In this issue we feature memoirs of a geophysicist who made many outstanding contributions to exploration geophysics.

Dr. William S. French was president of the Society of Exploration Geophysicists (1992-3) has been a university professor and a senior manager in both a major international oil company and several geophysical service companies. He is an Honorary Member of SEG and received the OTC 2000 Distinguished Achievement award for: "outstanding leadership in developing and commercializing 3D data processing technology to make 3D seismology practical, affordable and essential in offshore exploration and development."

Then *Now*

Bill French

Do it yourself

I was born and raised in the farmlands of Iowa. If a piece of equipment broke down in the field you didn't phone the repairman, a supervisor or a team specialist – you solved the problem yourself. I developed a keen appreciation for a creative solution to a problem.

My interest in science was kindled by my High School math and science teacher, Lee Smith. He had a gift of letting students see how math, chemistry and physics worked. It was all very practical. It was all very interesting. I was hooked!

In the fall of 1958 I enrolled in Iowa State University (ISU) to study math and physics. In order to pay for my education I worked summers in a foundry and as a truck driver. During the school sessions, I worked at odd technical jobs for professors in the Physics Department. I recall sitting for hours punching numbers into a Friden motor driven mechanical calculator. This was my first encounter with a "computer". Inside that Friden was a maze of gears. Division was performed by subtracting the divisor until underflow occurred, backing up one step, shifting the residual dividend by one decimal place and repeating the process. The machine would whir and click for over a minute to produce a square root.

I was using the Friden to calculate the trajectory of electrons in the ISU synchrotron. After making the calculations on the Friden, I plotted the results by hand. We transitioned to making the calculations on the ISU Cyclone Computer – a huge auditorium-size vacuum tube computer constructed at ISU using the design of the Illiac at the University of Illinois. Input and output was on punched paper tape. The memory was a bank of cathode ray tubes each displaying a grid of dots which were read by a vidicon tube. The year was 1962.

This experience with early mechanical calculators and early vacuum tube computers gave me a keen understanding of how complex mathematical computations could be broken down into a series of incredibly simple operations.

From A to Z via earthquakes

In 1962 I received a BS degree in Physics from Iowa State University "on time and under budget", as I would subsequently learn to recite. Graduate school beckoned and I accepted a Teaching Assistantship in the Physics Department at Oregon State University (OSU).

One day during my second year in graduate school, I was taking a break in the Physics Department coffee room when the office supplies started rattling on the shelves. The rattling increased and then the room started moving around. "Earthquake" said Professor David Burch. I had never experienced an earthquake in Iowa and I found this a slightly panicking situation. Fortunately, the motion stopped after a few seconds and that was the end of the earthquake. It turns out that the effect on me would last for years.

I went directly to the library to educate myself about earthquakes (remember, the personal computer, the Internet and Google were not even vague ideas in 1963). While much of earthquake seismology was descriptive, there was a very rich body of mathematical and physical research on the subject – it was quite interesting for a classical physicist. Earthquake seismology and geophysical research in general were being conducted at OSU in the Oceanography Department by Dr. Peter Dehlinger and Dr. Joseph Berg. Peter Dehlinger accepted me as a PhD candidate in geophysics. At the start of my third year of Graduate School, I switched from physics to geophysics. I went from **A**lbert Einstein to Karl **Z**oeppritz via earthquakes!

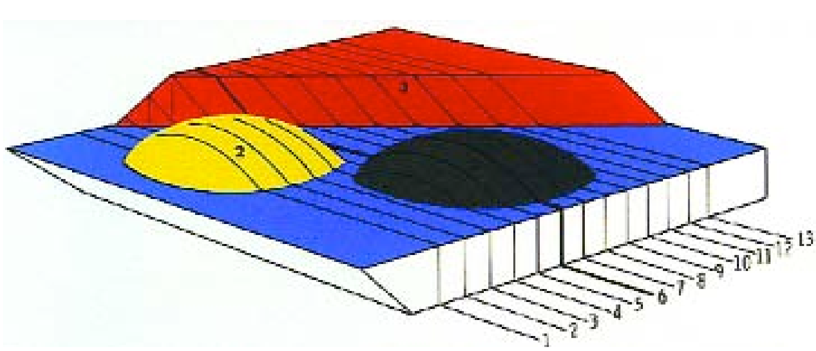

Figure 1. Model used to test the 3D survey concept.

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Gollyology

In my third year in graduate school, I found myself taking an eclectic mixture of graduate and undergraduate geology courses. Dinosaurs, crystallography, meteors and mountain building – this was grand stuff! I was also interacting daily with research geologists. I discovered an interesting phenomenon. Mathematicians and Physicists prove an assertion by manipulating symbols according to a very small number of very specific rules. One starts with the given and arrives unambiguously at that which was to be proven. Geologists, on the other hand, declare something proven if they can cite a critical number of experts who have published the same opinion as theirs. I see physics and geology as the two end members of science. Geophysics is somewhere in between. Geophysics was the lifeline that I used as I plunged from the stable platform of Newtonian simplicity into the complex uncertainties of the real world.

Use every data point

In 1965 OSU and Scripps Institution of Oceanography conducted a joint seismic refraction survey over the Juan de Fuca Ridge off the coasts of Washington and Oregon. New theories of sea floor spreading, magnetic striping and plate tectonics were swirling around us and the two institutions were making their contributions. I was a scientist onboard the OSU vessel and spent time at Scripps analyzing the data. I recall Dr. George Shorr saying that it was possible to explain every single wiggle on each refraction record. Coincidentally, a short time later, Dr. Peter Dehlinger, my major professor at OSU, suggested that I try to explain every event for the first 10 seconds on earthquake recordings. That suggestion formed the basis of my PhD dissertation and, as I would learn later, displayed a fundamental difference between academia and industry. Every data point tells a story in academia but exploration geophysicists in industry throw away 90% of the stories by muting, filtering and stacking!

By using 3D earthquake radiation patterns and calculating travel times and amplitudes for reflected and converted waves at the earth's surface and base of the crust, I was able to generate model seismograms which closely matched actual seismograms. A significant parameter I had to vary in the model to match actual seismograms was earthquake depth. Thus, I was able to determine earthquake depth by using any seismic recording stations within the range of about 150 km to 1000 km from the earthquake. Prior to that, one had to be very lucky to have a seismic station in the near vicinity of an earthquake (<50 km) in order to determine its depth. This rarely occurred except in very specific locations such as southern California.

All of this earthquake modeling was very three-dimensional, required a lot of interpretation, used details of earthquake seismograms which were normally ignored and required a great deal of numerical calculation. Fortunately, I had access to the OSU IBM 360 computer. The IBM 360 series was introduced in 1964 and was the first mass produced electronic computer. Before that, all computers were individually designed. We used machine level language to program the computer via punched card input.

Instant family – an incentive to get a job

In 1967 I met a wonderful girl. Circumstances had left Marilyn a single mother with five young children. I fell in love with the whole family. Before I met her, Marilyn had worked nights as a waitress in a Chinese restaurant to support her young family. At the same time, she studied at OSU to be a math and science teacher. While working and caring for her family, she earned a four year teaching degree in three years – "under time and under budget" – I liked that!

We were married in 1968 when I was in the last stages of my thesis research. I now had significant family and financial obligations so I started interviewing for a job with the intention of going directly to work and doing the actual writing of the thesis at night.

Gainfully employed

Dr. Edward J. Mercado hired me as a Research Geophysicist at Gulf Research and Development Company (GR&DC) in Harmarville PA, just north of where Gulf Oil had its headquarters in Pittsburgh. Ed hired me at the PhD salary scale with the understanding that I would finish my thesis within a year on my own time, which I did.

Oil company research centers were wonderful institutions in those days. Their mission, as best I could tell, was to: "study anything

Figure 2. Hans Thurnheer and I about to set off on recording the first marine 3D survey.

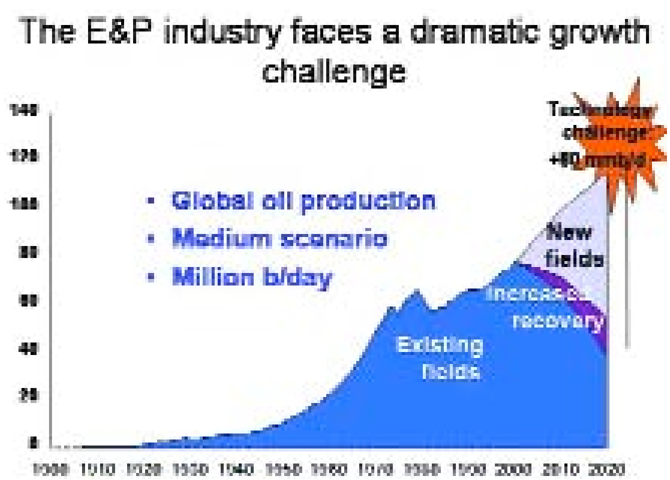

Figure 3. The E&P Industry faces a dramatic growth challenge. What R&D projects would you propose to meet this challenge?

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which may have a future impact on the company". Dr. Mercado was an expert in digital signal processing and while he gave researchers in his group specific assignments, he always encouraged us to come up with projects on our own. I became interested in digital migration of seismic reflection surveys using computers. Because of my thesis work, I always viewed geology and seismic waves as three-dimensional (3D). I was having a hard time understanding why Oil companies were taking a two-dimensional approach to the problem.

Don't ever say "never"

Gulf had developed an Experience Broadening Course where operational people came to GR&DC to take short courses from the research staff. I taught part of the signal analysis course and had the opportunity to have informal discussions with a lot of exploration people about my idea that 3D was needed. Someone would always ask: "how many times has this been done?" When I replied "never" the discussion would end. The message I got from the exploration people was unanimous:

They felt they were getting everything they needed from their conventional seismic surveys.

- They didn't need 3D surveys!
- They didn't want 3D surveys!
- They wouldn't pay for 3D surveys!

In 1969 very few decision makers, with the exception of Ed Mercado, thought 3D seismic reflection surveys could ever be performed in the field. Even as late as 1985, an internationally respected research geophysicist (name not to be revealed here) stated that 3D did not provide anything that 2D surveys could not provide.

Models to the rescue

About the same time I arrived at GR&DC, a new PhD scattering Physicist, Mike Marcoux, also joined Mercado's research team. Scattering physicists also think in 3D so Mike and I did a lot of brainstorming together. We decided that if we built an acoustic model laboratory, we could demonstrate the pitfalls of 2D and the benefits of 3D in a very simple way. I took the approach of extending conventional 2D surveys to the third dimension. Mike took the approach of introducing scattering theory ideas into

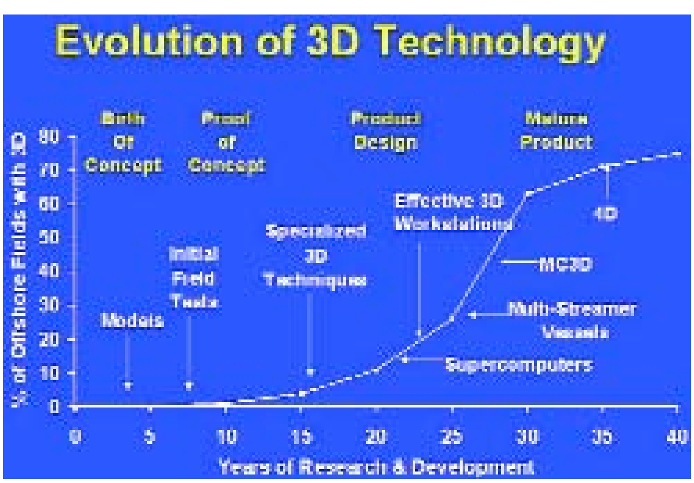

Figure 4. The evolution time-line of 3D technology.

exploration seismology. An electrical engineer, Dr Terry Matzuk, was brought in to help assemble the equipment.

The modeling system we built consisted of a water tank about a meter on each side. Scale models of geologic structures were suspended on fine wires in the tank and pulse-echo reflection surveys were digitally recorded using small transducers to create and record the sound pulses. The model geometry and recording format mimicked conventional seismic reflection surveys. The scanning mechanisms allowed for the recording of 2D or 3D data above the models.

One of the silicone rubber models I designed is shown in Figure 1. This model was 12 inches long, 12 inches wide and about one inch thick – it scales up to a geologic feature 2 miles long, 2 miles wide with about 500 ft of vertical variation in height. Both 2D lines and a 3D survey were recorded over this model. Both 2D and 3D migration were performed on these data sets using a new computer system GR&DC had recently purchased from Electro-Magnetic Research (EMR). It took 55 hours to generate each vertical slice of the 3D migration result.

Needless to say, the 2D result gave an incorrect picture of the model while the 3D result gave the correct picture. I finally had visible proof that 2D seismic surveys gave the wrong picture of the geology and 3D seismic results gave the correct picture. Off I went with these results tucked under my arm to the New Orleans exploration office to get funding for an actual 3D survey in the Gulf of Mexico.

Speak for yourself

There are three kinds of people you have to convince in order to get funding for a new technology. First, you have to get the people doing the work interested in using your technology. Second, you have to get the technical advisors to approve the credibility of the technology. Third, you have to convince the money men. Three completely different arguments are required for these different groups.

The Regional Geophysicist (RG) bought into the plan based on the model results. Fortunately, I was considered the technical advisor so no problem there. The RG said he would take the proposal and model results to the Exploration Manager (the money man). I told him I didn't think the Exploration Manager would connect with model results (never let someone else make your arguments for you). Instead, we both went to see the exploration manager. We didn't show him any data or maps. I just told him that the maps his people were using to choose drill sites around salt domes were wrong and that our research has shown us how to record seismic data to give accurate maps. He asked the RG if this was true and the RG said that it appears to be the case. The exploration manager approved $200,000 for a 3D survey. The whole conversation lasted 15 minutes.

Looking back it is hard to imagine that it was necessary to spend several years to get an "obvious idea" funded. (If someone asks you: "has it ever been done before?" don't answer, it may set progress back several years.) However, in 1970 we were not looking backwards at something that was obvious – we were looking forward into the unknown. There were very few of us at that time who understood the physics behind computer imaging of seismic data. An additional major obstacle was that interpreters had to change the way they did their jobs.

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Even today, these human factors have not changed. You have to spend as much time making your ideas look simple as you spend making them look difficult! Industry will not willingly accept new ideas no matter how good they are.

The first modern marine 3D survey

With the backing of the New Orleans Region, we acquired the first modern marine 3D seismic survey in 1974. By the phrase "modern 3D seismic survey" I mean a 3D survey designed with proper spatial sampling and aperture to be imaged using 3D migration algorithms on a computer.

I designed the proposed 3D survey over South Pass Block 62 as a scaled up version of the water tank model survey. Hans Thurnheer was the navigation expert on the project and Thomas Watson was the data acquisition/processing coordinator. We contracted the seismic vessel American Delta II from Seiscom Delta. Thurnheer and I met the vessel in Morgan City, LA (Figure 2). We had chosen a Cubic Autotape system operated by John Chance & Co as the ship positioning system. This was a range–range system with transponders mounted on suitable existing production platforms in the survey area. The output from the positioning system was plotted in real time on a mechanical pen plotter. The idea was to pre-plot the desired seismic lines for the 3D survey and then have the helmsman steer the vessel while watching the pen plotter so that the real time plot of the actual ship location followed the desired pre-plot line. The captain did not want that contraption in his wheelhouse but after we threatened to cancel the contract he conceded. Since vessels respond very slowly to the rudder, the first few ship lines were wild oscillations about the desired ship line. The helmsman's learning curve lasted one day after which he could track the pre-plot line quite accurately.

The position of the ship as determined by the Autotape system was also output on printed paper rolls similar to cash register receipts. We determined the position of the seismic streamer relative to the vessel by simultaneously recording the ships compass reading and the azimuth to a radar reflector on a buoy at the end of the streamer. These readings were written by hand about every minute on forms prepared for the purpose. Back at the processing center all of these rolls of Autotape paper, hand written forms and geometry of key points on the ship (navigation antenna, streamer tow point, etc.) were translated to punched cards and input to the computer to determine the position of each shot and hydrophone group. Incidentally, during all of this, GR&DC was transitioning to yet another computer system – one of the Univac models.

The processing of the 3D survey took over a year. The processing group had to learn many new tricks and even one of the best computers of the day was not up to the task. As a result, this first 3D marine survey did not play much of a roll in the initial development of the field. However, publication of the model results and general industry knowledge of this survey really started the 3D ball rolling. Unlike many other large oil companies of the time, Gulf Oil permitted early publication and conference discussions on its 3D research.

Academia (sort of)

As with many young scientists in industry, I often thought of returning to university life. At the precise time when my mind was pondering greater possibilities, Professor Richard Couch, Head of Geophysics at Oregon State University, offered me the position of Associate Professor of Geophysics. Oblivious to the difficulty of the task offered, I accepted. To make a long story short, I was involved in writing and submitting research proposals to some 25 funding agencies during my first year – in addition to hosting visitors, preparing lectures, conducting research and, in general, counseling and trying to keep ahead of brilliant graduate students. I tip my hat to all those academic heroes who keep the system working. As for me, I headed back to industry.

Marvin Hewitt hired me in the position as head of a newly created marine research group at Amoco Research Center in Tulsa, OK. Just doors away were the most innovative people I have ever worked with. To name a few: Sven Treitel, Ken Kelley, Ray Sanders, Rusty Alford, Mo Arnold, Larry Wood, and John Shanks. These were the good old days!

From Amoco's research center, I went to the New Orleans Region first as Regional Geophysical Technical Advisor then as Head of the Geophysical Department. In these positions (during the late 1970s), we invited service companies on several occasions to bid on the design, acquisition and processing of proposed 3D surveys.

I was puzzled that contractors were content to shoehorn 3D processing into their 2D processing software using oversimplified assumptions. I saw the opportunity to do things right but concluded that it required getting out from under the inertia of a large corporation.

Tensor

I resigned from the best job in Amoco to start my own company – Tensor Geophysical Service Corporation – with the purpose of writing a 3D software system to handle real world 3D surveys. My two partners in the venture were Jake Noullet and Richard Zoll. We purchased our first seismic processing system from Digicon, who financed the transaction by holding 90% of the shares of Tensor. Because we had to meet payroll every two weeks, we offered a high-end 2D processing service while we developed the 3D software. After three years, we fulfilled the Digicon financing terms and became 100% owners of Tensor.

We were fortunate to hire a brilliant mathematician, Wesley Perkins, who was employed as a welder at one of the shipyards near New Orleans when he interviewed with Tensor. With my hand waving on theory and Richard Zoll's hand waving on seismic operating systems, Wesley wrote the majority of the software Tensor used. We used various versions of VAX computers driving array processors manufactured by Floating Point Systems and Star Technology. We also developed seismic operating systems for Cray XMP and YMP computers and Intel i860 and Paragon massively parallel processing computers. Dr. Naide Pan and Dr. Julian Cabrerra contributed significant applications programs from tau-p transforms to steep-dip time and pre-stack depth migration algorithms.

Tensor had a great staff at all levels and expanded very rapidly for a technical company. It wasn't always easy though. During a

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particularly difficult downturn in the industry, we developed within a three month period unique interpolation techniques that allowed us to process dense 2D networks of seismic lines as a 3D survey. This type of innovation kept us in business. Technical developments were judged on the basis of what someone would pay for them. We learned to take a "grand vision" and break it down into steps where each step would make money in the short term while taking us to the "grand vision" in the long term – a simple formula for success!

Over all, Tensor was technically and financially very successful. However, we constantly had to upgrade our computer systems to implement our technical developments and to process the ever increasing amount of data being recorded in 3D surveys. Tensor was a closely held corporation and, as such, the three owners had to personally guarantee all of the loans required for the computer and other purchases. As the majority owner, I took on the lion's share of guarantees. After about a decade of having these huge loans hanging over our personal finances, we sold Tensor to Grant Geophysical in 1990.

Grant Tensor

Grant Geophysical was basically a land seismic acquisition company, and had just been awarded the largest land 3D contract ever offered at that time. Because they had no track record in 3D processing, Grant's 2D processing center was not chosen to process the 3D survey. Bud Grant purchased Tensor to fill this void and I was elected to Board of Directors of the combined company.

Bud had built Grant Geophysical by acquiring a number of very competent seismic acquisition companies (United Geophysical, Seiscom Delta, etc.) He viewed his company acquisitions as "brand names" which could be revitalized to take advantage of the emerging 3D market. Using this concept, he had successfully raised the needed capital through an Initial Public Offering just prior to purchasing Tensor. Again, to make a long story short, the various land data acquisition divisions of Grant Tensor (as it was renamed) were not able to deliver the exponential growth in land 3D that Bud had envisioned and were not recording enough traces to keep Tensor's supercomputers busy.

Bud turned to a strategy of combining Grant Tensor with one of the larger oil service companies. At the time there were no takers. Unbeknownst to the rest of us, Bud had been diagnosed with lung cancer during this period. Within three months of the announcement to his senior staff that he was ill, Bud passed away. He worked full days up to a week before his passing.

The Board of Directors of Grant Tensor named me Chairman, CEO and President to succeed Bud. The disparity between data acquisition capabilities and data processing capabilities continued. Petroleum GeoServices (PGS) a new player in the marine 3D data acquisition business submitted an offer to purchase the Tensor part of Grant Tensor. The sale was approved and I left Grant to run the Tensor processing company under the PGS umbrella. Grant Geophysical was left in good financial shape and was once again the proper operating size for the existing seismic market.

PGS

PGS was a new company and there were no legacy issues. Reidar Michaelson (Chairman and CEO of PGS) and Bjarte Bruheim (President of PGS) were excellent businessmen and provided the technical subsidiaries with all resources required to do their jobs.

In the early 1990s, 3D surveys were taking over a year from design to interpretation. The typical scenario was as follows. The marine acquisition crew put the seismic data on one set of tapes which they sent to the seismic processing center. The raw navigation data was put on another set of tapes and sent to navigation experts – often a separate company. Eventually, the processing company would merge the final shot and receiver locations with the seismic data. On every 3D survey I can recall,

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there were sporadic discrepancies between the navigation results and the seismic data once they were merged. The processing company would send inquiries to the navigation company. The navigation company would send inquiries to the acquisition crew which by then was off on another job. This cycle took place for every discrepancy. It was a nightmare! My solution was to get all these people in the same place at the same time to solve the discrepancies. This could be accomplished only by getting everyone on the marine acquisition vessel (at the time, satellite data transmission to a common location was too slow to work). In 1993 we placed Tensor's massively parallel processing computers onboard seismic vessels and for the first time had the capability of full state-of-the-art 3-D processing while data were being acquired. This meant that navigation reduction and all quality control steps were done in (almost) real time. It proved successful and drastically cut the time for full cycle 3D surveys.

With PGS Tensor running smoothly, I went over to PGS corporate as Vice President of Geophysical Technology. When we decided to expand our operations into the Asia Pacific region in 1995 I went to Singapore as President of PGS Asia Pacific covering an area from Pakistan to Japan and from Sakhalin Russia to Australia. My objectives were to introduce PGS services throughout the region, identify opportunities and start contract negotiations for the various PGS operating companies. I lived on airplanes and sat hat-in-hand in the waiting rooms of many government ministers! However, I was still implementing the lesson I had learned many years earlier – to be successful, you had to sell your ideas and products at all three levels.

Retirement (almost)

Within two years PGS Asia Pacific was on track to becoming a major profit center for the corporation, but emergency phone calls on a 24 hour basis from operations or from corporate financial people were not what I had in mind for myself at that stage of my career. I arranged to return to the Houston headquarters as Senior Executive Vice President with the understanding that I would be retiring soon. On July 30, 1998, I retired and became a consultant to the Chairman of PGS. My main duties as a consultant were to attend conventions and maintain contact with PGS clients for the sake of continuity.

In late 2001 I accepted a six-month position as the Haydn Williams Fellow at Curtin University of Technology in Perth, Australia. I was attached to the Geophysical Department for obvious reasons with the expectation that I would also interact with the School of Business because of my background in starting and heading several corporations. In fact, during my short tenure at Curtin I published a paper titled "Oil Company – Contractor Relationship" with Economics Professor Harry Bloch and his student Jo Voola.

I actually had only two directives in the position. First, I was to present the Haydn William's Lecture to a university-wide audience upon my arrival in Perth and, second, I was to keep Haydn William's name before the public – Haydn Williams was an eminent educator in Western Australia and a champion of Curtin University of Technology. Dr. Williams had been retired some years and passed away the year after my tenure.

The theme of my lecture was woven around the facts depicted in Figures 3 and 4. The projected discrepancy between worldwide oil consumption and the production decline curves of existing fields provided a great challenge for Exploration and Production technology. We need to find new fields and to increase production from existing fields. I posed the rhetorical question: "If your boss brought this diagram (Figure 3) to you and asked what research or technology should he invest in to solve this future problem, what would be your answer?" I then pointed out that it takes about 30 years for a major technology to impact our industry. I used 3D technology (Figure 4) as a specific case since I had traveled that path, but other technologies in our industry-such as Measurement While Drilling (MWD), Floating Storage and Offloading Ships (FPSO), horizontal drilling and sub sea trees along with eleven other technologies had, on average, this same 25 to 30 year evolutionary time frame.

With my wife Marilyn, I went on a lecture circuit to all the sections of the Petroleum Exploration Society of Australia (PESA) asking my rhetorical question. In April of 2002 we returned to our retirement home in Durango, Colorado.

My contributions have ended, but what are you doing about this problem?

Final thoughts

In the above paragraphs, I have mentioned over eleven generations of computers. Each successive computer was considered a significant improvement in throughput and cost/trace for seismic data processing. For those of you just starting out in this industry, the computer you are using today is the equivalent of the old mechanical Friden I used 47 years ago. The computers that will be available when you retire (and I doubt that they will call them computers) will have unimaginable capabilities. Keep this in mind when setting your career goals. Don't let yourself get stuck in the old-fashioned technology of 2006! R