Manik Talwani… a Memoir

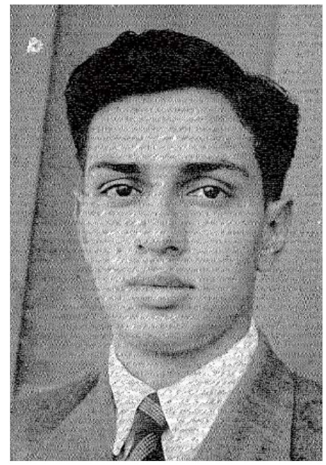
Dr. Manik Talwani is a well-known and experienced geophysicist who has used geophysics to study the ocean basins, the earth's crust and continental drift for over 50 years. He was at Columbia University's Lamont-Doherty Geological Observatory from 1955-1981 and has been at Rice University since 1985. He has received honors and awards from AGU, GSA and EGU as well as NASA's Exceptional Scientific Achievement award (for sending the first gravimeter to the Moon). He is currently a Research Professor of Earth Science at Rice University in Houston and Schlumberger Professor Emeritus of Advanced Studies and Research.

I was born in the princely state of Patiala, which was a part of British India. Patiala is still in India, but my father, a civil engineer, worked mostly in what is now the Punjab province of Pakistan. We lived in places away from cities, where there were no schools. So my early schooling was home schooling, and with an occasional tutor. At the age of eleven I was packed off to boarding school in New Delhi. I spent one year there and after an intervening year I was sent to a progressive Hindu religious boarding high school in Lahore. We crammed a lot and prayed even more. In fact I prayed so much that I believe that I might have prayed enough for the rest of my life. The end of the high school coincided with the partition of India. Lahore was one of the centers of the enormous upheaval. Even though my family and I were relatively safe, I can remember hearing the sounds of howling mobs in the distance.

The partition changed the intended course of my further education. Instead of going to a college in Lahore in more familiar surroundings, I entered Delhi University. For the most part this university was housed in the old viceregal lodge. The viceroy had moved a few decades earlier to the brand new capital, New Delhi, designed by Sir Edward Luytens. The university had beautiful, well maintained grounds and it was a peaceful place to learn, away from the crowded Delhi streets.

To choose my courses I thought I would opt for subjects that would help me towards joining the Indian Foreign Service. With that in mind I began to take courses in Economics and French. However, I found out soon that these subjects did not suit me and I dropped them. After some reconsiderations and consultations I was admitted to a three year honors course of studies in Physics. If a professional career can be considered to be punctuated by milestones, starting studies in physics was a first and important milestone for me. Fortunately, the courses in physics were taught by an excellent set of professors and I have to thank them for giving me a solid grounding in physics. I was not quite sure what I wanted to do after graduating with a Bachelor Honors degree. The default path seemed to be to continue to a Master's degree which I proceeded to take and obtained this degree after a two year period. I was nineteen years old when I obtained my Master's degree. For reasons that, looking back, are not entirely clear to me, I decided that I wanted to continue further studies and have a career in geophysics.

However, there appeared to be no opportunities for advanced studies in geophysics in India. When the Norwegian government offered a training fellowship in Norway, I accepted it. But Norway, at that time, had no formal university courses in geophysics. In Trondheim, Norway, I joined Geofysisk Malmleting, a government ore prospecting institute as a trainee. (More recently. Geofysisk Malmleting has been incorporated into the Norwegian Geological Survey). I was involved in shallow seismic experiments to determine the depth to basement, in electromagnetic experiments to investigate ore prospects, and in building magnetometers for airborne work. In all, I spent seven months in Norway. If I had to pick a seven month period in my life that influenced me most professionally, I would pick the seven month stay in Norway. I learnt two cardinal facts: in geophysics both theory and experiment are equally important and a profession which gave you scope for out door work was far preferable to one that involved mainly a desk job. This was the start of a life long association with Norway. (Many years later I returned to work in the Norwegian Sea. That work, which was carried out over a period of more than a decade, led to important scientific discoveries and associations with Norwegian scientists. I was awarded an Honorary Ph.D. degree in Oslo University in 1981 and was made a foreign fellow of the Norwegian Academy of Arts and Sciences in 1987.)



1953 just before going to Norway.

After my stay in Norway and introduction to geophysics, I realized that I needed to get advanced training at a university. I took the Graduate Record Examination (GRE) administered by the Education Testing Service in Princeton. This included general tests as well as one test in a selected subject. I chose physics. I applied to four universities in the U.S. for admission and scholarship. The best offer came from Columbia University, which offered the Eugene Higgins Fellowship, which was a sum of $1,700 to cover board, lodging and tuition for one year. I accepted the offer and sailed from Bremerhaven to Quebec on a ship full of returning American college students and German immigrants. I took the train to New York and entered the U.S. at the border town of Rouses Point in New York State in August 1954.

I commenced my studies in the Geology Department of Columbia University in the fall of 1954. My first two years at Columbia consisted mainly of taking classes. Columbia had an excellent faculty in the Geology Department. Arthur Strahler taught Geomorphology, Charles Behre taught Economic Geology, Marshall Kay, Stratigraphy. Walter Bucher, Structure, and Maurice Ewing and Frank Press,

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Geophysics. I took classes from all of these professors as well as a class in Elasticity and Hydrodynamics from a young Associate Professor in Physics, T. D. Lee, who incidentally was awarded the 1957 Nobel Prize in Physics

2003 in my office at Rice.

During the summer of 1955 I worked on Lamont Observatory's research ship VEMA. Starting as an iron hulled luxuriously appointed three masted racing yacht with teak decks, VEMA was originally named HUSSAR and was built in 1923 for E.F. Hutton. For a while it held the racing record across the Atlantic. After Lamont acquired it in 1953, it underwent a transformation. The teak decks were replaced by steel decks, the masts were taken down and the state rooms were replaced by spartan accommodations for scientists. However, VEMA compiled a record for obtaining more along track geophysical data, more sediment cores and more camera stations than any other oceanographic ship. During the decades of the fifties, sixties and seventies, VEMA travelled the world's oceans covering more than a million miles of track, a large part of it under its famed master Henry Kohler.

The summer of 1955 was my first experience of research at sea and I found it most enjoyable. Although I had not quite intended it, marine geophysics became the principal focus of my career. We spent that summer in the North Atlantic, doing underway geophysics, which was then limited to magnetic measurements as well as soundings. In addition we did a limited amount of seismic reflection work. We also took a number of sediment cores and made camera stations. In 1956, I again spent the summer at sea, again on the VEMA, this time in the Mediterranean, adding seismic refraction using a small boat as the shooting ship, to the shipboard tasks. In 1957 I undertook a project to make gravity measurements on the Bahama banks. Gravity measurements had been made by submarines in the channels but none existed on the banks. A remote controlled gravity meter was placed in a water tight bell and was lowered by a hand turned winch from a fishing boat. Doing geophysics from a fishing boat was a lot of fun. When we were not lowering gravity meters, we were fishing, and our meals consisted entirely of fried fish. I chose the interpretation of these gravity measurements and earlier ones made by submarines as my thesis topic. Joe Worzel guided me in my gravity work and Maurice Ewing was my thesis advisor. I defended my thesis in 1959. The only question at the thesis defense that I remember was posed by Polykarp Kusch, another Nobel Laureate at Columbia. The question was "You claim an accuracy of one part in a million in pendulum measurements. What is the source of this accuracy?" The answer, of course, which I produced after some struggling, was that the accuracy came from the crystal chronometer used to measure the time period of the pendulums.

After defending my thesis, my work at sea took an unexpected turn. Up until that time gravity measurements at sea in deep water were only possible on submarines. This was because the rolling and pitching and accelerations of a surface ship made gravity measurements by a gravimeter, which requires a stable base, impossible. These motions are vastly attenuated at a depth of a few hundred meters, a depth within the reach of submarines. Vening Meinesz, the famous Dutch geophysicist modified an existing gravity measuring pendulum apparatus for use on submarines. He sailed on submarines himself, somehow accommodating his six foot seven frame onto berths made for much shorter persons. He was able to correct the effect of the relatively small motions of submarines and obtain gravity measurements. His measurements over the deep sea trenches off Indonesia indicated very large negative gravity anomalies and created a sensation. Worzel at Lamont had replicas of the Vening Meinesz apparatus built in the Lamont machine shop and looked for opportunities aboard submarines to make gravity measurements. Such opportunities were obviously scarce; the prime purpose of submarines is not to make gravity measurements! However, an opportunity did arise. The British admiralty had plans for a submarine to spend four months sailing around Africa and would allow the installation and use of the pendulum apparatus on board. The Lamont version of the pendulum apparatus was installed on HMS ACHERON, a leaky world war two-diesel submarine. I joined the submarine at Freetown in Sierra Leone and spent the next four months on and off the submarine, and was able to make a few dozen measurements. Life aboard the submarine was a reflection of the British class system. There were three messes, one for the officers, one for the petty officers, and one for the sailors. Movies were shown separately for the three groups. The officers had access to regular drinks, the petty officers drank beer and the sailors had a ration of rum every day. Food was not of the gourmet variety; Spaghetti on toast was a frequent breakfast item. ACHERON was supposed to carry out exercises with the navies of Portugal, South Africa and Pakistan, but its engines kept breaking down. Otherwise life aboard the submarine was quite dull. These were about the last pendulum measurements made aboard submarines. Surface ships began to measure gravity in the sixties.

In 1961 I went back to sea as chief Scientist on the VEMA. Subsequently I sailed on more than 30 marine geophysical expeditions on Lamont ships Vema and Robert D. Conrad as well as on ships belonging to other organizations. During the period 1961 to 1981 I was at sea every year for about a two month period. The underway work, which I have mentioned earlier also began to include surface ship gravity and periodic sonobuoys. Seismic reflection using explosives was one of the more dangerous programs carried out on both ships. This involved getting a half pound charge of TNT ready, lighting the fuse and throwing it over the side. This was done every three minutes around the clock. Unfortunately, this program led to a fatal accident. John Hennion, chief scientist on the VEMA, was sawing explosives to make up half pound charges when they exploded, killing him instantaneously. This created quite some consternation at Lamont. So, when I was asked to take over as chief scientist after the accident, I agreed to do so but with considerable trepidation.

Over the years the reflection work paid off, Lamont was able to obtain the thickness of sediments in all the oceans of the world.

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The newly discovered layering in the ocean basins raised the question of what these layers consisted of. This spawned an entirely new marine scientific program aimed at answering that question. This program was the Deep Sea Drilling Program.

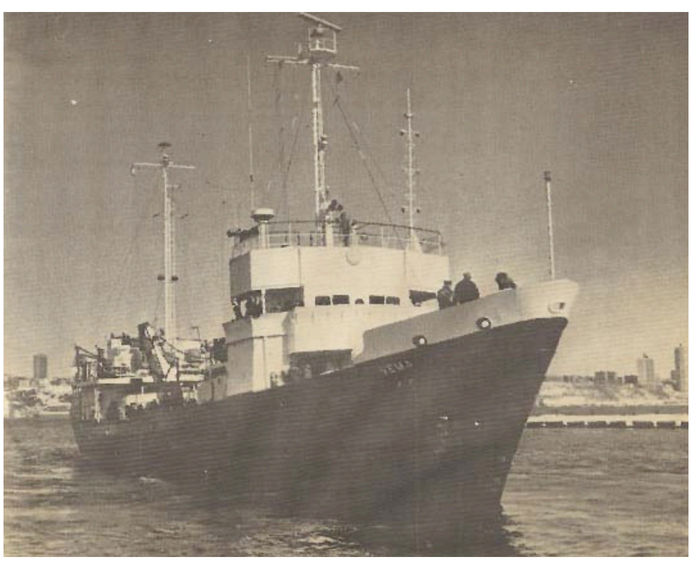
Lamont's program of exploration also compiled magnetic anomaly data in all the oceans of the world. These data proved to be of enormous value when the Sea Floor Spreading theory was established and the data were used to decipher the evolution of the oceans.

Lamont's research was supported almost entirely by government funds, first entirely by the U.S. Office of Naval Research (ONR) and later on supplemented by grants from the U.S. National Science Foundation (NSF). I can recall nostalgically that two page proposals to ONR sufficed, in contrast to the enormous size and complexity of the proposals sent nowadays to NSF.

After obtaining my PhD, I continued my research at Lamont and in 1967 I was appointed Associate Professor in the Geology department, in 1970 Full Professor, and in 1973, Director of Lamont Doherty Geological Observatory, a position I held until 1981.

At Lamont, throughout my tenure, even as director, I continued to engage in research projects. These research projects were in two related directions. One of the directions involved theory and algorithm development and the other geophysical measurements at sea and their interpretation.

Actually, while I was still a graduate student, I developed algorithms and computer programs to make gravity and magnetic calculations. The 2D gravity program is, even at the present time, in wide use and its development needs some elaboration. In doing some 2D modeling for the Bahamas project, the existing algorithms utilized horizontal and vertical sided bodies which are of course unrealistic geologically. I recalled that in my undergraduate studies, my professor Mr. Nandy asked the class to compute the gravity effect of a 2D body with a triangular cross section. The solution to this problem turned out to be the basis for the 2D gravity modeling algorithm. Cross sections that contain bodies with angular sides are much more geologically reasonable but their calculations which involved trigonometric and logarithmic terms were too tedious for hand computers. I was lucky to be at the right place at the right time. IBM had made available the IBM 650, the first reliable digital computer to Columbia University and it could be used to program the necessary algorithms. This computer used vacuum tubes and had a total storage capacity of 2000 hexadecimal words for the program and data. The program had to be written in machine language. But the 2D gravity program worked. Often we had the use of computers at night, and on weekends when the air conditioning was tuned off. The vacuum tubes generated so much heat that we generally stripped to our shorts. My wife, who I was courting in those days, thought it very strange when she came to visit that research had to be done by students running around in shorts! The 2D gravity program led to the 2D magnetics program and later on to 3D gravity and magnetics programs. To this day these computer programs are some of the most widely used gravity and magnetic programs both in industry and in academia.



Research Vessel VEMA on which Manik did a large part of his research.

Measurement of gravity on surface ships was a topic of great interest to me. Lamont obtained a gravimeter from Anton Graf, the inventor of the Graf gravimeter in the early sixties. This instrument had a highly damped beam to minimize the effect of ships' vertical accelerations and was placed on a gyro stabilized platform to eliminate the effect of roll and pitch. At about the same time Lacoste launched the Lacoste Romberg sea gravimeter, but instead of placing it on a gyro stabilized platform, he allowed it to swing in a gimbaled frame in response to horizontal accelerations. By measuring these accelerations an appropriate correction could be applied. In a paper Lucien LaCoste and Chris Harrison stated that the highly damped beam of the Graf gravimeter would move in phase with horizontal accelerations (water motions generally being circular), thereby giving rise to an error known as the cross coupling error. There would also be errors in the position of the vertical reference used for the gyro stabilized platform, which again, coupled with the horizontal accelerations would give rise to another cross coupling error. Thus a gravity meter with a highly damped beam, placed on a gyro stabilized platform could be subject to large errors. Lacoste and Harrison were right in theory but not quite right in practice. The magnitude of the errors depends on the instrument parameters. It turned out that the cross coupling error due to beam motions was small. I was able to build a cross coupling computer and correct for the error. The error due to error in the vertical reference was also small and could be ignored. It also turns out that the error in the vertical reference applies not only to the gyro stabilized system, but applied equally to Lacoste's system through the correction for horizontal accelerations. LaCoste realized that and he also found that in the presence of large ship motions, his gimbal system was unsatisfactory. Without fanfare he switched to placing his gravimeters on a stable platform and computing the cross coupling error. This is the system that all Lacoste Romberg sea gravimeters use at the present time.

My career was not all hits. There were some important misses. While we had access to a large amount of magnetic data on most of the ridges in the world's oceans, it was Vine and Matthews who outlined the theory of sea floor spreading, not any of us at Lamont.. However, Lamont scientists did make use of the extensive magnetic data to unravel the evolution of the various ocean

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basins. Walter Pitman and I outlined the evolution of the North Atlantic and with Olav Eldholm; I traced the evolution of the Norwegian Greenland Sea. I spent many summers at sea in the Norwegian Greenland Sea, tracing in part the accumulation of sediments off Norway, which has obviously become very important for oil exploration. I was also able to renew my acquaintance with the scientists at Geofysisk Malmleting that I had met in 1954. Another miss involved the measurement of the magnetization of sediment samples from cores. I did build an astatic magnetometer but lost interest after measuring the magnetization of a few samples. Measurements of core samples by others later on were crucial in substantiating the theory of sea floor spreading.

I would like to mention two other discoveries made at sea, that I was involved in. While sailing along the central axis of the Reykjanes Ridge south of Iceland, Charlie Windish and I made an interesting observation. We were monitoring the fathometer and the magnetometer readings. To our surprise, they increased and decreased together, which led to the inference that a large part of the magnetization of the Mid Ocean Ridges lies in a thin layer at the top. This was the discovery of layer 2A of Mid Ocean Ridges. The paper in which this discovery was presented was among the most cited papers in a decade. Another discovery concerned the layered seaward dipping reflectors at continental margins. More than one oil company considered these layers to be sedimentary in nature but found to their dismay that they were drilling through seemingly endless layers of basalt. By making seismic refraction measurements we were able to postulate that these were igneous rocks, which was subsequently borne out by drilling.

An area of much interest to me was off the west coast of India. Using results from Lamont's ships, Bhoopal Naini (then a graduate student) and I were able to identify two very interesting geologic features, the Laxmi Ridge and the Laxmi Basin as well as to ascertain the overall geological history of this area.

Strange things can often happen at sea. One of the strangest happened while on the VEMA in the Barents Sea. We were launching sonobuoys while underway and listening to the recording by the sonobuoy which was transmitted to VEMA's antenna. Instead of fading with distance, the recording would suddenly stop. It turned out that a Soviet ship was following us and would routinely pick up our buoys. We were treated more hospitably when we put in to Murmansk at the end of the cruise to pick up cheap diesel fuel. We were given a tremendous reception and party, right in the middle of the cold war.

US Navy's Transit satellite, a fore runner to GPS was developed in the sixties. I was the first to install and use it on a civilian ship. There were some interesting results. At one port in the Caribbean the position given by the Transit satellite differed from the coordinates on the chart by almost a mile. It turned out the difference was due to the deflection of the vertical which caused errors in the astronomically derived chart readings. The Transit satellite was right; the chart was wrong.

Some of my research at Lamont was not confined to marine problems. With George Thompson, I derived a crustal cross section across the California margin on the basis of gravity and magnetic data, and similarly with Stephan Mueller a crustal section across the Alps. More recent findings based on plate tectonics have superseded these earlier findings.

I was the Principal Investigator of the Lunar Traverse gravimeter experiment carried out by the Apollo 17 astronauts Gene Cernan and Jack Schmitt. I teamed with engineers at MIT's Draper lab to build the instrument sent to the Moon. The instrument was based on Bosch Arma's vibrating string accelerometer. This instrument made the only gravity measurements ever made on the Moon. To my horror, I had to watch from NASA mission control center in Houston as Cernan threw away the instrument after making the last gravity measurement. As he threw it, he said he had all along wanted to see how far he could throw this instrument on the moon.

In 1981 I was invited by Gulf Oil to found and direct its Center for Crustal Research I decided to accept the invitation and leave Lamont and Columbia to work for industry. I continued later on at Gulf as Chief Scientist. My employment for four years at Gulf was an important period in my professional life. I began to appreciate the notion that applied research could be every bit as challenging and interesting as academic research. Two of the projects that my team and I tackled while at Gulf were to estimate the hydrocarbon resource potential of the U.S. East Coast margin (based on Gulf's enormous geological and geophysical data base) and to carry out a two ship seismic experiment in the Gulf of Mexico to learn about its crustal structure. When in 1985 Chevron acquired Gulf, Rice University persuaded me to stay on in Houston. I accepted two concurrent positions – the Schlumberger Chair in Advanced Studies and Research at Rice University and the (founding) directorship of the Geotechnology Research Institute (GTRI) which was a part of Houston Advanced Research Center, HARC (an entity created by George Mitchell, an oilman and philanthropist). Even after I left Gulf, I have continued to be interested in problems related to industry. I have also continuously sought out programs in which industry and academia could collaborate.

I taught at Rice and my students and I carried out research at GTRI. A large part of the research at GTRI was devoted to developing algorithms for advanced seismic processing and to working with industry partners to applying them to industry data. A seismic 2D prestack depth migration program installed on an NEC supercomputer available at GTRI was particularly popular with industry partners. GTRI also included a Geochemistry lab (donated by Texaco), and a Rock Properties lab (donated by Unocal).

A principal academic project that I led at GTRI (in collaboration with investigators from a number of other academic institutions) was the EDGE project. The objective of this project was to obtain the detailed crustal structure of the U.S. continental margins, using principally advanced seismic reflection and refraction techniques. Two areas were chosen for detailed investigations – the Baltimore Canyon trough off the U.S. East Coast and the area off the Aleutian Islands. The project which was jointly funded by NSF and an energy company was able to obtain the most detailed crustal structures in both areas.

Another project, which was carried out by two graduate students, John Bradford and Jim Loughridge, used Ground Penetrating Radar and involved not only detecting subsurface layers, but also detecting the nature of the layering with amplitude vs. offset studies. Such studies could be very important in detecting subsurface layers that contain pollutants.

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I had been involved in the Law of the Sea negotiations held at the UN in 1980 as a member of the US delegation under Ambassador Elliott Richardson. My interest in the Law of the Sea continued and in the early 1980s I drafted Iceland's claim to its continental shelf at the request of its ambassador to the U.S., Hans Eriksen.

In 1998 I resigned my position at GTRI to carry out both my research and my teaching activities at Rice. I devoted a large part of my research activities to gravity gradiometry, an area that had recently become very exciting. This research started in collaboration with scientists and engineers from Lockheed Martin. We investigated the possibility of making time lapse measurements of the steam oil interface in heavy oil fields where a steam drive was used to produce the heavy oil. The large amount of heavy oil reserves makes it a very valuable resource. It is not generally realized that the majority of oil produced in the lower forty eight United States is heavy oil. The heavy oil reserves in Venezuela and Canada match the oil reserves in the Middle East. I wrote an Op Ed piece published in the New York Times entitled "Will Calgary be the next Kuwait?" Of all the scientific papers I have written, this was obviously the most read and translated into most languages. A very sensitive Lockheed Martin gradiometer was the key to the project. We obtained a patent for the project. Its feasibility has been established on the basis of actual data from heavy oil fields and by making repeat measurements. The heavy oil project which involved working together with personnel from Lockheed Martin and various energy companies was most interesting and enjoyable. It also led to an interesting offshoot. In constructing the strategy for interpreting the time lapse gradient data, I developed and programmed algorithms for space domain non linear inversion of gradient data. The method has been extended to invert magnetic data as well as to perform joint inversions.

Working with gradiometry led me towards another project. Airborne gravity gradiometry was pioneered by BHP and Lockheed Martin to prospect for minerals. Could this technology be used for academic research? In 2003 I obtained support from the state of Texas, several energy companies, and the US National Science Foundation to have a gravity gradiometer survey flown over the San Andreas Fault drill site. No detailed 3D seismic reflection data exists at this drill site. Gradiometer data would help in learning about the subsurface. Excellent data were obtained and I am presently working on an interpretation of the gravity data in conjunction with other available data.

In 2004 I shifted gears. I was offered the position of President and CEO of IODP-MI an international non profit corporation created to manage the Integrated Ocean Drilling Program (IODP). My previous experience in drilling consisted of serving as Chief Scientist on the GLOMAR CHALLENGER, drilling in the Norwegian Sea as part of the Deep Sea Drilling project and chairing several scientific committees that made plans for the drilling project. I took a two year leave of absence from Rice and accepted the position. IODP involves, the state of the art Japanese drillship, the CHIKYU, the US drillship, the JOIDES RESOLUTION, as well as mission specific drillships leased to drill in shallow water and polar areas and managed by a European consortium. IODP is an ambitious and expensive (present annual budget about $200 million) 10 year program. While at IODP-MI I had discussions with Indian officials and was able to persuade them to have India accept an invitation to join IODP. I also worked with industry scientists and academic scientists to put together a proposal for drilling by the JOIDES RESOLUTION to solve scientific problems of interest to both academia and industry. The proposal which was entitled "Ocean Drilling Consortium" grew out of a workshop supported by industry. The proposal was sent to industry for possible funding but at the present time the slowdown in the energy industry makes its funding unlikely. At any rate a step will have been taken to bring industry and IODP closer.

I left IODP-MI when my five year contract was over in 2009 and rejoined Rice as Emeritus Professor and Research Professor. My current project is to interpret the gradient data obtained over the San Andreas Fault drill site which was collected just before I joined IODP-MI.

I have been fortunate to receive a number of honors and awards during my career. These came from three continents. The Indian Geophysical Union awarded me the Krishnan medal and I served as the Distinguished Sackler Lecturer at University of Tel Aviv in Israel. From Europe I received the Alfred Wegener Award of the European Union of Geoscience, an Honorary PhD from the University of Oslo and the Ludger Mintrop award from EAEG. Just recently in March 2009, I received the Emil Wiechert Award from the German Geophysical Union.

In the U.S., I have received the Macelwane and Maurice Ewing awards from the American Geophysical Union (the latter jointly with the U.S. Navy), NASA's Exceptional Scientific Achievement award, and the George Woollard award from the Geological Society of America.

I am or have been a member or fellow of a number of learned societies and academies These include fellowship in the American Geophysical Union, the Geological Society of America, the Society of Exploration geophysicists, the Norwegian academy of Arts and Sciences, the Russian academy of Natural Science, and the Geological Society of India.

I have served on a number of national and international committees. While serving as the chairman of the JOIDES Executive Committee, I led the formation of Joint Oceanographic Institutions (JOI), which was instrumental in advising the academic deep drilling projects at sea. I served as the first president of JOI.

My career involved working with a large number of students and coworkers too numerous to detail here. Most of my scientific papers are coauthored with students and coworkers. Geophysics, by its very nature, leads to cooperative efforts. Clearly, a very large part of my success is owed to this very large group of people. I am even more indebted to my wife Anni and my family. In Anni I am fortunate to have a wife who always supported me in my career even at times when things were very tough for her. Field work in geophysics often involves long absences. Working weekends is useful for science but not for the family. Luckily, we all survived. Anni and I have been blessed with three wonderful children and eight even more wonderful grandchildren.

In my career I have been most fortunate in having opportunities that came my way, and having received the support of family, friends, students and many coworkers. R