ASEG Oral History – Ken McCracken

Ken McCracken 2005

Introduction

This file contains a transcribed copy of an oral history interview of Ken McCracken conducted by Bob Smith and Joe Cucuzza on 21/07/2021.

The interview objective was to record Ken's life and career with particular emphasis on his contribution to, and perspective on, developments in exploration geophysics during his lifetime.

Ken has been active in many aspects of physics during his career but his main connection to geophysics, and particularly exploration geophysics, was as initial leader of the CSIRO Division of Mineral Physics which conducted many collaborative projects with industry through AMIRA during the late 1970's, 80's and early 90's.

Prior to the interview a list of proposed questions was sent to the interviewee and agreed to so that he could prepare responses.

The interview was conducted via ZOOM and transcribed by Microsoft Word. Both interviewers and the interviewee were able to edit the final document before its' release.

Bob

Question 1

Please tell us a bit about your background. Where you were born and educated and how you became a physicist/geophysicist. We are mainly referring to the period from your birth to the end of your formal education, but you could even go back before your birth and describe your family background if you wish to. That's over to you.

Ken Thank you Bob. It's my great pleasure to be able to engage with ASEG and AMIRA in this way. Great idea. My family background might explain how a space scientist happened to even think about going into the mining industry. On my mother's side, my great grandparents were Germans who immigrated to Australia after they failed to strike it rich in the California Gold Rush. They ended up running an antimony mine in Queensland, east of Gympie. My grandfather was a Scottish underground shift boss in the Gympie gold mines until he died in the flu epidemic of 1919. So I have always understood that mining was an important part of my history. So now to me. I was born in Brisbane. My father was a Scottish accountant who came to Australia when the Glasgow shipyards shut down at the end of World War One. He had left school at 12 to earn money to keep the family and went to night school and qualified as an accountant.

He was employed by the Australian Taxation Department and his job meant that we moved several times during my school years. I attended primary schools in Brisbane, Melbourne, and Canberra, secondary school in Canberra and Hobart. So, I became very adept at change. Nothing like that frightened me. Somewhere along the line the arithmetic of the various departments of education got a bit mixed up and I ended up matriculating near the top of the state at the age of 16 years and one month. The University of Tasmania refused to take me at that age. So, for a year I was the "laboratory boy" in the research department of the Electrolytic Zinc Company on the outskirts of Hobart. I had always been a bit of an experimenter and that gave me great scope for various things that the EZ Co didn't expect me to do. For example, there was a huge explosion in a derelict processing building when I built a rocket that didn't work. Somehow, both EZ Co and I survived, and I went on to the University of Tasmania in 1951.

I had always been keen on chemistry. With the encouragement of my father, my plan was to become a chemical engineer, in all probability in the mining industry. However, mischief was afoot. I was awarded the mathematics prize in first year mathematics and used the prize money to buy a book called the "Sourcebook of Nuclear Physics". It described all the things that people like Rutherford and Oliphant, and other people little older than I had done. I began to think of physics as well as mathematics as my goal and graduated in those subjects in 1953.

I proceeded to an honours degree and ultimately a PhD. The Physics Department of the University of Tasmania was then extremely active in the study of the "cosmic radiation" that bombards the Earth from outer space. I was given the job of developing an entirely new instrument, the "neutron monitor", that had been invented in the US several years previously. I built three of them which were established in Hobart, Mawson (Antarctica), and I took one and several other instruments to establish a geophysical observatory in Lae, New Guinea, for the "International Geophysical Year 1957-8". While I was already good at electronics (vacuum tubes, not solid state}, this taught me an enormous amount about "ruggedizing" equipment so that it would not breakdown in hostile environments. So, there I was in New Guinea; people were still being eaten by the cannibals. The locals called me "Lic

lic skule boi" (little schoolboy). A very interesting time, and, as I was to learn later, a major influence on my future career.

Joe Was all this during your university days, or after your graduation?

Ken Yes Joe. This was my PhD stuff. In those days, PhD students were frequently doing things totally on their own. Basically, I was told "get it working and come back to Hobart when it is". Back then we knew very little about how you keep electronics working in the tropics. Several of my power supplies produced 3000 volts; the pulses from my proportional counters had an amplitude of millivolts; and the thought of 3000 Volt equipment in highly humid climate was rather unsettling. Luckily, I had developed an "*el cheapo*" insulation technique that really worked, and we never had a problem. But we certainly didn't know that when I went there. So anyway, that was all my PhD stuff. I learned a great deal of practical stuff in the real world in the process. That, and my role as a sergeant in the Citizens Military Force rounded me out to interact with all levels of society.

Bob

Question 2

How did you spend your first years after initial graduation, presumably in activities and/or research of your choosing?

Ken I was offered a research fellowship in the physics department of the Massachusetts Institute of Technology in Boston. Astounding, and yet I almost turned it down. Why astounding? Well, it was from the very top man in cosmic ray physics in the world, Bruno Rossi, who had also been the head of the Instrumentation laboratory at Los Alamos where the atom bomb was developed. The thought that I was being invited to make a total idiot of myself almost caused me to turn it down. I didn't.

Bob Could I just interrupt for a moment? What year were you born? And what year were you invited to MIT?

Ken Yes Bob I was born in 1933 and I was invited to MIT in 1959.

Joe I might add that 1959 was the year when AMIRA was formed.

Ken MIT was an enormous culture shock for someone from the smallest University in Australia. Bruno would spend as much money on a six-hour balloon flight as we would on a year's cosmic ray research in Tasmania. Bruno turned out to be an absolutely marvellous guy. He was extraordinarily friendly and helpful. And he taught me to ask the stupid question which was probably the most important lesson I was ever given. Stupid questions frequently are the prelude to great understanding.

Bruno told me to look around and decide which of the two satellite projects that were in progress in his group I would like to work on (an instrument to detect the "solar wind" or a gamma ray telescope). In the process, I learned that there was a very large computer down in the basement – an IBM 704 - one of the largest computers in existence then. The instruction book said it broke down every three minutes. Nevertheless, I proposed to Bruno that I use it to solve - up till then a completely impossible problem - to determine the paths taken by cosmic rays in the sixth degree simulation of the geomagnetic field. NASA had recently decided to send astronauts to the moon. What I was proposing was important in order to preserve their virility, or even being killed by major explosions on the Sun (solar flares). So, I was funded by NASA. I taught myself FORTRAN and did it. Over the next year each of 200 computations ran for 20 minutes and the computer didn't break down once. So much for handbooks. I published a number of important papers. Direct descendants of my original program are still in use today

That work lead to my entry into “hands-on” space research at the University of Texas. No one had ever measured the directional properties of the cosmic radiation in space. This information was important, once again, to protect the astronauts on the Moon. I proposed an instrument to do so in 1962 for flight on the interplanetary Pioneer spacecraft. The “cosmic ray anisotropy experiment” was full of ideas that were later used in SIROTEM. It simultaneously recorded 8 channels of data using “integrated circuits”, the prelude to the modern microprocessor chips. NASA gave me “a ride” for that instrument on four Pioneer spacecraft (Pioneers 6-9) and Explorers 34 and 41. By 1968 I was getting data back from 300 million kilometres away from Earth when Pioneer 6 was behind the Sun. It was great physics. I became deeply involved in radiation protection in the US space programme. They were exciting years. And they laid the foundation for my next adventures.

Bob What years were they Ken?

Ken Thanks Bob. 1962-1970

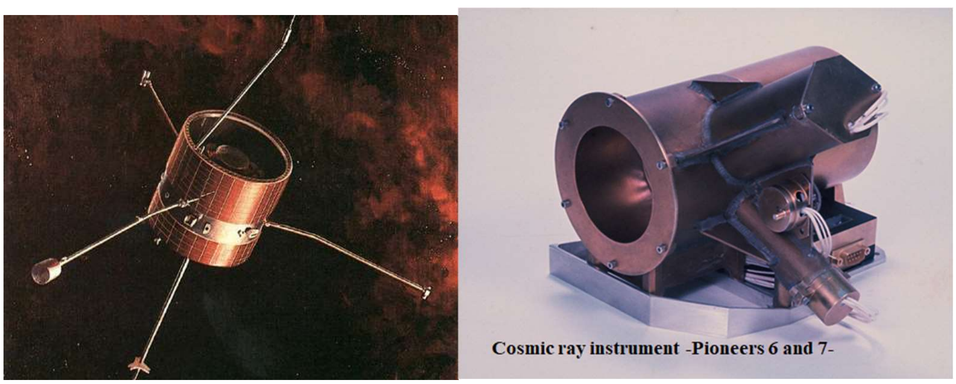

Figure 1 - “SIROTEM” in space.   Left- Pioneer 6 (1965); Right -My Pioneer 6 instrument- an 8-channel time domain cosmic ray detector that looked out the belly band of the rotating satellite. We received data from it when it was 300 million Km away behind the Sun. Weight 2.1Kg.

In 1966 I was appointed as the professor of experimental physics at the University of Adelaide. X-ray astronomy had just been discovered by my MIT mentor, Bruno Rossi. Using detectors carried on very big balloons, and rockets flown from Woomera, my Adelaide and Tasmanian colleagues and I made the pioneering observations of the X-ray stars in the southern sky. And then in 1969 I got an invitation for appointment to a senior professorship at MIT. We didn't really like the idea of going back to the US, but- well, a full professorship at MIT? That was tempting and I did accept it. We packed up and sold our house in Adelaide and were back in Tasmania saying goodbye to the family. Then I got a phone call from the chairman of CSIRO, Jerry Price. He said he knew I was going back to MIT soon. However, Professor Eric Rudd, the professor of economic geology at Adelaide, had told him I had a lot of ideas on how the discoveries of the space era could be useful in the application of geophysics to mineral exploration In Australia. Could I come to Melbourne and outline them.

Bob Ken, could we just pause there? So far, we've covered questions 1 and 2. And we're now at **Question 3A**. Which was, as you put it, what you were doing up to joining the CSIRO. You have told us that you were learning the new space age technologies. So, I think you've covered that also. We are now at question **3B**. I'd like to hand that and a couple of subsequent questions over to Joe.

Joe Thank you, Bob. Why did you take on the CSIRO job? What were your thoughts as a non-exploration person, stressing the role of the CSIRO executive at the time had in this? And when exactly did you take on the role?

Ken OK Joe, I will
I go back to the interview. I went across to Melbourne and, to my great surprise, was interviewed by the whole five-man executive committee of CSIRO. I talked about the conductive Australian regolith; the skin depths that defeated the frequencies used in instruments designed for well glaciated terrains; about the advantages of remote sensing from satellites; the reduction in the weight of field equipment by a factor of ten, or greater, using microchips; noise reduction algorithms; numerical analysis of field data; using physics for on-stream analysis, etc. I mentioned that I had discussed some of this with the existing geophysical contractors who said that they knew it all and that my ideas were academic waffle. The physicist on the executive committee, Victor Burgman, loved it. He was the guy who had led the development of the distance measuring equipment (DME) that Australia was the first in the world to install in aircraft for aircraft safety, and he quickly got the drift of the great advances that were possible. After two hours of question and answer, the chairman explained that CSIRO had been under great pressure from the mining industry to build up a research programme in exploration geophysics and that none of the existing Divisions of CSIRO were interested.

So, Jerry Price got to the point. "We know you have been appointed to a senior position at MIT, but would you consider setting up a new CSIRO laboratory to do the sort of work we've been talking about".

I was astounded; it had never occurred to me that that was where the discussion was going. I said, why me, I don't really know anything about the mining industry. Victor Burgmann leapt in -"that is precisely why we would like to offer the job to you. Ideally, we want a physicist or engineer with knowledge of the problems faced by today's exploration geophysicist, but also with hands-on knowledge of big and small computers, semiconductors, satellites, and management. And the space-age advances in radioactivity and magnetic measurement techniques. And who has experience in working with big industry, big contractors and bureaucracies. You fit the bill, completely".

I suspect there was another reason, too. My "stunt" in being able to fly X-ray astronomy detectors in Skylark rockets from Woomera in 1967: essentially "over the back fence"; was well known to senior people in CSIRO. I had the reputation that I didn't muck about and that I could find my way around a problem in somewhat unorthodox ways.

However, Jerry Price then hastened to say - "if we can get the money". We had never been that happy about going back to the US, and recent events there made it even less attractive. I said I'd think about it. They said they would look for the money.

Joe Were the members of the CSIRO executive just scientists or were business people involved?

Ken Yes, just scientists those days. They were people who had led the CSIRO research for the agricultural, mining, manufacturing, and other industries for many years and they were very practical, results oriented people. They were from the era when CSIRO was completely focussed on solving industrial problems peculiar to the Australian environment. With excellent connections in the industries they serviced. You didn't last long in a senior CSIRO position then if you weren't.

There was somebody else, not on the executive, who had great influence, Ivan Newnham, who co-ordinated the work in the five CSIRO laboratories engaged in mining and geotechnical work. A chemist, recruited from industry and with great industrial connections. I suspect that he was the link between Professor Rudd and the executive.

Bob Can I just interrupt for a moment? I think it's correct that Stan Ward was brought out here to do some sort of a review of exploration geophysics in Australia to assist CSIRO in their planning. Was that before you met the executive?

Ken Thank you Bob for reminding me. Yes, that is correct. First there were the discoveries by WMC at Kambalda and that was great geology and geophysics based on time-domain EM. Then Poseidon rocketed up from $0.50 to $280 in about a month. And then there was the Tasmanex disaster based on Induced polarization, I think. As I said the executive were under a lot of pressure. No existing division would branch out into exploration geophysics, so they contracted Stan Ward to visit major exploration companies, assess the situation, and suggest an appropriate role for CSIRO. I think this contract was placed before the executive even knew I existed. Stan did his tour. I didn't meet him at the time. I believe they interviewed me before he submitted his report. I guess they received his report before they made the final offer when I was in India in May 1970. There never were any issues regarding whether I was doing things that were different from his suggestions. As you probably know, Bob, I went to work with Stan and Jerry Hohmann in Utah in 1979 for three months, and we had great discussions about time and frequency domain exploration in conductive, noisy terrains. Jerry and I even wrote a paper about time domain EM that was published in Geophysics.

Back to 1970. According to our original plan my family and I went to India to work with the nascent Indian Space Research Programme for 5 months. CSIRO confirmed the offer in May 1970. The US social situation was not improving and the NASA space programme was beginning to wind down after the first astronauts went to the Moon in 1969. We decided to come home to Australia.

Joe So when did you actually take up the position?

Ken The 1st of June 1970 .

Joe **Question 4**.
CSIRO years (early 70's until 1989): What was your vision for the new division, and how did you go about achieving it?? Did your background offer an advantage in achieving the Division's vision? How important was the support of CSIRO management and was there anything unique about it?

Ken CSIRO put me in an army hut in the Division of Mineral Chemistry in Port Melbourne for a year during the planning phase. Soon after my arrival, Ivan Newnham led a tour of a number of mining sites by the chiefs of the five CSIRO mining divisions and me. We went to both Broken Hill Mines, Mt. Isa, Western Mining, and various head-offices. We asked them to identify their needs for research. New Broken Hill gave us a list of 150 topics. This tour gave me a very useful snapshot of the perceived needs and practices of the geophysicists in those companies. One clear memory was that the company geophysicists we met were all trained in the 1940s and they had only a rudimentary understanding of modern physics and electronics technology. I learned a lot.

And their equipment!!! I had expected that by 1971 the rich and affluent mining industry would have the latest in “space age” technology. No way! All their geophysical instruments used vacuum tubes (aka radio valves), the electronics were heavy, and chewed up power, requiring large batteries, resulting in the instruments being referred to as being “luggable” (certainly not portable). Data were obtained by averaging by eye the position of the pointer on a flickering voltage meter. The geophysical contractors were using this older equipment and in no hurry to change. Interpretation was based on comparing the observed readings with a catalogue of “type curves”’ corresponding to a small number of possible targets. Apart from Professor Gordon West at the University of Toronto, Misac Nabigian at Newmont and the Swedes, no one seemed to be developing new equipment using the enormous improvements possible based on semiconductors, noise theory, mathematics, and all the electronic wizardry developed since 1950.

Then I made another very important visit to Western Mining (WMC) at Kalgoorlie and their field camp at Kambalda. Hugh Rutter was overseas, however I talked to his colleagues about their experience with the conductive overburden. They had been using a demonstration Soviet time-domain instrument, the MOPPO, and had just ordered one. I asked many questions and obtained their views of the other time domain instrument in use at that time by Misac Nabigian at Newmont. I was particularly interested in the signal processing and noise reduction techniques they were using (essentially-none) – just brute force and great equipment weights.

Another important discussion was with Tim O’Driscoll, the WMC photogramitist. He was the only exploration geologist I met then who had even heard of the United States Geological Surveys plan to launch the first remote sensing satellite, the Earth Resources Technology Satellite, ERTS-1 (later called LANDSAT). He was keen on it. I had been an amateur photographer, and his discussion about technical issues such as illumination angles, reflectivity of arid soils, etc made great sense to me. In particular, he quantified the problems with the current method, a mosaic of aerial photographs. That visit to WMC was very influential in reinforcing my ideas of what a CSIRO division could contribute to modern exploration in Australia. We would need physicists, electronic engineers with signal processing skills, and mathematicians for modelling. So back to the army hut in Port Melbourne.

I developed my plans over the following year. EM exploration, mathematical modelling, remote sensing, and on-stream analysis would be the key innovations. There would be laboratories as well to improve our knowledge of the magnetic and radiometric properties of the regolith and mineralised regions in Australia. Clearly, my background was extremely useful in the planning phase. Hands-on building equipment for the Antarctic, New Guinea, and later, space; my very successful mathematical modelling at MIT; committee work with hard-bitten people from the space industry and NASA; and my hobby of bushwalking in the tough bush of Western Tasmania meant that I had a reasonably good understanding of where there was important “low hanging fruit”.

I had a curious visit while in the army hut in Port Melbourne, long before the existence of my nascent laboratory was public knowledge. The receptionist at the Division called me to say “there is an American out here who wants to talk to you about mathematics’. He came in - Art Raiche by name. He talked about his mathematics for the US defence department. I think he was surprised that I understood what he was talking about. I told him about my mathematical models back at MIT. He asked for a job. I said we might be advertising a suitable job for him in six months. We did; he applied; was employed; and went on to run one of the most successful exploration research programmes in my Division and a whole series of AMIRA projects.

Oh yes. CSIRO management. They were very helpful. They provided me with adequate resources to employ my initial staff; space in a new building in Sydney; occasional senior contacts with industry via Ivan Newnham, and in all other respects, kept out of my way. I had a charmed life. That basically was the old CSIRO- the Division Chief ran the show. And it was not a government department.

Joe I guess you sort of laid the groundwork in terms of what you were going to do in that first year. And the work of Stan Ward must have provided you some of the basis on which to build your plans for the division. When did the division start doing some concrete research work in geophysics?

Ken I started advertising positions in late 1971. I appointed the EM team, Jock Buselli (physicist) and Brian O'Neill (an electronic engineer from the Woomera Rocket Range) in 1972 and an experimental version of SIROTEM was assembled from instrumentation designed for the study of radioactive material. Tests at Kambalda, W.A, and in NSW helped define the noise suppression, data stacking, and other details, and design of the prototype SIROTEM was commenced. Initial appointments were made to develop the magnetics and radiometrics laboratories. Art Raiche was appointed to initiate research into mathematical interpretation. With John Perry from the BMR, I was doing the initial organisational stuff to gain access for Australia to data from the LANDSAT remote sensing satellite which was to be launched in mid-1972.

Joe When did Andy Green and John Huntington come into the picture?

Oh yes. I think I employed Andy in early 1973. Originally from Perth, he came from a post-doctoral position with an Australian, Ron Lyons, who was a professor of remote sensing at the University of California. I had decided we would need to have our own satellite interpretation facility long before they were commercially available, and a computer electronics engineer, Guy Roberts, was appointed about then and commenced building it. John Huntington was employed later- I will talk about that later.

At first, the data from LANDSAT was received by a tracking station in Alaska. Computer tapes of the Australian images came to us in the "diplomatic pouch" from our embassy in Washington. In those days there were "scientific councillors" in several Australian embassies. This saved this project a great deal of money. Andy and Guy started experimenting with techniques to improve the Australian images. The use of images from space was still very controversial and many in the mining community called it "Remote non-sensing".

It was about then that I had the most important meeting that determined our subsequent crucial interaction with the "boots –on- the –ground" geophysics and geology professionals in the mining companies. It was with Jim May from the Australian Mining Industries Research Association (AMIRA). We had been having sporadic meetings with some of the industry professionals in our several areas of interest, but they really didn't work that well. Jim explained how the AMIRA projects worked and in particular, that AMIRA would convene six monthly project reviews. The AMIRA research funds would be very useful- but the vision of key exploration professionals from many of the top companies sitting in one-day meetings with my research people was magic. I jumped in, boots and all. I knew some research people might find it difficult at first - but they would learn to like it. Most did. Twenty one 3-year AMIRA projects were initiated with Mineral Physics in 1956-89 and many thereafter.

Figure 2 - Technical discussion between Ken and Jim May, AMIRA director.

AMIRA projects based on R and D commenced while I was at CSIRO Mineral Physics

Technology	**Years Funded**	**Key Personnel**
EM /Sirotem	1975-1993	G. Buselli, B. O'Neill
Remote Sensing	1977-1999	A.Green, J. Huntington, G. Roberts
Mathematical Interpretation	1980-1998	A. Raiche
Magnetic Properties	1978-1998	B.Embleton, D. Clark, P. Schmidt
Radiometric Properties	1988-2002	B.Dickson

Joe **Question 5.**
What do you think were the main achievements during your term with CSIRO? How did AMIRA come into the picture and how important was the AMIRA-CSIRO relationship?

Ken Let me first answer the last part of your question, because it largely explains what I consider to be our main achievements.

The AMIRA - CSIRO relationship provided a sense of common purpose and teamwork with the industry that was a major contributor to our successes, and their up-take "in the field". An important contribution to that relationship was that CSIRO had provided the funds to provide small full –time research teams to develop new ideas and facilities (eg Remote sensing; mathematical interpretation, SIROTEM, the magnetics and radiometric laboratories) and we could then present concrete proposals to the industry with well-defined and achievable goals within the duration of the proposed activity. We were doing it at the right time; there was a lot of "low hanging fruit".

So, to the achievements.

Time Domain EM. One of our first AMIRA teams was for the time domain instrument we were developing, SIROTEM (= "CSIRO Time-domain Electromagnet Measurement"). Five companies joined it. A key outcome was that I asked them to define ten test areas to

evaluate the properties, and deficiencies, of the two prototype instruments we were building. They chose well-known targets that ranged all over the continent; from almost trivial, to the one they deemed “almost impossible” (“Elura”, near Cobar, NSW).We put two teams in the field and went for it for three months. We learned a lot of operational things, but always saw the target loud and clear. The companies saw SIROTEM in action, sometimes on their own land. That was until test site 7, Teutonic Bore” in WA. Before my team could even contact me, the grapevine informed me- “it doesn’t work- it sees spurious responses everywhere”. Brian O’Neil and I raced out there. We found there were many drill holes with metal lining that we hadn’t been told about. We soon learned how to avoid that problem. Then we realised the data were somewhat noisy. Using an oscilloscope Brian saw what seemed to be big random, millisecond - long spikes on the time-domain signal into SIROTEM. The penny dropped - we were seeing “sferics”- the radio waves emitted by lightning flashes, worldwide. A digital sferics filter was designed quickly and installed. And so, to the last “almost impossible “target, Elura (NSW). The result was embarrassingly good.
By then we had advertised for a company that would be licenced to manufacture and sell SIROTEM. There were 36 applications. We licenced “Geoex” in Adelaide to manufacture the commercial model (Henderson, Preview, 172, 39-46, 2019). The AMIRA sponsors of the SIROTEM project ordered one immediately. It was an excellent example of how a research institute and the industry could work together. Then Murphy’s Law struck. A press conference was arranged to celebrate the delivery of the first production model. Big event for both Geoex and CSIRO. While the event was scheduled well in advance, it turned out that the wrong version of the microprocessor that was the heart of SIROTEM had been ordered and they did not work properly. Panic. By good luck Professor Keeva Vozoff (Macquarie University) was on sabbatical at the University of California. I made a quick phone call to him; he drove to the supplier and bought the right ones and posted them to Geoex. But it was too late for them to be installed before the press event. So it was that the first SIROTEM was delivered ceremoniously to BHP with the electronics replaced by a brick.

There were four extensions to that AMIRA contract (1975-1993). Geoex designed and manufactured two improved versions, SIROTEM 2 and 3 and they sold a total of about 100 SIROTEMs worldwide.

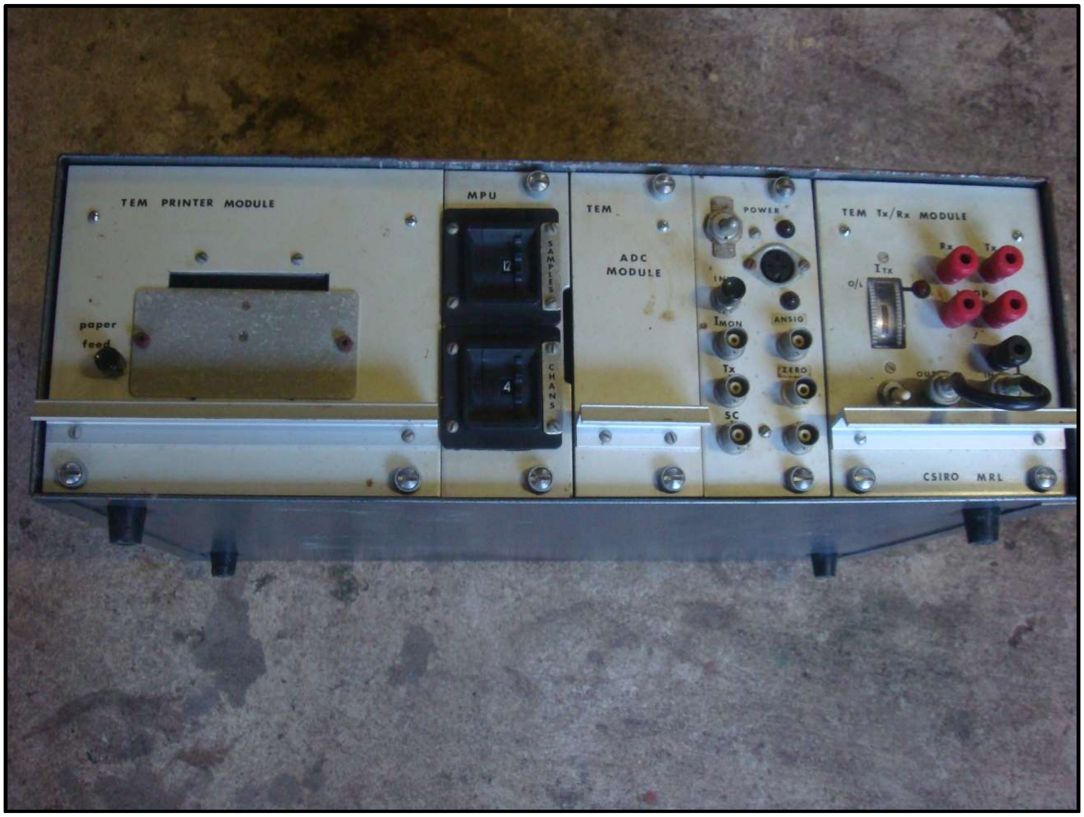

Figure 3 - SIROTEM Prototype 1972, without the brick (from ASEG archives)

LANDSAT. In 1977 we issued a proposal through AMIRA for a three year “remote sensing” project, when remote sensing was still viewed with great suspicion by some in the mining industry. We included an absolutely eye-watering image of the Marble Bar area that Andy Green and Guy Roberts had produced on their image analysis system. We were almost killed in the rush. Eleven companies subscribed. We initially employed Jon Huntington (geologist) with the AMIRA funds. The interaction between my team and industry was marvellous. From memory seven of the sponsors installed their own image processing systems later - to maintain secrecy on some of their investigations, etc. Some years later, NASA improved the spatial resolution of LANDSAT 4, and changed their radio down-link frequencies. The Australian government didn’t have the funds to adjust the reception facility they had recently installed at Alice Springs to this change. I approached AMIRA, agricultural, and other industries and obtained the funds to provide a temporary reception and higher resolution image analysis system until the government got its act together three years later. Called the “Signal Processing Experiment” (to ameliorate departmental sensitivities) it gave the Australian mining industry a very fast start on the application of the higher resolution imagery in practical exploration projects. There were five (1977-99) extensions to that AMIRA project.
Andy Green, Jon Huntington and I were recipients of the “Australian Prize (1995)”for “Advances in Remote Sensing”. (The Australia Prize was replaced as Australia’s senior science prize by the Prime Minister’s Prize for Science in 2000).

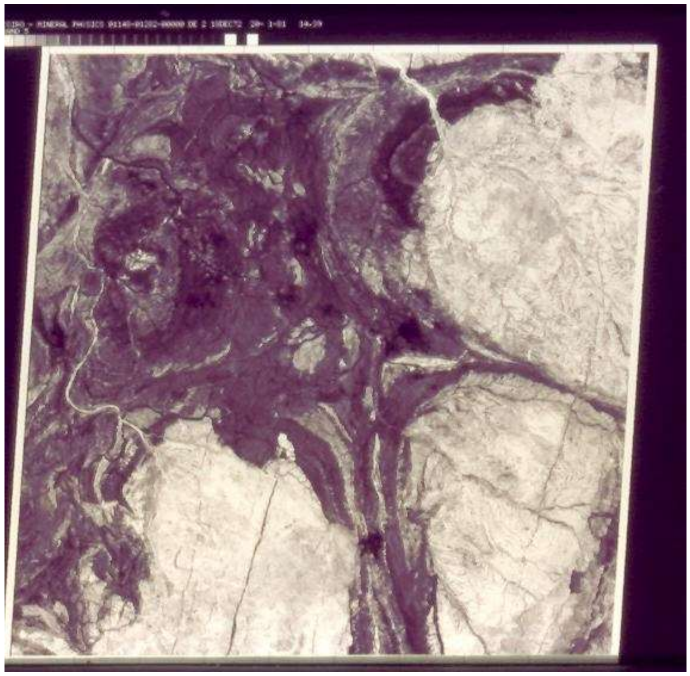

Figure 4 - Landsat 1 image of the Marble Bar area (80 meter pixels) used to illustrate our first LANDSAT proposal to AMIRA.

We initiated AMIRA projects in Mathematical Modelling (Art Raiche,1980-1998), Magnetics (Brian Embleton, Phil Schmidt, Dave Clark, 1978-1998), and Radiometrics (Bruce Dickson, 1988-2002). Each of our AMIRA projects initially ran for three years; most of them were then continued for a number of three year extensions. More companies joined in. Good relationships, and trust was established between the researchers and the geophysicists and geologists in the industry.

A number of companies were involved in several of the AMRA projects, with different members of their exploration divisions attending the various 6 monthly progress meetings. I sense that this resulted in a wider acceptance of our work within the companies. And the AMIRA –CSIRO relationship did wonders for me in the role of Chief of the Division. AMIRA did all the hard work of assembling the individual programmes based on our proposals; collecting the money; and organising the project meetings. It allowed me, and the project scientists to concentrate on the science and technology. This was an ENORMOUS advantage.

So, what were our main achievements. It is important to recall that we were established at the "sweet spot" in the development of science and technologies world-wide following World War 2. Advanced forms of semiconductors (e.g., the first microprocessor chips); Satellite technology; Personal desk computers with lots of power; Early GPS; The development of signal processing theory; Major advances in geophysical detectors, theory; and understanding of the Australian terrain. We had the resources and industrial support to use ALL of these.

Obviously, we introduced new instruments and mathematical and interpretation skills tailored to the Australian environment. We established measurement programmes in magnetics and radiometrics that became important as airborne geophysics became the norm. However, I think our main achievement was in assisting the overall revolution in the exploration technologies in Australia in the 1970-80s. The AMIRA project reviews provided a marvellous two-way path – between the practical needs of the industry - and what was becoming possible at the cutting edge of science and technology. The companies would often send their more recently trained staff who had received the very good modern training available in the Universities. They would push the researchers - it became a real team effort. They would come into the Division with "strange results" –that on investigation- would be some unknown effect. Great progress was made on all sides by these interactions

Bob One of the first things that you and your team did was to build an instrument (SIROTEM) which could make the sort of measurements that we needed. But once we started using it, we began to get results that we couldn't understand. We, that is the industry people, came to you and said we don't understand this, something is not quite right.

Ken Yes you personally used to do that, Bob, quite frequently to great effect.

Bob Well, the first of them was, I guess, that what we observed in the field with SIROTEM did not agree with the properties we had already been measuring with other methods.

Ken Super Paramagnetism.

Bob Yes, well what we observed was that when we calculated the resistivity of the earth, using SIROTEM data and AMIRA developed software, the earth appeared to become more conductive with increasing depth. This conflicted with what we had come to expect from IP and other resistivity measurements, and we expected the opposite. In general, we expected resistivity to increase with depth. What we were trying to point out was that something was going on which we didn't understand.
It was the good work of your team, and Jock Buselli in particular, who came up with Super Paramagnetism as the cause and then also came up with solutions to it. That was really quite an achievement.
The next one, was that we simply kept getting negative responses, and I remember you coming in one day and saying that from the physics of TEM, this response can only decay from a positive number down to zero. It can't go negative. However, it kept on doing it. We had all sorts of brains involved in this, Stan Ward got involved and Jerry Hohmann in Utah and Art Raiche started tinkering with the problem. I think we suggested to Art that he should insert a Cole - Cole model into his modelling software, to simulate IP effects. He did and, lo and behold, he got signals which went negative.

Ken Yes Bob. It was exactly those types of real-world discoveries and interactions that made a great difference. The same thing was going on in all our programmes. Not just at the AMIRA progress meetings. It was very common for me to visit one of my project teams and find someone from the industry explaining some peculiarity they had seen out in Woop Woop. And this had another benefit as Bob said. Understanding a weird observation sometimes required more than one of our projects to be involved. The real world resulted in greater interaction between our projects.

Then there were the politics. About 1976 the Minister of Industry suddenly "transferred" the CSIRO mining divisions into several government departments while the Prime Minister was overseas. All hell broke loose. When the PM returned the transfer was rescinded, and for good measure, some research groups in the Atomic Energy Commission were transferred to CSIRO. The excellent "on stream analysis group', led by John Watt, was transferred to my division. John and his co-workers had a long-standing relationship with the industry, and this extended our interaction to the processing components of the mining industry.

Joe Ken would you care to mention how the executive and management of CSIRO changed during the period with there? And your reasons for moving on.

Oh yes. In the late 1970s, I think, money got tighter. That didn't affect my Division that much - we were doing very well on mining industry and government funding for specific research. There was a public inquiry into CSIRO (the Birch Report); a new management structure; a CSIRO Board; A CEO and a chief scientist; and the position of "Director" introduced between the chiefs of the Divisions, and the Chief Scientist. Ivan Newnham had been working in the role of Director for the mining and geotechnical Divisions for almost ten years and it worked well for us and little changed while I was there.

However, I was getting itchy feet. I had always regretted that Australia did not have a space programme. In 1983 I proposed that a CSIRO Office of Space Science and Applications (COSSA) be established, and I was appointed its Director. Funding research in a number of different Divisions, I concentrated our effort on improvements in remote sensing. By then it was beginning to have better acceptance, and I was certain it would become even more important in the future. We also supported research in the then almost unknown technology – the Global Positioning System (GPS). The Australian government established a Space Office in the Department of Industry and Commerce. I was appointed to the Space Board. Over the years I developed a heart problem and was invalided out of CSIRO in 1989. My wife and I bought a 340 Ha farm in the Southern Highlands of NSW.

Joe Can I just interrupt? Obviously, space is a big thing now. And it's interesting that you say that it was in fact not seen in a positive light during your time at CSIRO. Do you have any inkling as to why we had this attitude? It seems to me, if we had been positive, we could have been far ahead of a lot of countries in space.

Ken Oh, definitely. The Woomera rocket range was established in South Australia in 1947 as a "joint-project" between the UK and Australia. The primary purpose was to test rockets for the UK intercontinental ballistic missile program. There would also be a scientific programme - atmospheric and ionospheric physics, solar physics, etc primarily conducted by university and other civilian research groups in Britain and Australia. As part of the deal, the UK gave Australia 6 Skylark rockets a year for our own research programme. The Australian universities, CSIRO, and others proposed experiments using them for atmospheric, geophysical and astronomical research, particularly for the International Geophysical Year (1957-8). Committee meetings over many years resulted in no action and no flights for scientific purposes.

At the dawn of the space age the United Nations set up a committee regarding the peaceful uses of outer space (UNCOPUOS). Australia was chosen to chair that rather important committee; Dr. D.F. Martyn, a senior CSIRO scientist of world-wide repute, was assigned to this position. Following the launch of Sputnik in 1957 the USA offered to give satellite launching rockets, and to launch them, to six countries (Britain, France, Italy, Germany, Canada, and Australia). Australia was the only country to decline that offer due to inter-departmental rivalries. Subsequently, CSIRO launched atmospheric experiments on NASA rockets launched in the USA. Young Australian scientists like me with interest in space research went overseas. They did well – the Australian can-do attitude was ideal for those risky days of space research when 2 years of hard work could end up in the Atlantic Ocean in the flash of the eyelid.

My ex-PhD superintendent, Geoff Fenton, and I went to the UK version of NASA in London in 1964 and proposed to fly x-ray detectors on Skylarks as part of the UK programme. (We Australians still had British Passports then). And so it was that those well -known British Universities, Adelaide and Tasmania, made the pioneering detection of x-ray stars in the southern sky in 1967. Woomera closed soon after that. A "left over" US rocket was used to launch an Australian satellite in 1968 (called WRESAT- the Weapons Research Establishment Satellite) and that was the end of our space research programme until 2000.

Yes, we missed the opportunity of the century. And largely as a result of that, the Chairman of CSIRO contacted me in 1970, and my space-derived knowledge was transferred to the mining industry. In the event, a good outcome from a rather dismal situation.

Figure 5 - A cartoonist's take on a public comment I made circa 1990 that Australian space research was still in the Stone Age. *NOTE. This situation changed in 2020 with the creation of the Australian Space Agency located in Adelaide.*

Bob **Question 6**. Why did you leave CSIRO and what have you been doing since, particularly anything connected with geophysics/exploration geophysics? I think you have answered the first part so perhaps we can go on what you have done since.

Ken Well, the first thing I did was adopt a less stressful lifestyle. My wife and I bought a 340Ha cattle farm. I did a bit of consulting for mining companies, and a couple of geophysical contractors. I helped with the design of an airborne EM system. Then there was the airborne gravity story.

As you will recall, Bob, CRAE sponsored investigations into the use of a gravity gradiometer for air-borne use at the University of Western Australia in the early 1980s. The problem was to detect the gravity signal buried in a six orders of magnitude noise field due to the linear and rotational accelerations of the aircraft due to wind and other inputs. In the early 1990s BHP contacted me to assist them in their assessment of the possibilities. That was good - I like things that seem to be almost impossible.

In the early 1970s, the US government had spent $400 million on the development of a gravity gradient detector for use in their nuclear submarines to permit them to compensate for irregularities in the earths gravitational field to aim their missiles more accurately. The development of GPS meant they didn't need it any more. They offered the technology to the exploration industry. The prototype weighed several tonnes and filled a large caravan. Most mining people laughed and left quickly. BHP studied it and saw promise. I assisted them in the development of the "Falcon" gravity gradient instruments, which are now flown in single engine "Skyvans". Yet another example that your geophysical needs might be found in unlikely places if you are prepared to look.

The word got around the international space community that I had retired from CSIRO, and I was very quickly asked to assist in research focussed on understanding the dangers to high altitude civilian air travel posed by solar flares. This was based, believe it or not, on the mathematical programme I wrote at MIT in 1960 and the results of the instruments I had flown on the Pioneer and Explorer spacecraft in the 1960s. A good friend of mine who had been the chief scientist of NASA invited me to join him as a research fellow at the University of Maryland. It was there that he, a Swiss nuclear physicist, and I pioneered the use of the traces of cosmogenic Beryllium in ice-cores to study of the behaviour of the Sun and the interplanetary magnetic field in the past. The signal processing skills I had learned in assisting the mining industry were very important in doing so. First, we looked at the past 10,000 years, and more recently the past 150,000 years. We have demonstrated that there are a number of well-defined periodicities that allow us to predict the future behaviour of the Sun and Earth's climate. In a sense, I have been and am still, studying the geophysics of the past 150,000 years.

Oh yes. I have written two books. One - a light-hearted autobiography ("Blast Off- Scientific Adventures at the Dawn of the Space Age") of the early days of space research. The second - as a co-author of a book on the use of the cosmogenic radioisotopes for practical purposes. And I have published a rather large number of scientific papers in the top journals. I have kept the brain working.

Bob OK thanks Ken. Well, I think so far, we've been talking about things that that you've been doing and have done. But then the last few questions I've been looking more at your perspective on trends and new directions and what we can do in the future to improve.

Question 7. What is your perspective on trends in geophysics, particularly exploration geophysics since you left CSIRO. This might be advances in instruments, software tools and applications and theoretical advances in general which might be related to future advances in applied geophysics

Ken I am afraid I don't know enough about present practice to make a reasonable assessment. There have been good incremental advances in airborne geophysics; much improved remote sensing resolution; and development of airborne gravity. Instruments have been developed that use cryogenic detectors to reduce the thermal noise in EM and other technologies. No doubt there have been major advances in mathematical modelling - in the field and in the office. I suspect that the development of drones and robotics will have had a big influence. I suspect that the capital cost of geophysical equipment will have reduced "in-company" geophysics and increased the reliance on contractors. However, I stress I am out of touch with modern practice, and the above comments are merely what is obvious to a knowledgeable outsider.

Bob Now, what would you think were the major advances in your time? You might have answered this before, but just let's go put down a list.

Question 8 Looking back, what were the main advances in exploration geophysics during your career?

Ken Yes, good. I refer now to the whole Australian scene, not just to CSIRO.

(1) The role played by AMIRA in galvanising the coordination of the research workers and company in-field professionals was a crucial contribution.
(2) As was the recognition by the mining industry and CSIRO that there was a missing cog - a well - focussed laboratory devoted to the needs of mineral exploration in the Australian environment.
(3) The excellent training provided by the Universities.
(4) The use of semiconductor electronics so that field equipment became much lighter permitting much improved acquisition strategies - e.g., multichannel recording to minimise the effects of noise, and speed - up exploration.
(5) Improved understanding of the physical processes in electromagnetics in non-glaciated terrain.
(6) An overall understanding of the full spectrum of noise in geophysical measurements, and its minimisation through smart signal processing.
(7) The development of interactive mathematical modelling and interpretation routines.
(8) The understanding of what you can see from space, and how to use it. And of course, the steady increase in resolution from 80m pixels at first, to 30m, and even better.
(9) The role of the ASEG in increasing the dialogue, knowledge, and cooperation within the professional community.
(10) Greatly increased manufacture of and acceptance of locally developed geophysical instruments in Australia resulting in improved feed-back from the field to the manufacturer.

Joe Bob, can I ask the questions again? Ken, suppose you were to be invited by CSIRO today to make suggestions on leadership in research and development. What would you say to them?

Bob Ken, I was going to ask a very similar question which might be: If CSIRO came today and said look, we are going to set up a new division to look at mineral exploration, and tools for exploration, including geophysics. Budget is fine. We've got all the money we need. We want you to take it on. What would you say?

Ken Yes interesting questions. Firstly, I will indulge in some history and philosophy. Repeatedly during the past century there have been discoveries and new concepts that have reverberated worldwide and improved science and technology in many disciplines. Aeroplanes. the vacuum tube, radio, continental drift, satellites, solid state electronics, the internet, Wifi, etc. In mineral geophysics, the 1970-80 revolution because of semiconductors, satellites, computers, and noise theory. The use of redundant gravity technology for mineral exploration. That is - the big advances in response to big goals have frequently originated outside the community that ultimately uses them. The trick is being able to identify the BIG and REALISTIC goals and recognise the opportunity presented by a new idea/ scientific discovery /technology from outside. Few people have the ability or confidence to do both.

So I would say….

FIRST. Decide what are the BIG worthwhile requirements of the industry that would yield order of magnitude improvement to the industry and the nation. That is a situation identical to that when the mining industry asked CSIRO for assistance in 1970.

SECOND. I would say - carefully examine NEW ideas / technologies that would greatly improve the existing situation. Myself, I would personally start with the oldest trick in science – using new technologies to "turn the problem around". So, for geophysics - we cannot change the laws of physics, but does some new idea or technology allow us to use them in a much better way than we do now? At the same time, examine the whole spectrum of science/technology. Are there things or concepts in the medical, military, IT, robotic industries that already exist that can be adapted to exploration.

So we need to identify two totally different things- first, what are the major goals that the industry needs. Secondly - looking at the whole spectrum of NEW science and technology to see what may assist in meet those goals.

Answering those two questions would require two totally different professional inputs. Such as with Stan Ward in 1969 - a leading expert in exploration geophysics, -and me who knew nothing about exploration geophysics but was stuffed to the gills with the new technologies. Alternately, obtain inputs from two really competent committees. The methods are several, but the questions are the same. The two inputs would determine the Go/No Go decision.

Perhaps, now, I ask you both your opinion on some of these questions you have been asking me. Realistically, what progress did we make back then. What is appropriate now, from the industry point of view; etc

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Joe I left AMIRA in October 2019. 70s and 75 and 80s. I call those the golden period of geophysical research in Australia, which catapulted Australia to a world leader in exploration. It's a different universe now and with different drivers and so forth, so it's not as easy dealing with the industry. And so what must we do to drive up geophysics research? Bob might be able to add to that too.

Bob Well, I totally agree with you Joe that in looking back I think all three of us have been very fortunate to have been involved in the golden years of exploration geophysics, in mining. I can't say similar things for the oil and gas field, I just haven't been involved. But if for example, quantum computing was with us and functioning and so that on our little desktop computer we can do marvellous things that we couldn't do previously. We could in the blink of an eye, do a very complex EM modelling or inversion or whatever. But if we had the tools there to do these big jobs very quickly, what would we do with them? Any ideas?

Ken No. Not yet. Sometimes you can overdo the data to death. Maybe with higher spatial resolution -- say from a fleet of drones- we could drag more information out about the regolith and the putative target. May I ask you a question Bob. How much exploration are the big companies doing now?
I presume that it still happens at a reasonable level. However, how much is left to the contractors and small companies. What are the main tools that are used these days?

Bob Well, it's certainly still happening. I mean, we've had our slack periods, but it's coming back now. There's a lot of activity going on.

There's more being done from the air. Of course, Air Mag/Radiometrics is almost considered basic. If you haven't done it, you're missing out, that is it's a basic tool. It's the first tool in a new area. It's probably already been flown by the government at a fairly coarse scale and, if so, filling in in more detail is almost the first thing you would do.
Airborne gravity is certainly becoming more doable. It's still quite expensive, particularly for small companies or on small tenements. It seems to be getting more and more work in government surveys where you can fly long lines and do it more efficiently.
Forward modelling and inversion, using the tools that people like Art Raiche developed, are valuable basic tools for interpretation. A lot of this is being done, but I don't think it's all being done well. The people using these tools are generally young and competent with the computer tools but there is a tendency to press a button, spit out a model and send it back to the client. The client might conclude that it represents what must be down there. There doesn’t seem to be much appreciation that this is simply one possible model. I know there is some work going on trying to run multiple models with different, quite different, settings and get some idea of what the highest probability is, or the best model, the one that the most likely and so on. Sadly, there's a lot of reliance on these things now, often with little real appreciation of the quality of the input data. The guy who makes the measurements in the field is not involved and the data quality (or lack thereof) is not appreciated. Data collection is often largely automated, and it is tending to become more automated. If you start off with bad field data, well, you'll get bad results.

Joe Yes, if I can add a couple of things to Bob's comment. The two major trends that I've seen is the increasing role of governments in making available, at least in Australia, regional datasets. Geological surveys are now playing a critical role, more so than they did 20-30 years ago, through the provision of these types of data sets. The second trend that I've seen, is that if you look at the big companies now, compared to even ten years ago, the number of geophysicists on staff has declined drastically. In Rio Tinto, I am told that there is essentially only three. I think this situation is not unique, which means that companies big and the small now rely more on contractors to do the geophysics. I don't know whether that's good or bad.

Bob Well, I think the contractors are the right people to do the data collection, but they need to have someone overseeing them, telling him what to do, how they want it done and using the data when they get it back. That's where people like you and me, Joe, used to come in. If the big companies now have a smaller number of geophysicists in house, they're relying on the contractor as well. That can be a mistake as the contractor may not have adequate instructions and is rarely going to be involved in the final interpretation.
Of course, COVID restrictions have not helped. I have recently sent a crew into Queensland to undertake 3D IP measurements. They must fly into Brisbane, go into isolation for two days while they are tested and, if cleared, then proceed to the site. After two or three weeks they are meant to go on a break but there is no guarantee they will be able to leave Queensland or return if they do.

Ken Thank you Joe and Bob. Yes, technology can be a trap as well as a benefit. It seems the situation has reverted to something similar to that back in 1970. That is, as seen by the company exploration manager, usually a geologist, there are now two black boxes in series largely out of his/her quality control. First, the geophysical contractor who is invariably conservative and cost-sensitive, followed by the gung-ho computer guys who are convinced of their invulnerability. Possibly the remedy will be when the industry, government, or someone else identifies and achieves the order of magnitude goal we discussed before. That would get the attention of senior management and change the culture.

Now may I *ask another* question to Bob. Am I right that the big companies like Rio and BHP and the mid –tier companies tend to absorb discoveries made by smaller companies instead of initiating it themselves?

Bob Yes, I think that is often the case. Big companies do have to spend more time planning and protecting their backsides as they are worth suing if or when something goes wrong. Smaller companies can, and do, take more risks. If they make a discovery, then they are often happy to do deals with the big companies who are better equipped to build and manage a mine.

Joe These days, before a crew can go on site, particularly in a brownfield environment, they have to spend considerable time on safety inductions, obtaining permits and so on.

Bob I think that's probably covered question 8.

Question 9. What is your vision of where we should or will go in the next decade or two, in geophysics in general but with particular relevance to exploration geophysics?

Ken

I will answer in two parts-in general - and for exploration geophysics.
I believe the BIG challenge for geophysics in general is to understand how the earth's environment will change in the future as a consequence of geophysical changes. In addition to the role of the addition of CO_2 to the atmosphere, the variability of the Sun has had major effect on terrestrial climate for hundreds of thousands of years. Thus the Oort(1030-1070), Wolf (1300-1350), Spoerer (1392-1530), Maunder (1645-1715), and Dalton(1795-1830) "Little Ice Ages" coincided with very low solar variability (weak sunspot cycles) and weak interplanetary magnetic fields. The ice core records tell us that there have been 26 Little Ice ages in the past 10,000 years. What is the physics of these climatic effects? And why does the solar activity vary so much in the first place. Thus there is the superposition of the major periodicities in solar and interplanetary activity; the Hale (22yr),Gleissberg (86 yr), DeVries(210 yr) , Eddy (1050 yr), Halstatt (2300 yr) periodicities and others stretching 150,000 years into the past. What is the physics of these periodicities? There is a much scorned hypothesis that they may be due to the motion of the planets that, maybe typically, I endorse. Then there is steady decline in the strength of the geomagnetic moment for the past 3000 yr. Ice core data tell us that the geomagnetic dipole moment was only 10% of the present value during the Laschamp event 41,000 yr the past. Why? What effects will even a 10% decrease have on us on Earth.

Having spent the last 25 years in solar physics and glaciological research using the cosmogenic isotopes ^{10}Be and ^{14}C, I am quite out-of -date with exploration geophysics. However, I suppose there are still four goals, deeper, more accurate: faster and cheaper. Perhaps attaining all four could be achieved by transitioning from the world we three knew of the three-man team lugging 20 Kg instruments through the scrub, one station at a time. The silicon revolution allows a large number of small cheap instruments to be manufactured, so old ideas can be "turned around". For example, for deep penetrating TEM, a matrix of say 100 or more cheap detectors spread over a large area (say 10 square km along strike). Linked by WIFI they would integrate simultaneously for a day or more, and then invert them all simultaneously to map the currents and conductivity in the whole area. And perhaps much more powerful transmitters based on modern high intensity permanent magnets. Such "out-of- the –box" ideas might do wonders for the signal to noise ratio and give better depth penetration. In a way- emulating the CAT scan used by the medical fraternity. I suspect that focussed investigations using our new technologies would greatly assist in achieving the goals outlined above.

Bob **Question 10**.

This was a bit broader and philosophical. Ken, what would you like to change in the current methods of education, research, development, and applications? If you had the power to change the system, what would you do?

Joe You have an enormous number of years of experience behind you and one would be foolish to discount your views on things. It seems to me that you might not be able to comment on some specific questions like Bob and I have just asked, but your experience over the years would tell you what. What not to do? What not to do in R&D, particularly in leadership? Do you have any final words on what not to do?

Ken In retrospect, I have been extraordinarily lucky in the way my career developed. So why do I say that and how does that relate to your questions?

My University Research was about an entirely academic subject – cosmic rays. Nothing much was known about anything. I learned excellent experimental skills. I was exposed to a world - wide community of theoreticians. Crazy theories abounded. I developed the ability to work along many lines of investigation, often concentrating on the craziest ones (often the best theoreticians come up with the new insight that most people, not understanding them, called crazy). This gave me a good understanding of how research really works. In my opinion this is what University research should do. Lots of uncertainty- lots of what ifs - lots of negotiating dead-ends.

Then I started working with the American National Aerospace Administration. High pressure targeted research at the cutting edge of knowledge. Excellent colleagues. Exposure to the latest theories and latest technology. Stress- instant decisions. Politics and commercial interactions**.** Exposure to the real world.

Then my years with CSIRO and working closely with industry with the assistance of AMIRA. Using the latest scientific discoveries to develop new instruments and interpretation methods. Jointly discovering previously unknown phenomena and understanding them. Making practical advances to society through good science and technology

Now to answer your questions.

In my opinion the scientific scene was well balanced in the 1970s and 1980s. The Universities were doing pioneering research. National laboratories such as BMR, the AEC; CSIRO were conducting focussed research of importance to the nation and its economy. The mining industry contributed ideas, experience and financial assistance to research via AMIRA and their in-house development. So, my opinion is simple - return to a situation similar to that back in the 1980s. Stated briefly, it seems that the situation has reverted to the three isolated camps in practice before 1970.

QUESTIONS POSED BEFORE INTERVIEW.

1. How did you spend your first years after initial graduation, presumably in activities and/or research of your choosing?
2. What were you doing up to joining CSIRO and how/why did you take on this job?
3. (3a) What were you doing up to joining CSIRO-stressing learning the new technologies (3b) how/why did you take on this job-and stressing the role of the CSIRO executive in appointing a non-exploration person to the job.
4. CSIRO years (early 70's until 1989): What was your vision for the new division, and did you achieve it?? Did your background offer an advantage in achieving the Division's vision? How important was the support of CSIRO management and what was unique about it?
5. What do you think were the main achievements during your term with CSIRO? How did AMIRA come into the picture and how important was the AMIRA-CSIRO relationship?
6. Post CSIRO: Why did you leave CSIRO and what have you been doing since, particularly anything connected with geophysics/exploration geophysics?
7. What is your perspective on trends in geophysics, particularly exploration geophysics since you left CSIRO? This might be advances in instruments, software tools and applications and theoretical advances in general which might be related to future advances in applied geophysics.
8. Looking back, what were the main advances in exploration geophysics during your career?
9. What is your vision of where we should or will go in the next decade or two, in geophysics in general but with particular relevance to exploration geophysics?
10. What would you like to change in current methods of education, research development and applications?

SCIENTIFIC PUBLICATIONS

Some 140 papers in high level refereed journals- e.g., Geophysics; J. Geophysical Research; Exploration Geophysics; Nature; Astrophysical Journal; Physical Review, Solar Physics, Space Weather, etc. A few are listed below

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"Blast Off – Scientific adventures at the dawn of the space age", New Holland, 2008

Cosmogenic Radionuclides. Theory and Applications in the Terrestrial and Space Environments, Springer. Beer, J., K. McCracken., and R. von Steiger, (2011), ISBN 978-3-642-14651-0

Honours and Awards

ASEG Gold Medal 1989

Australia Prize 1995 (Andy Green, Jon Huntington and Ken McCracken)

AAS Pawsey Medal 1967

AAS Ian Wark Medal 2001

AAS Haddon King Medal 2003

COSPAR Space Science Award 2020; Minor Planet named 8258 McCracken