organic farming will get a boost because it does away with petroleum derived pesticides. Other energy sources e.g. hydrogen fuel cells with hydrogen derived from water and / or natural gas, will become serious competitors. There will be commercial ventures to produce cellulosic ethanol from biomass like perennial grasses, wood chips, etc. which will have 85 per cent less CO_2 emission. Hybrid cars run by petrol and batteries will become more common on the road and, in general, many other oil conserving devices will become common. As mentioned earlier, liquefied natural gas and liquefied coal will begin to meet large extents of global energy needs. Nuclear power will be more important and global efforts will be directed towards fusion energy. The higher the price rise, the greater will be the developments in energy conservation technologies and strategies.

The scenario, of course, will be different if there is a fall in price. Airlines will thrive. The automobile sector will expand. Technology will no doubt continue to advance and hybrid cars will be plentiful. They may use biofuels, liquefied gas and coal also for lowering pollution levels. Plastics from oil will continue to rule the world.

IS OIL A RENEWABLE SOURCE ?

It is well accepted that petroleum is a product of geothermal decay of marine organisms over millennia. Accordingly, remmants of living organisms are found in oil deposits. However, some deposits have been found with little trace of molecules that could come only from living matter. That is, some deposits, at least, may be non-biological in origin. A Russian theory, not widely accepted, holds that oil is actually a product of chemical reactions sped up by intense pressures and temperatures deep inside the earth. This implies that oil may not have trickled down from rotting marine animals to go down to sedimentary rocks for storage but, instead, it may be continuously thrown up from the depths of earth.

There is, of course, no solid proof for the alternative theory of oil deposits and laboratory experiments will be difficult. Yet some scientists have initiated experiments, some of which have produced simple molecules such as methane in experiments mimicking geothermal conditions necessary. If there is any truth in this theory, then there is indeed cause for rejoicing.

Hem Sankar Ray

Learning to write is learning to think.

— Carlos Baker

PRESIDENTIAL ADDRESS

THE DECCAN TRAPS : AN EPISODE OF THE TERTIARY ERA

PROFESSOR B. SAHNI,* M. A., SC. D., D. SC., F. R. S.

When a man of Science accepts the position of honour in which I find myself this evening it is usually understood that he undertakes, among other things, to engage a large public audience, having the most varied pursuits in life, on some topic of general scientific interest. At the same time he is expected to have at least something to say that he can claim as his own and, what is more, to say it in plain language. Such a man, I assure you, is a man to be sympathized with, for he is shouldering a heavy task.

A WORLD OF FRAGMENTS

The student of Science lives in a world of fragments. Nothing in that vast array of visible things that we call Nature appears to our restricted vision as a complete picture. True Artist that He is, the Creator never reveals the whole of His design at once. Like the child with a jigsaw puzzle we try to piece together the fragments of the picture.

We have our moods, too, like the child. Sometimes we gaze wistfuly at fragments of the universe far beyond our reach. Sometimes we are bent upon a quest of the minute ; a sort of splitting process that is awe-inspiring in its endlessness, for as we probe deeper and deeper it unfolds to our wondering eyes systems within systems, worlds within worlds. Sometimes, again we are engaged in the reverse process ; of building up fragments into what we like to think is a plausible whole. Not that we ever get at the real and complete whole ; nor ever shall. For none of us has even a fraction of all the pieces, and each has his own way of putting together what little he has.

To the Onlooker, who alone holds the key, the seriousness with which we go about our little attempts must seem pitiable. For after all there can be only one real solution, one Truth. Some of us may boast that we have got at that one Truth ; we only delude ourselves. None the less, curiosity lures us on, for there are few pursuits so absorbing as this study of fragments that we call Science.

Yes, this is real Science, the Science of the original scientists, the seekers after Truth.

At times, in our search for the Truth, we come upon things we can make use of in a worldly way. And we know that some of these things we can use, as we like, for good or for evil. But if we are mere seekers after Truth, we care no more about them but turn them over to others ; and out of this comes much that is good and noble and beautiful. But sometimes, alas, as we see today, Greed comes to conflict with Truth, and lust for dominion harnesses Science to ignoble ends. For all that Science may have done to civilize him, man, it seems, can still be no less of a brute than he was. In the lurid light of happenings we see that civilization is not the same thing as culture.

But this is a sad digression which I had not intended for this occasion. My object this evening is to spend a brief hour with you in the contemplation of Nature.

* General President. Twenty-Seventh Indian Science Congress held during 31st January to 5th February, 1940 at Madras.

THE EOCENE AGE : A "DAWN OF THE NEW"

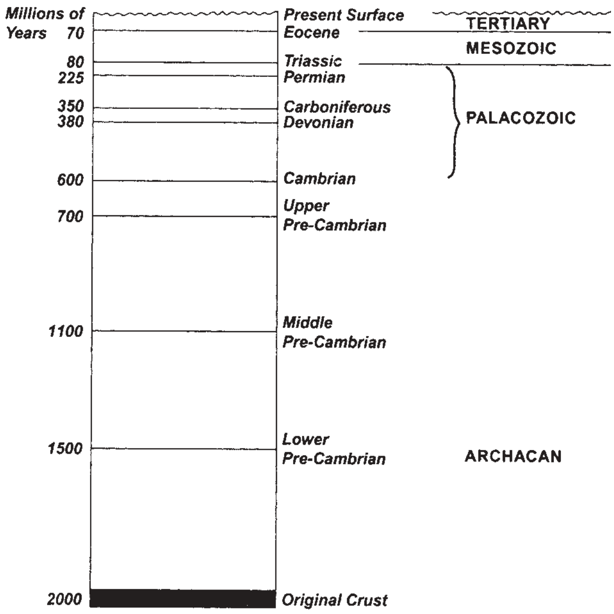
Less than six months ago the British Association for the Advancement of Science met under the presidentship of a renowned scientist. In his address at Dundee Sir Albert Seward gave a vivid account of the way in which, by a study of fragments, such as samples of rocks and of the remains of plants prserved in them as fossils, he was able to visualize a scene in the west of Scotland at the dawn of the Tertiary era (*The Western Isles through the Mists of Ages,* pp. 1–19, Aug. 30, 1939). As a pupil feel tempted to follow his example, and to attempt a reconstruction of an Indian scene at about the same period of the earth's history.

But I would ask you to bear with me if I seem at times to be telling a fairy tale. For at this distance of time we can only see a dim outline of the world as it was, and the exact language of Science is ill suited to the description of visions.

Competent authorities place the dawn of the Tertiary era between sixty and seventy million years ago (see Table of strata). It is the birth of a new era in a very real sense. Stupendous forces, surging in the womb of the earth, had already caused gigantic rifts in the crust, and these rifts are gaping out into oceans. From smaller fis-sures in the crust, molten rock is now pouring forth in repeated floods of lava which will cover millions of square miles of land and sea. Vast areas are being converted into desert by showers of volcanic plateaus as a dominant feature. The face of the earth is rapidly changing. She puts on a more modern grab of vegetation ; the land, lakes and rivers become peopled by creatures more familar to us. Still there is no sign of man. But the stage is being set for his arrival. For this critical period foreshadows the birth, out of the sea, of the mightiest mountains of the world ; and the heaving bosom of the earth, somewhere to the north of India, is to be the cradle of man.

Such was the Eocene age : it was literally a "dawn of the new".

Table of Strata : Showing the position of the Eocene period in the geological time scale. A thickness of one centimetre represents a span of 200,000,000 years. (After Seward, based on data from Holmes.)



Early History of the Deccan

To arrive at our early Tertiary scene in India we can either work backwards from the present, or approach it from a still earlier past and try to visualize the setting in which that scene was laid. I prefer the latter course, although for a few moments it will take us far behind the period with which we are specially concerned. For we shall have to go back to a time when neither the Atlantic nor the Indian Oceans were yet born.

Opinion is by no means agreed upon the broad distribution of land and sea prior to the Tertiary era. But according to a theory now generally associated with the name of Professor Wegener, who died a hero's death in Greenland a few years ago in the pursuit of Science, all the land area of the globe were once directly united together into one world continent. The two Americas lay much further to the east, while Europe and Africa lay further west, than at present. Greenland, Iceland and the British Isles were all much closer together and were wedged in between Canada and Scandinavia. South America fitted into the great angle in the west coast of the African continent. Australia and Antarctica lay close up against the south-eastern coast of Africa, with the southern tip of India in contact with Madagascar and wedged in between the African and Australian blocks. As this remote period the South Pole was somewhere in Cape Colony.

At intervals during a period of millions of years disruptive forces of unthinkable magnitude have caused ever widening fissures in the crust. The Great Rift valley of Africa is believed to be one of the youngest of these fissures, still in the making. The Red Sea rift has now become two hundred miles wide ; the Atlantic rift is already an ocean. And thus, like iceberg breaking off by the formation of crevasses from the snout of a glacier, or from the edge of an ice-sheet that has spread out to sea, the continental blocks are supposed to have drifted away into their present positions. But these continental movements have not been all movements of separation. They have also brought into contact with each other land blocks formerly sundered by the ocean.[1]

Here in Madras we stand at the eastern edge of one of these blocks which, according to Wegener, has drifted–and perhaps is still drifting–north eastwards from its former position in the southern hemisphere. To the north of it formerly lay the great Tethys Sea which once separated it from the main Asiatic mass. The Asiatic block, in turn, has moved south-west, towards India. As the two great land masses approached each other, narrowing down the width of the intervening sea, parts of the ocean floor were caught up as between the jaws of a gigantic vice, and they have been squeezed, crumpled and uplifted into the chain of the Himalayas.

A PRIMEVAL LANDSCAPE

By far the greater part of the Indian Peninsula is made up of rocks that have solidified from a molten state. But the igneous activity which these rocks indicate took place in distinct periods separated from each other by a span of time of which no adequate estimate is yet possible.

The eastern and southern portion of the peninsula (shown red in geological maps) forms one of the most ancient land surfaces of the globe. Parts of it are believed to belong to the primeval crust of our planet as it first cooled and condensed from a gaseous or liquid mass.

From time to time other molten rocks from the interior have burst through this crust and solidified in the cracks, forming thick sheets or walls cutting across the older rocks. The early convulsions of the earth, while she was young, are still recorded in the complex folds into which these archaic rocks have been thrown. Over large areas the original rocks have been fractured by earth movements or so badly crushed and altered that we can no longer tell their mode of origin.

This was the kind of primitive surface on which, long afterwards, life first originated (in water) and on which the stratified crust of the earth was laid down. With the passage of time the greater part of this crust has worn away, and the old surface has again been laid bare. But portions of the strata still remain, protected in deep trough-like hollows in the old river basins, the Mahanadi, the Godavari and the Narmada, and in a string of outlying patches along the east coast, from Trichinopoly as far as Cuttack. These deposits were laid down chiefly in lakes and rivers, but partly also in shallow seas that flooded the land from the north and east.

[1] A working model of Wegener's draft theory was projected on the screen. "A World of Fragments."

The wealth of evidence these strata contain tells of great changes of climate and of a long succession of floras and faunas that lived on the vast southern continent of which India once formed an integral part.

Except for these temporary incursions of the sea the plateau of the Deccan has remained a land area, so far as we know, ever since the original crust was formed.

We have seen that the eastern and southern parts of the peninsula are composed mostly of rocks of great antiquity. Similar rocks, in fact, form the foundations of all the continental blocks, the eroded tops of the ancient mountains often projecting through rocks of more recent date. The Nilgiris, and the Palni and Annamali Hills are composed of large dome-like masses of semi-molten rock which have heaved up the overlying crust and have later been exposed by the denuding action of rain and rivers. These primeval hills usually have rounded, undulating outlines. Occasionally an isolated dome rises suddenly out of the alluvial plain. There it stands, like a petrified sentinel of the hoary past, with his face obliterated and his feet buried in the dust of ages.

Through untold aeons of Time, Nature has carved this ancient surface into fantastic shapes. Great masses of rock sometimes lie uneasily perched one on top of another in threatening piles, like dilapidated towers. Vast areas are strewn with enormous weathered blocked lying in utter confusion, as if a great city, where only giants must have lived, had been laid in ruins. Occasionally a huge sphere of granite lies precariously poised on the rounded back of a hill as if one could, with a mere push, send it hurtling down the hillside. A later day has seen the handiwork of man superimposed upon Nature's in sculptured epics like those at Mahabalipuram–unsurpassed in the grandeur of their conception or in the depth of devotion that inspired them.

THE DECCAN TRAP COUNTRY

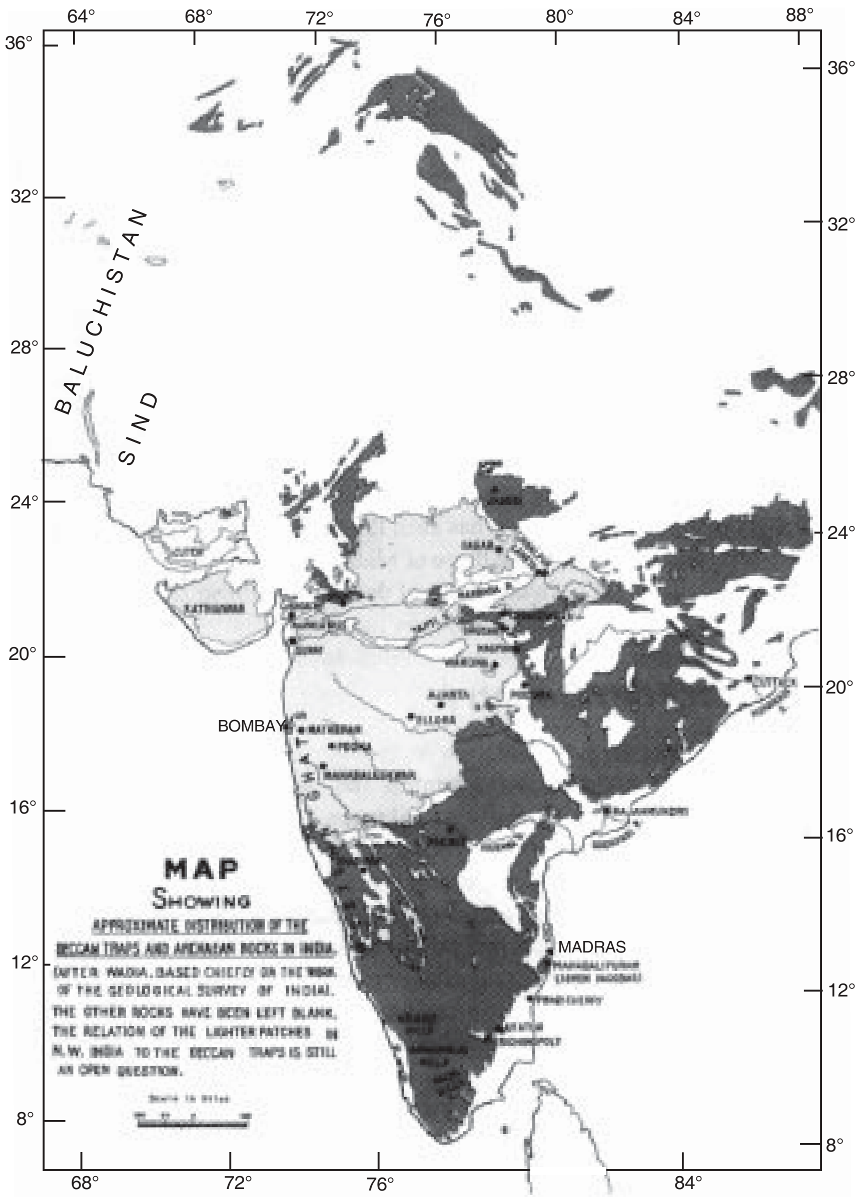
Very different is the landscape in the central and western parts of the Deccan, coloured green, by convention, in all geological maps. This is much younger ground, for as we step over from the red part of the map to the green we traverse, at a single bound, a vast span of geological time ; in many places the newer rocks rest directly upon the eroded surface of the old foundations. Abruptly we are transported into a new era of the earth's history. In fact we have arrived at the dawn of the Tertiary. After a long period of quiescence the volcanic energy pent up in the interior of the earth is now bursting forth in floods of lava on a scale never witnessed before or since.

Delegates to this Congress who have travelled here from the north by way of Bombay or Nagpur must have noticed the long, low, flat-topped hills which dominate the scenery over the greater part of country drained by the Narmada and Tapti and by the upper reaches of the Godavari and Krishna rivers (**Figs. 1, 2**). The same type of scenery

Fig. 1. Flat-topped Deccan Trap hills near Sausar, C. P. (after Fermor). Several of the fossils here described were picked up by the author in the ploughed fields in January, 1926.

Fig. 2. Deccan landscape near Nawargaon, Wardha district, C. P. Here Mr. V. B. Shukla of Nagpur has found many fragments of petrified woods of palms and dicotyledons.

extends into Kathiawar and Cutch, and for at least two hundred miles north of the Narmada. Crossing the Western Ghats from Bombay to Poona the railway climbs up through gorges cut through a series of terraces at different levels, like the remnants of a gigantic staircase. These terraces are the exposed surfaces of successive sheets of lava which were poured out at intervals, during a period that must have extended through any thousands of years, and which on the west coast were piled up to a thickness of six to ten thousand feet.



THE DECCAN BEFORE THE ERUPTIVE PERIOD

With the fragmentary data at hand let us try to picture the Geography of the Deccan during the Cretaceous epoch which preceded this era of fire and devastation. The south-east coast is flooded by a shallow sea, teeming with life, from Trichinopoly as far as Pondicherry. The same sea stretches north-eastwards into what is now the province of Assam, for similar types of fossil shells have been found in the two regions. Near Utatur we may pick up fossil timber, riddled with holes made by extinct types of wood-boring molluses. The shells of the creatures still lie in their burrows, petrified within the wood ; the logs must have drifted down an east-flowing river into an estuary or lagoon a hundred and fifty miles south of Madras.

The northern sea has also overflowed the land, in the region of the lower Narmada. But the fauna here is very different, because the barrier of the plateau cuts it off from the southern sea. The northern fauna is more allied to the European– in fact, the same ocean stretches on one side into Europe and on the other as far as Tibet and China.

But of our western coast at this period there is no evidence ; either India has not yet split away from Africa ; or, what seems more likely, it has brought away with it a large tract of land which lies to the west. By the sinking of this tract the gulf between India and Africa will widen out into the Arabian Sea, isolating our triangular island of the Deccan which, like a gigantic raft that has been cut adrift, will continue on its long journey to the north-east.

Amongst the denizens of the land, dinosaurs abound in the forests of the Central Provinces. Many of them belong to types peculiar to India but, strangely enough, they have their nearest relatives among the dinosaurs of Madagascar and South America ; there must still be some land connexion left that allowed these reptiles to intermigrate. But they are rapidly running out their race. The last of the Deccan dinosaurs lie buried in the Lameta beds near Jabalpur and at the village of Pisdura near Warora, to the south-east of Wardha.

THE DAWN OF THE TERTIARY ERA

We are now approaching the end of the Mesozoic era. The old southern continent is breaking up. The gulfs widen. The same sea that washes the northern shores of the Deccan receives the rivers that drain parts of Egypt, France, Belgium and England. It also laps the shores of Mexico in the far west. In the far east, it sweeps southwards, past Borneo. This is the equatorial ocean of the time, the birthplace of the great mountain ranges of the world in the era that is to come.

It is over such a scene as this that the Tertiary era dawns, to the accompaniment of volcanic outbursts. There are, indeed, no volcanoes in the familiar, Vesuvian, sense. The lava usually wells up quietly through fissures in the earth. But these fissures are hundreds of yards wide and stretch for miles across the country, with crooked cracks branching off to right and left, all brimming with the fiery liquid. In the Rajpipla hills near Broach, in Cutch, Kathiawar and other parts of Western India, some of these old fissures can still be recognized, with the lava solidified inside them in the form of walls or dykes.

The Deccan lavas, being rich in iron, are of a specially fluid kind that takes long to set. They flow almost like water, filling up hollows in the land and spreading rapidly in horizontal sheets, covering miles of country before they harden into the basalt or "trap" rock that is familiar to us. In its devastating march the "fiery deluge" bakes up the soil and consumes all surface vegetation. The very earth is on fire.

Pools and tarns begin to seethe as the lava flows over them. Here and there a stream is dammed up and collects its waters in a temporary lake till it finds or makes a new channel, or the lake itself is covered up by another eruption. The bigger rivers not so easily blocked, manage to keep their old course, gradually cutting their way through any lava flows that might cross their path. But the eruptions continue from time to time, and from place to place over an enormous area, originally perhaps half a million square miles, from Rajahmundry to Cutch and from near Dharwar almost as far as Jhansi ; piling sheet upon sheet of molten rock and loading the old foundations under a plateau thousands of feet thick. Even after the continuous erosion of millions of years the Deccan traps still cover an area of 200,000 square miles, and you can travel all the way from Nagpur to Bombay, a distance of five hundred miles, without ever stepping off the volcanic rocks. Their abrupt ending along the west coast, where they are thickest and form the great scarp of the Western Ghats **(Fig. 3)**, leaves us no real measure of their original extension into the tract of land that foundered into the Arabian Sea.

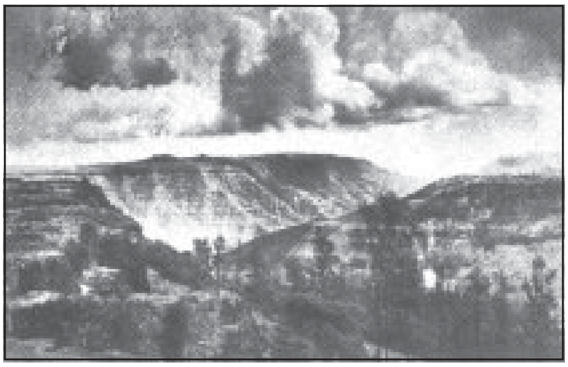


Fig. 3. Gorge cut through the Western Ghats, near Mahabaleshwar, showing terraces of Deccan Trap.

It is difficult to tell where, in the enormous area of the Deccan traps, this igneous activity first began. The lavas of the Nagpur-Chhindwara region were certainly among the earliest to be poured out and, so far as we know at present, the highest flow of the series is to be seen on Malabar Hill and at Worli in Bombay. It appears as if the vulcanicity began in the eastern parts of the Deccan and gradually spread to the west. But we really do not know this for certain. There is nothing to show that the eruptions did not break out at a number of distant places at the same time.

The lava flows vary in thickness from a few feet to as much as a hundred. As one flow overlaps another, it seals up the old fissures, and any later eruptions have to force their way up through the entire pile. There is a tremendous outburst. A fresh crack has been rent open, or an old one has split wider. The yawning mouth of Hell roars with thunder, and hurls fire and smoke and ashes miles up into the sky, as if spitting curses on Heaven itself.

The ash comes down again, raining upon the lava still hot round the fissures, perhaps raising a mound here and there ; as it expands the desolate waste by burying under its weight any fresh vegetation further afield. Beds of volcanic ash abound in many parts of Western India, for example, round Poona and Mahabaleshwar. There must be an eruptive centre in the vicinity.

If a lake or river happens to be nearby, the ash settles down on the water, forming a sort of volcanic sediment in which the creatures living there find a speedy grave. But it is an immortal grave. For, through a process that is still largely a mystery to us, the bodies of these plants and animals become imperishably preserved. Particle for particle, cell for cell, the plant tissues are replaced by silica derived from the ash, or from a lava flow that may have overwhelmed the lakes and in the end we are left with an exact replica of the original in hard, indestructible silica.

This is not a mere cast or an impression of the external features of the plant, but a petrification in the strict sense, which you may cut into thin sections and of which you may examine under the microscope the minutest details of the anatomy (**Figs. 5, 7, 14, 22 and 23**). The preservation of the tissues is sometimes so perfect, and the resemblance with the tissues of modern plants is so complete, that while engrossed in their investigation in the laboratory we are apt to forget that we are dealing with forms of plant life that existed millions of years ago.

Partly with the heat of the lava, but largely through the action of percolating minerals, the entire bed of the lake becomes hardened into a kind of flint that rings under the hammer like a piece of steel. Embedded in the mud and silt are also the remains of any land plants, or the bones of animals living on the banks, that may have been carried down by a stream. Thus we may have a whole flora and fauna sealed up in a bed of volcanic ash, or in lake and river deposits interbedded between sheets of lava.

The number of places where such fossiliferous beds are exposed must be legion. They crop out on the surface chiefly on the slopes of hills, or on the sides of gorges cut by streams. Sometimes the farmer tills a patch of rocky soil and his plough turns up a boulder rich in fossil remains. The weathered surface reveals already to the naked eye the shells of molluscs, seeds and fruits, fragments of fossil stems, roots and leaves ; the interior holds promise of an unknown wealth of petrified microscopic life.

Among the localities that have yielded our material I may mention Sitabaldi and Takli within the precincts of Nagpur town, Hinganghat, Seoni, several villages east of Chhindwara, e.g. Mohgaon Kalan and Jhilmili, numerous places in the Sausar Tehsil, and Sagar in Central India. At Mohgaon Kalan the bed of a stream, carved through a fossiliferous stratum, is strewn with boulders of petrified palm wood, some of which the village folk have built into a neighbouring well, possibly also into their huts. At a hamlet not far off, the stump of a big palm tree still stands rooted in its native soil.

LIFE IN THE DECCAN THAT PERIOD

After what I have said it will be easy for you to picture the conditions in the Deccan trap period, and to realize how valuable for the historian of plant and animal life must be the documents preserved in these intertrappean beds. They have their value, too, in the study of rocks, for the state of evolution of a flora or a fauna gives a measure of geological age as trustworthy as any yet discovered.

The age of the Deccan traps has now been a matter of discussion among geologists for over seventy years. The main point at issue was whether the volcanic period began during the decline of the Mesozoic era or at the dawn of the Tertiary. To most of us the wranglings of geologists over the age of a stratum may seem rather futile and meaningless. But apart from its scientific interest, a precise knowledge of the positions of strata in the geological time scale is of value in the exploitation of the mineral wealth of the earth.

We shall revert a little later to the question of the age of the Deccan lavas, for on this question the flora of the intertrappean beds gives evidence which, I venture to believe, is decisive. First let us examine a few selected specimens from this remarkable museum of plant antiquities.

By far the greater part of our knowledge of this flora is based upon collections made in the Nagpur and Chhindwara districts. This is a fortunate fact because here, as we have seen, some of the lowest beds of the series are exposed. According to Sir Lewis Fermor these are the oldest beds in the whole series, so that if we could fix the age of the fossils preserved in them we should know when the volcanic activity began. From here we have a great variety of spores, seeds and fruits ; abundant remains of water ferns and other aquatic weeds ; different species of the lowly fungus order, sometimes found within the tissues of other plants which they have reduced to decay, as well as petrified timbers, especially pieces of plan stems in bewildering variety and number. Associated with these plant remains are the relics of animals that lived at the same time ; the shells of many types of freshwater snails, the scales and bones of different kinds of fish, the wings of insects, and the skeletons of many other creatures of land and water. All these relics lie buried in a common grave.

Some of the earliest plant collections were made about ninety to a hundred years ago, chiefly by Christian missionaries, medical men and military officers in the service of the East India company. Among these men the name of Stephen Hislop will always stand out prominently. It is a pity that this valuable material was not described in Hislop's day, for some of his most interesting specimens, mentioned in his published letters, can no longer be traced. I owe to the kindness of Mr. W. N. Edwards of the British Museum the loan of what remains in London of the Hislop collection. The rapid sketch I am about to attempt is based partly on this material, but mostly on specimens collected in recent years by members of the Geological Survey of India, by Professors K. P. Rode, S. P. Agharkar and P. Parija, by Mr. V. B. Shukla and myself. In the investigation of this material several workers have taken part and it is a pleasure to aknowledge the assistance I have received from the late Professor B. P. Srivastava, Mr. H. S. Rao and Mr. K. N. Kaul.

The intertrappean plants of the important area near Rajahmundry, which must have lived in the brackish waters of an estuary, are being investigated by Professor L. Rama Rao and his associates at Bangalore. These Rajahmundry beds are also low down in the series, and the plants probably lived at about the same time as those of Nagpur-Chhindwara.

Among the commonest of fossils in the Deccan beds are some extinct species of stoneworts known under the expressive name *Gyrogonites*, derived from their tiny spirally twisted fruits (**Fig. 4**). The great majority of species of this genus, described from England, France and other countries, are of early Tertiary age, and it is interesting that some of these are identical with our Deccan forms.

Some microscopic branched filaments, no doubt belonging to fungi, are seen attached to reproductive organs of two different kinds. One form (**Fig. 5**), with more or less spherical closed bodies of a dark colour, recalling the fruit bodies of modern mildews of the family Perisporiaceae, has been described as a new species, *Perisporiacites varians*. The other has flask-shaped bodies, and for this the genus *Palaeosordaria* has been created (**Fig. 6**). Very little is known of the fossil history of the Perisporiaceae and Sordariaceae, but the few previous records, whatever their worth, are all from rocks of Tertiary age. The Decean fungi were discovered in certain lake-muds at Sausar, midway between Nagpur and Chhindwara.

In the same lake deposits were found, in great abundance, the remains of *Azolla*, a familiar genus of small floating water ferns which even today

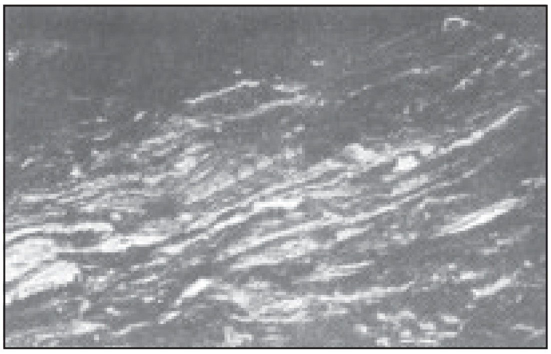


Fig. 4. Section through a block of silicified lake-mud from Sausar, showing the mode of occurrence of the fruits of *Gyrogonites* along the planes of bedding. The spiral twist of the fruit is not seen in the photograph. Numerous fragments of *Azolla*, as well as the fish-scale shown in Fig. 29, were found in the same block. Enlarged 5 times. (B.S.)

Fig. 5 Perisporiacites varians Sahni & Rao. Branched filamentous body of a fungus, with attached reproductive organs. From Sausar, C. P. Enlarged 370 times. (B. S.)

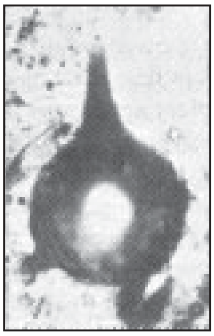


Fig. 6. Palaeosordaria lagena Sahni & Rao. Flask-shaped reproductive organ of a new genus of fungi, with some filments of the body attached to it at * (faintly seen). Enlarged 170 times. (B. S.)

cover stagnant pools in many parts of the world (**Figs. 7–9**). The extinct species from Sausar, which has been named A. *intertrappea*, is geologically the oldest known form of the genus ; a striking example of the tenacity with which even highly specialized forms of life can persist through the ages. The preservation is so perfect that most of the details of the anatomy, specially of the reproductive bodies, which are highly characteristic of the genus, have been studied. Some hollow spherical bodies, associated with the *Azolla*, no doubt belong to an unknown genus of water ferns, probably related to the modern Salvinia ; the provisional name *Massulites* has been given to them (**Fig. 10, 11**). The spongy mass of which the body is composed

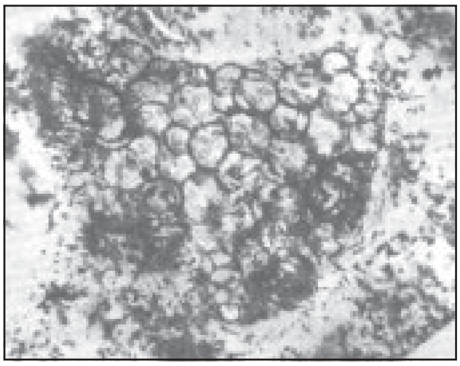


Fig. 7. Azolla intertrappea Sahni & Rao. A "massula" (male reproductive organ with a spongy structure, bearing hooked bristles and containing small spores). From Sausar. Enlarged 300 times. (B. S.)

Fig. 8. Azolla intertrappea Sahni & Rao. Another massula, showing more clearly the anchor-tipped bristles or "glochidia" of the male reporductive organ, which help it to cling to the female organ (Fig. 9). From Sausar. Enlarged 300 times. (B. S.)

Fig. 9. Azolla intertrappea Sahni & Rao. A female reproductive organ. The helmet-shaped body at the top is a spongy mass which acts as a float for the large and heavy spherical spore at the bottom. From Sausar. Enlarged 120 times. (B. S.)

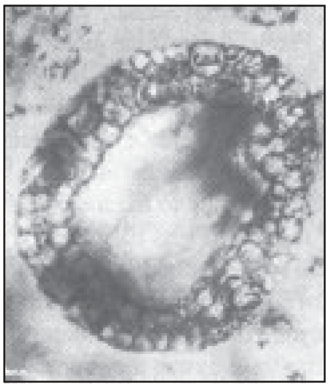


Fig. 10. Massulites coelatus Sahni & Rao. A new type of massula, probably of a waterfern, differing from that of the modern Azolla in its hollow spherical structure. From sausar. Enlarged 280 times. (B. S.)

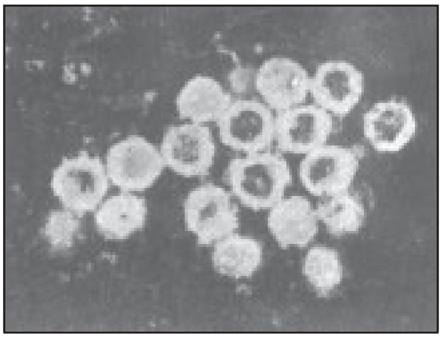


Fig. 11. Massulites coelatus Sahni & Rao. A group of massulae, probably a bench belonging to a single plant. From Sausar. Enlarged 45 times. (B. S.)

contains small spores embedded in it much in the same manner as in *Salvinia*. Among many types of free-lying spores seen in the same rocks are two which deserve special mention. They are of two very different sizes, but they resemble each other so much in certain peculiar features that they appear to be the large and small spores of one and the same species, most probably another water fern. The interesting point about them is the close resemblance they show, both in their structure and in their mode of germination, to the two kinds of spores, large and small, of the rare genus *Regnellidium*, which today is confined to South America. So far as I know, the water ferns are unknown from rocks older than the Tertiaries.

In the Hislop collection at the British Museum there are a number of seed-bearing cones ; some of them were found embedded in volcanic ash. The new name *Takliostrobus* has been given to one of them after Takli, a suburb of Nagpur, where it was discovered (**Figs. 24–26**). Another has been named *Indostrobus* (**Fig. 27**) ; a third was referred to the old genus *Pityostrobus*. All these cones have peculiar features of their own but the fact that in all of them the scales bear a pair of elongated seeds on the upper surface indicates that they were distantly related to our modern pines and deodars.

Of the several kinds of seeds found at Sausar, there is one intriguing type, *Sausarospermum*, remarkable for its several antique features (**Fig. 12**). It recalls the seeds of certain fern-like plants from the coal measures of Europe, but it is

Fig. 12. Sausarospermum Fermori Sahni & Srivastava. A peculiar type of seed from Sausar. Enlarged about 91/2 times. (B. S.)

hardly conceivable that there is any real affinity between them ; at present it is best to reserve opinion on his matter. The name *Viracarpon* has been given to a cylindrical fruit, derived from a number of small flowers densely crowded on a thick axis **(Fig. 13)**. This is from the Hislop collection and it may be the very specimen which

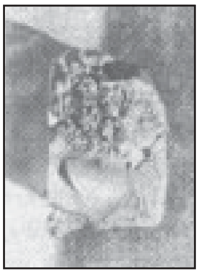


Fig. 13. *Viracarpon hexasperum* Sahni. Part of a cylindrical aggregate fruit. Hislop and Hunter collection (British Museum). Natural size.

he mentions in his writings as a mulberry-like fruit, though unfortunately he never described it. The resemblance to a mulberry is purely superficial, for each flower produced a group of six seeds. It is impossible to say anything yet about the affinities, except that the nearest resemblance that I have so far been able to trace is with the fruits of certain palm-like plants of the family Cyclanthaceae, now confined to tropical America.

A very interesting fruit, *Enigmocarpon*, was first discovered by Professor Rode near his home at Mohgaon Kalan, east of Chhindwara (**Fig. 14**). The name is eloquent of our ignorance concerning its

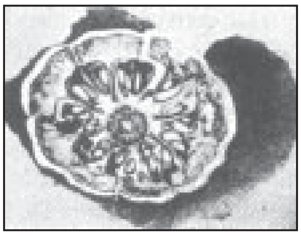


Fig. 14. Enigmocarpon Parijai Sahni. Cross-section of fruit from Mohgaon Kalan, east of Chhindwara. Enlarged 2 times.

affinities, but the structure is perfectly preserved. It is an ellipsoid 8-chambered fruit about the size of a large pistachio nut, with numerous dicotyledonous seeds in each chamber, attached on a central column from which the eight partitions radiate. The wall of the fruit is thick and spongy ; the fruit was no doubt dispersed by water. To let out the ripe seeds the fruit wall bursts length-wise, neatly, down the middle of each chamber.

Among Hislop's specimens are two species of cardamoms (**Fig. 15**), both very like the small green kind that we commonly offer, with other

Fig. 15. Amomocarpum affine Sahni. A species very similar to the modern small cardamom Elettaria Cardamomum. Hislop and Hunter collection (British Museum). Natural size photograph of a plasticine cast from the original.

spices, to guests in our homes. One of the specimens was so deceptive that a friend actually tried to peel it, till he discovered that it was petrified. In one broken specimen the seeds are exposed, showing their characteristic wrinkled surface.

The other monocotyledonous fruits all belong to palms ; some have been described under the general name *Palmocarpon* (**Fig. 18**) which may include fruits belonging to widely different kinds of palms. One was named *Tricoccites* because of its supposed resemblance (which has proved deceptive) with the fruits of the Euphorbia family (**Fig. 19**). It has

Fig. 18. Palmocarpon (Iriartites) takliensis Sahni. A palm fruit from Takli, near Nagpur. Hislop and Hunter collection (British Museum). Natural size.

Fig. 19. Tricoccites (Palmocarpon) trigonum Rode sp. In places the outer rind has been worn away, exposing the "canals" to view. From Mohgaon Kalan, C. P. Natural size. (B. S.)

three large chambers (**Fig. 20**), each occupied by an equally large oblong seed. The fibrous fruit wall is thick and adapted for dispersal by water. It seems to have been divided up into a number of

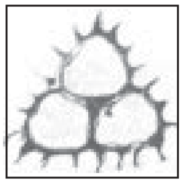


Fig. 20. The same, seen in cross-section. Practically the whole of the rind is missing. Natural size. (B. S.)

longitudinal chambers separated by partitions of hard tissue. The "chambers" may have been quite empty, or filled with a loose spongy tissue which acted as a float. The surface was covered by a thin, smooth, watertight rind. The whole fruit wa about the size of a walnut.

But the most interesting of the Deccan palm fruits is one which Hislop writes he had found, but of which we have not been able to trace the original specimen. It is the fossil genus *Nipadites*, so called because of its resemblance with the fruit of the modern stemless palm *Nipa fruticans*, which forms dense clumps today in many tropical estuaries, and is common in the Sundarbans. Eighty years after Hislop's discovery was announced, Professor Rode found another specimen at Mohgaon Kalan (**Figs. 16, 17**). This specimen shows all the

Fig. 16. Nipa (Nipadites) hindi Rode sp. From Mohgaon Kalan, east of Chhindwara. Natural size.

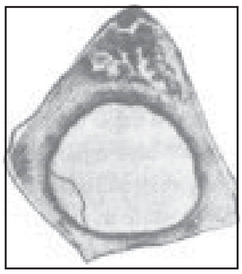
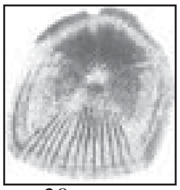


Fig. 17. The same, seen in cross-section. Natural size.

characters of the modern genus, so we need have no hesitation in calling it a *Nipa*, although the species is different. The fruits of *Nipa* are by far the commonest fossils in the London Clay, which everybody agrees was deposited in the Eocene period ; they have also been found in the Eocene of Belgium, and of the Paris basin, in fact, in the very grounds of the old Trocadero, now dismantled ; also in the Mississippi basin, in southern Russia, in Egypt and in far-off Borneo. These fossil records of a brackish-water plant help us to draw at least roughly the coastline of the old Tethys sea, an arm of which must have washed the northern shores of the Deccan not far from where Chhindwara now stands. This important genus is scarcely known from rocks older than the Eocene.

It is interesting to see this evidence of brackish-water conditions in the Deccan supported by the fossil remains of aquatic animals. Dr. Hora describes several kinds of fossil scales belonging to types of fish which ordinarily inhabit freshwater near the sea-shore but are capable of descending to the mouths of rivers (**Figs. 28, 29**). It is interesting,



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29

Fig. 28, 29. Fish-scales, modern and fossil, for comparison, 28, from the living species *Pristolepis fasciatus* (kindly sent me by Dr. Hora) ; 29, impression of a closely related fish-scale from the lake deposits at Sausar. Both Enlarged 41/3 times.

too, that on the whole the evidence of the fish-remains from the Deccan beds, first emphasized by Sir Arthur Smith Woodward over thirty years ago, and now confirmed by Dr. Hora, is in favour of an Eocene age ; and Professor Bonnema wrote to me that the same is the case with the remains of some small crustaceans which show a treacherous resemblance to the seeds of plants.

But we must return to the palms, for these are by far the most important constituent of the intertrappean flora, and no doubt must have dominated the vegetation of those days. As a rule we only find bits of petrified stems which we assign to different species based upon differences in the anatomy (**Fig. 22**). For lack of a proper system of classification, we lump these species together under the artificial genus *Palmoxylon* ; although among them there must certainly be many distinct genera that we could easily recognize, if we only knew the flowers of fruits. Sometimes we come across entire trunks, or large portions of them, with the thick mantle of roots still attached round the base, or the scars of fallen leaves marked like girdles round the stem (**Fig. 21**). At the Nagpur

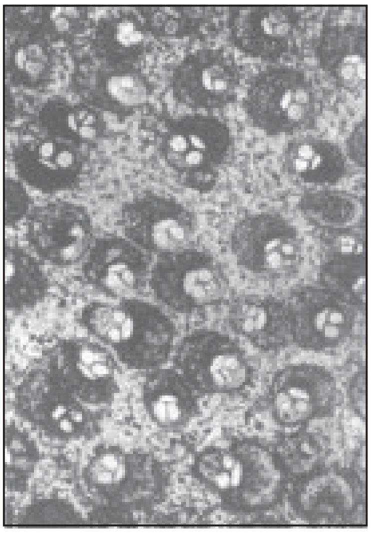

Fig 22. Palmoxylon sundaram Sah. Thin cross-section showing anatomy of stem. Numerous bundles of fibres and food-conducting vessels lie scattered in a softer ground-tissue of small cells. The dark patches are the fibres, cut transversely ; the circular holes, of which generally two in each bundle are very large, are the cut ends of the vessels of the wood. Enlarged 10 times. (B. S.)

Fig. 21. Palmoxylon intertrappeum sp. nov. Stump of a petrified palm tree about 21 inches long, with old leaf scars. The scale is in inches. From the Wardha district, C. P. (Found by Mr. Bhattacharji of the Geological Survey of India.) About 4/11 natural size. (G. S. I.)

museum there is a fine specimen, probably discovered at Sagar in Central India well over a hundred years ago ; and in 1934, I was able to unearth from the dust and oblivion of the vaults of a Bombay museum a heap of petrified palm stems, some of which were certainly collected at Sagar before the year 1857. It is this very collection that H. J. Carter mentions in a paper of that date, but which had apparently been lost. Luckily, silicified plants do not deteriorate with age ; they are immortal, as I have explained already ; but alas, most of the labels are gone, except those that were painted on the specimens.

By their sheer number and amazing variety these palms of the volcanic period compel the attention of geologists, because from all accounts it appears that this family of plants, although it first arose in the Cretaceous period, did not rise to any prominence till after the Tertiary era had begun.

THE AGE OF THE DECCAN LAVAS

I have tried to put before you, as briefly as I can, what we know today of the fossil flora of the north-eastern part of the Deccan. For deciding the question of the age of the Deccan traps it is perhaps unfortunate that so many of the plants are new to Science and confined to this country ; but, of course, they have an interest of their own. For the rest, you will have noticed that from what we know of the geological history of the stoneworts, the fungi, the water ferns and particularly of the palms, which formed such a vast proportion of the flora, everything seems to point to a Tertiary age. What is more, the fishes and the crustaceans, too, seem to fall into line with the plants. This is lucky, for otherwise we should never know whether to rely upon the plants or upon the animals, and the fossil evidence as a whole would lose its value as a guide to geological age.

So much for the Nagpur-Chhindwara traps which, according to the geologists of the Indian Survey, are the oldest in the whole series. For all we know, the Chhindwara traps may have flowed out into an arm of the northern sea which was not far off. The lavas of the east cost, too, seem to be equally old. Professor Rama Rao and his colleagues, Messrs. Narayan Rao and Sripada Rao, have quite recently found stoneworts and other algae of early

Tertiary age in the estuarine beds of Rajahmundry, at the head of the Godavari delta.

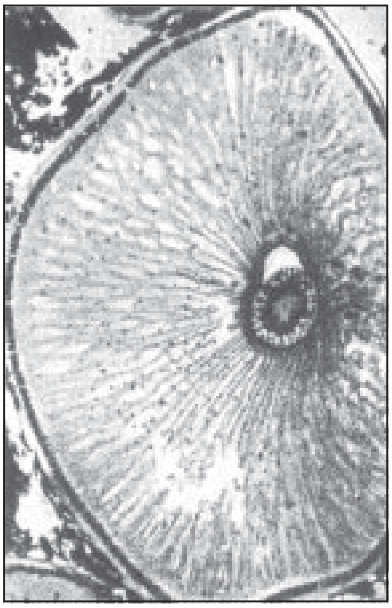

Fig. 23. Root of a petrified palm (*Rhizopalmoxylon sp.*) seen in cross-section. Round the central cylinder of conducting vessels and fibres the soft tissues of the cortex lie in radial plates, with big air spaces between them. Mohgaon Kalan, east of Chhindwara. Enlarged 10 times. (B. S.)

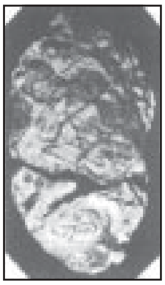

Fig. 24. Takliostrobus alatus Sah. A seed-bearing cone of a conifer. British Museum. Natural size.

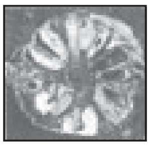

Fig. 25. The same, in cross-section, showing the paired seeds. Natural size.

Fig. 26. Another cone of same species, with the scales worn off and showing the ends of the paired seeds. From Takli, near Nagpur. British Museum. Natural size.

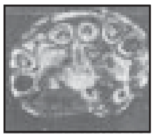

Fig. 27. Indostrobus bifidolepis Sah. Another kind of seed-beading cone of a conifer, with paired seeds, seen in cross-section. British Museum. Natural size.

It is curious that no intertrappean beds at all have been discovered in the middle part of the series, which we cross as we travel towards the west coast. Not until we actually reach Bombay Island, where the highest members of the Series are exposed, do we again come upon any sedimentary beds. It may be that during the middle part of the volcanic period the lavas were poured out in such rapid succession that no time was allowed for any plants or animals to colonize the desolate surface. Still, I think, a search ought to be made for traces of fossils along the planes between the lava flows, e.g., at Matheran, Poona and Mahabaleshwar.

In the highest intertrappean beds, namely, those at Malabar Hill and Worli, plenty of organic remains have been collected, including a multitude of skeletons of a pigmy species of frogs (**Fig. 30**). I have not seen any plants from here and cannot say whether these beds are much younger (geologically speaking) than those of the Central Provinces. But this seems to me unlikely.

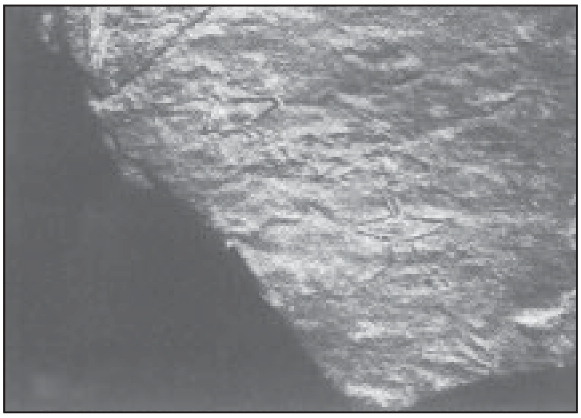

Fig. 30. Fossil skeletons of two pigmy frogs (*Indobatrachus* sp.) from the 'Frog Beds' at Worli, Bombay. Natural size. From a specimen given me in 1926 by Mr. Jayme Ribeiro of Bombay. (B. S.)

About seventy years ago W. T. Blanford found that near Surat and Broach the traps were covered by marine beds containing *Nummulites*, an extinct group of sea animals which is regarded as a sure index of the Eocene age. Evidently, the volcanic activity here must have already come to a stop before the sea began to encroach upon the land in early Tertiary times. But if we are to fix the age of the underlying traps we must know whether there was any long geological interval between the last of the lava flows and the marine incursion. About this important matter we are still very much in the dark. Blanford, it is true, had thought he saw evidences of a long period having passed during which the topmost lavas were exposed to denuding agents before the Nummulitic sea invaded the surface. It seems it was this fact, more than anything else, that influenced him in suggesting a Cretaceous age for the volcanic series. Blanford rightly enjoyed a great name among geologists. His view was not only officially adopted by the Geological Survey of India but, until only a few years ago, was accepted almost without question by geologists all over the world. But, as Mr. S. R. Narayan Rao has recently suggested, Blanford's evidence may be open to another interpretation. For all we know, the Surat traps may not be much older than the nummulitics ; they may belong, like the overlying marine beds, to the Eocene, although to the very base of that series. According to Professor V. S. Dubey the radioactive content of some of the traps in western India also indicates an early Tertiary age.

Thus the chances are that the whole of this imposing thickness of thousands of feet of igneous rock was poured out within the relatively short interval of the Eocene period. Quite probably this terrible drama of fire and thunder was only a brief episode of the very earliest part of the Ecocene. The thickness of a stratum is by itself no measure of time. For after all it would not take long for a lava flow a hundred feet thick to be poured out like a flood from a fissure volcano, once it came to business. It is the deposition of the relatively thin sedimentary beds during the quiet intervals that must have taken up most of the time of the Decean trap period.

The conclusion that the Deccan traps were poured out at the dawn of the Tertiary era and not at the close of the Mesozoic, brings them into line with other vast outpourings of Ecocene lavas ; for example those that now cover at least 200,000 square miles of the north-western United States and the equally widespread lavas of the old Thulean continent that once united the Western Isles of Scotland with Iceland, Greenland and other arctic lands.

Before I close I ought to say that this idea of the Tertiary age of the Decan traps is by no means a new one. Indeed, it is over a hundred years old, for it was first put forward, so far as I know, by Malcolmson in 1837 ; and it was repeatedly expressed by Hislop and others in the middle of last century. In later years the question was discussed and rediscussed by so many, and from so many different angles, that we could hardly see the wood for the trees. On various indirect grounds, which it would take too long to discuss here, the foremost geologists in India began to favour Blanford's idea that the earliest of the Deccan lavas were poured out before the end of the Cretaceous period. This view was almost universally adopted, and I confess I once believed in it myself. But I think the pioneers were right, as they so often are. They saw things more clearly because they worked with a clean slate and, as we all know, a clean state is a very useful thing.

The pioneer geologists were right also for another reason. They did not despise the mute but eloquent testimony of the plants that suffered the fiery ordeals of the dawn of the Tertiary era.

Six years ago, when we last met in Bombay, serious doubts were raised against the Cretaceous theory by a cursory review of the flora of which I have tried to give you a glimpse this evening

(*Proc. 21st Ind. Sci. Congress, Bombay, Jan.,* p. (27) = 319, 1934 ; see also an article entitled 'The Deccan Traps : Are they Cretaceous or Tertiary' in *Current Science*, Vol. 3, 1934, p. 134). Since then the evidence for a Tertiary age has steadily accumulated, and support has come in from unexpected quarters. A healthy sign is that some of the sceptics have become enthusiastic converts (see joint discussion on the Age of the Deccan Traps, *Proc. 24th Ind. Sci. Congress, Hyderabad,* pp. 459–471, 1937). Hugh Miller once wrote that "*geology* is a *science* in which the best authorities are sometimes content to unlearn a good deal", and, as Professor Seward said recently, it "helps us to cultivate the not too common virtue of amitting that it is possible to make a mistake". Let us hope that this is true of all Science.

Thus it is that the plant-fossils have come into their own. They tell their own story. For, as the first flashes from the fissure volcanoes flared up on the eastern horizon, the stalwart Palm said to the little *Azolla* :

This lurid light is not a sunset glow—

It is the herald of a morn.

CONCLUSION

We have now seen the contrast between the red part of the map and the green. Between the two lies a vista of time stretching back through well-nigh two thousand millions of years. But man, a recent creature of the earth, has united them in one poem of duty to his Creator ; if the foundation rocks of the south have given us Mahabalipuram and the Seven Pagodas, the Deccan traps have given us Ajanta and Ellora.

ACKNOWLEDGEMENT

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The originals of the specimens marked (B. S.) are in the author's collection ; others belong to the British Museum, the Geological Survey of India and the Benares Hindu University.

NANOSCIENCE AND NANOTECHNOLOGY—THE PRESENT AND PROSPECTS

Shruti Sharma*

Nanotechnology is the science that deals with the materials and devices at the nanoscale (1~250 nm). Such materials can be made by either top down approach by breaking down a bulk material to finer and finer particles or by the bottom up approach by putting atoms or molecules in a desired pattern. Nanomaterials have remarkable properties entirely different from those of bulk materials. In fact, everything "*micro*" is fast getting replaced by "*nano*" e.g. *nanoelectronics, nanochips* or *nanoprocessors* etc. Nanotechnology is aptly considered as the most important scientific development after industrial revolution and it would significantly impact many areas including information processing, communication and medicine in the near future. The developments in nanoscience which have made it possible to play around with individual atoms and molecules would enable us to make or synthesize anything we can "imagine".

INTRODUCTION

Nanotechnology, the "buzzword" today, has started appearing in the media frequently. As such, everybody is curious to know what lies inside this science and associated technology. That is the motivation for this article. Nano (10^{-9}) is a prefix derived from the Greek word nanos (very small or dwarf) meaning a billionth part. Thus 10^9 nanoseconds make a second and 10^9 nano meters, a meter.

Properties of different materials depend on the size of particles and arrangement of the constituent atoms or molecules[1,2]. The following are consequences of these two types of changes :

(a) As the particle size decreases, the relative number of atoms on the surface increases. There is an increase in the ratio of surface area to volume. High surface area is an important factor in catalysis and in electrodes which leads to improvement in the technologies of fuel cells and batteries. As the particle size reaches the nano range (1~250 nm) the phenomenon of size quantization becomes operative. This is because the particle size is comparable to the de Broglie wavelength of its electrons and holes. Similarly, the electrical, optical, chemical, mechanical and magnetic properties also change as the particle size decreases. Thus, these properties can be modulated by engineering the size, morphology and composition of the particles.

(b) There are marked changes in properties of materials by changing the arrangement of constituent atoms. Some examples are as follows.

(i) Graphite, diamond and fullerenes have carbon as the constituent atom. They differ in the arrangement of carbon atoms and subsequently there is interesting difference in their physical properties.

(ii) Sand and computer chips have the same main constituent atom (silicon) but a lot different properties.

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(iii) If we rearrange the atoms in water and air (carbon dioxide) and add some of the minerals from soil we can (*at least imagine to*) make all living organisms.

The atoms and molecules have dimensions in the nanoscale. A comparison of items in different scales is given in **Table 1**.

Table 1. : Comparison of the sizes of some items

Hydrogen atom	0.1 nm
Buckyball	1.0 nm
Width of DNA (the hereditary material) :	2.5 nm
Virus	100 nm
Circuit lines on chip	Nearly 1000 nm
Red blood cell	10,000 nm
Human egg cell	100,000 nm
Edge of a coin	Nearly 1000,000 nm
The range of nanoscience & nanotechnology	1~250 nm

nm, nanometer.

Richard P. Feynman (1965 Nobel Laureate in Physics), physicist at California Institute of Technology first raised some fundamental question in a lecture delivered[3] on December 29, 1959. The title of the lecture was : *There is Plenty of Room at the Bottom*. The questions he raised were :

(a) Why cannot we write the entire 24 volumes of the Encyclopedia Britannica on the head of a pin?

(b) Can the electron microscopes be improved by nearly hundred times so as to see the individual atoms ?

(c) Can we determine the structure of a chemical substance by looking at it and see where the atoms are ?

(d) Taking a cue from the tiny biological systems, can we make very small devices which are at our beck and call and do what we want ?

(e) Comparison of the little computer in human head and the man made machine.

The above posers to the scientific community 45 years ago were provocative enough to set the pace for the development of science at nano scale (nanoscience) and its application called "nanotechnology".

Developments in nanoscience and technology are all pervasive in different branches of science and engineering. As a result this single area of science is attracting maximum investments from governments and venture capital[4-6]. Nanotechnology is being aptly described as the most important technological revolution after industrial revolution.

In the quest of the development of materials with novel properties, two approaches have been used :

(a) Decrease the particle size to the nano range in order to have materials with desired novel properties : *top down approach*.

(b) Design novel materials by putting atoms together in an *imaginative way* or rearranging the atoms : *bottom up approach*.

There is no limit to what we can achieve by the above two methods. The greatest motivation for novel designs at nano level comes from the living systems. Consider the following facts.

(a) Human brain is the best and the fastest computer.

(b) The eyes and the connected vision machinery is the most sophisticated camera.

(c) Heart is the most efficient pump which starts functioning in the womb and works with absolute fidelity for years on end.

(d) The organs of locomotion like flagella, cillia composed of microtubules and the proteins with contractile function (actin and myosin) are the examples of nature's motors.

(e) How nature (biological systems) stores information and fabricates structures at the nanoscale ?

The basic functional units of all the above systems are biomolecules or supramolecular assemblies in the nanoscale. So, the effort is to understand the functioning of living systems at the molecular, atomic and subatomic level and design nano sized novel materials and intelligent devices for engineering and biomedical application. Richard P. Feynman has exhorted in his famous lecture quoted above to make novel elements as well.

TOOLS OF NANOSCIENCE

Conventional manufacturing methods like casting, grinding, milling or lithograph, involve cutting or removing millions of atoms at a time while giving shape to the products. For the top down approach of nanoscience for preparation of nanoparticles four processes (wet chemical, mechanical, form-in-place and gas phase synthesis) have been used. All these are refinements of the existing techniques. The first requirement for R & D by the bottom up approach was the appropriate tools (tweezers) which would allow to handle and work with individual atoms or particles at the nanoscale[7,8]. The technological wonder which made it possible to see and work with individual atoms is

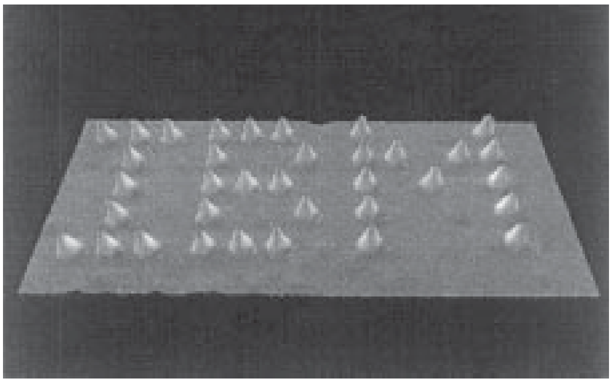

Figure 1. IBM's Initials spelled with nexon atoms (Courtesy : IBM Research, Almaden Research Centre) The image now hangs in the IBM's "STM" gallery (http://www.almaden.ibm.com/vis.stm/atomo.html).

"Scanning Tunneling Microscope (STM)". The first breakthrough using STM (invented in 1981) was the image of I.B.M.'s initials using 35 individual atoms of using xenon (Figure 1). Creation of this image was a landmark in the bottom up approach in nanoscience. STM had the limitation that only conducting samples could be imaged. This limitation was overcome by the development of atomic force microscope (AFM). AFM measures deflections that a sharp probe experiences when dragged over a surface. STM and AFM together are called scanning probe microscope (SPM). Another important innovation is the laser "tweezer". By using the momentum of photons it is possible to isolate in a single location, collections of several hundred molecules or atoms. Before this invention the possibility of isolating a few molecules or even a few hundred molecules was not considered possible. The milestones in the development of nanoscience and technology are given in Table 2.

Nanoparticles can make metals stronger and harder, give ceramics enhanced ductility, enable normally insulating materials to conduct heat and electricity and make protective coatings transparent. Nanoparticles are larger than individual atoms and molecules (they follow the laws of quantum chemistry) but smaller than bulk solids (they follow the laws of classical chemistry). Nanoparticles are often crystalline and are referred to as nanocrystals[9,10].

Table 2 : MILESTONES IN THE DEVELOPMENT OF NANOSCIENCE & TECHNOLOGY

1959 : Feynman delivers historic talk "Plenty of Room at the Bottom"

Richard Feynman postulated that we would someday manipulate matter on an atomic scale. This talk is considered as year zero for nanotechnology because it provided the impetus for R & D at the level of nano scale.

1974 : First molecular electronic device patented

IBM files the first ever patent of a molecular electronic device.

1981 : Scanning tunneling microscope (STM) invented

The device uses quantum tunneling currents between the microscope tip and the material being observed to produce images with atomic resolution. Inventors of the STM, Heinrich Rohrer and Gerd Karl Binnig, were awarded the Nobel Prize for physics in 1986.

1985 : Buckyballs discovered

Spherical cages of 60 carbon atoms were discovered by Richard Smalley, Robert Curl, Jr., and Harold Kroto. The new form of carbon these represent is called buckminsterfullerene. They were awardred the Nobel Prize for chemistry in 1996.

1986 : Atomic force microscope (AFM) invented

Offering similar resolution to the scanning tunneling microscope, the AFM works like phonograph, by moving a tip across a surface and detecting the vertical movements.

1986 : Publication of Dexler's "Engines of Creation"

Dr. K. Eric Drexler presented the ideas of molecular nanotechnology to a wide audience, outlining the potential and dangers he envisaged.

1987 : First observation of quantization of electrical conductance

Research groups at Delft University of Technology, elsewhere in Holland and in the UK observed step-like variations in conductance through tiny conducting strips, i.e. the conductance is quantized, demonstrating that nanoelectronics is not just smaller, but different.

1987 : First single-electron transistor created

Theodore A. Fulton and Gerlad J. Dolan of Bell Laboratories constructed a transistor where the current being switched consisted of the movement of a single electron.

1988 : First "designer protein" created

William deGrado and his group at DuPont designed a new protein, and then made it.

1989 : "IBM" written with 35 xenon atoms

Using the tip of a scanning tunneling microscope, scientists at IBM in Zurich showed that individual atoms could be moved and positioned precisely.

1989 : Single Electron Transistor Discovered

M. A. Kastner of Massachusetts Institute of Technology discovered "Single Electron Transistor.

1991 : Carbon nanotubes discovered

Sumio lijima (NEC Corporation, Japan) discovers tubes of graphite, called nanotubes, which turned out to have extraordinary strength and interesting electrical properties.

1992 : Nanobacteria discovered

R. L. Folk of University of Texas reported nanobacteria (size : 50–200 nm).

1993 : First nanotechnology lab in the US

The US's first laboratory dedicated to nanotechnology was created at Rice University.

1997 : DNA-based nanomechanical device created

New York University's Nadrian Seeman demonstrated that DNA can be used as a building block for nanoscale mechanical devices.

1997 : Single-nanotube electronics

At Delft University of Technology the first electrical transport measurements were performed on a single nanotube, revealing a host of electrical phenomena.

1999 : Scientists created electronic molecular switch

Yale scientists Mark Reed and James M. Tour created an organic switch in a single molecule.

2000 : US launches National Nanotechnology Initiative

Investing nearly $422 million into nanotechnology research, the US government launched "National Nanotechnology Initiative" implying recognition to the strategic importance to the U. S. of this field.

2001 : Nanotube logic

Researchers at IBM and Delft University created the first transistors, and then logic gates made entirely from carbon nanotubes.

Nanotechnology is now the hottest topic of research and a number of breakthroughs are appearing at frequent intervals. Many of the posers raised by Richard Feynman have turned from fiction to fact.

The fundamental knowledge gained through nanoscience and developments in nanotechnology will certainly accelerate over the next several decades. With the control of materials at the nanometer dimension, engineers are already able to create new types of products and services. Yasuo Takahashi, Device Physics Laboratories Japan working on *single-electron transistor* (SET) plans to apply SET for the fabrication of *artificial brain*[11]. Today, cosmetic manufacturers use liposomes with diameters of a few tensof nanometer to reduce the dehydration of skin. There has been a rapid growth in the companies in the area of nanotechnology during the last few decades (Figure 2).

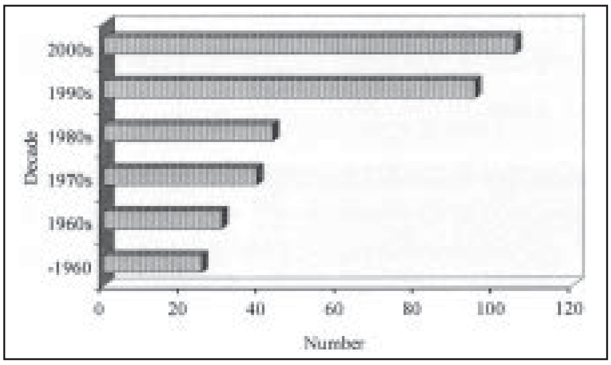

Figure 2. Growth in the number of nanotech companies

Applying the scientific method to further understand the behavior of atoms and molecules at the nanometer scale will push forward the frontiers of human knowledge. When the ideas and concepts that are discussed as part of the nanotechnology revolution are fully implemented, what is not possible[12]? Imagine, all of the history (documents including music and movies) will fit in a small package that will fit in our pockets. Our world will be safer because the computers and sensors will be detected and warn us of dangers. Life will be extended because we can create devices that replicate the functions and systems in our bodies and fight incurable diseases. Quantum computers will make calculations billions of times faster than today's digital computers. We can create new types of molecules and novel materials with the desired properties. Common terms and abbreviations used in nanoscience and technology are given in Table 3.

Table 3. COMMON TERMS AND ABBREVIATIONS IN NANOSCIENCE & TECHNOLOGY

Assembler : A nano-robotic device that can use available chemicals to manufacture nanoscale products

AFM : Atomic Force Microscope

Bottom up : An approach of building up things by combining smaller components (compare with top down)

Buckminsterfullerene (buckyball) : A sphere of sixty carbon atoms (C60)

CNT : carbon nanotube

CVD : chemical vapor deposition

DWNT : double-wall nanotube

MNT : molecular nanotechnology

MWNT : multi-wall nanotube

Nanotube : A tube with nanoscale diameter dimensions (generally used to refer to carbon nanotubes. A common non-carbon variety is made of boron nitride).

Nanoelectronics : Nanoelectronics refers to electronics at the sub-micron scale.

Nanodot, nanocrystal, nanoparticle, nanorod, nanowire : All these terms mean the same as the conventional terms like dot, crystal, particle, rod, wire except that the dimensions are in the nano range.

Nanobot : nanorobot, still a fiction.

NEMS : Nanoelectromechanical systems.

NNI : National Nanotechnology Initiative of USA.

Photolithography : The process used to make computer chips today. Photolithography uses a beam of light to etch the geometric patterns that will become circuits onto a chip.

Photonics : Electronics using light (photons) instead of electrons to manage data.

Quantum dot : Material (usually a semiconductor) capable of confining a single or a few electrons, and in which the electrons occupy discrete energy states just as they would in an atom (quantum dots have been called artificial atoms). They are made from a variety of different compounds, such as cadmium selenide.

Quantum computing : A new mode of information processing that can be performed by harnessing physical phenomena unique to quantum mechanics (especially quantum interference).

Qubit : A qubit is a quantum bit, the counterpart in quantum computing to the binary digit or bit of classical computing.

Self-assembly : The process whereby components spontaneously organize into more complex objects. Biological systems do it all the time.

SET : Single Electron Transistor

SPM : Scanning probe microscopy (includes STM, AFM, etc.)

STM : Scanning Tunneling Microscope

SWNT : single wall nanotube

Top down : Opposite of bottom up. An approach of building up things by cutting them into smaller and smaller size.

Two-Dimensional Material (TDM) : Materials that are one molecule thick.

FUTURE SCENARIO

The future scenario depends upon the human genius and ingenuity only[13].

I. The most marvelous nanomachines are the living systems consisting of molecular, atomic and electronic switches, channels and wires e.g. transport across biomembranes, functioning of ion channels and nerve conduction. I cannot think of (at present) any man-made device which can synthesize as efficiently and economically as the photosynthetic apparatus, respond to stimuli as deftly as "touch-me-not" and a fine filtration assembly like glomeruli in our kidneys. The simple *mantra* is to understand the nanoscience of the living systems and mimic and even excel.

II. Richard Feynman in his oft quoted talk narrated the following :

"A friend of mine (Albert R. Hibbs) suggests a very interesting possibility for relatively small machines. He says that, although it is a very wild idea, it would be interesting in surgery if you could swallow the surgeon. You put the mechanical surgeon inside the blood vessel and it goes into the heart and looks around. It finds out which valve is the faulty one and takes a little knife and slices out. Other small machines might be permanently incorporated in the body to assist some inadequately-functioning organ." The scientists and engineers are already working on nanomaterials and nanomachnines to convert the imagination of Feynman's friend from fiction to fact.

III. Artificial organs which are the perfect replicas of the organs in humans and animals.

IV. The United States Government "National Nanotechnology Initiative (NNI) report states : "The impact of nanotechnology on the health, wealth, and the lives of people could be at least as significant as the combined influences of microelectronics, medical imaging, computer aided engineering and man made polymers developed in the century just past."

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RESOURCE BIOLOGY AND GENECONOMICS

G. Tripathi*

Resource biology and geneconomics are new dimensions of biology and bedrock of a sustainable socioeconomic development without damaging environment. 'Life benefits environment and environment benefits life' principle works here. Record of economic potentials of resource organisms and their valuable genes may be prepared for future perspective and accomplishment.

INTRODUCTION

Lifeless molecules constitute life. Life is dependent on sun energy. Only 0.06% of sun energy falling on earth is captured by life and transformed to build up biomass. Nevertheless, this small amount of energy was sufficient to sustain the evolution of the incredible multitude of life forms. Fascination of life resides in its unity and diversity. Unity deals with information transfer by the genetic code, energy transfer by polyphosphates, structure and function through proteins, etc. However, diversity dictates variations in biological species (genetic lines), genes and habitats. Variability among organisms at species, genetic and ecosystem level is collectively known as biodiversity. The word 'biodiversity' was first coined by Walter G. Rosen in 1965. This term became popular when it entered into political arena in the United Nations Conference on Environment and Development at Rio de Janeiro in 1992.

Some of the biological species may act as a constant source of benefit to Man and Environment. These species may be referred to as resource biospecies or resource organisms. Study of resource organism is resource biology. Bioresource species have valuable genes to synthesize useful products of economic value. Analysis of economic aspects of genes may be called as gene economics or geneconomics. Now the entire world is gradually moving towards geneconomics and a clear picture will emerge within a decade or two. The importance of resource biology and geneconomics has been presented here to look into future perspectives of resource organisms.

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MOLECULES TO SPECIES

The chemical message of life centers around nucleotides. Probably, RNA molecules evolved from ribose and other organic molecules by learning to copy concept. RNA began to synthesize proteins. Protein facilitated RNA replication to synthesize more proteins. These molecules served the purpose of biological structure and function. Self-splicing RNA and antibody catalysis reflect some evolutionary significances and molecular diversification. Functional proteins (enzymes) also helped the RNA to make double stranded version of itself that evolved to DNA. This is how the life has been derived from RNA world. It is interesting to note that the genetic (RNA and DNA), metabolic (protein) and energy (ATP) languages are universal to all forms of life, from bacteria to man. This outstanding molecular uniformity transformed the Darwinian biological evolution into the chemical languages of life.

The gene transcribes into mRNA which is translated to form protein as a second universal complementary language of biological information. The most advanced life of today (i.e., human being) has about 7 billion nucleotides in 46 chromosomes of each nuclei of trillions of cells of the body. No material is important as RNA and DNA because they provide the genetic and metabolic basis of the evolutionary process generating billions of different life forms that have occupied the Earth since the emergence of life. Very little differences in genes constitute different species. For instance, there is much similarity in the genes of rat and man. In genetic term, the origin of life means the appearance of the first replicating molecules about 4 billion years ago. The self-replicating naked genes might started molecular evolution that led to cellular life on the watery planet Earth. All the earth's genes, species and ecosystems are the products of about 3 thousand million years of evolution. Some species became extinct and other survived in nature. Most of the extinct species evolved and vanished in the last 600 million years during Phanerozoic time.

SPECIES TO DIVERSITY

The notion of 'species' was first developed by Carolus Linnaeus. Later on, many inconsistencies and the basic problems emerged for the adaptation of criteria to define a species. Species can be defined in various ways. On the basis of breeding, a species is a group of organisms capable of interbreeding and producing fertile offspring. Ecologically, a group of organisms sharing the same ecological niche fall under one species. Genetically, a species is a group of organisms showing close similarly in their genetic karyotypes. However, in evolutionary perspective, a group of organisms sharing a unique collection of structural and functional characteristics belong to one species. The concept of interbreeding individuals as species cannot be applied to microbial realm where horizontal gene transfer between species is common. Therefore, modern biologists are inclined to base species identification criteria on the composition of genome. Two individuals sharing more genetic traits with one another compared to third one are declared genetically closely linked. But many pertinent questions can be raised at this juncture : How many genes should two populations be apart to be called two separate species ? Can insertion of a foreign gene into a plant variety or animal race (transgenesis) create a new species ? Human populations also have about six billion aliens and few homozygotic twins. Can they be considered separate species ? Therefore, the criterion of genomic composition will be of little help to define limits between species. It would be more comfortable, then, to speak of 'genetic lines' instead of 'species'[1].

The total genetic lines of a distinct population is gene pool which holds the genetic diversity of a conventional species or subspecies (variety or race). The species showing pure parasitism entirely depends on other species for food and habitat. Such species are known as secondary species. These species may also have one or more species entirely depending on them. They are referred as tertiary species. There is no viable figure about the number of secondary and tertiary species for all major groups of life forms except mere guess. Organisms belonging to a given species rarely exist naturally as a single large population. It is usually for species to exist as small interbreeding populations, called demes, each with its own genetic pool. Geographical races are the phenotypically different populations of a species living in well separated geographical habitats for a long time. Populations adapted to ecologically dissimilar habitats are referred to as ecological races or ecotypes. A species exhibiting a gradual change in phenotypic characteristics throughout its geographical range is known as a cline. However, the species showing marked phenotypic variation, within a population according to their degree of geographical isolation, are known as polytypic species (intraspecific speciation), or two different species may give rise to a new species (interspecific hybridization). Intraspecific speciation occurring in separated populations is known as allopatric speciation. Whereas the speciation occurring in the populations of same geographical area is called sympatric speciation.

Each habitat (or biotope) has hierarchical structure with vertical relations. In certain sense, a species may dominate in its habitat. This species is known as key species e.g., elephants in a forest. According to key species model of conservation, a habitat will start to degrade when the key species disappears. But this model does not represent the possible horizontal links and the role of man. So, one has to move towards species-web model for habitat and species conservation. In fact, all species of a region and their interactions form a web in which each species has its function. The species-web model got support from ecological studies where relation between biodiversity and biomass was measured. Biodiversity is a boon to ecosystem and not the species and the individual species could not always benefit from diversity[2].

DIVERSITY TO RESOURCE

The number of biological species currently existing on Earth ranges from 5-30 million. Although some scientists believe it to be up to 100 million, which is very high and not widely acceptable. Only 28.26% species have been identified and 71.74% are yet to be identified. Approximately 1.5-1.8 million biological species have been documented so far[1,3]. Controversies also exist about the number of species of different groups of organisms. Majority of biological species are found in tropical rainforests. About two thirds of the total vascular plant species, 30% of the terrestrial vertebrate species and 90% of the arthropods occur in tropical forests. Loss of even one species directly or indirectly harms human being ; however, loss of humans will not harm biospecies. This is the point where the importance of biodiversity lies for human subject. Since the beginning of the 17th century, 21% of all mammalian and 13% of avian species have vanished. About 50% of species are thought to die out during deforestation. Approximately 39% of the frontier forests (natural forests) is threatened by human activities. The fossil records show that the average life span of a species is about 1-10 million years. Based on this the background extinction rate of species could be 1-10 species per year. The current rate of species extinction has been estimated to be 100-1000 times higher due to pollution and habitat loss.

There are about 30,000 edible plants in the world, out of which, 7000 plants are grown and collected for food. The current food supply depends on only 29 major staple crops which deliver 95% of our proteins and calories. Among these, three crops (wheat, maize, rice) dominate the scene and provide us more than half of our energy source. Earthworm may be used as a potential bioresource[4] for waste management, vermifertilizer production, land reclamation, animal food, detoxification, etc. A large food requirement of the world is also fulfilled by animal resources such as fishery, poultry, etc. Entire range of enzymes have been identified in micro-organisms that are useful for catalytic process in industries. Fungi produce antibiotics and antiviral proteins. Other usages of microbes may be in biocontrol, bioremediation, biomass utilization, etc. Animals are also utilized as resource for human. Silk worm producing silk, lac insect producing lac, honey bee producing honey, marine annelids producing toxins and many other examples of animal resources are available.

RESOURCE TO ECONOMICS

Plants and animals are a treasure-trove for food proteins, oils, flavors, fibers, resins, lignin, glues, biocides, gelatins, wax, latex, chitin, enzymes, silk, etc. The market for herbal medicines was about US$ 2.2 billion in Europe. In USA, plant-based drugs hold 25% of the pharmaceutical market, representing $25 billion in 1998. Seven of the 20 top-selling drugs in the USA are based on the plants. The world market for natural product-based pharmaceuticals has been estimated at about US$ 50 billion. The US National Cancer Institute (NCI) screened 35,000 samples from 12,000 temperate plant species for anti-tumor activity and found one out of 4,000 plants having economic potential[5]. From this, three compounds have been derived in pre-clinical development for treatment of AIDS. A number of plants have pesticidal properties and biopesticides may be prepared from these plants. Ecotourism contributes significantly to the budget of developing countries. In smaller countries such as Ecuador, Kenya and Rwanda, ecotourism is a major earner of foreign exchange. In South Africa, land that yields US$25-70 per hectare before, now yields US$200-300, spent by visitors interested in watching animals[6]. Kenya's parks are visited by 500,000 tourists per year who spend approximately US$ 3000 million, representing 14% of the country's GNP.

A handsome money can be earned from the culture, production and utilization of different resource animals. Vermitech industries are now playing an important role in uplifting economy and cleaning environment. In 2003, India exported US$400 million shrimps to the USA alone. In addition to food fisheries, there is also much scope of earning from ornamental fisheries. The global ornamental fish trade is approximately US$ 9 billion (FAO). Asian countries export more than 50% of the aquarium fishes. Singapore imports ornamental fishes from Asian countries and exports them to USA, European Union and Japan. The global import market is around US$ 250 million. In this, fresh water represents 90% of the trade as against 40% marine fishes. Approximately 90% of the freshwater fishes are cultured and rest are caught from wild. However, in case of marine fishes, 99% fishes are collected from wild and 1% are farmed. Among the total 2118 species of fishes harboring in Indian aquatic environment, 600 fish species have promising market as ornamental fish. The domestic ornamental fish market in India is around Rs. 500 million and the demand is increasing annually at 20%. The total global export market for ornamental fish is estimated at US$ 427 million. Among marine coral resources, *Goniopora* sp. is used to replace broken bones in place of metal rods. Some corals have properties that prevent hypertension, cure diabetes and cardiac problem.

The total economic value of biodiversity is the sum of use values that include direct use values like fisheries, agriculture and foretry, indirect use value implicated in the supply of direct use diversity, option use value comprising bequest value both use and non-use values, and quasi option value based on future value of the information in diversity[7]. Virtually, it is difficult to count the real cost of biodiversity. There is a basic problem to estimate the value of non-use benefit because they have no market value. Hedonic pricing model helps in valuation of biodiversity by placing a value on ecosystem goods and services for which a market actually exists. However, contingent valuation method is used to valuate non-market goods and services by determining biodiversity values directly. Travel cost method is applied to measure the value of diversity, in which, proxy consumption costs are substituted for the market price of the environmental goods and services. Since genetic and species diversities have benefits in terms of input to production process and agricultural industries, their values can be measured by various methods. Biodiversity should be linked with a systematic economic valuation and it must be incroporated into accounting of national economics. The values of species, genetic and ecosystem biodiversity should be taken into consideration during economic analysis. Decline in biodiversity should be converted into monetary losses.

GENECONOMICS

Watson and Crick proposed the double helix structure of DNA which has become icon to modern biotechnology. It has brought medicine, agriculture and industries to a new threshold. The first biotechnology-derived drug was recombinant insulin developed by Genentech. Rapid strides in molecular biology and biotechnology have helped in sequencing the genome of a number of organisms including bacteria, yeast, roundworm, fruitfly, mosquito, mouse, fish, rice, banana and human beings. Banana and potato have been modified to produce human vaccines against infectious diseases such as hepatitis B and diarrhea. Fishes have been designed to mature more quickly. Nut trees have been changed to yield years earlier. Several genetically modified plants and animals have been produced as a result of biotechnological advancement in recent years. We can derive many-fold benefits from our microbial plant and animal resources after identifying species and their biological and biotechnological potentials.

It has been estimated that there may be some 10^9 genes present in the world biota[1]. One can earn millions of dollar by exploring potentials of important and useful genes. For an instance, commercialization of a new sugar rich variety of hybrid tomato has benefited the tomato industry by about US$ 8 million per year. This hybrid variety is a cross breed of wild tomato and edible tomato. Wild tomato is a weedy species but its potentials was identified by hybrid crossing. If its potentials had not been identified, the valuable gene for sugar biosynthesis could have been lost easily through habitat destruction and elimination of weedy species. Thus each and every species may act as resource. The international market of only medicinal plants related trade is about US$ 60 billion per year. It is growing annually at approximately 7%. India shares only 2.5% of this market and it can be increased by collecting knowledge about beneficial bioresources from local people. For example, the potential of the plant *Trichopus zeylanicus* was first recognized by Kani tribal in Kerala. A tonic 'Jeevani' has now been prepared by this plant for boosting immune system and providing energy. Similarly, the fuel potentials of *Jatropha curcas* plant has been identified. This plant was introduced into Asia and Africa by Portuguese as an oil yielding plant. Biofuel is attracting increasing attention every where.

Biological world is full of useful genes to meet our present and future needs. Here is the point where 'gene economics' or 'geneconomics' is required for evaluation of economics potentials of biological resources. Geneconomics may deal with the values of genes and their conservation costs. It has been proposed to impose a levy of 1% on all pharmaceutical products which would raise sufficient money to finance either the discovery and description of new taxons or the screening of taxons per year. The money may be better spent by analyzing the genomes of known plants, thus using their genetic potentials at maximum. According to Primental[8], about US$ 2.9 trillion should be spent on conservation of the planet's biota. Since destruction of biodiversity has serious socio-economic implications, there is a need to save biological resources. Protection of ecosystem and species can strengthen and diversify regional economics.

A fee per biospecies collection and royalty on all sales of species products may be imposed. This will earn a lot for conserving and propagating bioresources. For instance, InBios has made an agreement with US company Recombinant Biocatalysts, Inc. (RBI) for developing gene libraries from microbes. RBI is intended to clone directly the microbial genes instead of cultivating the organisms. The main part of the fees is directed to support InBio's work. About 10% of the research budget is donated to support biodiversity conservation and 50% of royalty is shared with the Government. Geneconomics is also relevant for future economics of a country. If we view World in terms of biodiversity and technology, there are four categories of countries. There are countries with advanced technology and poor biodiversity, moderate technology and rich biodiversity, moderate biodiversity and advanced technology and poor technology and poor biodiversity. In the future race of geneconomics, countries with moderate technology and rich biodiversity will be ahead of all. Thus countries like India and China may be economic superpower provided they explore biological and biotechnological potentials of their bioresources.

Man has a measurable impact on global climate and biodiversity. Climatic change will effect food production and human life through changes in qualitative and quantitative composition of biodiversity. Ecologists have started analyzing life forms in a changing world[9]. If we lose incredible multitude of life forms, or increase the risks to our own long term survival, we may ultimately disappear from this world[1]. Thus our old saying of Charkasamhita (4^{th} – 5^{th} century AD) comes true that "so long as this earth is full of nature (wild plants and animals) the human race is going to flourish". There is a need of bold and visionary international policy on global bioresources and biofuture[10].

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DO YOU KNOW ?

Q1. Who or what is famous in the name of Asimo ?

Q2. Who was Karel Capek ?

Q3. Which are more common-boy twins or girl twins and why ?

INTEGRATED WATER SYSTEMS MANAGEMENT IN SOUTH ASIA
—*Outline for a Regional Research Agenda*

Jayanta Bandyopadhyay*

South Asia, the region with the largest population density in the world and widespread poverty, has been identified by many as an area of quickly emerging water crisis. This paper presents an outline for a regional research agenda towards mitigation of this problem through integrated water systems management.

INTRODUCTION

With the largest population density in the world and widespread poverty, excepting the island areas the region of South Asia covers about 3.3 percent of the terrestrial area and receives 6.8 percent of the annual replenishable amount of water of the world. With this land and water resources, the region supports 21 percent of the world population. The challenges in water systems management are rooted in the common objective of all the countries—poverty alleviation and sustainable development. The growing and conflicting demands from food security, commercial farming, domestic water needs of the rapidly increasing urban population, hydropower projects, industrial demands, damage due to rampant pollution, etc. need to be rapidly solved with informed political wisdom.

The scope of a new research agenda includes institutional mechanisms for promoting sustainable use, stakeholder cooperation and conflict resolution. In spite of the overall commonality of the nature of the challenges related to water systems management in various parts of South Asia, the available literature on the region deals mostly with national level strategies and very little is available as a regional strategy. Several non-official attempts have been made at creating a framework for a regional level approach to water systems mangement. So far, however, not much progress has been achieved except in relation with flood forecasting and alerts. The need for regional collaboration in South Asia has been rightly recognized in the context of economic relations and trade. In the case of shared rivers, regional collaboration has been slowed down by, what can be called, the dominance of an acute hydrological nationalism. As a result, addressing shared waters has become a highly emotional issue in the region.

While the general perception in the rest of the world links the presence of overwhelming poverty of a region or a country with lack of water, in parts of South Asia, like in Bangladesh, the state of Bihar in India, the mid-hills of Nepal, that principle does not get mechanically verified.

Water availability in South Asia in the form of rainfall is governed largely by the interaction of the Monsoon with the uplands and the mountains in the region : for example, the Himalayan range and other uplands in the north and north-east of the subcontinent, the (Western and Eastern) Ghats for the southern parts of India, and the central highlands in Sri Lanka and India. The months of July to September are considered the Monsoon months. In this paper, attention will mainly be focused on the connected landmass of Bangladesh, Bhutan, India, Nepal and Pakistan. Sri Lanka has a stand alone hydrological situation. Among these countries, Bhutan and Nepal are mountainous ones while Bangladesh is largely a flat country on the delta of the Ganges-Brahmaputra-Meghna (GBM)

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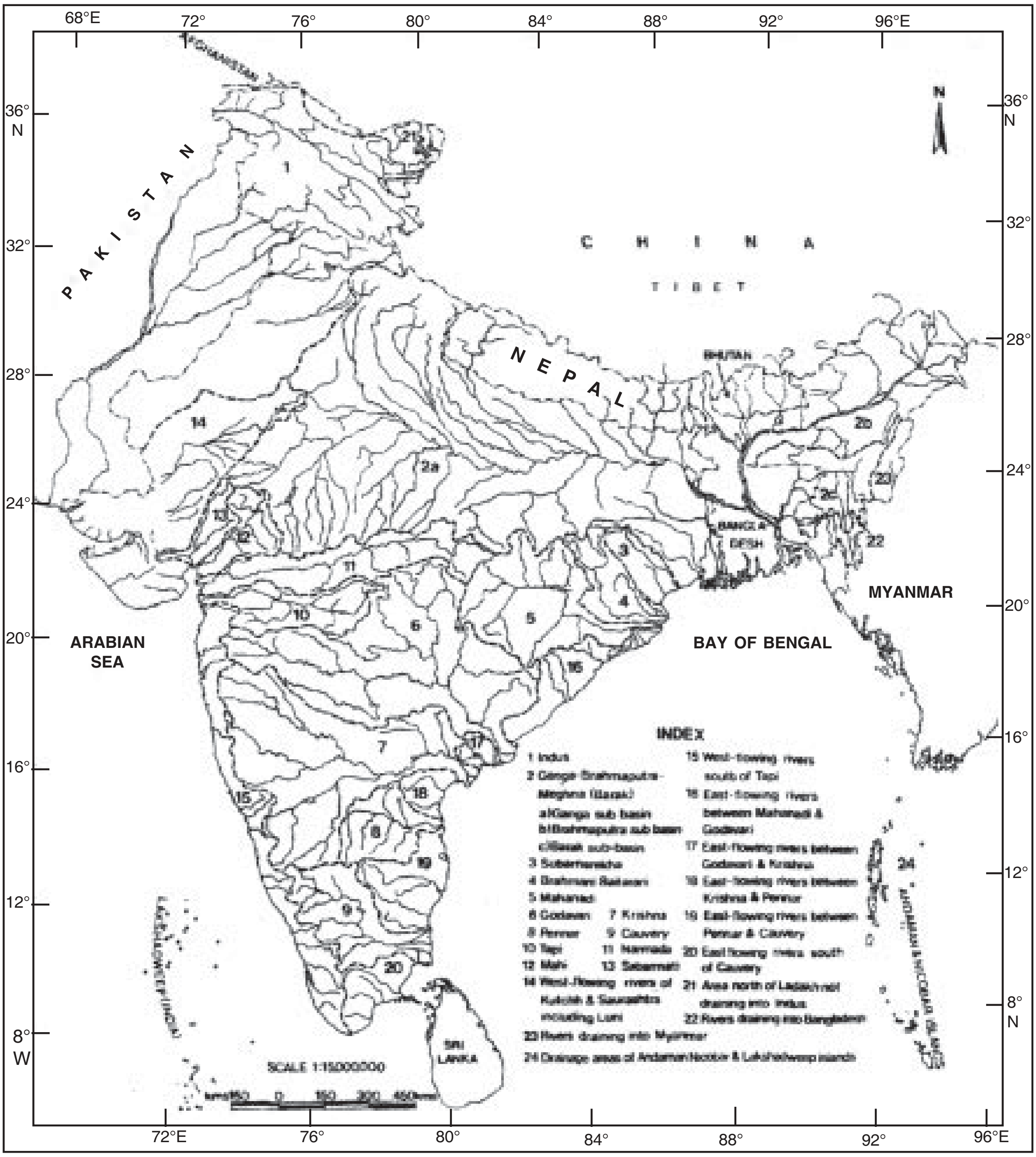

Figure 1 : River Basins of Mainland South Asia

basin, except smaller regions in the Chittagong Hill Tracts. Both India and Pakistan have diverse physiographic regions, starting from high mountains to the fertile flat plains to the active delta. Sri Lanka is an island country, with most rivers originating from its central highlands. South Asia has a comfortable water supply position when precipitation per unit area is considered. Bangladesh, located at the end of the GBM basin, receives a great volume of summer Monsoon run-off and about 40 percent of the country is usually inundated during the Monsoon months. With its very large population closing on to 1.5 billion, the region has quite an uneasy position when the volume of utilzable water is assessed on a per capita basis. Increase in population has led to a 70 percent decline in the per capita water availability in the region during 1950-1995.

The Monsoonal precipitation results in great temporal and spatial inequities in its regional distribution. This causes very large river run-offs during the Monsoon period and very low flows during the lean seasons. This variation is of special significance in the areas outside the basins of the Himalayan rivers which enjoy the advantage of critical pre-Monsoon flows from the snow melts. In addition, across the lines of social divide, access to water is very much uneven and has caused chronic water insecurity for a great number of economically backward people. In large parts of the region, groundwater has been the traditional source for the satisfaction domestic water needs. In the rain scarce areas of western and southern India and large parts of Pakistan, groundwater is virtually the lifeline for the population. South Asia has a long tradition of water management for irrigation and human societies in the region have been characterized as to belong to a 'Hydraulic Civilization'. However, the region has seen rapid growth of population and demographic change in the last two centuries and requirements of economic growth and poverty alleviation have created crucial and additional demands on water in South Asia.

The use of surface water for irrigation has received very high priority in planned development and has so far been perceived as the main tool for poverty alleviation. In addition to surface water, from the 1960s, groundwater has also become an equally important source for irrigation providing about 210 cu kms of water. Thus, both gravity driven surface water and pumped groundwater sources support the world's largest irrigation system in South Asia. The irrigation potential in South Asia has expanded rapidly in the post-independence period and stands at more that 160 mha. Over the decades, the growth in the water demand from irrigation has also created the basis for conflicts at various levels and raised questions whether agriculture is raiding South Asia's water supplies. The rapidly growing industrial sector and urban areas are increasingly able to transfer water away from the rural areas, irrigation or poorer areas in cities. In this context, the satisfaction of water needs for maintaining the ecosystem services has also started to emerge as an important issue for allocation in South Asia.

While structural interventions in the water systems of South Asia have a long and impressive history, the more recent absence of effective links between research at the local, regional or global levels that are constantly producing new knowledge and options for new management practices leading to relevant and quick policy changes, pose a serious problem in the region. This trend is not going to change soon. The need for accepting a broader knowledge base and promotion of integrated water systems management in the countries of the region have been analyzed by many. For example, at the national levels, Datta and Das Gupta et at for Bangladesh, Ghosh-Bobba et al and Niemczynowicz et al. for India, Gyawali and Faruqui in the case of Pakistan and Abeywickrema for Sri Lanka have analyzed challenges facing integrated management of water systems.

The initial knowledge base and institutions for the present form of water administration in South Asia came from the European engineering tradition. In order to expand irrigated agriculture and to transport the agricultural products through waterways, the British rulers made systematic engineering interventions, specially in the form of canals. These interventions had a greatly positive economic impact as a result of which names of British engineers Sir Arthur Cotton or Colonel John Pennyquick are remembered in the Godavari and Vaigai basins of South India as those of saints.

For the smaller Himalayan countries of Bhutan and Nepal, the growth of the institutional structure for water systems management was greatly influenced by that of the engineering education and practices in the rest of South Asia, specially through the educational system in these countries and the water related projects on the Himalayan rivers. Thus, the European paradigm of water management, directly or otherwise, maintained a long and decisive presence in the South Asian region. The post-colonial period is characterized by the continuation of practices based on the same knowledge base as was introduced by the British, large investments in surface water projects and an explosive growth of groundwater based irrigation in the 1960s. During the 1990s, the social and environmental impacts of the rapidly expanding water projects and irrigation systems, based on both surface and groundwater, started to make themselves visible through movements of the displaced and environmental criticisms. Accordingly, the last 15 years have witnessed the growing opposition to large water projects on the issue of their partisan social impacts and negative ecological impacts.

DISCONNECT BETWEEN WATER SYSTEMS RESEARCH AND DEVELOPMENT

In the post-colonial era, with the end of the British rule in large parts of South Asia, an important change took place in the water administration in South Asia. The recent developments in water systems science and principles for its management are so fundamental that the transformation has received the status of an emerging paradigm shift, specially when the growing recognition of the water needs for maintaining the ecosystem services is concerned.

It may be that in the post-colonial institutional set up for water management, by design or otherwise, open professional criticisms, so much needed for the growth of water science anywhere, was overpowered to the commitment to institutional hierarchy. Thus, vital professional criticisms were not articulated, lest they are seen as an indicator of non-compliance with the institutional hierarchy. This is a characteristic of most ex-colonies and Wescoat expressed this situation of colonial influence on the water mangement culture of South Asia in the following words :

Cultural and ecological dimensions of water management fell outside the formerly colonial and new international research paradigms, both of which focused on irrigation systems, hydropower and public health to the relative neglect of fisheries, flood control and watershed management.

One important example of this tendency towards cognitive stagnation is the absence of any refinement in the official process for project appraisal and approval, in particular in the water sector. It is not to say that the region has no centre for high quality research on water systems. However, their scope is in need of substantial expansion.

Further, the difficult access to or official restrictions imposed on the open availability of detailed hydrological data, particularly on the international river like the Ganges, have acted as obstructions to research and the growth of high quality scientific knowledge on the water systems of South Asia.

The process of induction of new interdisciplinary knowledge in the governmental practices in South Asia is even more difficult due to the externalization of the critical elements of new research publications. There are several reasons for this. Firstly, much of the environmental publications in South Asia are made by NGOs. Excepting a few cases, for instance, like the pesticide contents of soft drinks there is a tendency to publish sensational matters, without adequate background research. Such reports get easy exposure in the media. Secondly, much of the good quality research publications on water in South Asia are made in journals published from the industrialized countries. The governmental departments, NGOs as well as research organizations have very limited access to this. Then come the publications made from within the region. No serious engagement of the government engineers and the independent water professionals is expected on many important issues, and thus, no transfer of new knowledge. This provides a rather restricted potential for a research agenda on integrated water systems management to be able to quickly and effectively address the practical challenges in South Asia.

CHARACTERISTIC FEATURES OF WATER SYSTEMS

Any attempt to provide an overall picture based on sets of average data on the water systems in the whole region will be quite unrealistic, because of the wide spatial and temporal variation in the precipitation and great diversity in the geo-hydrological features in the region. The interaction of the south-west Monsoon with the eastern Himalaya and the smaller hills in the North-eastern states of India and Bangladesh results in heavy Monsoon rainfall in these areas and Himalayan foothills in Bhutan and Nepal. The heaviest average annual precipitation of 11,873 mms is recorded at Mawsynram, a small town near Shillong, in the Meghalaya Hills in India. About 80 percent of the annual precipitation in South Asia occurs during the three Monsoon months, from July to September. Many areas in the region face regular annual inundations to accommodate the intense Monsoon rainfall and run-off. Sri Lanka and the eastern coasts of the Indian state of Tamil Nadu also receive substantial precipitation during the winter.

The Himalayan crest line limits the south-easterly movement of cold air from Central Asia within its northern aspect, limiting winter precipitation largely within the trans-Himalaya. As a result, the Monsoon precipitation on the Southern aspect of the Himalaya provides the most significant run-off in the region. The rivers fed by tributaries originating in its southern aspect of the Himalaya, carry by far the largest share of river run-off in the region. The larger of these rivers, the Ganges, the Brahmaputra and the Indus, are international rivers and connect the region hydrologically and culturally. In the past several decades, these rivers have also been the source of political discord in the region. With growing use of Himalyan rivers for irrigation and hydro-power generation, coflicts arose. The sharing of the lean season flow of the Ganges had been a matter of bitter disputes between Bangladesh and India, while in the case of the Indus basin, the construction of a hydro-power project at Baglihar in India positioned India and Pakistan on opposing sides, needing the appointment of a neutral Swiss expert appointed by the World Bank to arbitrate. In the same basin, the Pakistan provinces of Punjab and Sindh, are involved in a heated dispute over dams in the upper Indus (mainly in Punjab province) and their impacts on the Indus delta in the Sindh province.

Though the Tibet region of China is not considered as part of South Asia, two major South Asian rivers, the Brahmaputra (Tsangpo in Tibet) and the Indus emerge from the travel through long distances in the trans-Himalayan areas in Tibet. The Ganges sub-basin is shared by Bangladesh, China, India and Nepal. The Brahmaputra sub-basin is shared by Bhutan, China, India and Bangladesh. The Meghna sub-basin is shared between Bangladesh and India with small parts belonging to Myanmar. The three sub-basins together constitute the Ganges-Brahmaputra-Meghna (GBM) basin with the third largest annual run-off in the world. The other major international basin in South Asia is of Indus, which is spread over China, India and Pakistan with a small part belonging to Afghanistan. Bandyopadhyay and Gyawali have analyzed the ecological and political complexities in the management of Himalayan rivers. One important aspect of the Himalayan rivers is that river flows and political boundaries are, almost without exception, cross each other. An early attempt to divide the region politically along river basins quickly became unacceptable to the politicians.

The non-Himalayan rivers, which are all rain fed, are the main sources of water in parts of the region falling outside the basins of the Himalayan rivers. These areas are located mainly in India and Sri Lanka. All of Bhutan and Nepal as well as most of Bangladesh belong to the GBM basin. However, within the GBM basin, there are many areas receiving annual average precipitation as low as 200 mms. The Indus basin covers about 70 percent of the area of Pakistan. The Karan desert and the arid Makran coast of Balochistan fall outside the Indis basin. Sri Lanka, being an island, has a stand alone hydrological situation. Areas in western Pakistan, north-west India, south India have arid and semi-arid conditions and are water scarce. They are vulnerable to variability in precipitation, characteristic of the Monsoon system. In these large but less water endowed area, the perennial rivers are not many and ground water has been the main source of water for domestic and irrigational purposes.

At the South Asian level, total water withdrawals have reached the 50 percent mark. Irrigation accounts for about 85 percent of the utilized water supply in South Asia. In Pakistan, more than 90 percent of the surface water withdrawls is for irrigation (ADB, 2003a : 5). For various reasons, in large areas of South Asia, groundwater has become the main source of water for irrigation. About half of the water supply for irrigation comes from ground water sources. The demography of the region has been rapidly changing towards extensive urbanization, while the economy of India, the largest country in the region, has been growing at a rapid rate with equally rapid growth in demand. Such rapid growth in water requirements needs to be addressed with a wise approach to avoid potential conflicts as well as degradation of the water related ecosystems.

Increasingly, urban and industrial supplies have started to compete with rural supplies and irrigation for the same sources. The importance of secure domestic water supply is recognized with water being given the status of a human right. On a regional scale, the result has been disputes over water at all levels, starting from the farm level to that of the countries sharing a river basin. The South Asian dilemma on water systems is that the region, in spite of receiving more than the global average of annual precipitation per unit area, is the home of the largest number of people living in a state of poverty. The area is not water-poor as per water poverty assessments and poverty in South Asia does not follow the traditional correlation between water poverty and economic poverty.

Long term impacts of the upstream diversions for irrigation are expressing themselves through conflicts with the downstream fishery and water needs for maintaining the deltaic and estuarine ecosystem services. The ecological decline of the Sunderbans, the largest mangrove forests in the world in the GBM basin and shared between Bangladesh and India or the delta of the Indus in Pakistan, have been frequently reported in this context. Faruqui has given a description of the decline of the Indus delta.

The solutions lie in the adoption of new and innovative institutional arrangements and the use of interdisciplinary knowledge in integrated water systems management. Such processes are needed equally at the international as much the national level.

ARTICULATING INTEGRATED MANAGEMENT

The various ideas circulated for the description or articulation of Integrated Water Resource Management (IWRM) can be a starting point. Uncritical approach of most governmental officials on this need for a change, has led to several problems in South Asia, as in other parts of the world. As EI Ashry points out :

The water crists is real, but we can not underestimate its complexity and linkages to poverty, food and environmental insecurity, and hopelessness. The problem is not just lack of water. It is also the degradation and depletion of water ecosystems—the lakes, rivers and wetlands that are the life support system for citizens and economies of developing countries.

However, a conceptual framework, that could provide a clear operational alternative to the present approach to water, is yet to emerge and receive widespread acceptance.

There is a need for a gradual development of IWRM. There may be greater need at the normative and strategic levels, to provide context or a framework for different types of approaches at an operational level.

Among these new aspects of water systems management, the emerging economics of water and valuation of its ecosystem services need special mention. While developing an approach to a research agenda for the region, the physiographic diversity of the region needs to be kept in mind, since the mountainous and upland watersheds, the foothills and the floodplains and the delta areas differ widely both in terms of the natural environment and the social relations with water systems. Based on a review of the available literature, the following themes are identified as important elements of a research agenda on South Asian water systems.

1. Generation of eco-hydrological knowledge on the water systems, in particular on the

ecosystem services and assessment of environmental flows

2. Generation of eco-hydrological knowledge for groundwater systems and institutional mechanisms for its sustainable use and protection from pollution
3. Methodology for comprehensive assessment of water transfer projects on social, economic and ecological grounds–protecting water security for the poor
4. Application of economics in the making of water policy and valuation of ecosystem services of water to promote conservation and sustainable use
5. Promotion of ecological perspectives of extreme hydrological events, like floods and droughts and regional mechanisms for the mitigation of their impacts
6. Social dimensions of water systems use, local governance and water conflicts
7. Emerging technological options in water systems management
8. Global change and water systems in South Asia : Scenarios and Adaptation
9. Issues of regional cooperation and conflict resolutions

ELEMENTS OF A RESEARCH AGENDA ON WATER SYSTEMS MANAGEMENT

Financial institutions like the Asian Development Bank have examined the role of water in the alleviation of poverty in South Asia in 2003. Poverty alleviation being the common challenge to water systems management in South Asia, the place of water as the focal point for regional development in the region as a whole cannot be underestimated.

Generation of Eco-hydrological Knowledge on the Water systems

Large dams have been built in South Asia in great numbers to successfully store and provide water for green revolution agriculture and avoid widespread food scarcity in the region. The irrigated areas in the fertile Indo-Gangetic plains spread over Bangladesh, India, Nepal and Pakistan, when added together, account for the largest irrigation system in the world and stands out as a great success story in the struggle against hunger. More recently, dams are also being thought of for meeting the demand for water from the rapidly growing urban-industrial sector. In terms of research, quite an impressive record exists as far as the engineering aspects related to the construction of dams and barrages on the rivers and the economic analysis of the positive impacts of irrigation projects are concerned.

Notwithstanding their success in the growth of irrigation and the rapid increase in food production, the diversions by dams or barrages have also altered the flow characteristics of rivers, for example. Examples of the Indus and almost all the rivers in Peninsular India can be given in this regard. Right from the upland watersheds till the delta and estuaries, water performs diverse ecosystem services. In the traditional approach to project assessment, these are hardly considered. As the long term environmental impacts associated with the altered flow regimes due to engineering interventions in the river systems of the region are slowly but steadily expressing themselves in the downstream areas, serious ecological degradations are becoming apparent.

In the absence of a comprehensive eco-hydrological knowledge base, simplistic reports influence public perceptions and even opinions of political leaders, as is the case of the perceived links between the deforestation in Nepal and the state of Uttaranchal in India with the annual Monsoon floods in the plains of Bangladesh. Public perception on South Asian floods was stuck with the idea of the population growth and environmental degradation in the Nepal and Uttaranchal Himalaya as the creator of devastating floods in Bangladesh. It needed a painstaking eco-hydrological correlation of rainfall events in these catchments and flods in the plains to delink such perceived correlations. Ecological impact is seen in the degradation of the delta and estuaries in the Indus river basin where, in the upper parts, several large dams have been built.

Accordingly, research to understand and quantify the elements of the hydrological cycle in the South Asian region in its entirety is recommended. There are serious questions to be answerd on, for example, the hydrological role of tropical forests on the assessment of environmental water allocation in the East Rapti river in Nepal. Similar studies need to be initiated in many other basins.

GENERATION OF ECO-HYDROLOGICAL KNOWLEDGE FOR GROUNDWATER DEVELOPMENT

Indeed, surface water conflicts are by far the most visible identity of the water problems in South Asia, whether it is the issue of Ganges or the Indus between two countries, or of Cauvery or the Indus between two provinces of a country. The conflicts over international river basins water scarcity in South Asia are all about dwindling river flows. Several areas in the region, specially the Indo-Gangetic basin, is very rich in groundwater, both static and dynamic. Half of the region's vast irrigated area depends on supplies from groundwater and conflicts over groundwater do exist. However, they are more localized and involve individuals and not sovereign states, since the property rights status of groundwater is very different from that of surface water. Declining groundwater levels in the drier parts of South Asia calls for long term research on the eco-hydrology associated with groundwater, its recharge mechanisms and sustainable use. While, traditionally, groundwater had been used as the purest source of domestic water supplies, rapid decline in water table has resulted from the rapid growth of irrigation based on its unsustainable exploitation. Declining water levels can reduce India's harvest by 25 percent or more.

There is another face of research challenges in groundwater. In both India and Pakistan, where surface water is supplied for irrigation, irrigation-induced water logging has resulted in rising groundwater levels. The other important part of the decline is related to the quality of groundwater, from pollutant discharged by agriculture, industry and human settlements. There is need for research to improve the recharge rate for groundwater in water scarce areas.

Ghosh and Sharma have provided a detailed account of the research challenges related to groundwater hydrology in India. The picture is not very different for other parts of South Asia. The other aspect of sustainable use is the institutional mechanisms for limiting groundwater exploitation within limits of sustainability.

One more source of degradation of groundwater affecting large areas in Bangladesh and eastern India is the release of naturally occurring Arsenic through geo-chemical processes. In view of the widespread human suffering caused in the region by the presence of Arsenic in groundwater that has been used for drinking by the local people for several years, understanding of the associated chemical processes and technological measures for the provision of Arsenic free drinking water offers an important research area. Intensive use of groundwater is being seen as a solution to the water problems of the world but serious questions have been raised on such prescriptions. These potential policy research areas include work on an ecologically informed property rights regime and constitute a no less necessary area of research related to studies on policy, law and mangement of water system. The related areas of research would be spread over engineering geology to soils sciences to sociology of local water institutions etc.

Methodology for Comprehensive Assessment of Water Transfer Projects

After independence of the then India (and new Pakistan) from British rule, major projects have been constructed for long distance water transfers. At various scales transfer of water has been going on in South Asia and they have been seen popularly as the main creator of root of new rural prosperity. Plans for several large projects have now been made in many parts of South Asia. The lack of suitable responses to the ecological damages and large scale displacement due to large water projects in South Asia gave birth to people's movements in all parts of the region. The World Bank had to withdraw from the Sardar Sarovar Project in India, from the Arun-III hydro-electric project in Nepal. The Flood Action Plan in Bangladesh was discontinued after a study and no action was taken. All these reconfirm the need for new approaches to project assessment and approval in South Asia.

Right from the early days of the introduction of water transfer projects in South Asia, the image of such projects as unmixed blessings for the people was tarnished by the slow and steady appearance of many negative ecological externalities, suffering of the involuntarily displaced from highly inadequate rehabilitation and resettlement. Obviausly, the traditional methodology for the appraisal and approval of projects is outdated and needs urgent reworking.

So far, water related projects in South Asia had mainly been taken up by the government departments, like irrigation and public health. However, the public-private partnership and outright private sector participation in the water sector is also gaining ground. In the era of liberalization and globalization, scarce water runs the risk of being cornered by the rich and the politically powerful. Accordingly, the need for every water transfer project being painstakingly and openly assessed with the ultimate goal of human wellbeing and maintaining of ecosystem services. In the absence of such a mechanism, big investments in water projects, like irrigation, may get approved without due considerations of the agro-climatic appropriateness or proper rehabilitation of the displaced people. The Tawa project in the state of Madhya Pradesh in India is an example of the first type. About the second type, almost all major water related projects in the region have a bad record.

APPLICATION OF ECONOMICS IN THE WATER POLICY AND ECOSYSTEM SERVICES

In South Asia in the making of water related policy or water systems management, the use of economics has been kept rather limited to making very simplistic benefit-cost analysis of water related engineering projects. Planned development in the region has not used economic research on matters related to, for instance, pricing, allocation under conditions of physical scarcity, etc. These aspects of water supply have been an exclusive domain for the engineers and politicians.

While water is a material input for all economic activities, it has not been identified with a market price, though economic analysis of water supply and management is rapidly evolving. In South Asian countries if the dependence of the poor on the services provided free by water related ecosystems is considered, ecological economics can become a very useful tool in protecting and promoting livelihoods of the poor. Further, a method for the valuation of non-provisioning ecosystem services can alter the whole scenario for water systems development. The use of ecological economics in water systems studies is, however, in a very embryonic stage in the region.

In South Asia, commoditization of water started with the emergence of water markets, which have been reported and analyzed in the case of the states of Gujarat and Bihar. The arrival of bottled water for drinking marked another step towards commoditization of water. While there have been no NGO protests on the first form of water markets, many NGOs take a stand against bottled water.

As South Asia exposes itself more and more to the process of globalization, it needs to go beyond the populist approach to the economics of water systems management and research can be of great help in this process. Otherwise, growing demands, inefficient use in irrigation, callous attitude towards industrial pollution, dire neglect of the water based ecosystems, will surely make the region a fertile ground for water related conflicts.

Ecological economics can help in the clearer understanding of the economic contributions of water systems and provide the tool for breaking new grounds in sustainable management of water systems. Thus, it can help clear many water related impasses in South Asia, including very sensitive matters related to sharing of river flows. The research on this subject would be rooted in eco-hydrology, sociology, plant sciences, animal sciences, chemistry, ecological economics, environmental economics, etc.

PROMOTION OF AN ECOLOGICAL PERSPECTIVE OF EXTREME EVENTS

The variability inherent in the Monsoon dominated climate of South Asia frequently creates conditions of very intense precipitation as well as rainfall scarcity. Further, global climate change is expected to have its own share of additional influences on the nature and distribution of these extreme events. Floods and droughts are regular events in South Asia and one of the countries in the region. Bangladesh, has an image of being a country where poverty and hunger are caused by devastating floods, while many other parts of the region, specially the western parts of India and Pakistan, are known for suffering frequent drought conditions and in the next few decades, Pakistan will face serious food shortages due to scarcity of water.

In this region, there is a clear and disturbing tendency among the political leaders, and increasingly among the common people, to brand any event of inundation or scarcity of water as 'natural disasters'-of floods and droughts. While it is advantageous for the politicians, such a situation also acts as an obstacle to the growth of holistic and scientific understanding of the underlying natural processes.

Natural extreme events related to water are, by themselves, important objects for research for understanding the hydrological and geomorphic processes associated with them. These are quite specific to regions and, hence, are not addressed significantly in global water related documents. If effective mitigation of the impact of such extreme events is the objective, there is also a vital need to distinguish between the natural reasons behind floods and droughts and the human contributions to the accentuation of the impacts of climatic variability. Such a separation requires a close understanding of the associated ecological processes and ecosystem services.

The strengthening of ecological knowledge base would surely work against the 'disaster' syndrome and articulate the positive ecosystem services, specially of the annual inundations. Referring to the water scarcity in the states of Gujarat and Rajasthan in the drier part of India. What is happening in Gujarat and Rajasthan is a 'natural disaster'. It is truly a 'human-made' or rather 'government made' disaster. In the last several weeks strong non-governmental opinions have been expressed about the possible links of the recent floods in India with unscientific operation of dams. New research should be able to answer such questions of grave public interest. In designing appropriate mitigation measures such a knowledge base will be essential. By undertaking research on the ecology of drought and flood events, it will be possible to separate the natural and human induced aspects of their occurrences.

Ecological perspective and knowledge of the ecosystem services is needed for water related extreme processes in all the countries of South Asia, individually, as well as in river basins spread over several countries. At the level of international basins, like the Ganges-Brahmaputra-Meghna, cooperative mechanisms exist for advance warning on flood events. What is needed is, of course, far more. The need is to initiate eco-hydrological research on the flood processes by the countries sharing the basins. Such studies on flood and drought events should also be undertaken within the national limits. This is particularly important in the case of the floods in South Asia, which provide a great number of ecosystem services to the floodplains. Interdisciplinary research on these event would need the involvement of meteorology, hydrology, sedimentology, fisheries sciences, hydro-geology, sociology, regional studies, political science, etc.

SOCIAL DIMENSIONS OF WATER SYSTEMS USE

The governmental departments have, traditionally, been very focused on the large engineering interventions. For milennia, water at the local levels in South Asia has been managed by community based organizations. The nature of these organizations is as diverse, as are the water endowments and physiographic characteristics of the specific areas. With the introduction of larger engineering interventions, human societies, in addition to receiving the gains of such projects, had also to bear the huge costs, in terms of involuntary displacement. The issues became so important that the World Commission on Dams (WCD) was established to look at the complex linkages of dams and human societies. Bandyopadhyay has outlind the basis for potential and present conflicts over dam building on the Himalayan rivers in the background of the Report of the WCD. It is well-known that, neither by complete dependence on the local organizations, nor a complete institutional monopoly of the governmental departments, can water management challenges in the various spatial levels be effectively addressed. This offers an important gap to be filled up by interdisciplinary research on water systems.

In areas with good social leadership, human societies in many water scarce areas of South Asia have evolved appropriate practices for the conservation and equitable use of water. There are now conflicts on both quantitative aspects of sharing and the qualitative aspects of degradation of resource. The situation is expected to become more complex with increasing economic role of the private sector in the region.

Further, water would not only be needed for food security, in the coming years, increasingly it is expected to be demanded for commercial farming, including for bio-fuel cultivation in the coming years. In view of the clearly emerging water conflicts in large parts of South Asia and clear sings of decay of the riverine systems, social dimensions of water systems, local level governance and mechanisms for conflict resolution would be a very critical interdisciplinary research area.

EMERGING TECHNOLOGICAL OPTIONS

South Asia being the largest user of water in a relatively lower efficiency irrigation system, technological innovation towards increasing efficiency of irrigational water use and quicker transfer of technologies constitute the important subjects of research. A very promising technological option on which research needs to be taken up is technology for desalination, which has the potential for bringing dramatic changes in the domestic water supply scenario all along the South Asian coasts. The other aspect is the issue of re-use of water and innovation of related technologies. Research on this subject would involve contributions from engineering sciences, law, economics, public administration, technology transfer, etc.

GLOBAL CHANGE AND WATER SYSTEMS IN SOUTH ASIA

The fact that the global climate change will have an important impact on the climate of South Asia is well-known. There is possibility of greater frequency and intensity of the extreme events related to water. Thus, on the usual climatic variations characteristic of the Monsoon, will be superimposed the additional impacts of global climate change. Preliminary indications do indicate that, in addition to the reduction in the snow and ice cover in the Himalaya, water scarcity and extreme events in the region may be accentuated by global climate change.

This opens up two major areas of research, one on the nature and extent of the climate change, and, the other, on ways to adapt to these changes. This area of research is of particular importance for South Asia also from the point of sea level rise. There can be sea level rise in several very large cities, starting from Dhaka in Bangladesh to Chennai and Mumbai in India and Karachi in Pakistan. In addition, all the coastal areas are the habitat of millions of rural people who depend on marine fishing. This is a vast area of collaborative international research. The research on such topics would involve input from disciplines of oceanography, atmospheric sciences, sociology, etc.

ISSUES OF REGIONAL COOPERATION AND CONFLICTS RESOLUTION

Regional cooperation and conflict resolution is seen as an important area for research and there are several possible mechanisms for cooperation on South Asian waters, not necessarily limited between or among nation states. While at the global level the Convention on the Law of the Non-Navigational Uses of International Watercourses, which was opened for signature in 1997, provides some framework for addressing conflicts, this area is quite open for research in the South Asian context. Research activities on this subject would involve expertise in hydrology, ecology, diplomacy, economics, sociology, history, regional development, etc.

CONCLUSIONS

South Asia, with its high level of poverty, rapid industrialization and urbanization, and larger than average water availability per unit area, presents a real challenge to innovative research on water systems management. The challenges for water systems research are trans-disciplinary and involve expertise as much from the engineering sciences, as the social sciences. The region is rich in potential expertise for undertaking such research, only if the disciplinary barriers can be overcome. The nine points for the development of research, as described above, need to be taken up for the creation of individual research programmes and projects in universities and institutions interested in South Asia. The topics outlined include eco-hydrological understanding of surface and groundwater, social aspects of water use, greater use of economics in water systems management, etc. However, professional research on the suggested topic of regional cooperation and conflict resolution will have the potential of making the most important inputs to the challenge to the use of water systems for poverty alleviation and sustainable development in this region.

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