T. S. Balakrishnan (1928–2018)

T. S. Balakrishnan, a geophysicist, who worked all his life exploring for oil and decoding the tectonic features of the Indian subcontinent, died in Bengaluru on 8 August 2018 after a short period of age-related illness. He was 91. Born in Thrissur, Kerala in 1928, Balakrishnan did his education in Bombay and Allahabad Universities and completed his postgraduation in Physics, in 1947. He started his scientific career working on X-ray crystallography, at C. V. Raman's laboratory in the Indian Institute of Science (IISc), Bangalore where he worked from 1947 to 1953. He joined the Geological Survey of India in 1953, where he started his work in geophysical exploration. His interest in geophysical exploration found its most fertile ground as he joined the Oil Natural Gas and Commission (ONGC) in 1956, as one of its earliest geophysicist recruits. During the days of his early service, Balakrishnan initiated geophysical surveys in the Cauvery (Tamil Nadu), Jaisalmer (Rajasthan) and Jwalamukhi (Punjab/Himachal Pradesh) basins. After an eventful stint in geophysical data acquisition, he took over as the Head of Exploration in the ONGC's Institute of Petroleum Exploration (IPE) in Dehra Dun, where he worked from 1974 to 1982. He moved to Bombay in 1982 where he led the offshore project and superannuated in 1986, as the Director of Geophysics. His pioneering efforts in oil exploration led to offshore drilling in the Gulf of Cambay, a project that he steered. Post retirement, he continued to live in Bombay with his wife Jaya, and it was after her demise in 2006 that he moved to Bangalore to live with his daughters.

I have known Balakrishnan from the time I was a Masters' student of Applied Geophysics at the University of Roorkee. During the final semester of my course, I used to visit IPE quite frequently to do the computational work for my M Tech dissertation. His elder daughter, Meera, who was pursuing her Bachelor's in Engineering, was my contemporary and a good friend. She suggested that I visit her home, and meet her parents who could be of great help to me. That is how I got introduced to Balakrishnan, as a fellow student of geophysics and as Meera's friend. His wife was an endearing woman, who would welcome me as if I was her daughter staying away in some hostel, returning home with cravings for south Indian food.

Although I chatted much with his wife, I was quite distant from Balakrishnan, who I knew was a busy and senior official, the Director of IPE. During the later years, as a practising geophysicist, I have had the opportunity to meet him and discuss about various topics. I have found his work on the tectonics of the west coast of Kerala quite useful to our research.

However, it was after he moved to Bangalore in 2007 (around the same time that I moved to the IISc), that I became more closely acquainted with him and learned more about his work on the tectonics of India as interpreted from geophysical data. Most of the time he used to stay with Meera who was working for Infineon Technologies at that time and living in the Whitefield, Bengaluru. However, he used to occasionally be with his younger daughter, Rohini Balakrishnan, a faculty in IISc, staying on campus. That is when my husband C. P. Rajendran and I used to meet him more often. Every time he visited, he would ask Rohini to invite us and that is when we started to interact closely with him. During these visits he mostly talked about his latest interpretations of the tectonic map of India that he was working on. The last of these visits was in October 2017 on his 90th birthday, when a small gathering of friends and relatives had assembled in Rohini's house to wish him. He received us with his characteristic smile and talked energetically. He even found time to update us on his recent interpretations of the tectonic map of India that he incessantly worked on.

It was amazing to watch the way he worked with the geophysical data and their connections with the major tectonic features. Some of his contributions, published as a Memoir of the Geological Society of India, *Major Tectonic Elements of the Indian Subcontinent and Contiguous areas: a Geophysical Review*, is an important collection of papers on the various tectonic blocks of India. His interpretation of the gravity and tectonics of India, *Structural and Tectonic Map of India and Contiguous Areas* (Balakrishnan, T. S., Unnikrishnan, P. and Murty, A. V. S. published by the Oil and Natural Gas Corporation Ltd, 2009) is another classic work.

Balakrishnan was fond of discussing his work with C. P. Rajendran, who perhaps visited him more often than I did, as he would specifically tell Rohini to call him. He also gifted us with a prepublication copy of the gravity map of India, which we have displayed at the Centre for Earth Sciences at IISc. This map would undoubtedly remain a useful template for the students of tectonics as well as exploration geophysicists. He had also completed an updated version of his earlier book, *Major Tectonic Elements of the Indian Subcontinent*, for which Rajendran wrote a preface. This book, yet to be published, despite his best efforts would be another basic framework for future works in geophysical exploration.

There is just one unfulfilled desire that he has probably left behind. That is to see India reaching self-sufficiency in energy from its geothermal resources, which he considered as huge. A larger part of these reserves are in the state of Gujarat, and he has marked the potential sites for drilling on the geophysical maps of India. He believed that geothermal energy is a better option for India, rather than going nuclear energy way, an idea that he has communicated to the Energy ministry and the Prime Minister's Office. During his conversations with us he often expressed his unhappiness that his plea to explore the geothermal energy potential, remains unheeded. He believed

that ONGC was admirably positioned for a transition to geothermal resource exploration.

Balakrishnan loved being part of field explorations and enjoyed living in tents and leading his team consisting of large number of geophysicists, technicians and other support staff. He always remained a part of the team, which is what made him a huge success as a leader. Talking to me about the early days of her life with Balakrishnan, his wife once recounted how she had to pack her baggage and accompany him to the field camp at Cuddalore (Tamil Nadu), soon after her marriage. That was their first trip after the marriage, she recalled. That was the nature of Balakrishnan. He was so passionate about his work, that other issues seemed quite peripheral.

As Balakrishnan devoted much of his time in the field searching for potential sites of oil deposits, he had very little time to work on publications. The ONGC's restriction on the publication of the data he collected was possibly another reason why he could not publish much of his work. He was busy building the foundations for oil exploration in India and remained focused on that mission. As a man who never sought name and fame, I think, he joins the ranks of an expanding company of unsung heroes of the Indian geoscientific community.

Working with maps was of course his ultimate passion and he carried that all along, until his death. We are told that during the months of October to December of 2017, he had travelled to Florida to live with Meera and the one thing he insisted on carrying with him was his set of maps. He continued working on them, marking boundaries of tectonic blocks and other features expressed by geophysical data. Two days after his demise we had visited Rohini's home where he spent his last days. The room where he sat and worked until about two weeks ago, when he was bedridden, remains the way he had left it. Maps showing gravity anomalies, tectonic features and locations of potential geothermal fields, marked by various shades and patterns, remain spread out on his work table. It looked as if he had run out of colour pencils to shade the newly found structures and had just stepped out to get more of them. Opening a large cabinet full of maps, his daughters recounted how they have grown up in houses with maps rolled and stacked up all around and how they have also developed a great love for maps. The maps he made would continue to illuminate structures of interest in future efforts of exploration. The geothermal spots mapped by him might brighten up as future sources of energy. He truly laid strong foundations for meeting India's energy requirements. Indeed, the country has lost a very talented geophysicist whose potential was not tapped to its fullest benefit.

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Cadatur Badrinathan (1930–2018)

It was with much sadness that friends, colleagues and admirers of Cadatur Badrinathan, known to all as Badri, received the news of his passing away on 11 April 2018 in Navi Mumbai. Badri, who was born in Salem, Tamil Nadu, on 20 September 1930, did his Master's in Physics from the University of Rajasthan in Jaipur before joining Tata Institute of Fundamental Research (TIFR), Mumbai on 23 November 1955. His early work was with E. Kondiah and was based largely around the 1 MV Cockroft–Walton cascade generator accelerator at the Institute. It was during this time that Badri completed his doctoral degree that involved extensive experimental studies of transfer reactions using deuterons and 14 MeV neutrons. He also utilized neutrons that were made available from the Apsara and Cirus reactors at Bhabha Atomic Research Centre (BARC), Mumbai. His level of enthusiasm and acumen for high-quality experimental work was evident right from the beginning of his research career. Within a short time of joining TIFR, he was publishing well-noticed papers, with colleagues like K. V. K. Iyengar and N. Lingappa, on various topics like the interaction with fluorine of fast neutrons arising from D (d, n), Be (d, n) and T (d, n) reactions using deuterons accelerated in the cascade generator, and on the width of excited states of isotopes of tin by studying nuclear resonance scattering of de-excitation gamma rays. His skills as a top-notch experimenter were exemplified in the large number and variety of instruments that he developed, including the building of many of the early detector systems that were used by him and his colleagues at TIFR and, subsequently, at BARC and further afield.

In the period from the mid to late 1960s, Badri spent two fruitful years at the University of California, Davis, USA and a year at the Max-Planck Institute for Nuclear Physics at Heidelberg, Germany. Not only was this time well spent in updating and further sharpening his skills in state-of-the-art experimental techniques, but he also contributed to cutting-edge basic research in nuclear physics, with studies that included what were amongst the earliest experiments on neutron–proton bremsstrahlung at 208 MeV – pioneering work that appeared in *Physical Review Letters*[1] in 1968. Upon his return to TIFR, Badri played a leading role in the 1970s in attempts to build, in-house, a tandem van de Graaff accelerator and, along with his colleagues, he succeeded in constructing a pellet-chain charging system and was able to demonstrate its ability to generate high voltages. Such a charging system lies at the heart of contemporary pelletron accelerators.

In the 1980s, Badri shifted his interests towards the emerging field of experimental atomic and molecular physics. He developed low-energy ion sources and various types of mass spectrometers for experiments conducted at low energies – over the range 1 eV to 5 keV – and helped incorporate them into a new generation of laboratory-made instruments designed to explore in adiabatic fashion, the dynamics of electron–molecule and ion–molecule collisions, especially those