Face to Face

This section features conversations with personalities related to science, highlighting the factors and circumstances that guided them in making the career choice to be a scientist.

Seismic Rays, Satellites and Sea Winds

Vinod K Gaur talks to Sujata Varadarajan

Professor Vinod K Gaur is a person of unusual breadth and sensibilities. Often unpredictable in his approach to problems, the questions he raises are deep and searching. A geophysicist by training, he studies a very physical world – the evolving structure and environment of planet Earth – through interactions between its solid, fluid and biological spheres. Using signals from earthquake waves reconnoitering the earth within, and orbiting satellites in space, and molecular concentrations of atmospheric greenhouse gases, he tries to understand the forces that drive and determine important environmental and geological events. He interprets these through numbers, mathematical models, theories and experiments and explains them in simple, compelling terms (with an occasional poetic outburst).

Vinod Gaur studied for his doctoral degree at Imperial College, London where he discovered and explained an unsuspected electromagnetic phenomenon – the host rock effect. He returned to India a few years later, in 1962, to work at the University of Roorkee as Reader, and subsequently, as Professor and Dean of Research. He developed this newly established academic unit into a dynamic national centre for geophysical education and research. In 1983 he was appointed Director of the National Geophysical Research Institute (NGRI) in Hyderabad which he transformed by establishing the country's first broadband seismograph, a world class mass spectroscopic laboratory, introducing digitalized geophysical sensors and initiating specially designed training programmes for scientists.

In 1989, he was invited by the then Prime Minister Rajiv Gandhi to serve as Secretary to the Government in the Department of Ocean Development (DOD). Here he implemented several high technology programmes including one aimed at mapping sea surface temperatures from satellite radiance data to delineate rich marine fishing grounds as well as providing this information directly to fishermen. He also structured the Antarctic science programme, which

Vinod K Gaur, Bangalore, 2010

included some key innovative research in areas such as boundary layer meteorology, ozone modelling and neuro-physiology.

In 1992, after leaving Delhi, Vinod Gaur worked at the CSIR Centre for Mathematical Modelling (C-MMACS) at Bangalore where he established the science of GPS Geodesy in India[1] – an initiative that resulted in the first quantitative estimations of the rate of Indo-Eurasian convergence and deformation rates in the Himalaya. In 1996, he was invited to join the faculty of the Indian Institute of Astrophysics, Bangalore, where he chaired the group entrusted with the installation of an optical and infrared telescope in Hanle (Ladakh) – the highest telescope site in the world. During this assignment, he recognized a unique opportunity to investigate two critical questions of planet Earth's dynamics and environment: the physical mechanism whereby the Tibetan plateau had been thickened and the seasonal regimes of carbon fluxes in mid-latitude Asia. The latter resulted in the first and to date the only operational system in the country for an ultra-high resolution measurement of atmospheric carbon concentration. Since this site is free from any local industrial or biotic contamination, it has come to be recognized as the world's unique station for carbon flux inversions.

Time has shown Vinod Gaur to be a sensitive administrator, a motivating teacher and a creative and extremely helpful scientist. He is a member of several Academies, a recipient of the S S Bhatnagar Prize, and the Flinn award of the American Geophysical Union. He moves from field to field with surprising swiftness, selecting an area that piques his curiosity and immerses himself in it. Equally at ease with people of different ages and walks of life: philosophy and science, mathematics and music, art and poetry, Vinod Gaur's conversation often begins with science and stretches far beyond it.

SV: Could you tell us about your early education and initiation into research?

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[1] GPS Geodesy is the measurement of form and dimensions of the earth, the location of objects on its surface, etc., using the Global Positioning System (GPS). GPS is a space-based navigation system maintained by the American government. It is comprised of about 24 active satellites in medium Earth orbit, control and monitoring stations. From signals received simultaneously from a number of satellites, by GPS receivers, scientists can derive the latitude, longitude and altitude of the receiver site with a high degree of accuracy as well as time, at any instant or place on earth.

VG: I grew up in a small village near Azamgarh in eastern UP, not far from Benaras, where my mother stayed with my grandparents while my father lived with my uncle's family in the nearby town, struggling to establish a legal practice. I didn't have a structured school education until about the age of eight when it was decided that I should be schooled in the town and live along with my father. This was a missionary school – the famous Wesley High School run by Australian missionaries. But I have no deep impressions of my 7 years in this school, except of the periodical dread of examinations especially, history, chemistry and the crafts. The teachers were rather violent, the Australians in their views and the Indians, physically so. Of these, I was somehow a frequent victim either because I did not perform well or ventured to question a statement whether in the *Bible* class or others, that made no sense to me. I now realize that so much was taught to us without ordering the facts so as to evoke curiosity, that learning became a tiresome and dreaded business. All this may of course be an alibi to subconsciously explain my gradual recession towards the bottom of the class except in English and arithmetic which I did more intuitively in my own way than through the 'correct procedure'. Thus, I stumbled from class to class, often barely scraping through, with few accomplishments, save a growing fondness for the rhymes of Urdu poetry and its delicate sensibilities, and imperceptibly began to absorb English poetry and language as well.

Towards the close of my school years, however, two notable influences kindled my interest in learning. One of these came from a young physics teacher and another from a village mathematics teacher whom I met at a relative's place during the summer recess. Within the space of less than a month, algebra, to me, became a simple matter of logically ordering a set of propositions using symbols and deriving therefrom a desired result using the basic operations of arithmetic, and I could not understand why I had shut my mind to it for over a year. Looking back, I realize that they were both extraordinarily kind, and had a way of explaining things although in slightly different tongues, one in delicate Urdu and the other in lyrical Bhojpuri dialect, that flew straight into one's understanding. They had a miraculous and I suspect an enduring effect on my entire attitude to learning and more consequentially on my credits in physics and algebra at the board examinations

This brief illumination, however, began to die again at college amidst a heap of formulae and equations, equally true for mathematics and chemistry. The latter classes were a constant source of bewilderment as teachers could not explain why chemical reactions were uniquely selected by Nature when the molecules could be arranged in other possible ways without violating conservation. But I had come away a long way from home to Agra College, staying with my uncle's family to save on living expenses. And, pangs of conscience forced me to glean as much understanding as I possibly could from the terse texts. I had partial success with physics and dynamics and through the credits earned in these papers, scraped my way to an undergraduate course at the University of Lucknow, helped by my father's somewhat improved circumstances, this time to study physics, mathematics and geology with a triumphal release from chemistry. But, physics became obscure again and remained a mystery until three years later, when drawn to a friend's book on modern physics, I suddenly experienced the spell of the fascinating structure of the universe that the concepts embodied.

From Lucknow, I migrated to Benaras Hindu University to study geophysics, hoping for relief in a strangely unfamiliar subject. This was not exactly pleasing to my father who had hoped that I would compete for a seat in engineering. But in my ignorance, engineering had come to symbolize for me, road building, machines and power houses representing forceful instruments of power and assurance that overwhelmed my village days' world still animated by the 'apparently valueless' and therefore, guilt-laced wonder at the night sky streaked by an occasional meteor, the annual passage of seasons, each with its own entourage of birds and flowers, fascinating flotillas of clouds shot by the sun, rain, thunder and lightening. Winsome folk songs of village girls that wafted from across the fields still resound in my ears as do the magical lives of fairy stories. It was a great disappointment to him, sadly turning into acquiescence of my mediocrity.

So, I studied geophysics at Benaras. This new department had recently been opened and had only two teachers. They were nice human beings but their classroom teachings consisted of facilitating transcription of textbook pages onto our notebooks. The University had a good physics department and I had access to physics texts of some of my friends from that department, which I found more exciting than the largely descriptive texts, save few, that constituted the geophysics courses. Miraculously, I did well at the examinations and was ranked first, but immediately faced the elusive question: what to do next? Somewhat buoyed up by my results, my father goaded me to appear for the Civil Services competitive tests. I genuinely doubted my capacity for concentrated studies required to compete, but out of curiosity, got hold of the previous years' question papers. I was appalled to discover my abysmal ignorance of the context of questions in 'general knowledge'. Close to a decade after independence, these still pertained almost exclusively to European culture: the columns of Greek architecture, the authors of *Iliad*, *Odyssey* and the *Divine Comedy*, the locales of La Scala, the Colosseum, the Acropolis, etc. Intriguing questions led me to the University library's humanities section, a rich collection of classics and the arts to which I was irresistibly drawn. But, my other siblings were ready to go to college, making it impossible for me to draw on the family's meager resources for a leisurely stint at the University. Shortly thereafter came two opportunities: one, a job in the newly created Oil and Natural Gas Commission and the other in the form of a fellowship to carry out research at Benaras. The increasing hold on me of the University library decided the toss and I stayed back with a provision to earn my board and lodging, although sadly, it would contribute nothing to the growing needs of the family as the other would have.

It was at this stage that I became aware of the recent discovery that the earth's magnetic poles episodically exchanged their positions, but not at periodic intervals. Since many igneous and sedimentary rocks contained grains of the magnetic iron oxide (Fe_3O_4), they in the process of solidification from a molten state, or settling from a fluidized suspension, aligned themselves with the magnetic field direction of the time which would thenceforth be frozen in the rock like a 'fossil', distinctive, in particular, of the latitude at which they were formed (because the dipolar magnetic field of the earth predicates a specific direction at a given latitude, which can be calculated with reference to the pole). So, if we investigate this fossil magnetization of old rocks and find it to be discordant with the present field, we infer that the landmass bearing that rock must have moved from its earlier 'fossil latitude' to the present one. Furthermore, in several cases of a sequence of rocks deposited layer by layer, fossil magnetization directions had been found to swing by almost 180°, prompting the inference that the earth's magnetic poles must have switched places between the deposition of successive layers.

Recognizing that the vast volcanic outpourings over west central India, about 65 million years ago, offered an ideal site for further testing these inferences and also determining whether and at what rate India had been moving, Professor Blackett of Imperial College, persuaded TIFR to initiate rock magnetic studies in India. I was naturally interested by this sudden opportunity to investigate these interesting questions, but lost out in the interview. The TIFR had found two brilliant scientists who eventually contributed important details to the mysteries of the Deccan lava flows. I returned to Benaras deciding to investigate the other important lava flows of the continent in eastern India – the Rajmahal Traps, but with the challenge to address my questions without even a rudimentary experimental facility.

SV: How did you check the fossil magnetization direction of these rocks in the field?

VG: I decided to make a crude copy of a sensitive magnetometer designed a few years earlier by Professor Blackett. For my crude copy, I took a razor blade (being of iron it acquires a magnetization in the process of being annealed) and breaking it longitudinally into two, stuck them antiparallely (north pole of one over the south of the other and vice versa), at two ends of a straight twig. I then fastened one end of this twig to a long hair begged from a horseman and suspended it from the lid of a glass bottle by piercing a fine hole in it, while a marked line at the bottom of the bottle indicated the direction of its twist when a rock sample was put underneath. This contraption I preserved more carefully than my limbs while negotiating the treacherous terrain. It worked wonderfully in discriminating normally magnetized rocks (that of today) from those in reverse, and helped me return to Benaras with a cart load of Rajmahal rock samples carefully marked by the compass and a spirit level before being plucked from their moorings, so as to reproduce their original setting in the laboratory whilst measuring tell-tale fossil magnetizations.

SV: Wouldn't the magnetization of the blades be too weak for it to become a measuring device?

VG: It was very weak indeed. But the anti-parallel assembly of two vertically displaced weak magnets turned it into an amazingly sensitive detector. I couldn't use this system to get a numerical value of the magnetization of rocks which would have to await accurately calibrated systems in the laboratory, but it enabled me to test the rocks in the field itself as to whether they were magnetized in the normal direction or reverse, so that I could collect the right set of samples for a detailed study.

SV: Does this reversal happen gradually?

VG: The magnetization begins to die slowly, becoming very small within a few thousand years before reversing. The earth's magnetic field has been measured since the 1830s and is found to have declined by about 10%, since. We suspect that this may be a portent of the next reversal.

SV: What do you do with the set of samples that share a common direction?

VG: The fossil magnetization direction frozen in rocks is specific to a given latitude, assuming that the poles do not shift, only exchange places. Conversely, from a given set of consistent magnetic directions, one can calculate the fossil or palaeo-latitude of the landmass when the rocks were formed, while the time of their formation can be determined from an independent method using radioactive decay rates of unstable isotopes such as Rb and Sr. One can thus chart the drifting course of the landmass through time. This approach, which was perfected by the mid-fifties, was extensively applied during the later 1950s, by scientists on different continents towards reconstructing the past geographies of landmasses. The results provided a massive testimony to an older, fiercely rejected theory that all the continents of the globe were huddled together in a connected landmass centred around the South Pole about 250 million years ago. This hypothesis was stimulated by the recognition that the west coast of Africa could almost snuggle into the east coast of South America and the idea grew that they had once been joined but subsequently drifted apart after being fractured. But this was rejected by geophysicists who demanded a plausible mechanism that would drive such large-scale horizontal motions. The tables were now ironically turned by fossil magnetic evidence in rocks, challenging scientists to discover that mechanism.

SV: What did you do with these rock samples?

VG: Shortly after my return with masses of Rajmahal rock samples plucked from the hills and still uncertain as to what to do with them without a well-equipped laboratory, I was asked by a cousin whether I had seen a CSIR (Council for Scientific and Industrial Research) advertisement for the award of scholarships to study abroad in any field of science, engineering and medicine. Upon my flippant reply that I rarely looked at advertisements or announcements, he said, "Why don't you apply? All you have to do is send a postal order of five rupees." The eligibility qualification for applying was a first class MSc, which I had somehow obtained, but "I did not possess even that princely sum", I told him.

He lent me the money and after some weeks, I found myself facing an interview board chaired by Sir K S Krishnan. The first few minutes went by without my being able to produce satisfactory answers to the questions asked: the magnetic field at Benaras, pressure at the centre of the earth and so on till someone asked about my interest in reading. I had no difficulty listing the books that had been my favourite – the Jane Austens. Then followed some discussion about her style which I debated reasonably well emphasizing her minimalism, citing the last sentence of the first paragraph of her *Pride and Prejudice*. It was then that Sir Krishnan asked me whether I was really incapable of calculating the pressure at the centre of the earth, to which I replied, "I could, given a pencil and paper, using my knowledge of the density variation inside the earth, its average radius and the gravitational constant, but I did not know its actual value."

That was the end of formal business that day after which I began my wandering of the city which, secure in the belief that I did not have a chance, I enjoyed immensely. The following evening, I again appeared at the CSIR headquarters to collect my train fare. Suddenly, I heard the large loudspeaker announce 7 successful names, which as expected did not include me. This was not a surprise and there was no disappointment. But as I turned to go I heard my name being called and asked to report to the office.

The man in-charge asked, "Where do you come from?"

"From Benaras."

"When are you going back?"

"Tonight,"

"No don't do that," he said. "We're sending your name to Maulana Azad (hospital). It's the place you should go tomorrow morning and get yourself medically examined."
"Why?"
"Well, there's a possibility we might give an 8th scholarship this year, in which case it will go to you."
"I doubt if there is a chance, I think I should go back tonight."
So, this man got very annoyed, "You behave like a child. I'm not supposed to tell you but right now, Professor Krishnan and the whole committee are meeting to consider granting an 8th scholarship, because he was surprised that your name was not amongst the 7. And when Sir Krishnan proposes something, there would be none to question."

So.. that started a new story. I was very pleased at the prospect of going to England, the land where people spoke Jane Austen's English, which turned out to be a mirage. What I would do there was not very clear except for the excitement to experience new worlds: new sights and sounds, perhaps theatre (I loved playing Hamlet in a closed room). Perhaps, even some exciting new science.

I arrived in England, a good 4 weeks after we had sailed from Bombay. The ship was not in very good shape, on its last journey before being dismantled on arrival. But it was destined for a greater voyage. Six hours after we left Bombay harbour, the Suez Canal was bombed and closed by the British and French Air Forces to browbeat the independent-minded Nasser of Egypt. Our ship changed course south on a reverse track of Vasco de Gama's. I journeyed mesmerized: through the placid equatorial waters mirroring the night sky, unworldly hues of sunset, the proximate roaring forties that heaved the sea in a mountain of water, the changing twilight at each turn and re-turn of the solar gaze, and fascinating new faces and places as we circumnavigated the Cape. A friend I had known at Benaras facilitated my disembarkation at London's Tilbury Docks, and helped me settle down temporarily.

Next morning I went to see Professor Bruckshaw who asked me what I had been doing, and I told him of my Rajmahal work.
"That's fine," he said, "It will be nice to have someone investigate the fossil magnetic regimes of that area. India took a long way moving from Antarctica and the rock magnetic tapes of Rajmahal may have some interesting tales to recount."
"I understand", I said, "but I've lost interest in that."
He looked at me in incomprehension, but continued, "What would you like to work on?"
"I should like to work on some problem which involves electromagnetic theory."
"Well, there's an exploration company which has just started flying a transmitter in an aircraft

to look for buried mineral deposits. A detector also mounted on the aircraft receives signals that would be expected to be perturbed where conducting minerals may be buried underneath. We still don't know how to interpret these signals. Would you like to address that challenge?"

"It sounds interesting." And that ended the interview.

So I started thinking about that problem and the way people were looking at it: considering the response of buried conductors as if they were immersed in air. For, it was argued, the earth surrounding rich ore bodies was over a thousand times less conducting and therefore could be assumed to be absent or replaced by air. I felt uneasy with this assumption as I visualized a buried ore body to be electrically coupled with its environment and, therefore, unlikely to behave as a simple linear system. So, I decided to test this experimentally by designing an electrodynamically-scaled model of the real earth-airborne transmitter system that, if designed properly, would quantitatively mimic the signals detected by a real aircraft flying over the ground. The theory of such electrodynamically-scaled models is neatly distilled from the electromagnetic field equations. The challenge was to translate it into an experimental simulator that could be realized using available materials. After a long search for commercially available materials that would realistically mimic a mineralized ore body in my reduced scale model and several calculations for convenient dimensions, I decided to use graphite sheets available with some specialized agencies, to represent, say, a copper ore body.

There was also the possibility of simulating this entire problem on a computer which, although they were coming into their own, were at the time, still hard to find. Next I proceeded to design and build a suitable measuring system.

When it was finally ready I checked the results by suspending the ore body model in an empty tank, that is, without the surrounding host – the earth. The results reproduced all the expectations of an analytical model, but the moment I brought the surrounding earth in the tank by filling it with a saline material, the field perturbations transformed dramatically. The nature and the scale of transformations were so incomprehensible at first as to demand step-by-step elimination of all possibilities of signal contamination. This was tedious work and took several months, but even as each test turned out to be negative, I was becoming more and more assured of it being a real result and some plausible explanatory arguments were already taking shape in my mind.

So I went and talked to the professor and he said, "What do you think could be the reason?" I said, "Well, I have a possible explanation which is not quantitative but qualitative and the analytical treatment of this will be so involved I won't be able to complete it."

"That's fine", he said, "It's a new result you've discovered."
This now goes by the name of "host rock effect".
A few days later, whilst I was still writing my thesis, Professor Bruckshaw said, "The aircraft company would be interested in your staying back."
I said, "Well, I'm just looking forward to completing my exams and then going to the Sorbonne, where I have a postdoctoral fellowship."
So, after my viva, I went to Paris, and to another Professor who cursorily perused my thesis and said, "This is very interesting work. It will be good to pursue it further."
I said, "No, I've got bored with it. I want to explore potential theory."

Thus started a new passion and that is another story. But, looking back, I find it hard to understand why I remained so unconcerned with the implications of this attitude of getting untimely bored, which meant that where I could have produced half a dozen papers, mopping up all the intervening details, I didn't persevere. Having produced one, I lost interest. Having understood in a sense what lay underneath, I found it no longer interesting. And that happened time and again till I had students to care for, which compelled me to write.

SV: What were your experiences at the Sorbonne?

VG: At the Sorbonne, I learnt to look at geophysical fields in a new way which was very refreshing. And, Paris was picturesque and aesthetic. I found myself particularly drawn to the interminable sections of the Louvre, as much to the modern day impressionists as the worlds of yore proclaimed by artifacts, sculpture and bits of architecture plucked from the ancient ruins of Egypt and Mesopotamia.

By then, I had become engaged to Eryl and I had no clear direction in sight. Someone at the National Physical Laboratory in England asked Professor Bruckshaw to recommend a scientist who understands electromagnetic problems. They had a programme to refine the measurement of the ratio of the electron charge to mass using nuclear magnetic resonance and a decelerating cyclotron. A few months later I returned to England, joined the NPL, and became engrossed in the theory and design of a decelerating cyclotron. However, the excitement soon wore off by the tedium of the assembly work, although life had become somewhat more settled. Eryl and I were married and cherished a vast fund of warmth and goodwill from a wide section of friends, associates and public men and women, although neither of our families participated. We found a charming little flat in Bedford Gardens where our living room looked upon a grove of trees and avian families including an owl who often greeted us at the window at bedtime.

Then, one day I received a letter from the Vice Chancellor of Roorkee University offering me a Reader's position with the responsibility of developing Geophysical Sciences at the University. I had just completed my 25th year and the prospects of working with students in an academic environment attracted me greatly. Incidentally, it also released us from my wife's resolve not to raise a family in UK where racism albeit subdued formally, was epidermally alive except in ethnic localities.

I liked the University at Roorkee, its graceful renaissance style building with sprawling green lawns from where were visible not only the various blue tiers of the outer Himlaya but presiding over them, the 400 km luminous arc of the great Himalaya that glowed in the sun. I plunged straight into the design of geophysics courses for approval of the Academic Council. A full-fledged geophysics programme would still be two years away; meanwhile, I taught courses in physics and exploration of the earth to geology students. They were a small lively group interested in nature and ethical issues and as my wife had still not arrived, joined me in exploring the flora around and staging mock theatre. Thus, was I launched on a new enterprise of the mind and spirit, which never palled during the two decades that I stayed there.

The very first research students who came expressed an interest in looking further at the work that I had done at Imperial College. Since we had very little funds for buying equipment, what with a war intervening, I decided to set up some basic geophysical experiments with the help of a local entrepreneur who was excited in assembling the systems that I designed at very low cost. So, I wrote to Professor Mason who I knew at Imperial College, "All that gear which I had designed and assembled for my experiments is, perhaps, still there, maybe in your stores. Could you kindly ship it to Roorkee to help us continue this work, but I don't have money to pay for it." It was done. And the student here re-assembled this equipment and eventually received his PhD. He got a glowing report from one of the stalwarts in the US working in the same area, who in fact wrote to him saying, "I'm going to Australia to give a talk on this subject. Can I reproduce some of your figures?"

Roorkee had recently also formed a new department of earthquake engineering – an interdisciplinary field between civil engineering and geophysics, which offered a splendid opportunity to nurture the science of seismology which was being fast developed globally, because of its critical role in testing various implications of the newly established theory of Plate Tectonics[2],

[2] The earth's outer crust is broken into large plates that drift atop the soft underlying mantle. Over long time periods, the plates change in size and shape as their boundaries are crushed together, added to or pushed into the mantle. Different kinds and rates of such movements can result in seismic activity, volcanic activity, mountain building and ocean trench formation. Plate tectonics explains the manner and rate of movement of these plates, and how this affects the earth's surface.

and the strong suggestion that the Himalayan foothills north of Dehradun, barely 70 km away, constituted a plate boundary. So seismology, of which I had only a very rudimentary knowledge, I set out to establish from scratch – going back to first principles. And when you begin to lecture to students who were always encouraged to question, you have a great opportunity to learn. And, that's what happened to me, branding most of my significant researches since.

I finally got enthusiastic support from the UGC for equipment and more importantly, faculty. My most cherished reward at the time was, therefore, a successful persuasion of three of the best geophysicists then available in the country, to join this endeavour. They helped put the department on the map of the world and rooted the culture of high academic values that are in some measure, still sustained.

In 1983, I was persuaded by the then Director General of CSIR to meet a committee appointed for selecting a director for NGRI at Hyderabad, although I was not an applicant for the post. This led to a wrenchful departure from my students-centred life in Roorkee, but I took this assignment as a mission to infuse rigorous science at NGRI. The first thing that I did was to encourage the scientists to criticize their own work and refine their ideas. They also had the freedom to embrace new research avenues which they considered more exciting. Meanwhile, I began to systematically modernize field and laboratory equipment into digital systems, and establish a state-of-the- art laboratory for isotope studies and a modern computer system. These initiatives required commensurate sharpening of analytical frameworks. To catalyze this in the minds of our scientists, a series of intensive courses were designed and delivered by some of the most extraordinary academics. Most of the younger and a few senior scientists enthusiastically welcomed these approaches and in some ways, helped forge a creative transition that also gave me time to dream about my own new science. Thus, I seized every opportunity to discuss with some of the imaginative colleagues, new approaches to imaging the earth underneath, especially the emerging tools of tomography to CATSCAN.

At this time I persuaded a distinguished Indian American friend, Dr H M Iyer, to spend his sabbatical with us and help implement an experiment to investigate the nature of the crust beneath the Deccan Traps using seismic rays: to determine whether they were riddled with plumbing channels (as had been suggested by some) or by some other source indicators of the immense eruptions that cover over 500,000 sq km of west central India and even more extensively, perhaps, of the adjoining ocean. I was fortunate too, to enlist in this endeavour the enthusiasm of two graduate students who had just joined NGRI. They wrote the first doctoral dissertations on this subject in the country, which I had the privilege of supervising, and have proved their mettle since, by greatly expanding upon their earlier work.

SV: Did you have to generate the rays or were they naturally occurring?

VG: We recorded the arrival time of seismic waves, that travel through the earth in the form of rays, from earthquake sources around the globe so as to obtain a dense set of their intersections required for tomography. Fortunately, earthquakes of magnitude 5 occur almost every day in some or other part of the world from where their energy fans out in the earth. By recording these on sensitive detectors located at appropriate sites for a few months, one can assemble a good number of criss-crossing rays, and unscramble their signals to obtain information about the physical properties of the materials crossed by these rays beneath the recorders. We deployed a set of seismometers from Pune to Hyderabad to investigate the underlying earth.

SV: Did you also continue your research on the Himalayan plate boundary processes?

VG: With a research career, in part, evolved in the wake of the heady revolution in earth sciences, it is hardly ever possible to rid oneself of the Himalayan obsession. In fact our key results whilst I was at Roorkee, revealed two facts: one, that the Indian plate slides underneath the Himalayan foothills at the rate of at least 1 cm a year, and the other that at the current epoch the maximum concentration of elastic strain (which upon reaching the bearing strength of the material, snaps, creating an earthquake) occurs at the southern front of the Great Himalaya – the 20 km or so wide Himalayan belt of majestic snows. But, these results still needed to be explained in a coherent framework of Himalayan tectonics, a development that was first stillborn at Hyderabad but fortunately completed after I came to work at C-MMACS, grown under the administrative umbrella of the National Aerospace Laboratories (NAL) at Bangalore.

SV: How was it stillborn at NGRI?

VG: Well, scientists who were using various independent approaches to make some estimates of inter-continental displacements across plate boundaries had, by balancing global circuits, proposed that the Indian plate moved northward, colliding with the Eurasian continent at the rate of ~ 5 cm/year, but there was no direct measurement from the continent to affirm this, for example the annual contraction of the distance between Bangalore and Lake Baikal. Even more urgent was the answer to the question as to how this figure was partitioned between the various segments of the earth between these locations, particularly across the Himalaya–Tibet region. This was a question most seminal for creating a quantitative framework for assessing Himalayan hazard. So I decided to address the first of these, by using the centimeter precision Very Long Base Line Interferometry (VLBI). The experiment relies on simultaneous reception of radio signals from very distant stars, notably Quasars (Quiet Sources of Radiation) far out in the universe, at two sites on the globe several thousand kilometers apart, and using the time difference between the arrivals at these sites, of similar phases of the signal to accurately estimate the distance between the two sites.

So, I talked to NASA (National Aeronautics and Space Administration, USA) and there was a wonderful man there who was actually the designer of most of their satellite programmes aimed at exploring earth features. He was Edward Flinn, unhappily no longer alive, and he said, "You install a 10 metre telescope at some site near Hyderabad, and find two bright scientists, who after some basic training in signal theory and instrumentation may be sent to NASA. We will give them all the facilities to fabricate the front end of this telescope which they can bring back with them and we could begin joint experiments as soon as these are ready."

I discussed this with the Director General of CSIR and he showed his enthusiasm by including this project amongst a dozen from CSIR, for brief presentations before Prime Minister Rajiv Gandhi. Thereafter, the CSIR released a sum of one crore rupees asking me to go ahead with the installation of a telescope, with promise for further funds to take the experiment forward. I followed this diligently, with the selection of two bright young doctoral students and processing a protocol with the Electronic Corporation of India (ECIL) for the production of a 10 m diameter telescope. Apparently, however, the CSIR presentations to the PM had begun to stir some other developments. At that particular meeting I was told by everyone that my presentation was greatly appreciated. I had briefly explained the science questions and the technology challenge, all at the frontiers. It could have been one of those things which, probably, was on Rajiv Gandhi's mind when he asked me to come to Delhi. Most regrettably, the outcome was the closure of the VLBI project by the next CSIR Director General, apparently on the advice of the director(s) who succeeded me at NGRI.

Early in 1989, I was in Bangalore, at a meeting of the Academy, and I got a message that the Prime Minister wanted to see me. When I appeared in his aircraft chamber, because that is where the meeting was arranged, during a flight from Delhi to Nagpur on Martyr's day, he quipped, "I want you to come and clean up this department which has been no more than a public relations office – although there have been many objections which have been put against you." I wasn't aware of all this, and spontaneously replied, "You must heed those objections – there may be a lot of truth in them."

So, he laughed and we exchanged some pleasantries between which I tried to gently argue that I had no natural inclination for a bureaucratic occupation. He eventually sealed my words, saying, "How do I improve things if promising persons say no!" Seven days later I moved to

Delhi, having resolved my apprehensions through sagacious advice by two extraordinary individuals: the late Mr. Narayanan, the then Minister of Science and later President of India, and Mr Prakash Narain, the then Chairman of the Railway Board

SV: How did you react to your new assignment at DOD?

VG: After I took charge as secretary, I was called by Mrs Sarla Greval, Secretary to PM who conveyed to me assurances, on behalf of the PM, that all my ideas and proposals would receive the highest consideration. Fortunately, with a clear resolve to work there for three years (as promised to the PM) and no longer, and the belief that I had nothing that could be taken away which I will not more willingly give, I moved decisively to implement the programmes that I had dreamed, urged by Rajiv Gandhi's most unforgettable phrase: " I would like you to design and implement systems that would ensure that the possibilities of high technology and science can be brought to bear on improving the quality of lives and works of ordinary people."

SV: Could you highlight some striking new projects that you initiated?

VG: With Rajiv Gandhi's words ringing in my ears, my first thoughts flew to the large number of coastal fishermen who contribute a major portion of our fish production and constitute a sizable self-employed workforce. But their lives and work, I found, was laced with uncertainties and risks. Many would go out to the sea in the morning to toil all day in search of a profitable catch, sometime tempted to stay until dark or even overnight, unwary of a brewing storm. But available technologies had the potential of mitigating these hardships. Rich fishing zones were being routinely mapped by other countries to harvest the marine fishery stock. Effective information systems such as the present cell phones supported by appropriately spaced coastal radio towers, could be used to provide timely warning of impending bad weather, and wave-generated power to light their coastal habitats – also, perhaps catalyze the growth of cottage industries potentially capable of adding value to their main occupations – even fish culturing some day in prefabricated protected environments. I assiduously worked on these possibilities, magnificently assisted by Joint Secretary Sardana, and relentlessly pursued scientific establishments around the country to persuade them to undertake some of the needed development works. There were two heartwarming responses. One resulted in an operational Marine Satellite Information Service providing bi or tri-weekly information to fishermen about the locations at sea of potentially rich fisheries. This became a reality within just about 18 months from the word go, thanks to a most touching support by Professor Deekshatulu, Director NRSA (National Remote Sensing Agency), Hyderabad. The second was the installation of a wave generator designed and installed by the engineers of IIT Madras, at Vizhinjam near the Trivandrum coast.

SV: How do satellite data reveal rich fishery zones, and do these zones shift with time?

VG: Fish in the sea, congregate to areas which are rich in food, in turn, created by fresh influx of nutrient-laden waters where two different water masses usually of different temperatures and densities meet. These nutrients could be in the form of zooplankton or minerals and the zones of their concentration are marked by steeper temperature gradients which can be revealed by abstracting surface temperatures of different sea surface patches from satellite radiance data, and processing these to derive a temperature gradient map. This information can be conveyed to fishermen through one of several means available today. But, we began by using FAX machines to direct them. Since water has large thermal inertia, the sea surface temperature regime takes time to change. The maps are therefore valid for a couple of days and have to be revised every few days.

This became one of the flagship programmes of DOD which has been greatly expanded since. Another programme that I implemented was aimed at understanding the dynamic of the coastal ocean waters and their biogeochemical regimes. Accordingly, an ambitious programme was launched to monitor the physical and biogeochemical parameters of the 25 km-wide belt of the coastal ocean from Gujarat to Bengal and the Andamans on a regular basis round the year, through a consortium of over a dozen scientific institutions, who together covered the entire coastal stretch with purposefully designed overlap to help control data integrity. These programmes had been underpinned by carefully designed space-time measurement protocols that interdisciplinary groups of scientists had brainstormed and formalized.

All these endeavours, of course required a very high level of scientific knowledge understanding and expertise and I realized that in order to purposefully sustain these at a high level, we needed counsel of thinkers, planners and designers – a kind of a Think Tank which was eventually formed under the chairmaship of Dr S Varadarajan, the famed architect of IPCL, Baroda and scores of technology initiatives. Thus, I had the immense privilege of receiving valuable guidance from extraordinary minds: Dr Vardarajan, Professor Roddam Narasimha and Dr A Gopalkrishnan. Each gifted the nation enduring visions and accomplishments in some frontier areas: Drugs from the sea, ocean state modeling and sea-bed mining.

SV: How successful were your other initiatives?

VG: Not all my endeavours were successful. Some of the deeply lamented failures were: the development of an unmanned submersible vehicle, a network of coast to fishermen communication service, the installation of a hybrid land-sea aquarium and regular scuba diving courses at a few coastal universities which had the potential of not only catalyzing the spirit of adventure amongst the young but also stimulating their imagination by engaging them with evocative experiments such as documenting aquatic diversity, and the behavioural patterns in the marine food chain. These failures were entirely due to a lack of imagination and purpose on the part of those who had promised to develop them, apparently drawn more by the prospect of scavenging funds from the Government rather than delivering a product or rooting a valuable cultural activity. I often wonder how much of possible cultural embellishments the Indian nation continues to miss by not securing the ablest to serve its many establishments.

SV: Your department also had the charge of developing Antarctic Science. Could you name some exciting activity that you established there?

VG: Indeed, making the Antarctic Science programme meaningful was the greatest challenge that I faced when I entered the DOD. Parliament had been extremely critical of it and the PM was so peeved that he only grudgingly accorded approval for the yearly expeditions to Antarctica. He had said as much to me, perhaps to forewarn me. In fact, I too had often wondered at the rather casual manner in which these expeditions had been organized, when there were so many exciting scientific possibilities at this unique global site of a magnetic pole stuck into a giant refrigerator. So, the first thing that I did was to write a policy paper on Indian interests in Antarctica and, given the nature of the extant treaty, the overwhelming desirability of asserting our presence in it through high quality science. Simultaneously, I set about generating worthwhile substance to characterize our Antarctic science endeavours by holding brainstorming sessions and persuading the DST and CSIR to make long-term commitments to fund some of their respective institutions to contribute to this national programme.

As a result, a number of research initiatives had been formulated and provisioned for the next Antarctic expedition in November 1989, in fact for two concurrent expeditions that year, addressed to two different sites in Antarctica. Everyone advised me against it, citing Parliament's displeasure and the PM's own reservations. But, I had written a detailed dissertation explaining the rationale of my proposal. Miraculously, the PM's approval for both came within 4 days, weeks ahead of the ships' sailing. Thus, we were able to launch some truly interesting programmes over the next two years. These included interesting scientific studies: of the weather system in the atmospheric layer close to the ground, of super-granulations – an intriguing dynamic structure in the solar corona, of human neuro-physiological responses in extreme and isolated environments, and high resolution monitoring of dynamic earth and environmental data: GPS-controlled geological mapping and of round the year ozone intensity, using both emission and absorption spectrometry. I even reserved a berth on the ship for a creative writer or artist who would be interested in creating some unique expressions of his/her experiences of an extraordinary natural ambience and phenomena: vast stretches of pristine snow devoid of any landmark, the horizon circling the Antarctic summer sun, the fabulous display of auroral fireworks funneled by the pole converging magnetic lines of force and, of course, the fascinating world of the penguins, seals and the Antarctic tern, which testifies to the infinite design potential of lifeforms to establish the most unimaginable ecological structures. This provision, however, was deleted on my departure.

SV: What did you do after your promised three years at DOD?

VG: My decision to leave the Government after three years and return to academia, had been firmly taken at the time of my joining DOD. The option I was most seriously considering was to return to Roorkee as a Professor in a supernumerary position. When I wrote to the Cabinet Secretary alerting him of the irrevocable date of my departure from DOD, he informed me that the Government had created a scientist position for me in CSIR and I was free to work anywhere I chose to. Then one day, Professor Roddam Narasimha who was then Director of NAL (National Aerospace Laboratories), and was visiting Delhi, suggested that I should come to Bangalore and work at the newly instituted CSIR Centre of Mathematical Modeling and Computer Simulation. It proved to be one of the most consequential pieces of advice in my life, and the decision to accept his invitation, a most rewarding act.

SV: What did you plan to pursue at C-MMACS?

There were two lines of enquiry that I had set out to explore whilst at the NGRI after our tomography experiment: the relative velocity of the Indian plate with respect to others, using VLBI (Very Long Base Line Interferometry), and higher resolution imaging of the crust beneath Hyderabad and thereafter elsewhere in India, using broadband seismology. The first thing that I did after I came to Bangalore was to request the broadband data generated by the NGRI station so that I could analyze and invert it for visualizing the underlying structure. This whilst not refused, was never available, but fortunately the data had also been stored at the worldwide network which I eventually extracted through the internet during a visit to Cambridge University in UK. The broadband data recorded at the NGRI had remained fallow for 8 years and showed no sign of being recognized for their value in revealing the structure underneath. Fortunately, however, this first broadband study of a part of the Indian continental crust, published in 1996, catalyzed a lot of interest and several scientists in the country have since used it to thus characterize the crust underneath a large part of the country.

New developments in technology, had in the meantime, led to a fast refinement of the GPS receivers, now capable of millimeter precision in locations, close to that of the VLBI. This was adequate for determining inter-plate velocities and regional deformation rates. So, I began reformulating the problem of determining deformation rates in the Himalaya, using GPS Geodesy. However, these systems whilst enormously more simple and cheaper than the VLBI, were still quite expensive, about $ 25,000 a-piece, and I had no research funds at that time to procure them.

So, I wrote to a friend, Roger Bilham, at the University of Colorado at Boulder, whom I had known in Cambridge, asking if he would lend half a dozen of his GPS systems for 6 weeks, which we could use to re-measure the coordinates of about 20 monuments in southern India belonging to the Great Triangulation Survey of the 19th century, in 3 or 4 deployments by occupying each station for 3–4 days. Since the coordinates of these monuments had been measured 130 years ago, and meticulously documented in 14 volumes of Survey of India memoirs, we could, by comparing these with the new values, determine the accumulated deformation of the region spanned by them. These documents at that time were unavailable to Indian scientists, having been classified, but were available in libraries around the world, so that we could access them for our experiment. Roger enthusiastically agreed to bring these systems to Bangalore, meeting the cost from his ongoing projects. I believed that this feasibility experiment, if successful, could catalyze more systematic support from the Ministry of Science and Technology, to address the larger question: what is the rate at which India is deforming in different parts of the country, especially the Himalaya?

Soon, we were all set to launch this experiment, but a few issues remained to be fixed. We needed a firm bedrock of unfractured rocks at some easily manageable site in Bangalore to set up a reference receiver, and some 10 persons who would help operate 5 receivers simultaneously at different sites of the network that we had selected, for about 20 days.

We knew that there was a secondary triangulation site on an unfractured bedrock exposure within the campus of the Indian Institute of Science (IISc) which would prove to be an excellent protected site for the reference station. So, I asked Director Padmanabhan if we could use this place with a 15 sq metre space around, marked by a fence. His response was positive and very warm, offering whatever assistance was needed. Today, it is the only reference site in India with real time connectivity with the global network. This is an indispensable requirement for determining the precise coordinates in space, of the various globe-orbiting GPS sites at every instant of time.

We also received enthusiastic support from all the young research students at C-MMACS, who irrespective of their discipline, offered to participate in the GPS measurement campaign in southern India.

Our results provided the first experimentally determined velocity of the Indian plate with respect to the Eurasian, and showed that the yearly rate of strain in the southern peninsula was no higher than 10^{-9}. Obviously, the continent as a whole was moving more or less as a rigid body right up to the northern latitudes such as Delhi, perhaps accumulating all the strain of the postulated plate convergence in the region north of it. This initial experiment spurred wide-spread activity around the country to use GPS Geodesy for identification of strain accumulation zones as prospective locales of future earthquakes.

SV: How did you validate your measurements as you were using a different technology than was used for the 19th century measurements?

VG: The 19th century surveyors followed the steps suggested in a meticulously formulated scientific dissertation written by Colonel Lambton in support for his proposal to the then East India Company, to establish a unified reference frame for India through a chain of connected triangles covering the entire territory from the Cape to the Himalaya, which the East India Company or the British nation would finally rule. This included direct (as distinct from the figure derived from the solution of triangles) measurement of a dozen or so specifically selected sides of the triangulation network, designated as 'baseline lengths' to enable distribution of errors as the net expanded. They made these direct measurements with great care and finesse and showed through reverse coverage that these were correct to an accuracy of one millimeter in a kilometer. One such 11 km baseline existed in Bangalore with one of its ends in the park near the Mekhri Circle. So, we first occupied the two ends of this base line by GPS receivers for over 3 days and calculated the GPS derived distance between them. Our result turned out to be close to the 19th century value of this baseline within the accuracy claimed at that time. We thus felt it justifiable to go ahead and check the other monuments of the network between Bangalore and the Cape and calculate the accumulated strain suffered by the region over the past 130 years.

SV: How far did you pursue this work to extend it to the Himalaya?

VG: Whilst this experiment was being planned, a most fortunate circumstance brought a young bright scientist, Sridevi, to C-MMACS. She showed interest in the GPS work and assiduously set about establishing a reference station at the original site in the IISc campus, as by that time we had received some funds to pursue our work more extensively. We immediately designed experiments to investigate the strain field in the central Himalaya along the river Goriganga in Kumaon, and across the western Himalaya in Ladakh, with a second reference station at Delhi in the JNU campus where we received warm support from Dr Rajamani of the School of Environmental Sciences.

Our Ladakh experiment was also designed to settle a long-debated physics question as to what was the mechanism whereby Tibet accommodated the northwards advance of the Indian plate: whether by slicing parts of Tibet along east-west fractures to move them eastward out of the way of India's advance, or by viscous thickening. The two mechanisms required different rates of eastward movement of Tibet north of the Karakoram fault in northern Ladakh. The first, about 30 mm/year, and the second only 4 mm/year. The two scenarios also differed in the way they predicated the rheological equation of state of the material, the one purely elastic, and the other visco-elastic, to be chosen for quantifying earthquake hazard. Our result clearly showed the elastic model to be invalid and was eventually published even as it was fiercely resisted as it flew in the teeth of the reigning paradigm. Furthermore, our results showed that Ladakh was advancing over India at the rate of ~ 18 mm/year, like a fluid body because all the velocity vectors in the region were directed towards the Indian plate, and what was most significant, normal to the Himalayan arc. Meanwhile, our Kumaon work and Roger Bilham's Nepal work also required a similar rate and style of convergence across the Himalaya. Later, extension of this work in eastern Himalaya also confirmed this consistent inference. Buttressed by these results, we believe that we now have a fair understanding of the progression of strain building across the Himalaya and their eventual release through a giant leap of the mountains over the plains.

In July 1996, I superannuated and Professor Ramnath Cowsik, the Director of the Indian Institute of Astrophysics (IIA) invited me to join his faculty, which I did. He was setting up a high altitude optical and infrared telescope in Ladakh – to form the world's highest observatory – and asked me to Chair a committee entrusted with the task of setting this up. This was an interesting new activity which taught me much exciting science and also provided me with an opportunity to set up a permanent GPS and a broadband seismograph at this site.

Several years later, around 2003, as I was quietly receding from GPS science, I accidentally walked into a new area of enquiry that seemed to suddenly materialize during a dinner hosted by C-MMACS for a visiting French delegation which had come to finalize the substance of their collaborative researches in the field of Atmospheric Sciences. I cannot recall how, but the conversation veered at some stage to the outstanding problem of quantifying carbon fluxes (the amount of carbon flowing annually from the atmosphere into different parts of the global ocean and terrestrial biota, or the other way round) around the globe at different seasons of the year. It could be approached in two different ways: through a dense network of monitoring stations although oceans would still pose a challenge, or by using the formalism that the atmospheric CO_2 concentration at a site at a given time can be mathematically expressed by the generalized product (convolution) of the area-wise fluxes and an atmospheric transport function (Green's function) which is reasonably well known. Thus, given the concentrations at reasonably well-distributed sites on the globe, one could calculate the desired fluxes. I then suggested that the Indian Astronomical Observatory at Hanle in Ladakh, would constitute an ideal site for measuring the concentrations as it had no local sources of biotic or industrial CO_2 fluxes, and therefore, should provide an unbiased sample for global inversions.

India's first ultra-high precision laboratory for measuring atmospheric carbon concentrations thus became operational in August 2005, and one of the first interesting results obtained was a significantly reduced value of carbon fluxes as compared to that which had earlier been attributed to temperate Asia based on US station data. This work continues whilst we address some other related but more basic questions that would help reduce uncertainties in carbon flux estimations around the globe. Meanwhile, two energetic scientists at C-MMACS, Swathi and Indira, are engaged in setting up additional monitoring sites that would enhance our understanding of the ocean fluxes in the Arabian Sea and the Bay of Bengal, by instrumenting two new sites at Pondicherry and at the Andamans.

SV: What are your current interests?

VG: One of the interests that has intensified in recent years, begs an understanding of how contingent developments influence the course of societal processes. The seed goes back to the last week of May 1991, when India was obliged to airlift 67 tons of gold to European banks in order to shore up its grievously wounded credit rating, as an earnest for a loan from the International Monetary Fund (IMF). I was then a part of the Government and we were all asked to suggest austerity measures. Manmohan Singh, who had just been inducted into the cabinet (Narasimha Rao was the Prime Minister) told us at a meeting that there was very little money available and the situation called for the greatest vigilance in expenditure. As a part of the IMF conditionalities, not of any planned design, the Government took some precipitous steps: reducing the crippling high tariff (average of over 100%) and declaring a negative list of imports, which, of course, miraculously unshackled Indian entrepreunership, until then held ransom to a license-permit regime, and eventually helped India redeem its honour; it recently bought 200 tons of gold from the IMF.

So, at that meeting when we were all exhorted to be mindful of reduced budgets, I raised my hand and said, "I have a simple-minded proposition: Society is also a *system* with inputs of human and material resources and outputs in the form of a representative quality of life. With reduced inputs, however, there are two options: acquiesce in a proportionately reduced output, or so restructure the system as to become more efficient with only marginal sacrifice of output." In other words, what I was saying was, why not do something to reform the parasitic structures of governance? Since no one would answer this, the question was lost. But, it keeps returning to haunt me when I read of massive leakages of resources. I believe that the only instrument to defeat these dissipative cultural traits would be civic society initiatives, catalyzed by knowledge and understanding.

Yet another concern is the growing intolerance in society towards the minorities and it wounds my spirit to see the intrinsic ethos of our people, their unselfconscious acceptance of diversity: ethnic, linguistic, even faith, so brutalized by the proportionately much fewer, but more aggressive of our citizens who are more readily persuaded by the force of their passions than by the passion of reasoned persuasions.

SV: Is there anything you would like to communicate to the students?

VG: Yes. Our age is characterized by the rapidity of change and the question arises – should we flow with the stream or design our course by influencing that flow? With all the new technology, liberalization and other possibilities, can the young people use their energy to think independently and steer society in the direction of their dreams? They have the numbers, the energy and freedom from unwholesome baggage of the past, and therefore the potential. Theirs' is the century and our future will depend on the vigour and integrity of their responses.

SV: What are some of your other interests?

VG: I have a deep interest in literature, and especially in poetry. When I go home, and Eryl is not at her piano, we read poetry and listen to music. She is much more widely read than I. So, I keep educating myself. That has been a kind of a positive force in my life.

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