Seismic Prediction of Possibility

By Keiiti Aki

Preface

An Indian tribe called Papago lives in a dry region of southwest America. The region is so poor that even a warlike neighbor tribe, the Apache, does not attack the Papago. The Papago people live by growing beans with rain water as it rains once in a while. It is said that, when they talk to each other, they sound as if they are laughing gently. The Papago men have to go on an adventure of any kind in their lives. Some men go to steal feathers from eagles' nest on a cliff. Others go across a desert to get a chunk of salt from the Pacific coast. However, adventures are not enough. They must put their adventures into songs and sing them in front of their people. If the song is accepted, the man's life is considered to be complete.

When I was a student, Seismology was not of social importance and it was, I would say, the poor land where the Papago tribe lives in a way. At that time, I ran into my neighbor on a train and the neighbor asked what I was studying at university. I still remember, when I answered that I was studying Seismology, the neighbor curiously looked at me in the face and said, "Well, it's good there is a person who studies something like that." I chose to study Seismology because I thought I could deal with nature that I have always liked since I was a child and that I could get along with geophysics for which I could use mathematics and physics, but for which I did not have to study biology. I was not good at biology as I had a poor memory. For 50 years since then, I have followed in the steps of the Papago and had some adventures. The purpose of this book is to put them into a song as the tribe does. If the song is accepted by everyone, my life will be complete.

When I was thinking in what style I would write this book, I recalled the book called "A Single Drop of Water in a Mighty River", written by Hiroyuki Itsuki, which my mother who is about 100 years old, told me to read. I read it again and thought that this book had not been written in the same style as usual autobiographies but that the author had written what was on his mind straightforwardly, and, consequently, what he had written became an autobiography. I thought this was exactly what I intended to do. The author and I are very different in terms of life experiences and the way of making a living, but we seem to have ended up in the same place at the end. I respect and adore many of people he wrote about in his book, such as Buddha, Lao Tzu, and Kukai. However, when I finished reading his book, I realized how happy I am to have spent my life as a scientist. Mr. Itsuki called the days when he had a hard time his "golden age"; the days when he worked in media his "bronze age"; and the days after he made his mark as an author his "fossil age", probably through modesty. As for me, I consider the present day to be my "diamond age" in my life. I am grateful for science because the fruits of work are built up to further broaden toward the end. In fact, I myself even feel as if I became an entire mighty river, rather than a drop of water. I attribute this to the fact that the nature of truth that people found before and after Galileo is different. What he discovered 400 years ago for the first time in human history is that mathematics can be applied to physical phenomena. Kenji Miyazasa wrote in his poem: "A tilt angle increases as the square of t" (I recently tried to find the original text of this but could not find it. It may be my verse that I wrote in imitation of Miyazawa). As a result of applying mathematics to physical phenomena, we can now accurately predict celestial motions. Scientific truths serve as humankind's heritage and bring benefits as long as we live. We tend to forget who discovered the truths in what way in course of time but discoverers are satisfied with the fact that they are connected (to the truth) for good. I hope to convey this pleasure of being a scientist in this book. However, when I think about the fact that this eternity depends on the existence of the human race, I feel empty.

Chapter 1. Possibility

The sun rises again into the blue sky over the Indian Ocean. It is not until I came here ten years ago that I realized the difference in the blue colors of the sky and the sea. I used to live near the beach in California for a long time but I had never noticed the difference until I came to this island, La Réunion, when I was 65 years old. I did not find the difference in the blue colors even in the song about a white bird wafting without being affected by the blue colors of the sky and the sea, which I had sung for many years.

The blue color of the sky is pure and that of the sea is sophisticated. This makes me think of the contrast between physical phenomena that can be understood by applying mathematics after Galileo and natural phenomena as it really is. Application of mathematics to physical phenomena makes it possible to predict the future accurately, which started with Galileo's ball rolling experiment 400 years ago. The reason why I started living in this volcanic island is that I wanted to try the seismic physical method to predict volcanic eruptions, which I have spent my whole life learning, in a place where volcanic eruption frequency is the highest on the earth.

I feel the presence of living nature in the blue color of the sea. According to Sari, who has taught me painting since I came here, the most difficult color is green. I think what she said is true when I see the green field in front of me. From young yellow to old brown, colors are intricately intertwined. However, these intertwining colors have harmonized over a long period of time and the blue color of the sea that I see now is placed between the blue color of the sky and the green color of the field in perfect harmony.

The source of magma of Piton de la Fournaise volcano on Reunion Island is also deep and old. It is said that the Deccan Plateau of India was yielded from the same source when India was connected to Africa a long time ago. Therefore, this is the most harmonious volcano that I can think of. In addition, this volcano is completely isolated from a geological point of view and it is easier to apply a physical mathematic method that has been learned from Galileo.

I decided to study Seismology because I was fascinated by the complexity and harmony of natural phenomena and I also thought that I should give up studying biology, as I did not have sufficient ability to memorize things, but that I could get along with geophysics. Thankfully, the subjects of the entrance exam for the geophysics course at Tokyo University are only mathematics, physics, and English. In those days, you had to take a risk to make a living as a scientist. My grandfather was a harbor engineer; my father was a river engineer; and my young brother is a dam engineer. I am from a family of engineers. Fortunately, my father was a man with political power and a broad vision who was involved not only with river engineering but also with natural resource issues in Japan, including natural disasters, by mobilizing many scientists. Before taking the entrance exams at the University of Tokyo, I hesitantly told him that I wanted to study geophysics. He said at once, “It’s good!” and I was very happy to hear him say that. This was about 60 years ago.

One day, when I was a student at the University of Tokyo, it suddenly occurred to me that my life purpose was earthquake predictions while I was standing absent-mindedly in the backyard of my geophysics classroom. I also used the term “earthquake prediction" for the title of this book. The other word "possibility" is something that warms up my life more than anything. "Possibility" means an uncertain future, not the bygone past that is already fixed. I first encountered this word when I was reading "Literature of Possibility" that Sakunosuke Oda wrote just before he died (when I was 17 years old). It is about a professional Japanese chess player who devoted his life to Japanese chess or *Shogi*. I can never forget this Osakan "King" who said "The Silver General is crying". The author, Sakunosuke, died young but his art was complete. This also holds true for another favorite author of mine, Zenzo Kasai. I believe that the words "possibility" and "completion" are the most delightful words that human beings have ever invented. When I had to make a speech as President of the Seismological Society of America 25 years ago, I could not come up with any idea as to what to say in the speech. However, once I decided that the title of the speech should be "Seismology of Possibility in the 1980s", I could think of all ideals smoothly. I could not put my thoughts together with the title "Possibility of Seismology" but, thanks to Sakunosuke Oda, I could organize them with "Seismology of Possibility". I realized how words, the best invention of humankind, work subtly. Another impressive work of Oda is called "Firefly", which is about a female owner of an inn for sailors in Fushimi, who sheltered *Shishi* at the end of the Edo period. Oda compares the samurai of the Satsuma clan, who died shouting "Stab him through me!" and Ryoma Sakamoto to fireflies. Since I began teaching at university, I have regarded my students as "my fireflies". As I have finally started feeling that I have completed my life in recent years, I would like to write about the way from possibility to completion in this book.

The first science book I read is Fabre's Souvenirs Entomologiques. I still have the image in my mind of a tumblebug (a kind of beetle) moving slowly along a country road under the midsummer sun. I went to a junior high school in Yokohama during the height of World War II and entered Mito high school after the end of the war. I was in the second last year of the old system. The high school was famous for its rough students. When the first year students entered the school, senior students asked them various questions holding bamboo swords in their one hand. The questions the senior students asked coercively were difficult to answer, such as "What did you come here for?" As this all day long barbarous ritual, called "Storm", went on for a week, it must have been an ordeal for the senior students, too. When I had to go through it, among other questions one of the senior students yelled at me asking what book I had read. I mumbled, "Fabre's Souvenirs Entomologiques" and another senior student gave me a kind smile. If I recall, his name is Sugiura and he made our dormitory song which I still remember. I recently visited a place on the outskirts of Tomobe, where there used to be the former basement of the Air Squadron, which was burnt out at the end of the war and then was temporarily used by Mito high school at that time but is now used for a psychiatric hospital. When I sang the dormitory song there, I could not stop crying. I have repeated the songs so many times for such a long time since I learned it that I might have changed the original song slightly. But the song has been engraved in my heart and brings me to tears. When I was in high school, I was engrossed in foreign literature except when I was in class and I discovered authors such as Hermann Hesse and Thomas Mann. Rural landscapes in Tomobe in those days matched well with their literature. Then Principal of Mito high school, Taisuke Seki, was famous as a scholar of German literature. I recall that I attended his special lecture about Goethe's Faust.

The French Entomologist, Fabre, did not believe Darwin's theory of evolution as he did not believe that anyone could create amazing harmonies in the insect world except God. But it is said that Darwin admired Fabre for his observation skills. The science book I used to read regularly other than Fabre is Wiener's Cybernetics, which was published when I entered the University of Tokyo. This book is not profound as Darwin's theory of evolution or Marx's Capital as it does not look into things from a historical point of view, but I was fascinated by the book that predicts natural phenomena with a mathematics model. I thought I wanted to introduce something new into Seismology in this direction. It is at that time that I decided to set myself a life goal of earthquake predictions.

As I wrote in the preface, around that time, I ran into my neighbor on a train and the neighbor asked what I was studying at university. When I answered that I was studying Seismology, the neighbor curiously looked at me saying, "Well, it's good there is a person who studies something like that." Back in those days, commuter trains were overcrowded and I learned how to flip the pages of books with one hand, holding onto an overhead strap in the other hand to spend one hour on the way to my university (Hodogaya in Yokohama to Ochanomizu or Okachimachi). I read Wiener's Cybernetics (thin, pirated copy) in that way. One day, the train stopped over Tsurumi River and did not start for a long time and then I had an odd experience. Troops, led by a seismologist, Beno Gutenberg, suddenly appeared in front of me and were fighting an earthquake disaster. It is then that I decided to be one of these soldiers in the troops. This was just before I set myself a life goal of earthquake predictions. Around that time, Gutenberg had just published a book about his most revolutionary study in human history, in which he and Richter who invented the earthquake magnitude scale quantitatively assessed earthquake phenomena all over the world. Ten years later I went to the California Institute of Technology as a postdoctoral fellow, where Gutenberg and Richter worked, and got to know them personally. At that time I was just considering how I could go beyond their perfectly completed classic seismology and came up with an idea of applying a model of statistical physics described in Wiener's Cybernetics to seismology, the result of which was summed up in my academic dissertation which seems to be still used even now about 50 years later.

I think I could understand the essence of science thanks to this academic dissertation. In science what you have to do as a starting point is to formulate a concept of a phenomenon that you are dealing with. It might be vague and broad but should become specific in steps. In my case it was something easy to which physical mathematics could be applied (we use the term "model" to call it). A concept of my academic dissertation was extending Wiener's time series model (one phenomenon is expressed as a time function) to the fourth dimension of time and space and using it as a model for various complicated seismic wave motion that were observed on the earth. I believe that this indefinitely broad concept contributed to the long life of this dissertation.

Once you have a concept, in the next step you make a theoretical prediction about the intended phenomenon based on a model you have decided to use. I dreamed of applying (my concept) to actually observing seismic volcanoes but it was impossible for a postgraduate student in view of Japan's economic situation at that time. What I could do is to examine something else called microtremor which was observed all the time in the backyard of my geophysics classroom (I knew it was caused mainly by traffic).

Firstly I decided to study a group of surface waves caused by the activities of traffic taking place everywhere as a model of microtremor. Once I made this decision, everything became easy. As the microtremor could be expressed by using Wiener's mathematical statistics model and its behaviors could be mathematized in terms of time and space, it became obvious what should be measured in order to test it. What I had to do was to examine correlations between fluctuations at different points by using two seismographs with respect to different frequency bands.

At that time I belonged to the laboratory of Professor Chuji Tsuboi and I learned how to make laboratory equipment from Mr. Yoshibumi Tomoda who became a member of the Japan Academy later. In the next-door laboratory of Professor Takeo Matsuzawa, Mr. Toshi Asada, who became Chairman of the Earthquake Prediction Committee（地震予知判定会）later, was studying microearthquake ahead of the world. So, at first, I borrowed a seismograph from Mr. Asada and then I made a special calculator to quantitatively determine correlations. I invested about $100 at the exchange rate of that time ($1=¥360; with this amount of money I could buy a bottle of delicious whisky called "Tory's") to purchase necessary component parts such as Dekatron in Akihabara which had already been the center of the electronics market, and then I made a device to automatically calculate correlation coefficients between the two seismographs. I made such investment money by doing a part-time job such as translation.

As I had to make the observations at night in order to avoid fluctuations caused by people walking in the neighborhood, I had my wife, Haruko, whom I had just married, help me. However, I found the isotropic nature of the microtremor soon and, therefore, I found out that I only had to observe one way. As a result, my research proceeded smoothly. I found out that the microtremor was a surface wave called "Love wave" and calculated the frequency dependence of the propagation velocity based on the observed correlation coefficients, and then I could infer a subsurface structure. Finally, I checked the inferred structure by digging a hole by myself to make a conclusion. Since then, this method that I described in my academic dissertation has been developed so greatly thanks to the hard work of Professor Hiroshi Okada of Hokkaido University, Mr. Tatsuro Matsuoka of the Center for Environmental Science in Saitama and other people that it can be actually used to help to predict strong motions. I secretly consider these people to be included in "my fireflies", too.

After I formulated my concept, it took me about one year to complete my academic dissertation. In the meantime, I believe, I learned the quintessence of science. Firstly, I started it by formulating a concept, based on which I created a model to enable a prediction. After that I found out what I should observe to test it and conducted the test. Finally I confirmed the results that I obtained in an independent way. It took me only a year to experience all these because the scope of my study was small, or narrow. Usually, if the scope of a study is broad, it takes long from beginning to completion and it is not possible to conduct it alone. This experience of writing the dissertation made me realize how important small things were. It is perhaps because of this that I still feel happy when I see small insects, small flowers, and young children.

My youngest daughter is six years old. Her name is Uka, which is a combination of "u" and "ka". A Chinese character used for "u" is the same as one used for the "universe" in Japanese and "ka" means "fire". "Uka" also means "eclosion". While Uka loves drawing pictures of many small flowers and birds, her 12 year-old sister Kajika (Japanese river frog; little frogs sing in chorus on the shores of a river) is good at mathematics and horse riding. I attribute my completion of science to my life with a mother of these daughters, who has been in charge of observing earthquakes at a volcano observatory on Reunion Island for the past decade. On the other hand, two sons (Zenta and Shota: 正太と善太) by my former wife, Haruko, were important to my life in America after I completed my dissertation. I would like to write about my fifty years of life which started with the possibility that I opened up in writing my dissertation and concluded with the completion.

Before I started writing the dissertation, I wrote about 20 theses in my early twenties, among which ones that still remain in my heart are divided into three groups. The first group is a summary of previous statistical research regarding earthquake occurrence. The second one is spectral analyses of earthquake records kept from the early twentieth century, which I was shown when I visited a latitude observatory in Mizusawa. The analyses were carried out by using a special calculator which was made by Dr. Toshio Ikeda of Fujitsu (his experience of fighting with IBM was made into a movie). The last one developed from the idea that a phenomenon of a seismic volcano can be regarded as a stationary process of transporting energy of the earth's interior.

The first discourse seems to be where a concept called "master model" was developed, based on which I established the Southern California Earthquake Center in later years of my life. The purpose of this center was to predict earthquake disasters stochastically based on all scientific data put together on earthquakes in Southern California. The germ of this idea was said to be first found in a comprehensive report of statistical seismology, which I wrote for a journal "Earthquake" when I was 25 years old. Back then, it was a rule in the Seismological Society of Japan that someone should talk about an overview of the current situation of a certain field every year. I was also given the topic "statistical seismology". Then I read about 200 related literary documents of all ages and countries, among which there was Conrad's 200 page long paper that is famous for the discontinuity inside the crust. The paper simply states that there is no regularity found in earthquake occurrence except what was discovered by a founder of the Seismological Society of Japan, Fusakichi Omori, which is that after a strong earthquake aftershocks occur that decrease with time.

As a result of my literature research, other than the law for the decrease of aftershock activity, I found out universally recognized successiveness of earthquake, or, in other words, once an earthquake occurs in a place, the place becomes prone to earthquakes in terms of time and space. However, what impressed me the most in this research was that various people had addressed the difficult issue of earthquake occurrence through various methods. As I thought I should not dampen the effort of those people, I systematically classified the methods and proposed the future direction for research by considering them all together. The same intention resulted in the establishment of the Southern California Earthquake Center in later years of my life.

The second group is a series of the research papers about a question of on what basis earthquake fluctuations spectrum are decided. I made a device to automatically calculate autocorrelation functions based on the old records written with soot and systematically and speedily examined how the spectrum was dependent on the characteristics of observation points, propagation paths, and earthquake magnitude. I asked Dr. Toshio Ikeda to make this calculator, who led Fujitsu to the heyday of its prosperity, by using a method of inferring the correlation function only with signs found by Dr. Yoshibumi Tomoda who is a member of the Japan Academy now. The telephone relay device was used to make it. When I look back now, I think what we did was revolutionary.

The old records that I used then were created by using the Wiechert seismograph of the Meteorological Agency and the Omori seismograph of the latitude observatory in Mizusawa. When I recently read a book about the discovery of spermatozoid of Ginkgo biloba, I found an answer to the question that I have had since I visited Koishikawa Botanical Gardens of the University of Tokyo about 20 years ago. Before this world-class discovery by Sakugoro Hirase, the first person who received the award from the predecessor of the Japan Academy is Hisashi Kimura, who studied latitude variation at the latitude observatory in Mizusawa, the countryside in the Tohoku region. The head of the observatory, Mr. Sugawa, kindly helped me to collect the records that had been kept for 50 years, which I took back to Tokyo to analyze. What I had found out from the results of the analysis deeply influenced my life of science. Put simply, a part of the spectrum of earthquake waves, which directly comes from a hypocenter, such as a P wave and an S wave is largely dependent on a propagation path, but the tail part of earthquake motion, Coda, which comes later is not affected by the propagation path anymore but is mainly dependent on earthquake magnitude. This is a starting point of my study on Coda waves, which I was not aware of at that time. As I enjoyed reading Kenji Miyazawa's book of poems "Spring and Asura" around that time, it was a pleasure to work looking at the scenery of Mizusawa which Miyazawa poeticized. When I think back of it, I still feel nostalgic.

The last part of my remaining work which I did before my academic dissertation aimed to apply the laws of physics and science in view of earthquake occurrence and volcano eruptions as a process of transporting energy and substances from the earth's interior. As I have been as interested in volcanoes since I was young as I have in earthquakes, I attended a summer school held at a tea house on the ridge of Mt. Asama by Professor Hisashi Kuno of the Geological Institute of the University of Tokyo and Professor Takeshi Mizukami of the university's Earthquake Research Institute. Around that time, when the second series of the journal called "Volcano" was decided to be newly published, new people in the field were asked to submit articles. The thesis of Dr. Kiyoo Mogi who is famous for his model of a spherical magma chamber appeared in the journal. I also wrote a thesis titled "Local Concentration of Magma as a Stationary Irreversible Process" for the same issue of the journal. In this thesis I applied a law that I found in a text book about the thermodynamics of irreversible processes written by a physicist, De Groot, (ドクルート) in view of volcanic phenomena as a process of transporting energy and substances. Before writing this, I also wrote a paper in view of earthquake occurrence as a stationary process of transporting thermal energy, the inception of which was initiated by Professor Takeo Matsuzawa's last work as a professor. It seems that I began to develop the habit of thinking earthquakes and volcanoes together around that time.

After that the assumption that the source of the phenomena of earthquakes and volcanoes is stationary on the time scale of the human society has been supported by the stationarity of plate motion and magma production in the mantle. In this respect I feel the basic possibility of deterministic prediction of earthquake occurrence and volcanic eruptions. As magma goes through various paths and rests at various chambers, an eruption phenomenon tends to be seemingly random. What is transported when a volcano erupts is a substance called magma but in the case of an earthquake, "seismic moment" is transported. This concept of seismic moment was developed some years

after I learned “Long-period seismology” at the California Institute of Technology after writing my academic dissertation. I will explain the inception of this concept later but it is simple but accurately shows the scale of earthquakes. It can be shared with seismologists in various fields such as geology, geodetic, damage investigation, old records, and earthquake engineering.
************* (I sent the above on 08-02-05, but I made some corrections later)

I first wished to work for the Japan Meteorological Agency following the completion of my academic dissertation. However, thanks to Dr. Setsuzo Miyamura at the Earthquake Research Institute, the University of Tokyo, I could start a research career in his laboratory. At that time, the Miyamura laboratory had a series of talented researchers such as Minoru Hori, Ken Tsuchiura, and Hideteru Matsumoto. With their help, I was given a chance to apply the method I had developed in my academic dissertation by studying microtremors to actual earthquakes. By the way, Dr. Miyamura’s first name ”Setsuzo” was given by his father who was the captain of two major battleships for the Japanese navy. Setsuzo inherited a Chinese character from each of those ships, “Settsu” and “Mikasa”. In after years, Dr. Miyamura was accused and held responsible for having stopped research functions of the Earthquake Research Institute for few years. Despite this incident, his contribution to seismology such as the invention of the world first wireless earth observation system, I believe, is something to be highly valued.

My first trial at the Miyamura laboratory was a tripartite observation in the yard of an elementary school in Kamakura. As I was surprised to experience the bewildering complexity of the seismic wave there, I chose to conduct the next experiment in Mt. Tsukuba, a longstanding observation site for the Institute developed by Dr. Takahiro Ogiwara. Mt. Tsukuba consists of uniform granite and the same seismic wave complexity was observed there. The same phenomenon was also discovered in the observations in Mt. Palomar, known for its observatory, when I visited the California Institute of Technology on the Fulbright scholarship. The finding that the same seismic wave complexity was observed both in a small island country like Japan and the American continent was quite surprising to me. At the same time, however, it gave me somehow a sense of relief to know that seismic crusts were commonly complex everywhere. I was then comparing the beach on a small island in the East Sea where my favorite poet, along with Kenji Miyazawa, called Takuboku Ishikawa played with a crab, with the vast land in California, which I was exposed to for the first time in my life after having travelled by a propeller airplane across the Pacific Ocean. I was then a twenty-eight years old man, who was so full of deep emotion.

In those days, the Japanese people were very poor and could not afford a television, refrigerator, vacuum cleaner, let alone a car. In America, I was equipped with all these items, which made my life completely different. Pasadena, where the California Institute of Technology was located, was an affluent, clean and beautiful place at that time. My modest apartment which cost me 75 dollars a month was surrounded by green lawns, palmettes and many other trees, and was a paradise for me. The owner of the apartment was a single aged woman. She was so kind as to treat me to tender ox tongue which I had never had before and thought was the most delicious in the world.

Every week, I oscillated between Mt. Palomar where the observatory was located and Pasadena to change the magnetic tape. The task used to take a whole day and I called the journey "Road to Pasadena". I have experienced a sudden encounter with a white horse in the deep mountain of Palomar on a foggy day. Although the road to Pasadena is now quite different from what it used to be after nearly fifty years, I sometimes visit there to enjoy the emotion evoked by the traces of the old days. As I said already, my favorite Japanese authors were Kenji Miyazawa, Takuboku Ishikawa, Sakunosuke Oda and Zenzo Kasai. In addition to them, I cannot forget the phrase I found in a novel of Masuji Ibuse, "Does emotion mean Sake?"（情緒とはお酒のことですか？）I was always comforted by Ibuse's poetry anthology "Yakuyoke Shishu". Strangely enough, I did not write a research paper based on the findings at Mt. Palomar. I think that it was probably because my study made a remarkable progress in the following year.

I spent the first year in California as a postdoctoral fellow under a professor called Dix (ディックスという教授) who majored in geophysical exploration. The opportunity was offered by Dr. Chuji Tsuboi and my travel expense was covered by Fulbright scholarships. My assumption is that Dr. Tsuboi gave me this chance because the method I had discovered a few years back to determine underground density distribution of based on the gravity data was useful for the lectures at some laboratories including that of a petroleum company Dr. Tsuboi delivered during his visit to America. It was the method I developed during the weekly seminars of the Tsuboi laboratory to configure underground density using the gravity quantified by the lattice point on the ground surface with a simple arithmetic calculation.

In those days, the Tsuboi laboratory was flourishing with the members including Dr. Hitoshi Takeuchi who later issued the science magazine "Newton", and Dr. Yasuo Shimazu who became a professor of Nagoya University and established various achievements. At a seminar, Dr. Tomoda raised a question regarding gravity. I provided an instant answer to his question recalling a theory included in an Iwanami kouza lecture book that I was as usual browsing in the train that morning. It was about the basic theory of electric circuit written by a physicist called Hidetoshi Takahashi. I was appreciated and encouraged by Dr. Tomoda's comment that I did not have to study for the next few years because I had already made an achievement. I felt then that this is real joy that one could get out of being a scientist

During the first year in Pasadena, I visited so-called "Seismo-Lab" which was the world leading center of seismology and there I came to know the authorities in the field including Gutenburg, Richter, Benioff and Press, an up-and-coming man, who just moved from Colombia University and became the head of the center. Seismo-Lab was then located in a suburb away from Caltech, in a gorgeous mansion which used to be a property of a rich man. The mansion was equipped with an elevator that gracefully brought you down to the garden with an orchard of orange trees and a tennis court. The observation point I set in Mt. Palomar belonged to "Seismo-Lab" and the people from the lab largely supported my study. I particularly remember the chief engineer named Francis Reiner (フランシス　レーナー) who kindly helped me there.

Back then, Dr. Press had just developed a method to determine underground structure from the Rayleight wave phase velocity, utilising the Seismo-Lab's observation network in Southern California. Working jointly with Ewing, he had just determined with the method the crustal structure of the United States. One day, Dr. Press took me to the data room at Seismo-Lab and showed the data of Long-period Rayleight waves he used to develop his method. I was surprised to find that they were by far simple in comparison with the complexity of Short-period wave I had experienced. The conversation I had with Dr. Press then was the most decisive experience in my life as a scientist. I asked Dr. Press why those scientific giants such as Gutenburg, Richter, and Benioff had never used phase velocity while they knew the existence of such simple data for a long time. Dr. Press promptly answered that it was because they had not believed in the theory.

Richter had just then completed a book humbly titled as "Elementary Seismology", which in fact contained full of observation findings which are still now very valuable. I found a piece of paper stuck on the door of his room ,which said, “You have your theories. I have my hypotheses. But they are just guessing”. Together with the words of Dr. Press, the message made me think of how deep and vast science was.

Thanks to Dr. Press, my stay in Pasadena was extended another year. I was given a room of my own and worked to determine the mechanism of seismic source by studying Long-period surface waves. At that time, some underground nuclear testings started and accordingly the importance of seismology was recognized for the detection. Observation networks were established and the state of art seismographs were set up all over the world. Such observation net works were above all important for my research activities. For example, the concept of seismic moment, which I will touch on later, was born out of the Niigata earthquake in 1964 captured by the network.

During my second year in Pasadena, I started to investigate on the mechanism of seismic source by examining Long-period surface waves. Therefore, soon, I joined the discussion of “single couple or double couple”, which was a major debate for the world of seismology back then. Scientists in the West had believed that an earth quake would occur by an earthquake fault and therefore they considered that the source could be explained by single force couple. However, Dr. Hirokichi Honda and his group at Tohoku University insisted that single couple could not describe the observation of S wave, and therefore double force couple that is a couple of two forces of the same size but facing opposite directions was more suitable. The result of my experiment with Love waves supported double couple. Around that time, I met Dr. Honda at an international conference in Canada and then he said to me “You finally started a real seismologic study”. Although his comment encouraged me, I realized at the same time that my previous studies based on statistic models had been off the mainstreams of seismology.

Looking back, I had repeatedly gone into and out of the mainstreams of seismology consistently throughout my academic life, which I think was the drive for me to introduce and promote new things. One needs to be in the mainstreams but should not keepstaying there. During my second year in Pasadena, I remember that I told Dr. Press that Short-period seismology was significant for an earthquake prediction, although I admitted the beauty of Long-period surface waves. The reason why I could freely move in and out of the mainstreams was probably because the world of seismology was still small and immature just like the world of the Papago tribe that I mentioned in the preface. And I leaned from Ethica of my favorite philosopher, Spinoza that being small and immature is a value for an individual with limited ability. After I returned to Japan with my first new-born son, Shota, in 1960, I continued in parallel the statistic research of local earthquakes by Short-period earthquake waves and the newly acquired deterministic research by Long-period surface waves.

Later, the "single couple or double couple" debate was put to an end by the theoretical studies of Dr. Maruyama and Buridge-Knopoff's, which argued that fault movement is represented by double couple force and faults are the cause of earthquakes. The impact and influence of their findings to the later development of seismology is immeasurably huge. When a seismic source is represented by double couple, the most basic physical quantity is represented by the size of its force, which is called seismic moment. Moment is represented by the multiplication of force and distance, and therefore it uses the same unit as that for energy; dyne centimeter in the past and currently Newton meter. Moment is proportional to the product of the dimension of a fault plane and the average displacement and the proportionality factor is the shear modulus, which is one of the crustal elastic constants. It was first successfully determined by the Niigata earthquake in 1964. The photo-optical records through the observation network implemented for the detection of nuclear explosions were gathered and they were quantified by the naked eye by Ms. Tatoko Hirasawa who was working under me at the Earthquake Research Institute as the secretary to an assistant professor, and the moment was calculated based on the crustal structure I had already known and the theory of surface wave generation. The result quantitatively supported that the earthquake was caused by movement on faults as the moment was in harmony with the fault area and the degree of displacement that were estimated by crustal movements near the seismic source and the observation of aftershocks. Since then, for forty years, similar results have been obtained in many earthquakes. It is now confirmed that an earthquake is caused by movement on faults, which now serves as the basis for engineering application in seismology.

When the Niigata earthquake which was the most important earthquake throughout my academic life occurred, I was away from Japan. I was then in Alaska for the observation of the aftershocks of the Great Alaska Earthquake which struck Alaska several months before, funded by the Japan-U.S. research cooperation project. The observation project was generously funded for a project of those days. The observation simultaneously was conducted with four vertical seismographs and a 3 Strain seismogram which were all transported by air to the Kenai Peninsula. We set up the instruments with a cable that ran a few kilometers, feeling afraid of moose and bears. I, Dr. Hori and Dr. Matsumoto from the Miyamura laboratory were together to cook our meals for ourselves and spent approximately two months to monitor and analyze the aftershocks, and marked the results with a pen on some rolled recording papers to report to Dr. Press. The major outcome of this observation was that the earthquake induced a deep aftershock sequence. It was surprising how the scientific cooperation was achieved by two nations, under the circumstances where the national income of America was incomparably big to that of Japan. Since then, I was invited to Fairbanks every summer by Dr. Nirendra Biswas, who is from India and became a professor at the University of Alaska later. In the1990s, the method we developed in California was applied to seismic disaster countermeasures of Alaska. Alaska thus became a memorable place to me.

As had been expected, the concept of seismic moment was born quite naturally as a result of the development of Long-period seismic observation and the relevant theories. When the concept occurred to me, I thought that it was so important that I had to write a thesis about it. However, in fact, I myself was not especially excited about the discovery. What I was by far excited about was when I found, after I returned from the United States in 1960, that the S-wave velocity structure of the crust and the upper mantle in Japan was slower by 5 % than that of America. I obtained the data for my analysis from the fifty Wiechert seismographs owned and placed nationwide by the Japan Meteorological Agency that successfully captured Rayleigh Waves from the Samoa shock which Dr. Press and Dr. Ewing utilized to determine the crustal structure of the Unites States(Those seismographs were established by Mr. Takematsu Okada (岡田竹松) who served for twenty years as the head of the Central Meteorological Observatory, the predecessor of the Japan Meteorological Agency, and were utilized as the basis of research conducted in the early 1920s by Dr. Kiyoo Wadachi to prove the existence of deep earth quake). I understood that the difference in the S-wave velocity structure was observed because the center of earthquake or volcanic activity called the mantle low-velocity layer was closely attached to the crust under Japan and I still have not changed my view about it. When I discovered this, I could not help but feeling something warm surging in my body. In cooperation with Dr. Katsutada Kaminuma who later became a professor of the Earthquake Research Institute, the University of Tokyo, the research was led to the discovery of the difference in crustal anisotropy from a phase velocity difference between Love Waves and Rayleigh Waves, which is now being recognized worldwide.

Having returned from Alaska, I started gathering the records of the Niigata earthquake from observation networks established all over the world. The earthquake in Niigata raised people's interest in earthquake prediction. I was asked by the Iwanami Shoten publisher to contribute an article to the forum in the magazine called "Science". Two years before then, a research work titled "Prediction of Earthquakes: Progress to Date and Plans for Further Development" was published by a group of scientists including Kiyoo Wadachi, Chuji Tsuboi and Takahiro Hagiwara, who played a central role in the work, which later became a world-renowned work as a "blueprint" for earthquake prediction research. In the forum, I emphasized the difficulties of earthquake prediction by comparing it with medical diagnosis, and gave three reasons.

First, the structure and conditions of deep underground where an earthquake occurs are not yet precisely explained. Observations on the ground surface are the only way to know about the earth interior and it is difficult to know clearly about the microstructure. Predicting an earthquake without knowing the microstructure is, in the medical sense of the term, something like trying to find out a cause of a disease just from external observations without knowing internal organ functions or the locations of blood vessels and nerves. Under such circumstances, you may put a hypothesis for a cause of an earthquake and try to prove the relevant theory from observations only to allow room for various unhealthy imaginations.

Secondly, a big earthquake is extremely rare to happen. If a big earthquake strikes one region as frequently as once a year, even without fully understanding the cause, we may be able to find out certain regularity in the phenomena that repeat. One reason why certain types of volcanic eruptions have now become predictable is because they erupt frequently. Indeed, scientists do try to find regularity in recurring phenomena, and it is absolutely impossible for them to wait for something that takes place only once at most in their life time.

Thirdly, observations for predicting earthquakes require a substantial amount of budget and labor. Regardless of whether crustal movement or microearthquake, an individual laboratory at a university is way too small to conduct a full scale observation even if a small area is chosen to be observed, and even if a young researcher has some ideas, he or she cannot conduct an observation independently to test his or her hypothesis. Indeed, an observation for earthquake predictions requires the involvement of a large organization and such institutional observations inevitably tend to be administrative and lack in flexibility which is an essential element for any academic studies.

The research paper I wrote forty years ago came back to my mind thanks to Professor Kenshiro Tsumura who now plays a major role in consolidating earthquake information and conveying it to the public. Looking back, I spent the last 40 years to overcome those three challenges. Shortly after the completion of the paper, the theory that an earthquake was related to fault motion was quantitatively provided, by which "quantitative seismology" that directly helps seismological engineering kicked off, and consequently the revolutionary theory of plate tectonic which explained the cause of earthquakes was developed. However, none of them fully answered the three questions. I remember when I met Professor Toshi Asada of the University of Tokyo who was then promoting studies on earthquake predictions at an international conference in Durham in the United Kingdom, he said a fault model would help earthquake prediction more than the plate theory did.

I believed that earthquake prediction that was reliable and catered to the public would not be realized unless the above mentioned three challenges were solved. Therefore, I first started with solving the first challenge. The outcomes are, as is described in Chapter 2 of this book, the studies on seismic tomography and coda waves which I conducted when I was in Boston. I faced with the second challenge, which is described in Chapter 4, when I migrated to la Reunion where I learned the basics of scientific forecast from predictions of volcanic eruption. I worked on the third challenge when I was in Los Angeles, which is described in Chapter 3, and examined there the idea of Master Model. Chapter 5 gives a comprehensive view from these experiences and draws the conclusion that earthquake predictions can be established on the solid ground of science.

I also participated in a meeting of the group to develop the Blueprint for earthquake prediction research which was established in 1965. I could not help but suggest that we should take up microearthquake as a research item in addition to crustal movement, the main topic of the project then, as Professor Toshi Asada, the father of microearthquake research, who was present there but remained silent. I explained that data from microeathquake research was essential to understand underground microstructure and delicate phenomena occurring there and that, because microeathquakes frequently occurred and its frequency band was wide, they were important as a source of information. I recall that my suggestion was accepted and included in the Blueprint thanks to Professor Hiroshi Kawasumi, who supported my suggestion from a different view point that we should consider energy balance between large and small earthquakes. Data of crustal movements by a geodesic method were dominantly collected from near-surface phenomena and phenomena happening in the heart of the earth were often unknown. However, I was sure that seismic waves could potentially tell us what was happening deep inside the earth and I still now believe so. My belief was also supported by what I learned from Claude E. Shannon's Information Theory which I came to know around that time; the fact that the amount of information was proportional to a frequency band width and a signal length.

What was more directly useful for me than Wiener's Cybernetics or Shannon's Information Theory was Wilks' Mathematical Statistics translated by Masami Ogawara of Meteorological Research Institute. I met Professor Ogawara in person and was taught various things by him. In one of my long-lived theses, I wrote about a method of estimating the b-value, or a parameter which shows dependence of earthquake frequency on magnitude by the maximum likelihood estimate and I think that I learned the basics of it from the Wilks' book. Thanks to that, I was able to make the acquaintance of Cornell who developed a statistical method for estimating earthquake damage and Robinson who played a major part in digitalization of earthquake monitoring in Massachusetts Institute of Technology (MIT) in later years. I, who tried to apply Wiener's theory to predictions of natural earthquakes, enjoyed conversation with Robinson who used the same theory to interpretation of artificial earthquake records for resources development just around the same time. I also owe it to my understanding of mathematical statistics that I was appointed as a chairperson of a committee for examining a statistical method for estimating earthquake damage by American Academy of Science when I moved to the University of Southern California (USC) from MIT as mentioned in Chapter 3. The result of this also led to the conception of the master model which became the guiding principles of the Southern California Earthquake Center (SCEC).

Thus, I gradually started to plant seeds for future development before entering my thirties. The soil on which they grew was my family and Earthquake Research Institute of the University of Tokyo, both of which are quite rare in the world.

I was born on March 3rd, or a day for the Peach Festival, in 1930, which can be written in numbers as 03-03-30 according to the Western calendars. The place where I was born is a house built by my grandfather Kyoichi in Sakuragaoka, Hodogaya, Yokohama. My grandfather is one of the pioneers in harbor engineering in Japan. After completing the reconstruction of Yokohama Port hit by the Great Kanto Earthquake of 1923 (12^{th} year of the Taisho period) as his last work, he retired from his official job and built a house for his post retirement years on a hill looking down over the new port he constructed. According to his two-volume biography titled "50 years of spring winds and autumnal rain" a government office building where he worked as Director, fortunately escaped the disaster and accommodated 300 employees including their families. After working consecutive days and nights for a month, a ship came alongside a pier and the reconstruction work was completed within a year.

Though this grandfather's house was attacked with 50 firebombs and burned during World War II, My father built a house in the same place. I spent my university days in a room next to my grandfather and grandmother's room in the house. My grandfather loved to read out Yojokun by Ekken Kaibara. The most memorable part of it is a phrase, "Enjoy life whenever you can. Rid your heart of worries." Comparing this with a western thought that orders us to keep Christ's cross and distress in mind, I have repeated this phrase again and again. It makes me think of the difference between serious looks of western sculptures in museums including Louvres and Pu-tai's smiling face.

Looking back on my life at the age of 75, it was full of fun without pain. As a result of working hard at a factory when I was a junior high school student, I had fatigue neuralgia and I still have rheumatism which makes my legs joints hurt and swell. It, however, makes me unable to walk for a while, stops daily repeated life and creates some opportunities for me to give birth to new ideas. I therefore appreciated this rheumatism instead of hating it. Mr. Matsumoto who went to Alaska to observe aftershocks together with me said, "Aki never falls without turning everything into profit." As falling makes some turning points, it is as important as going in and out of the main stream as mentioned before.

I think that the only smile that you can see in Western museums is that of the Virgin Mary except Mona Lisa. I first encountered the Virgin Mary when I read an art collection book titled "the Annunciation" in my father's study room. I was so impressed to know that there was such a beautiful woman in the world. The impression has persisted until today. When I read a book titled "Pilgrim of Eleven-headed Kannons" written by Masako Shirasu recently, I had the same impression. I have met the Virgin Mary and the Goddess of Kannon everywhere in the world for the past 50 years. From the viewpoint that both of them have given the gentlest mercy to people in the East as well as in the West, I think that these two are the same personage.

Another important thing I discovered in my father's study room is the complete works of Shakespeare translated by Shoyo Tsubouchi. While I became familiar with ones translated by Koson Fukuda and the originals in later years, I am always impressed with the width, depth and complexity of the world created by Shakespeare. I read Macbeth the most repeatedly. I think that I was fascinated to learn something supernatural such as witches. Another supernatural thing that I can think of is Mephistophelean who appears in Faust written by Goethe, which is also one of the books I have repeatedly read. Though the Virgin Mary and the Goddess of Kannon are also supernatural, they represent goodness compared with badness represented by witches and Mephistophelean. As Lao-tze says, goodness and badness are both indispensible to each other and it is both of them that make it interesting and profound to live as a man in this world.

What is noteworthy about my grandfather is that he equally gave all his boys names that end with "ichi" (which means "the first son" and is usually used for the oldest son's name). All my four uncles, their sons and my male cousins have names that end with "ichi". My younger brother Shuichi is not an exception. I think that my grandmother Kono (耕野) agreed with my grandfather about this as she was ahead of her time in that she came from Aizu-Wakamatsu by herself to go to Joshi-Shihan, the precursor of Ochanomizu University.

My grandfather, who was from Tokushima, worked his way through the third High School and the University of Kyoto. I heard that he had never failed to eat Sukiyaki on his birthdays although he was poor at that time. I remember that, even half a century later, in those postwar days my mother still invited around 30 relatives including my uncles, aunts and cousins to treat them to Sukiyaki on my grandfather's birthday, the 4th of February. I think that this annual event must have been very hard for my mother because the uncles were so fond of sake.

Though my surname Aki is so rare that it is hardly found even in a phonebook of Tokyo, I found that it was a common surname in Aki city of Kochi in the Shikoku area when I was invited to the University of Kyoto and visited the city during my free time around 1990. Then I found the Aki Shrine and a tragedy of Kunitora Aki who was enshrined there. The tragedy was described there as the history of the shrine, according to which he was defeated in the attack by the neighboring powerful families, asked them not to kill his family in exchange for his own life and committed *seppuku*. When I read a line saying that Kunitora let his son(s) go to Tokushima in secret, I thought about a relationship between the son(s) and my grandfather, being filled with a deep emotion. I heard from my younger brother Shuichi that this relationship had recently been certified.

According to the history of this shrine, Soga-no-akae, sa-daijin (minister of the Left), was transported to Tosa after being defeated in Jinshin disturbance in 672. His descendants called themselves Aki and Kunitota committed seppuku on the 7th of August, 1569. In later years I found out that Soga-no-akae made his two daughters empresses and I felt a little proud about his relationship with the Imperial family. In the morning before I went out for a trip during which I found the Aki shrine, I encountered Enmei- Jizō Bodhisattva by the side of the railway crossing in Obaku, Uji where I was staying, and read that Kobo-Daishi climbed this mountain when he was two or three years old and said the three words of heaven, earth and intellect. When I visited Muroto-misaki (Cape Muroto) where he called himself Kukai (meaning the sky and the sea) after visiting Aki-city, I encountered him for the second time. Just around the same time I visited the holy place in Koyasan (Mount Koya) he created and found a grave of Seitaro Izui (出井清太郎) in the forest of ciders aged 600 years old. He reported to the government as a prophecy that the army and the navy would take over the politics and that it would turn into a full-scale war in the future and was arrested for violating the Peace Preservation Law in the second year of Showa. It was written on the tombstone that when he found out that his mother had died, in the Ichigaya Prison on the 16th of March in the year of Showa 11, "Today I found that my mother had died without expectation and cried until no tears were left."

I believe that one of the reasons why this inscription impressed me was risks associated with making a prediction about the future. I had the same impression when I saw the Laocorn sculpture in Vatican, Rome. He predicted the danger of the Trojan horse that appeared in the Trojan War, which angered the Goddess Athena. As a result, he and all of his sons were bitten to death by a constrictor. His painful expression when dying in agony was not somebody else's problem for me whose life purpose is earthquake predictions. I think that it is because of the risks related with the predictions that I have evaded the media. I cannot stand it if researches on earth predictions for human beings make my whole life miserable.

Next to my family, the Earthquake Research Institute, the University of Tokyo was also important as the soil where my seeds grew and the benefits given by it were precious. This Institute, established by Kyoji Suehiro, an authority of naval architecture, in collaboration with Torahiko Terada, a top intellectual figure and physicist of the day in Japan, brought engineering, physics and geology together. When I started to work, Professor Kioshi Kanai was conducting basic research of strong ground motion based on microtremors and observations obtained in the deep underground of the Hitachi Mine. Another thing that is unique about this Institute was that it conducted research not only on earthquakes but on volcanoes. Back then Professor Takeshi Minakami was involved with eruption prediction of Mount Asama. Thanks to this, immediately after the program of the Engineering Department in NSF for strong ground motion predictions and that of the Energy Department for geothermal heat development started a few years after I moved to MIT, I participated in both of them and educated many students, invited efficient scholars from abroad and also invited (researchers) who paid their staying costs at their own expenses. These two programs were run for 20 years and not only served as a financial resource for my life as researcher in the United States but also created a great atmosphere where many talented visitors from all over the world interacted with each other. If I had not left Japan, I could not have achieved all these things. I became an American citizen in the ceremony at the North Church with a long history in Boson in 1976 when America celebrated its 200th anniversary as a nation. I felt a sense of freedom and a great feeling of release in the U.S. which I could not in Japan in those days. I thought that this was a benefit brought about by political thoughts by Washington, Jefferson and Lincoln.

Chapter 2.　The first escape

I believe that it is important for anyone to get out of a certain situation just like a snake casts off its skin in order to grow up as a person. After leaving the privileged post as an associate professor of the University of Tokyo, I moved to Boston with my ex-wife Haruko and my elder son Shota in the summer of 1966. When we arrived at San Francisco on our way to Boston, we were forced to stay in California for a while because all the airline companies were on strike and we were told that there were no rental cars available. I could therefore directly observe the fault caused by the Parkfield earthquake which had just occurred. This earthquake is the second most important for me, following the Nigata earthquake, as it is a starting point for strong ground motion predictions and the coda wave theory.

However, when you make an "escape" from a certain situation, you have to sacrifice your family. My mother told me just recently that she had cried for three consecutive nights after hearing about my decision to leave Japan. As my father was, however, at the very apex of his career in those days and even a photo of my family was posted on a magazine, Sunday Mainichi, I was not worried about my parents. As for my second escape from Boston to Los Angeles as mentioned in Chapter 3, I left two sons behind in the East Coast. I wasn't, however, worried about them, either, because they were already independent then. Though I had to divorce my then wife Haruko for my third escape from Los Angeles to La Réunion mentioned later in Chapter 4, I was in my golden age at that time and it was economically possible to do so. As mentioned in the last chapter of this book, these three escapes were imperative to the completion of my life as a researcher and that it seems nothing short of a miracle that I could achieve all of them.

In around 1966 when I made the first escape, there was a large income gap between Japan and U.S. and a tenfold monthly salary increase was also tempting. When I told Professor Hagiwara, then Director of the Earthquake Research Institute, about my decision to go to the United States, he said that Mr. Tsuneji Rikitake, who was trying to promote an earthquake prediction program, would be disappointed. Mr. Toshi Asada said, "Five years would be enough," and I understand that he wanted me to come back in five years. Professor Kiyoo Wadati, who happened to be visiting the Earthquake Research Institute, was kind enough to encourage me by saying with a big smile, “Sounds very promising.” I was informed from Dr. Press that Professor Hisashi Kuno whom (I) had met in an international conference around that time had said that my escape was heart-breaking. The escapes were not easy to be achieved and the later in life I made the escape, the larger its complex impact became.

After arriving at Boston, we started to live in the suburb called Newton. In the first year, we lived in a rented house. Carl Sagan’s ex-wife lived on the opposite side of the street, with whom we got acquainted after Shota became a friend with her child. In the next year, we bought a house with five large oak trees in the backyard and moved to the house where we lived for 18 years. As many Jewish families lived in the area, there were good schools for children. Shota made his mark as a football player in his high school days. My second son, Zenta, had a drawing talent, which led him to an opportunity to draw a large wall painting of a monster in a restaurant of his high school and he ended up making a living as an artist.

My first job in MIT was to give a lecture titled “Advanced Seismology,” for which I made preparations until 2 a.m. every morning. Though my class room was full of students on the first day, only five of them remained after three months. In the next year, it was only Ken Larner who formally registered. When I was invited to Chile by Armando Cisternas in the summer of 1970, I handed out the mimeographs of the lecture memos that I prepared for the lecture in MIT to students from all over the South America. I was also invited to a good beef steak place, San Juan, Argentine, and gave a lecture to seismologic engineers on strong ground motion predictions with fault models. When I started to talk, there was a roomful of audience but when I finished talking, I found that only two remained. After I had these two experiences, I stopped worrying about the number of audience and how others thought about me. I was convinced that I had found a new truth which would contribute to the betterment of all human beings.

Among those I met in Boston, the people that I cannot forget are Norman Haskell and Francis Birch. Both of them are unusual in that they themselves attended symposiums that were held in honor of their own lives as researchers while they were still alive. It was at a meeting of the Seismological Society held in Arizona in 1959 when I encountered Haskell for the first time. It was the first opportunity for me to speak in English. After I found out that a dignified man sitting in front of me at the lunch table was Norman Haskell by reading his name plate, I couldn’t eat anything anymore. His researches on coefficient of viscosity within the earth and Francis

Birch's researches on the lower mantle with the finite strain theory made a striking impact on my school days.

Seven years after my first encounter with him, I visited his office in Boston accompanied by Dr. Press in 1966 and met him there for the second time. No sooner did I meet him than the man of few words said to me, "126 atmospheres of pressure" with a smile. I was glad to know that he acknowledged the way to estimate stress drop on the fault plane of Niigata earthquake from seismic moment. The above-mentioned argument about on which was appropriate, "single-couple" or "double-couple" was resolved with the theoretical research of 1963 by Mr. Takuo Maruyama and that of Burridge and Knopoff in 1964. Though Haskell was skeptical of the matter at that time, his thesis was useful to derive a relational expression between seismic moment and a fault model parameter as I incited in my thesis on Niigata earthquake.

The third encounter with him occurred at my office in MIT. He explained that, after reading the preprint of my thesis which explained records of strong ground motion obtained near the fault plane during the Parkfield earthquake by using the Maruyama theory, he derived the same result by using a different method and asked me whether he should publish the result or not. I answered that he should definitely do so but I found out that the major problem that he had then was that he could not write computer programs by himself and that he could not trust his programmers. In any way, his method was taken over to Mr. Hiroo Kanamori and errors on the program were also corrected. It is now a serious problem for me that it becomes increasingly more difficult for me to cope with computers as I grow older.

The last encounter with him occurred at Huskell Symposium organized by Nafi Toksoz, one of my colleagues at MIT. At the dinner party many people admired his work on surface wave dispersion while few of them referred to his work on the earth source theory, which he slightly complained of in his speech at the end of the party. He died of cancer after about a year.

Francis Birch's symposium was much larger than that of Norman Haskell and researchers in a variety of fields came to Harvard University from all over the world. It was at a seminar in Harvard that I saw him for the first time. Though no conversation was made between us, I happened to sit behind him. I was admiringly looking at his bold head, thinking that it was the brain that was capable of bringing an understanding of the density distribution of the lower mantle based on the finite strain theory, and then I remembered that the model properties were spatially homogeneous. I realized that geophysics was one field of applied physics and that a simple model was required to use a method of physical mathematics.

It is Chapter 1 "Introduction to Seismology" of "Seismological physics", the 8th volume of Geosciences Lecture Series published by Iwanami Shoten that I wrote by reviewing the history of evolution of seismology after that incident at the symposium enlightened me. Though the title was given by the editor, Mr. Kanamori, I wrote the chapter with all my heart because I believed that this title would lead to Discourse on Method by Descartes. Starting from Robert Murray who considered that the seismic source of an earthquake was a point in the middle of the 19th century to a fault model, I stressed the importance of a simple model to which the laws of physics can be applied in order to understand a seismic phenomenon. This was praised by Professor Tuzuki who is a geologist and one of the editors for the Lecture Series.

The second encounter with him occurred at MIT. When I complained that research purposes were limited if I tried to obtain funds for educating students and that as a result freedom of thoughts indispensable for the development of science would be lost, he immediately answered that one could freely conduct researches even under such conditions in an institution like MIT. It was true just like he said. The last encounter with him occurred when he was almost 80 years old. When I sent to him the preprint of my treatise on seismic wave attenuation, he pointed out my obvious error (I doubled a certain figure which I should have halved instead), which I felt ashamed of.

When I worked at the U.S. Geological Survey (USGS) in Menlo Park in the summer of 1967, When I read the records of aftershocks to the Parkfield earthquake obtained through an epoch-makingly dense, two-tiered aftershock observation network having high-sensitivity and low-sensitivity, which was installed by Jerry Eaton, I found that the records of the spectrum of coda waves in the tail portion for the same earthquake were the same at different observation points and that those of different earthquakes were also the same at the same observation points. This confirms the findings on coda waves obtained from the above-mentioned records of Mizusawa and represented the starting point of the notion that coda waves were scattered waves from small-scale heterogeneity that was distributed widely and deeply in the lithosphere. When I told Eaton about this, he wondered with the same smile as Haskell's why I was concerned with the matter which nobody would be interested in. This is how this ended: after receiving a referee comment that "this can be published but nobody would read it", it was published on the Journal of Geophysical Research (JGR) in 1996 and became one of the most long-lived theses of mine.

Around the time when I wrote this thesis, the subject matters of my research were based on a deterministic approach, including the inverse problem of reflected waves with Jerry Wear and Clint Fraisier, researcs on free vibrations of the earth with Raul Madariaga and Jorge Mendiguren, precise continuous observations of seismic wave velocity by using an artificial seismic source with Tom DeFazio and Paul Reasenberg, research on the seismic source process of earthquakes and underground nuclear explosions by examining surface waves with Yi-Ben Tsai, the effect of discordance of discontinuity planes within the crust on seismic waves with Ken Larner. I considered that this thesis on coda waves would be my last work in the area of statistical research on local earthquakes.

Just at that time, however, I started a work to survey digital records of a large-scale earthquake observation network named LASA (Large Aperture Seismic Network) which had been installed in Montana in order to monitor Russian nuclear explosions. I found that seismic waves from a source distance of 1,000 meters away propagated like a cloud instead of forming an individual clear wave pattern and wondered if I could apply the statistical approach used for wave propagation in random media which I had read about in Chernov's book. As this book was difficult for me to read alone, I read it with students as a seminar course. To understand the book, we first started reading a book on waves in layered media written by Brekhovskikh, which we also used to understand difficult theses such as those written by Esherby and Kostrov. At a symposium held for celebrating my retirement in USC in March 2000, I was delighted to know that these seminars had become a starting point for my students' lives as researchers.

Be that as it may, by applying Chernov's theory I found that the underground of Montana was heterogeneous in the depth interval of around 10 kilometers down to 100 kilometers deep. Though we can confirm the existence of heterogeneity by applying the statistical approach, we cannot determine its spatial distribution. The belief that this heterogeneity exists, however, gave origin to earthquake tomography that uses data showing that the P wave arrival time depends on both of an observation point and a seismic source for the purpose of determining the three-dimensional structure of the lithosphere in an earthquake observation network center in Norway that is similar to that of Montana in the summer of 1974. This approach to confirm existence by applying the statistical method and then examine the details with the use of the deterministic method was applied to a variety of matters thereafter.

During my visit to Chile in the summer of 1970, I found it fun to make a speech in public and experienced the taste of wine for the first time. As a result, I not only regained the weight I had lost because of lectures for MIT but also drastically gained weight. I consider that gaining weight results from a mysterious mechanism of internal organs and that it is good. This visit to Chile was made as a result of the intention of Armando Cisternas to make Chile University a seismology center in the South America. The visit was made at just the right time as I was 40 year old and was thinking that I had fulfilled my duties as a professor of MIT. As mentioned before, the mimeographs of the lecture memos for students from all over the South America served as a starting point for "Quantitative Seismology" coauthored with Richards. Unfortunately, however, as Cisternas was so left-wing that he even gave a lecture on Marxism, he was forced to leave Chile after the collapse of the Allende government in 1972 and a seismology center in the South America disappeared. Still, I can't forget that I was told by him that he found the Marxian dialectic in my thesis.

During this visit to Chile I was invited to a meeting of the Physics Society held in Conception and gave a lecture on the theme "how to measure crustal stress". I still cannot forget that a cat was on the roof of my hotel in the previous night and I wrote in my diary, "Sound of rain in Conception, oh, it's the cat's meow." The theme of this lecture was what I was most interested in in the early years of my teaching career at MIT. By combining the two above-mentioned studies: the precise continuous observation of seismic wave velocity by using an artificial seismic source and the seismic source process of an underground nuclear explosion by using Love waves, I tried to measure the San Jacinto fault stress with Tom DeFazio, Paul Reasenberg, and Amos Nur in the summer of 1969. As this was a large-scale experiment and the experimental site was located at the bottom of a deep valley, it was necessary to protect a machine called caterpillar which was like a tank in order to drill a bore hall for explosion and we also needed to buy a large plastic swimming pool to provide water to an oscillator which was controlled by a crystal watch manufactured by Tom and powered by water pressure. Also, in order to fill it with water, we had to go to Los Angeles to find a four-wheel-drive water tank truck. As I wrote in detain about this experiment in Bulletin of the Seismological Society of America (BSSA), this experiment was a total failure for the purpose of measuring the crustal stress. I realized that even in a place like MIT what a research group could do was limited and that a large-scale natural phenomenon could not be grasped by carrying out an artificial experiment. Since then I have made it a rule to take a passive approach to passively study a natural phenomenon such as coda waves. I did not mention this failed experiment and mainly talked on Love waves caused by a large-scale nuclear explosion at the meeting of the Physics Society held in Conception. I cannot forget either that I was treated to a bowl of sea urchins after this lecture. I think that only people in Japan and Chile eat sea urchins with relish.

During my second visit to Chile in the summer of 1972, I examined coda waves of local earthquakes and was surprised to find that its attenuation was obviously longer than that of California. Soon after that visit, when I visited Japan and examined the records obtained from a spectral analyzing seismograph developed by Mr. Tsujiura in the Earthquake Research Institute, which kept continuous records of seismic wave spectra by dividing them into octave bands, I could confirm that the attenuation of coda waves found from the aftershocks of the Parkfield earthquake was not dependent on the earthquake or observation point. On my way back to Boston I reported this to Eaton and proposed to examine the attenuation of coda waves in the San Andreas fault zone. I dubbed my visiting trip in that summer as "triangle trade" in my diary of that time after the historical event in which people in Africa were captured as slaves and used for planting sugarcane in Caribbean islands, which was used to make rum in Boston. The trip was significant for my life as a researcher. During my visit to Norway in 1974, I found that attenuation of coda waves of local earthquakes there was one digit slower than those of Japan and California and had a firm belief that this attenuation parameter coda Q was closely related to the crustal earthquake activity rate.

At that time, Bernard Chouet, an aeronautic engineering student in MIT from Switzerland, changed his major to volcanology, which might have been due to the economic recession, and was looking for a theme for his academic dissertation. As he immediately understood my idea on the attenuation of coda waves, I asked him to examine the records obtained through Mr. Tsujiura's spectral analyzing seismograph installed in the San Andreas fault zone and wrote the results in the paper of 1975 on the JGR, which became a starting point for the coda wave theory. Strangely enough, most of the students who were in the regular course of seismology did not like studying coda waves. Those who played a major part in the study on coda waves such as Chouet or Mr. Haruo Sato, Professor of Tohoku University did not take such a course. I believe that it is important to go in and out of the mainstream for the development of science.

When the U.S. earthquake prediction program was launched in 1973, I wrote a proposal that mainly consisted of the measurement results of coda Q in San Andreas fault zone. In those days, themes such as the dilatancy theory and Vp/Vs ratio were at the center of discussions and, when I attended the first examination committee, I was disappointed to find that my proposal had been eliminated because it was not considered to be related to earthquake predictions and wrote in my diary after this examination committee, "My life tuned out to be a failure. I have tried a variety of methods for 7 years in MIT as I believed that it was important to understand that the crust microstructure first in order to predict earthquakes but I went the long way around." However, among the ideas that were proposed then, I think that it is only coda Q that still survives.

Back then, however, I never thought that coda Q would be of any direct use for earthquake predictions. It was about 10 years later when I met Anshu Jin and heard of her experience before the Tangshan earthquake that I thought of the possibility. It was when I merrily chatted with students in a room at the Geophysics Research Institute where there was a blackboard which read, "Welcome to our Institute, Professor Aki," during an international conference in Beijing that I met her for the first time. When she told me that she had been surprised to know that a magnitude measured by the amplitude of a microearthquake and that measured by coda duration had shown an unusual difference before the Tangshan earthquake in 1976, I began to consider that coda Q would be of direct use for earthquake predictions. Around that time, Gusev's thesis which stated that coda Q had indicated an extraordinary fluctuation before a big earthquake in Kamchatka also supported the idea. Anshu, Professor Haruo Sato, Gusev and Chouet were very important for the next 20 years of my life as a researcher.

It was in the summer of 1985 when she interpreted a series of my lectures for which I spent a month traveling from Beijing to Yunnan that I met her for the second time. As there were no air conditioners at hotels in Beijing at that time, I could not stand the heat in the hotel room and warm beer while I enjoyed receiving strong reactions to my lectures from Chinese seismologists. Then the plan to create a distribution chart of coda Q for all areas of China was made and it was carried out by Anshu. I wrote a paper about the result of this and provided it to BSSA, which is still a source of fresh ideas for me though 20 years have passed since then.

During my visit to Norway in the summer of 1974 which represents a starting point of earthquake tomography, I enjoyed the nature by fishing and picking mushrooms with my family in Karihaugen on the outskirt of Oslo, where there were many wild beautiful flowers growing. On my way there, I attended an international conference on theoretical geophysics held in Cambridge, UK and gave a lecture on the Chernov theory, the coda wave theory and their applications. What I still remember about the conference is Freeman Gilbert's remark, "Seismologists are happier than meteorologists because the former can explain everything with a linear theory." When the Loma Prieta earthquake occurred in 1989, I found from seismic records the nonlinearity of strong ground motion on the ground which geologists had discussed for a long time, by means of an integrated method using all of my previous research results on three effects of seismic source, propagation and ground. Then I wrote a thesis coauthored by James Chen for BSSA. As a matter of course, however, reactions from seismologists at that time were negative and it took 10 years for my idea to be finally accepted.

On my way to Karihaugen from Cambridge, I crossed the sea by ship, stayed at Gergen, a town of fiords, visited an aquarium where all the fish seemed happy and enjoyed music composed by Greek which I had long been fond of when I heard it on the train crossing over a mountain. In the first morning when I sat on the corner of a room in a modest barrack in Karihaugen, Eystein Husebye gave me a table indicating that the arrival time of P wave depended on an earthquake location and observation point. Looking at it, I immediately thought of the possibility of the three dimensional structure of earthquake tomography. I came up with the idea as I had had the belief that the three-dimensional heterogeneity existed as stated in the Chernov theory and learned that, even though there were many parameters of models, they could be dealt with a tool called resolution matrix in an inverse problem course in MIT which I had just started with Ted Madden.

As Eystein understood the importance of this idea, he improved a computer program which I had made and invited his friend Christoffson, a Swedish statistician to join our research team. As Christoffson was very skeptical of the damped least-squares method, it took about two years to reach an agreement. However, owing to a variety of discussions, after the thesis was published in the JGR in 1977, it was called the "ACH method" (standing for the initials of three of us) and cited as a persuasive method. I used to think that there was no point in arguing, but this experience taught me that argument was important for the development of science.

This idea, born in Norway in 1974, was applied to the data analysis of the California earthquakes conducted with Willie Lee of USGS in the following summer and became a starting point of a problem unique to local earthquake tomography, that is, a problem of determining a seismic source parameter and a structure parameter at the same time. During this visit, starting from Boston I drove across the American continent with a sailboat mounted on my car, having a great time in Canadian lakes sometimes. This was the second trip for me to drive across the continent. As for my first trip in 1968, it took about 10 days to drive across from Boston to San Francisco, during which I succeeded in quitting smoking by repeatedly swimming in motel swimming pools and drinking whisky after that, though I used to smoke three boxes of cigars every day by then.

Willy Lee came from Hong Kong. When he was young, he went to Canada alone and starting from high school, he took a degree in San Diego, California. I recently found that one of his examiners for his academic dissertation had happened to be Ruby (ルービー), who was a famous author of a thesis coauthored with Herbert (ハーバート) on the cause of a large slide along a vertical continuity plane within the crust. When he came to Japan as a consultant of NSF at that time, he provided funds to support Mr. Maruyama's postgraduate life and give birth to a classical thesis on seismic sources of earthquakes.

After that, Willie invited all my group members including students to a seminar he held in Menlo Park in the summer of 1980. Though I emphasized the importance of coda Q when I gave a lecture at that time, USGS did not accept it. The next significant encounter occurred in 1992 after the Landers earthquake, when he assisted me with my research on seismic waves captured by the Yongon Lee fault zone. By installing many seismographs which he had developed, I was able to make use of a system that kept digital records.

While my life as a researcher in MIT was thus proceeding smoothly, I sometimes felt hideously desperate with no reasons. When I was taking a walk in a large, quite cemetery in Newton in order to avoid feeling desperate, I said to myself that I had been born for the purpose of making seismology happy and beautiful. Then I started to devote myself to "Quantitative seismology", which I coauthored with Richards. When Richards agreed to work as my co-author, I thought that I could enter the mainstream of seismology at last. Though I could not complete anything alone and always needed someone's help, I made many cordial friends instead.

The theory on a seismic source process which was important for my life as a researcher in MIT was first developed by Mr. Ida who now plays a leading part in volcanic eruption predictions in Japan. The next person is Mr. Hamano who played a leading part in renovating an earthquake prediction program in Japan after the earthquake which occurred in the south part of Hyogo in 1985. Thanks to these two people's visit to MIT, I could found a clue to conduct a theoretical research with Shamita Das on seismic waves which were generated from an uneven fault plane. The result of the study was developed as a barrier model in an academic dissertation by Apostoros Papageorge, an earthquake engineering student, and applied to predict strong ground motion caused by earthquakes. Recently, at a ceremony where I received the Bowie Medal, Tom Jordan said that working together with a variety of people was like linked lines of a Japanese poem, *haiku*.

Chapter 3 The second escape

Chapter 4 The last escape

Chapter 5 Completion

Afterword

The sun sets again, letting the Indian Ocean lying beneath gray clouds shine golden.

Note

This unfinished autobiography was originally written in Japanese by Kei Aki in 2004. Here, we translated this in English with help of a translator, because many people ask us. This translation may not be accurate, especially in the yellow parts. If you find something wrong, or have a comment, please send a mail to the following address. Thank you for your help.

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