ATTACHMENTS TO PAPER:

A BRIEF HISTORY OF GEOPHYSICAL DATA AND IMAGE PROCESSING IN AUSTRALIA.

Contents

1. Doug Morrison's Story

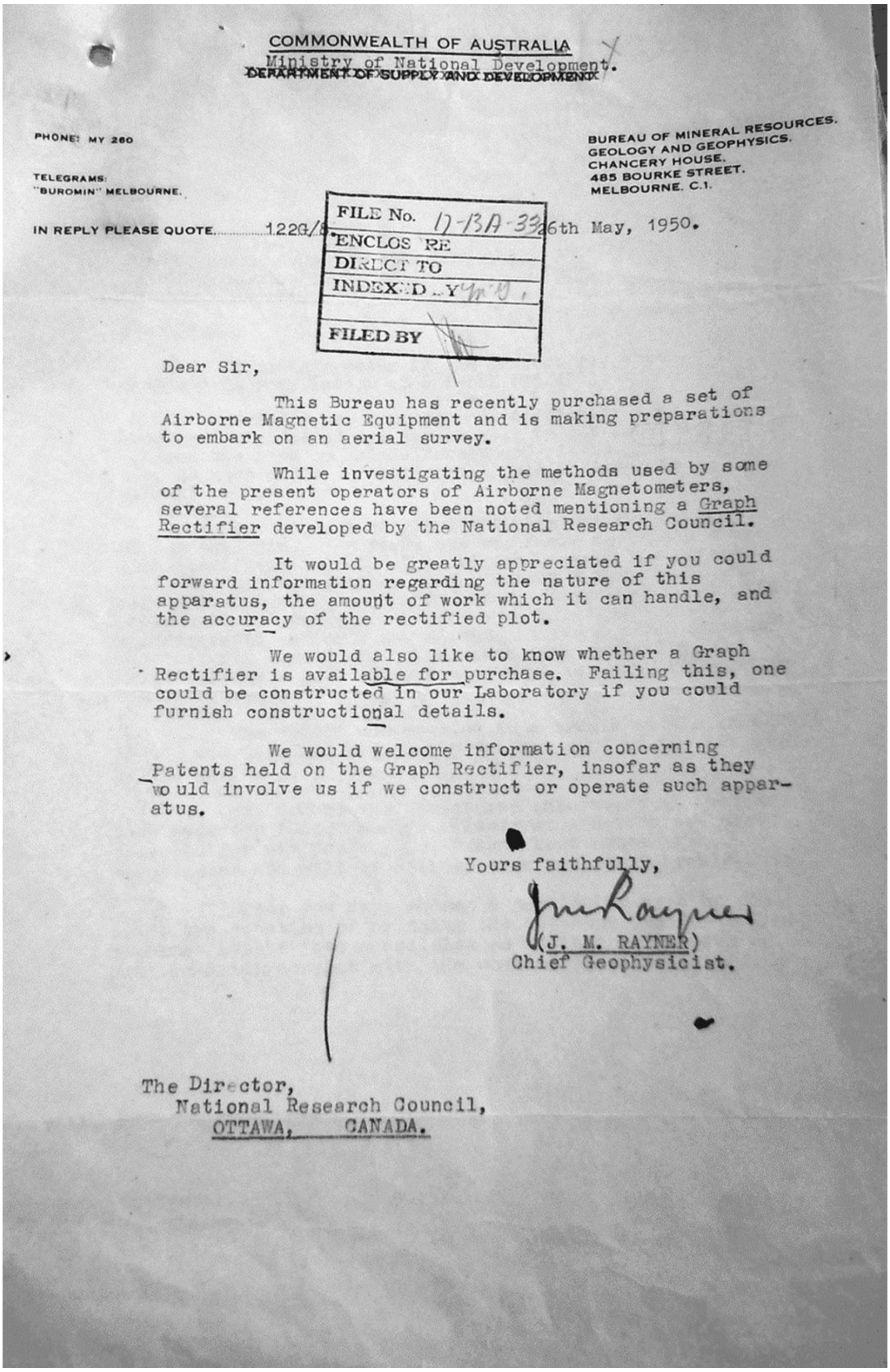
When I started in geophysical data processing with Aero Service Corp in 1962 it was pre digital acquisition but we had a few tools to help us out in getting analog data into map form. We had photogrammetric flat beds on our Wild A8 so we could automatically draw precise yard and metre grids at any scale although we had to calculate from published tables the geographics and plot them in whatever projection that was required. As a consequence a lot of the dog work with big 7 digit numbers was needed and we could add, subtract, divide and multiply on our electric Monroe6N (c1960 vintage) - it was better than slide rules although slide rules were used a lot for determining ' scaling' of data by proportion, for example easy to set up two map scales on a slide rule and from there convert both horizontal and vertical scale by direct reading.

Monroe6N electric computer.

We also had some pretty handy devices for converting analog chart data to maps. Aero Service used a device known as a transcriber and others had similar devices called 'graph rectifiers'. These were originally developed by the USGS in the late 1940s (see attached three pictures, one of me circa 1964 in a posed photo operating a transcriber and sitting on the desk behind me is a Monroe 6N). A separate photo of a Monroe 6N and thirdly a 'graph rectifier' which was in use by the Canadian National Research Council (Canadian equivalent to our CSIRO) in 1949 are also shown.

Doug Morrison operating a transcriber and behind, a Monroe 6N computer on a desk.

Also included below is a copy of an original letter by Jack Rayner, Chief Geophysicist of BMR to CNRC requesting details on the graph rectifier. There was ongoing correspondence on the matter with blueprints received by Rayner but it is not known whether one was built in Australia. Also included is a newspaper cutting showing an ECS Gerber plotter and a photo from an old Aero Service brochure (circa 1971).



COMMONWEALTH OF AUSTRALIA
Ministry of National Development.
DEPARTMENT OF SUPPLY AND DEVELOPMENT

PHONE: MY 260

TELEGRAMS:
"BUROMIN" MELBOURNE.

BUREAU OF MINERAL RESOURCES.
GEOLOGY AND GEOPHYSICS.
CHANCERY HOUSE.
485 BOURKE STREET.
MELBOURNE. C.1.

IN REPLY PLEASE QUOTE 122G/8 | FILE No. 17-13A-33 | 26th May, 1950.

ENCLOS RE
DIRECT TO
INDEXED BY
FILED BY

Dear Sir,

This Bureau has recently purchased a set of Airborne Magnetic Equipment and is making preparations to embark on an aerial survey.

While investigating the methods used by some of the present operators of Airborne Magnetometers, several references have been noted mentioning a Graph Rectifier developed by the National Research Council.

It would be greatly appreciated if you could forward information regarding the nature of this apparatus, the amount of work which it can handle, and the accuracy of the rectified plot.

We would also like to know whether a Graph Rectifier is available for purchase. Failing this, one could be constructed in our Laboratory if you could furnish constructional details.

We would welcome information concerning Patents held on the Graph Rectifier, insofar as they would involve us if we construct or operate such apparatus.

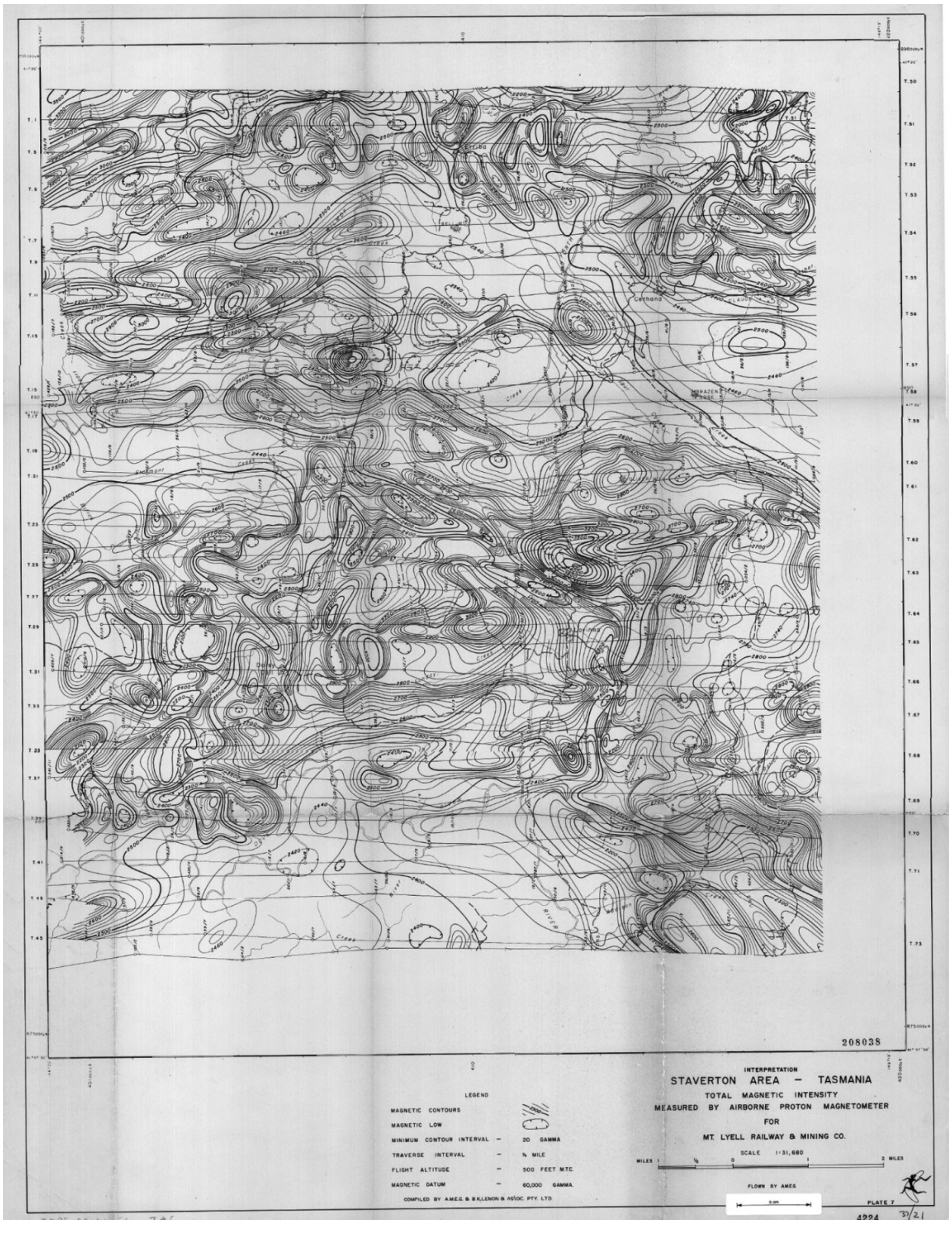
Yours faithfully,

(J. M. RAYNER)
Chief Geophysicist.

The Director,
National Research Council,
OTTAWA, CANADA.

A copy of an original letter by Jack Rayner, Chief Geophysicist of BMR to CNRC requesting details on the graph rectifier.

I know I have an example of ECS computer drawn contours from 1969 as I kept it because it was pretty crappy quality. I was forced to re-contour thousands of kilometres of data by hand for the customer (WMC) - WMC never got to see ECS's contours as I destroyed them at the time but I kept one small photocopy with my hand contours as an overlay. The ECS software could not handle 1 km line spacing in the environment of the survey area. I don't intend to put the example out there as it probably isn't fair. I spent three hours looking in boxes for that one sheet of paper today and couldn't find it but I know I have it somewhere. I did also have an example from John Pitt from the same era (from his original test area for us at GRD near Lake Lefroy WA) and I can't find it either.



Example of Doug Morrison's hand contouring of the Staverton Area, Tasmania.

Just one query for Dave Pratt. You mention QASCO possibly getting into aeromagnetics business circa 1971 and that rang some bells on two fronts as:

(1) I have seen an old photo somewhere of a QASCO Shrike/Aero Commander with a stinger or probe on its nose - I must dig it up -any idea what that was for as I assume it was around that time - just as the mining boom collapsed and

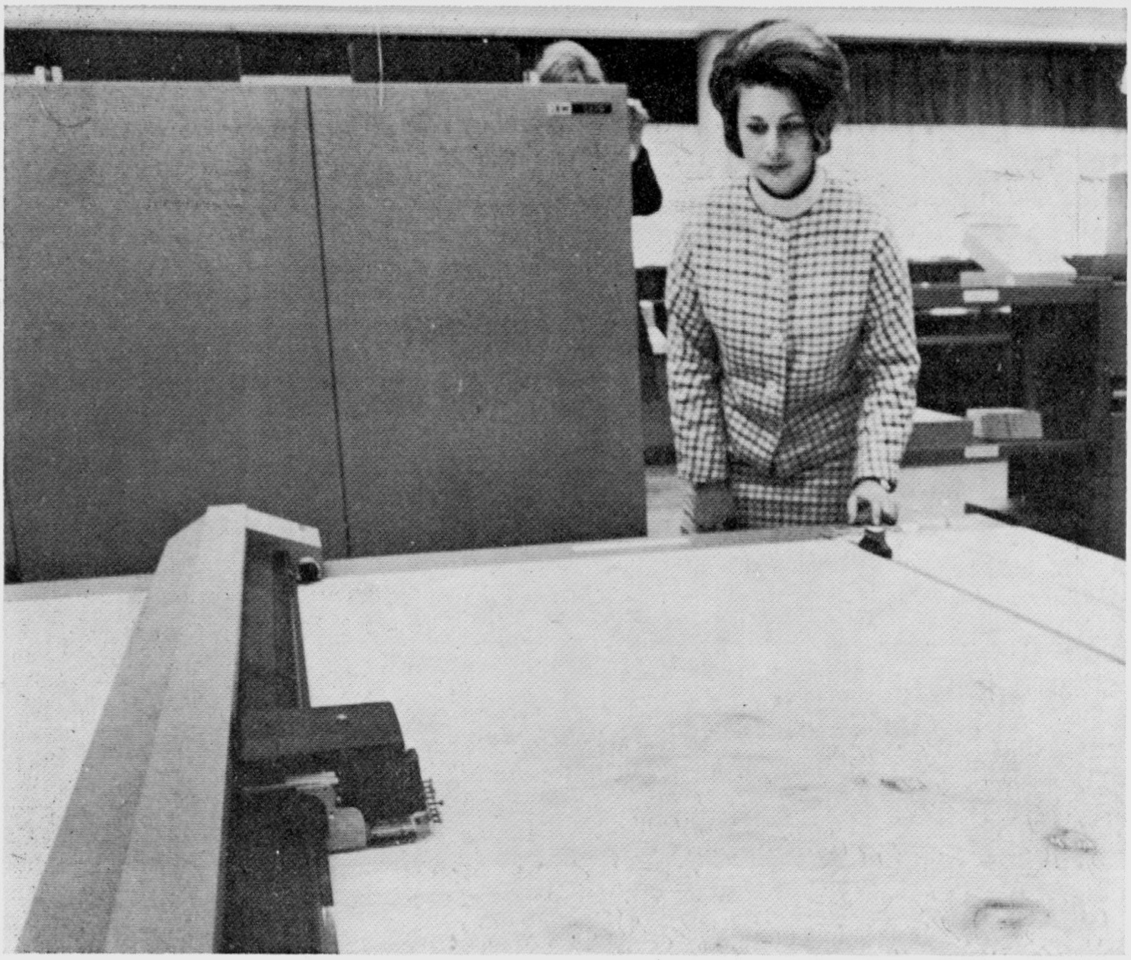
(2) I remember QASCO having some involvement with Brian Lenon (I was a co-director with Brian at the time in BK Lenon and Associates) and we were then handling GRD data processing in the late 1960s, maybe we were being considered at Ramsgate NSW as being involved with QASCO operations. A name James O'Brien?? rings a bell with me.

Not much else at this time - I must add I found lots of other interesting little bits and pieces in my boxes today including a nice piece of analog magnetic diurnal record from Mt Isa 1979 ex Dave Lyus 2 second sampling 100 nT fullscale which mapped a moving rotary clothes hoist beautifully.

I won't generally be copying in people here Roger but I thought the pictures might be of interest to others in this case. I MUST find that old contouring.

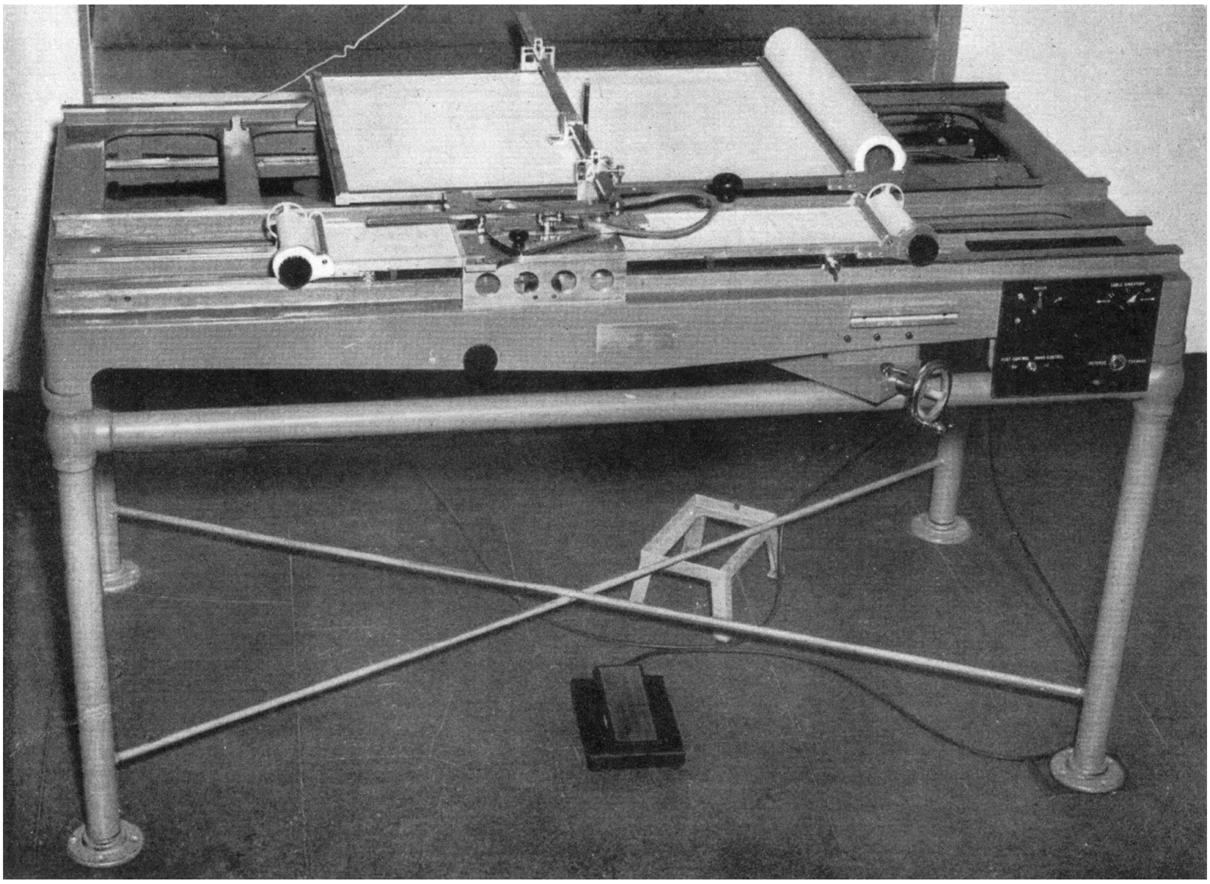
Regards
Doug

DIGITAL PROCESSING



Producing a geophysical contour map on the Gerber plotter in Sydney.

A Gerber plotting machine producing a geophysical contour map in Sydney.



Australian company to map mining data

Computers at a company in St Leonards, Sydney, are to process worldwide mineral exploration and mapping data under a new agreement — believed to be the first of its kind internationally — between the company and an American corporation.

Results of a huge and vital airborne survey in North Africa will be fed into the computers of the Australian organisation, Engineering Computer Services Pty Ltd, and transmitted back as graphical data to the company which is undertaking the survey.

The agreement is between ECS and Aero Service Corporation, of Philadelphia, whose airborne exploration headquarters in Australia is Canadian Aero Service Ltd at Cammeray, NSW. Aero Service is a division of Litton Industries.

Negotiations were conducted in Philadelphia last month, when the chairman of ECS, Mr Tony Cram, and consultant Mr Barry de Ferranti visited the Aero Service headquarters.

The general manager of Canadian Aero Service Ltd Mr R. N. Lambert, said, "We believe the Aero-ECS agreement is of much significance in that it permits us jointly to handle high-technology data reduction tasks on a completely computerised basis, which on an international level, have never been performed here before.

"The problem is that modern airborne geophysical exploration methods generate so much information about the earth beneath us that in many instances it is no longer possible to handle processing by the older type manual reduction approach, even if the manual system is computer assisted.

"In our belief, the total task of rapidly relucing the mass of data obtained from an aircraft's geophysical electronic instruments can only be resolved adequately, 'digitally' that is, by transferring the coded output totally to the computer, producing directly the results sought by the mining and petroleum companies, or the cartographers, as quickly-available graphical data.

"This is what the agreement between Aero Service and ECS is all about.

The EAI-430 digital plotter at Engineering Computer Services produces a final map for an aerial magnetic survey from data gathered by Canadian Aero Service Ltd.

A newspaper cutting showing an ECS Gerber plotter.

A piece of analog magnetic diurnal record from Mt Isa 1979 ex Dave Lyus 2 second sampling 100 nT fullscale which mapped a moving rotary clothes hoist beautifully.

2. Sliderule to PC

Reminiscing on 50 years of geophysical data processing

by Bob Richardson

When I was asked to write something about geophysical data processing I thought there was a risk that this could be a really dull subject, so in the following account I have tried to focus on some of the more interesting or unusual data processing episodes that I have participated in.

All geophysicists of my vintage will recall the crude computing tools at our disposal when we commenced professional work, in my case around 1965 – sliderules, mechanical Facit or Brunsviga hand calculators, log tables, or our own grey matter (very variable precision and accuracy). There was SILIAC in the Physics Department at University of Sydney, if you could get into the queue to use it. Even the arrival of electronic calculators with one memory in the late 60's got us excited and this was the beginning of the long road of computing hardware development to where we are today.

In my early fieldwork years, I was locating magnetic anomalies in the Wiso Basin region, 50-100kms south west of Tennant Creek. These were primitive times. There was no GPS and no good mapping control, so I had to determine our position by doing star observations at night using a theodolite followed by tedious reductions by the light of a pressure lamp, using seven figure log tables. We soon tired of this. After some research I found a marvellous device called a Chobham Navigator that was being used by the Weapons Research people in South Australia to search for spent rocket casings. This could be mounted in a Landrover and used fluxgate magnetic sensors for direction, and the speedo cable for distance travelled. These two inputs drove a mechanical "ball resolver" the output of which was distance travelled north-south and east-west. With careful calibration it enabled our AMG position to be determined to +/- 0.25% of distance travelled. We acquired two of these and they saw great service over many years in the Tennant Creek and Top End regions. So this was our first field "computer", albeit a mechanical one, but a computer nonetheless.

Much of my early geophysical career was centred on the Tennant Creek province, where our main client Peko-Wallsend was searching for small pipe-like magnetite bodies carrying high grade copper, gold and bismuth. The associated magnetic anomalies required precise analysis and modeling to specify drilling targets. Targeted bodies were often under relatively deep cover and could have any strike or plunge, and thus were easily missed by inclined core holes. During the early-mid 1960's, Lew Richardson, in conjunction with mathematician Bruce Kirkpatrick, developed a rigorous mathematical process to calculate the magnetic (and gravity) anomaly due to an ellipsoidal body with any orientation, and taking demagnetisation into account. This enabled precise modelling of the pipe-like and lens-like bodies typical of the Tennant Creek field. A key element that made the mathematical process doable within a reasonable timeframe was the use of a novel coordinate system, developed by Kirkpatrick. This coordinate system was based on the ellipses created by the intersection of the confocal ellipsoids with the ground surface. The anomaly values were calculated at the points of intersection of these ellipses with radial lines.

Using these mathematical processes and the skilful choice of body geometries and attitudes, Lew Richardson and Bruce Kirkpatrick pioneered the matching of calculated and observed anomalies due to discrete ironstone bodies, long before modern computer aids were available.

However, the calculations were slow and tedious using mechanical hand calculators, log tables and mental arithmetic. Later at L A Richardson and Associates ("LAR"), we streamlined the calculations and developed routines using standard printed forms to make the process as efficient as possible, without losing precision. Even so, to produce a contour map of the calculated magnetic field strength, due to an ellipsoidal body, with sufficient detail, took at least one day. I often think of that now, when I do the same process in a fraction of a second using current software and computing power.

A major break-through for LAR was the arrival in St Leonards of Computer Science of Australia ("CSA"), in 1970. CSA offered a time-sharing service via a dedicated phone line, at a reasonable cost. LAR became one of its first customers and we were set up with a teletype terminal in our Killara office. Programs could be written off-line and stored as paper tape. The entire calculations for one ellipsoid case now took about 3-4 seconds of Univac 1108 machine time and about 20 minutes terminal connect time.

This was a marvellous facility and it came at a critical stage in the growth of our main client Peko-Wallsend, and LAR. Peko was developing as a major Australian mining house and its exploration arm Geopeko was rapidly expanding its exploration activities beyond Tennant Creek and opened bases in Darwin, Mt Morgan, Townsville, King Is, Devonport, Parkes, and Perth. Geopeko became one of the most successful exploration outfits in Australia discovering 17 mineral deposits all of which became operating mines embracing a wide range of commodities. Several of these deposits were world class including the Ranger 1 uranium deposit, and the Parkes porphyry copper/gold deposits. LAR's geophysical contributions were critical to many of these discoveries.

Through the CSA facility we set about developing a range of software programmes using BASIC language. Our philosophy was to keep these processes a simple as possible, but precise and tailored to meet the exploration problem. We soon had a range of fast and practical software tools covering most of the standard models used for interpretation of magnetic, gravity and some electrical techniques. The "jewel in the crown" was our set of programmes that could calculate the magnetic (and gravity) field for an ellipsoidal body with any attitude and magnetic properties.

It was easy for geophysicists to be seduced by the fascination of computing and the fast-moving developments in computer technology. However, our prime function at LAR was the application of geophysics to mineral exploration and the discovery of ore deposits. I resisted LAR becoming a "geophysical computing house". Our computing capability had to be directly relevant to practical exploration requirements, especially the identification of worthwhile targets and precise drill hole targeting. Despite pressure from our main client to have our computing functions absorbed into their in-house computing division, we maintained our own management of these functions within LAR. The ongoing development of our computing tools was driven by actual day-to-day requirements at the exploration front-line. Thus our tools were sharper and more effective and this was a major reason for our success.

Consistent with this philosophy, we purchased a WANG 2200B desk-top computer in 1973. For its day this was a wonderful machine. (Google search reveals lots of enthusiasts - I wish I still had one!). Hard-wired in BASIC language, it was relatively easy to transfer our existing programmes onto this computer and further refine them. Connected to a small flat-bed plotter, we were soon able to plot model profiles and contours for quick anomaly interpretation, and then refine models for follow-up holes as early drill-hole results became available. We developed a full suite of geophysical modeling programs on this machine and they were put to good use on hundreds of prospects across Australia. Many successful Geopeko drillholes were targeted by LAR using this capability.

The WANG was replaced in 1976 with an HP 9825 desktop computer. I can't remember why – I think we just wore out the WANG.

Through the late 60's early 70's we became increasingly involved in the use of airborne geophysics and the processing of airborne data. Of course we were not the only ones, and the industry was served by many good contractors including GRD, Geometrics, Aero Service, Geoterrex, Geosearch and processing contractors Pittmen Data, and ECS. At LAR we were not content with accepting the standard services offered and paid more attention to planning and specifying surveys and processing to ensure that the end product met the exploration requirements.

Following the discovery of the Ranger 1 uranium deposit by Geopeko in 1970 we were in the hunt for further uranium deposits and this led to a deeper understanding of airborne gamma ray spectrometry, and the processing and presentation of multi-channel spectrometer data.

This all came to a grinding halt in 1972 with the election of the Whitlam Labor government and its acquisition (some would say theft) of the Ranger 1 deposit, which led to the cessation of all uranium exploration in Australia. LAR and Geopeko had acquired an advanced understanding of uranium exploration and related geophysical technology, but with no budget to use it. Following representations to the federal government, the Department of Overseas Trade offered to assist Geopeko to obtain work in other countries, principally in the Middle East.

This seemed crazy. Having prevented us from exploring for uranium in Australia, the Federal Government was encouraging us to use our skills to explore in other countries. Nevertheless we had a great team and we wanted to keep it together, so we began to investigate the possibilities. Following some dead ends, in July 1975 we were invited to meet with the Atomic Energy Organisation of Iran ("AEOI"). Western Mining Corporation ("WMC") participated in these early meetings with a view to pursuing a combined bid, however WMC pulled out when it became apparent that AEOI's first priority was the completion of an airborne geophysical survey and did not include geological work.

We were not an airborne survey company and had no aircraft, no airborne systems and no large scale computing capacity. However by now we knew a lot about airborne survey technology and, perhaps more importantly, its application to uranium exploration. We formed Austirex Aerial surveys Pty Ltd (Peko-Wallsend 87.5% and LAR 12.5%) as the lead contractor. We had a good working relationship with flying contractor GeoSearch and data processor Pittmen Data and so engaged them as sub-contractors for the purpose of our bid. Pittmen established and staffed up a subsidiary company Infographics for the job.

We were advised that AEOI wanted "the best technology that the western world could provide". During many discussions with AEOI, we provided extensive input into the design of the survey technical specifications, including input from an explorers point of view. In late 1976 Austirex won a contract for the completion of 315,000 line kms, for a price of US$52 per line kms. At the time the contract was regarded as the largest and most technically advanced ever called for. Prakla Seismos and CGG also won contracts.

There were several major computing issues to deal with on this contract. Firstly, we had to build an on-board computing capability to record 256 channels of spectrometer date from 50,000 cc downwards crystal detector and 8,000 cc upwards detector for radon monitoring, together with magnetometer and navigation data. As a joint effort, GeoSearch and Sonotek built a software-controlled system based on a Fabritek MP12 computer.   The system was mounted in an Australian built NOMAD 22B aircraft. As the survey progressed we became concerned about our dependance on one aircraft and system and acquired a second NOMAD and system, but this aircraft was never mobilised in Iran.

Secondly, Geosearch had no suitable mapping available to control the flying. Austirex had been assured that aeronautical maps at 1:50,000 scale would be made available by the Iranian government but when the time came the Iranian military vetoed this. Geosearch then had no option but to fly on lines of constant bearing i.e. "Rhumb" lines. To calculate and plot these lines on a map, it is necessary to take into account the geodesic curvature of the earth. Infographic's code developer Ian Campbell started working on software to calculate and plot Rhumb lines. Calculating the coordinates of rhumb lines had to be based on making moving approximations of the earth's curved surface. Ideally these surfaces are ellipsoidal and Ian struggled with attempts to mathematically solve the associated elliptic integrals until he was told by Terry Lee, who was with us at LAR at the time, that these integrals are unsolvable and could only be solved numerically. In the end Ian used spherical surface approximations which did the job and he was able to supply sufficiently accurate flight path control for Geosearch.

Thirdly, the data corrections and then production of approximately 5,000 maps required the processing of a massive amount of data. There were a number of very sticky technical problems to sort out along the way, including but not limited to flight path recovery, location issues, radon correction and noise "spikes". For spike removal Ian Campbell developed some clever automated routines using algorithms based on a method of "differences" that tested the validity of each spike and either accepted or replaced it.

Given the volume of data, the processing through to final maps had to be fully automated. There was no scope for operator intervention. This required a complete re-write of Infographic's software and many late nights for Ian Campbell.

The hardware for processing and map production included a Data General S230 in the Tehran office and a Data General S330 in Infographics Sydney office. However, the computer destined for the Tehran office never arrived. Upon arrival in Tehran it simply disappeared into a customs "black hole". About one year later we discovered that it had actually been stolen out of a customs warehouse by Esfahan University. So, one quiet afternoon an Austirex team (members remain nameless) organised a truck and a driver, slipped unseen into the University and simply stole it back. Of course by then we had sent another system, so now we had two. Just one of many dramas and delays involved in running a highly technical operation in a chaotic country.

Iran collapsed in revolution in December 1978 and we immediately pulled out the people leaving behind the computers and aircraft. By then we had completed approximately 85% of the flying and had the resulting data back in Sydney to continue the processing. We needed the computers back in Sydney, so six months later I went back with two Geosearch people to recover the computers and Geosearch flew the aircraft over the border to Pakistan and then back home.

Austirex went on to become a successful airborne survey contractor in Australia. It was subsequently sold to Aerodata. The airborne data processing software system developed for the Iran job by Ian Campbell was a key asset for Austirex and later Aerodata and World Geoscience.

Following my time with LAR, GeoPeko and Austirex, through the 1980's-2010's I was involved with smaller listed companies, principally Lachlan Resources NL and PlatSearch NL. These companies specialised in exploration project generation, identifying and acquiring tenement opportunities and then farming out to larger companies. With minimal staff we had to be efficient and fast on our feet and computing played a critical part in the process. The availability of low cost GIS software, powerful desktop computers and the internet availability of masses of regional digital data was a huge advantage, and continues to be so, for exploration companies of all sizes. Processing of airborne geophysics has now become so streamlined and fast that final data and maps can be available the day after flying.

It has been fun over the last 50 years, "surfing" the waves of computing technology development. Where to from here? I guess I'll miss the next wave – AI?, quantum computing? - but I will be watching with interest.

3. The ECS Story - Tony Cram – 1939 - 2014

Anthony Adrian Cram, or "Tony" as he was known, was born on March 20, 1939.

Only 12 years later alongside his father, who was a mineshaft sinking contractor, Tony first went down into an Illawarra coal mine. After this introduction to mining, Tony went into the family business, R.G. Cram and Sons, where he focused on civil engineering and ultimately natural resources development.

Tony went on to study Civil Engineering at the University of NSW, and completed his Master's Degree there in the early 1960s. Tony was a gifted problem solver, a true innovator who was often years, and many times even decades ahead of his time.

The technological legacy that Tony Cram has left with the world is astonishing and few people, if any, know the full extent of his achievements. Following is a list of some of his accomplishments, compiled from the collective memories of some of those privileged enough to share in Tony's journey:

1966 – Engineering Computer Services ("ECS") is formed. Early consulting contracts include:

- Project scheduling, engineering, and finite element analysis of the sails of the Sydney Opera House.
- A land use evaluation system for NCDC used in planning all Canberra suburbs in the 1970s, and satellite cities around Melbourne and Darwin after cyclone Tracey.
- Radio positioning software to site oil platforms in Bass Strait, and ships on New York Harbour.
- Software development of very early traffic control computer programs.
- Awarded a government grant later that year, ECS Research was formed and moved to Mittagong, in the Southern Highlands of NSW.

1969 – Exporting begins after winning a contract from the United States Geological Survey (USGS), which in turn applies that work to a study it was undertaking in Saudi Arabia. Under Tony's guidance ECS Research pioneers the processing of airborne geophysical data for resource exploration, providing state of the art maps to numerous resource based clients.

1973 – The OAPEC oil crisis forces countries to look at cheaper fuels, which triggers a coal mining boom. ECS responds with MINEX software, which is utilized throughout Australia and is ultimately exported around the globe, including to the United States, South Africa, Canada, Japan, India, Indonesia, South America and the Middle East.

1975 – The parent company ECS moves from Sydney to Bowral, in the Southern Highlands.

1980 – ECS develops a geometry based timeshare system for ships at sea to process geophysical data in Bowral.

1985 – SO_2 (sulphur dioxide) emission restrictions came into force and “cleaner” coal was sourced from increased underground mining activity. ECS responds with “MINEX Eclipse” underground coal mining software.

1996 – ECS develops the MINEX Gravel Scheduler for the Penrith Lakes Development Corporation and turns a sand and gravel quarry into the Olympic Rowing & Aquatic Course for the 2000 Olympics.

1997 – Tony decides to retire, and creates a plan to handover the business to ECS staff via a share purchase, and ECS International (ECSI) is born. Tony agrees to stay on and continues to innovate, guide, and mentor for another 5 years.

1998 – ECSI is awarded AustMine’s Emerging Exporter of the Year Award, and the NSW Premier’s Award for Exporter of the Year in the Minerals Industry category.

2002 – (Editor’s Note) – Surpac purchased ECSI and created the Surpac Minex Group. In 2006 the Surpac Minex Group was acquired by Gemcom Software International Inc. In 2012 Gemcom Software was acquired by Dassault Systèmes and the GEOVIA brand was created targeting the Natural Resources industry.

2002 – To pursue his love of sailing, Tony, a skilled sailor, moves to the South Coast near Bateman’s Bay. From time to time he consults on various projects, always keen to innovate and solve problems where he can.

An outstanding thinker, innovator, entrepreneur, leader, mentor, friend, and family man, Tony is sorely missed by all who knew and admired him. He was the epitome of how much one person can accomplish while positively influencing and helping others over a lifetime and his legacy will continue to do so for many years to come.

4. Ian Hone on ARGUS and Magnetic Map of Australia (MMA).

Airborne Reduction Group Utility System – ARGUS

ARGUS was a library of computer programs that operated on field data, taking airborne magnetic and gamma-ray digital data from field observations to final processed data and maps. It could handle almost any data type, but the dominant data types were magnetic and gamma-ray spectrometer. It dealt with magnetic tapes, disc packs, punch cards, paper tapes, graphic displays, maps, diagrams, graphs etc and descriptive texts.

BMR processing of airborne digital data was initially done on a CDC3600 computer located at CSIRO, and some machine contouring was done on CSIRO's Sydney CDC 6600 machine as early as 1971.

In November 1973 BMR's airborne data processing transferred to CSIRO's CYBER 76 computer. Leading up to that data processing programs had to be modified and the processing system documented. This was essentially the start of ARGUS.

At first tapes of data and job file card decks had to be transported to CSIRO. Eventually terminals were available in BMR. Because of costs (CSIRO charged), and competing priorities with other CYBER 76 users, BMR purchased its own Data General computer. The Airborne Group ran into problems with competition with other BMR users, so it purchased its own DG computer. David Downie and Tony Luyendyk designed a very efficient Airborne network separate from BMR's network, but having a gateway to the BMR system ARGUS then started to move from a very much centralised system to a distributed system which improved processing efficiencies and system robustness. The Airborne Group wanted to do in-field processing, and a move to a distributed system commenced based on Sun workstations. Because of costs and wide spread availability of off-the-shelf powerful personal computers a move to personal computers occurred.

A major shift occurred with the impetus of Professor Colin Reeves who joined the Airborne Group in about 1990. This move was made because of the difficult command line system used by ARGUS, Fortran code written to satisfy the restrictions of mid 1970s and earlier hardware, the advent of graphical user interfaces; the perceived large overheads incurred by BMR in operating an in-house system; and the desire for BMR's airborne data processing system not to be reliant on the expertise of a (very) few computer systems officers who might leave at any time. Accordingly Desmond Fitzgerald's Intrepid system was built to replace ARGUS and BHP's Pie in the Sky (PITS) system, driven mainly by BMR, and BHP (which had also recognised some of the problems identified by BMR in operating is own in-house system). Intrepid was also supported by a number of other organisations such as Aberfoyle and Stockdale.

Magnetic anomaly map of Australia (MMA)

The MMA was conceived in BMR by Geoff Young when he was in charge of the Airborne Section. A major part of the MMA effort was the digitisation and reprocessing of suitable old analogue aeromagnetic records. The basic output was levelled point located line data. Most of this work was done by contract in the late 1980s. The first Magnetic Map of Australia was released in 1993.

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5. The GRI Story

Development of Potential Field Acquisition and Data Processing Software in Australia

John Stanley

These notes should be judged for what information they contain rather than what they do not contain. I am no expert on the broader history of digital data processing, but I can record some information on developments that I know to be pioneering and in which I had some involvement as Director of the Geophysical Research Institute at the University of New England. In the 1970's there were two drivers for the development of software for potential field acquisition, computer-aided data processing and image processing. They arrived simultaneously. One driver was the development of magnetometers that could acquire and digitally record positioned potential field measurements at a very fast rate and the second was the evolution of the microcomputer that could handle the digital data recorded. The unique characteristics of this data at the time had special processing needs and so we had to develop these applications in-house. In the early 1990's the magnetometer development was extended to facilitate the simultaneous acquisition of both spatially varying magnetic field values and time varying magnetic fields associated with current flow introduced into the ground and electromagnetic decay waveforms. The technology (Sub Audio Magnetics) required a purpose-built suite of software and the enhancement of this is on-going today.

Prior to 1970, virtually all potential field measurements at ground level in Australia and most of the world involved serious under-sampling. Data recorded by hand were manually "smoothed" (low pass filtered) to subjectively remove artefacts of this under-sampling. The standard "image" representing this data was the contour map, produced by hand from hand drawn profiles, a process introducing further subjective filtering. In the late 1960's, some contouring programs were developed for mainframe computing and were mostly applied to airborne-acquired data or relatively smooth, gravity data.

Interestingly, it was the digitisation of aerial and x-ray photographs and the application of potential field mapping to archaeological exploration that led the way. Even before rapid sampling magnetometers were available, it was practical to properly sample potential field data over an archaeological scale survey area. In the early 1970's archaeologists in Europe were prepared to map areas with proton precession magnetometer measurements taken over a 1 metre grid covering one hectare in approximately 4 days. In the geological environments where this was done, sampling a

1 m square grid with a magnetometer held 1m above ground, the data was well sampled. These data were hand recorded and later typed onto computer cards for mainframe processing.

Probably the first potential field processing software that addressed more than just contouring, was developed at the Rheinisches Landesmuseum in Bonn in 1977. It was run on a DEC PDP-11 computer. This archaeological centre developed a program that was primarily designed to process digitised B&W photos and X-ray images but was readily adaptable to gridded potential field (magnetic) data. It contained a range of image processing routines such as one for "de-corrugating", and one for grey-scale imaging. In a very successful application, aerial photos of ploughed farmland could have the furrows removed by filtering enabling subtle soil colour or crop colour variations due to buried archaeological structures to be enhanced and displayed in grey scale.

In Australia, the development of the fast sampling, digital caesium magnetometer to be used at ground level created a unique demand for data processing. Positioned, digital data at 0.2 m intervals were first recorded in 1978 in a vehicle-mounted platform running a Z-80 processor. In 1979, digital recording of automatically positioned data was achieved in a hand-held magnetometer. Both these systems were capable of acquiring properly sampled data along survey lines. Archaeological applications required the survey line spacing to be 1 m for adequate sampling (0.5 m above ground) and in 1979 a one ha area could be mapped in about 4 hours. In mineral exploration applications, a survey line spacing of 10 m was common, but sometimes extended to 25 or 50 m.

The mineral exploration application required data processing with particular characteristics. The challenge was how to process and present data in a manner that preserved the full spectrum of the properly sampled data along line without introducing aliasing artefacts across line. In 1982, Julian Creedy wrote a program "Isoplot" for stacking full resolution survey line data to form an isometric image without introducing filtering between lines. This program was first run on a mainframe DEC 20 computer. A particularly useful attribute of this presentation was that low amplitude, very narrow, linear features (associated with thin dykes for example) and localised anomalies of shallow, dipolar source could be readily identified from a "mountainous magnetic topography" due to deeper source structures. This application had a big impact on coal mine development where even thin dykes would present a major problem to long-wall mining. In 1984 a trial of this form of data processing proved very effective in enabling discrete dipolar source anomalies due to unexploded ordnance (UXO) to be recognised from a rugged magnetic topography associated with the intensely magnetic, ironstone capped bombing range in Darwin.

Prior to 1986, Isoplot images were generated on the University's mainframe for archaeological, ordnance detection and mineral exploration applications where the full spatial resolution of the recorded data along line was required to be preserved.

In 1981 Malcolm Cattach joined the GRI team. In 1983 as a Master's student researching the comparison between different Induced Polarisation (IP) receivers, he pioneered the production of computerised pseudo-sections from IP measurements.

In 1985 the GRI were contracted by the RAAF to magnetically map 90 Ha over the former bombing range in Darwin where conventional metal detectors used for UXO detection had failed due to the intensely magnetic and conductive ironstone capping. The success in detecting dipolar (UXO) sources in this harsh magnetic environment using the Isoplot software led the RAAF in 1986 to contract the GRI to develop and supply the TM-3 magnetometer with PC's and PC based data processing software. Prior to this, all UXO detection had been achieved using analogue metal detectors that provided no audit trail from which the quality of the detection could be quantified. The RAAF contract initiated the development of an audit trail associated with data acquisition and processing. This was a first in the application of UXO detection globally and conveniently, just preceded the fall of the Iron Curtain, an event which created a world-wide demand for auditable UXO remediation from former defence sites.

During 1986 Malcolm Cattach developed a suite of data acquisition software to run on a Z-80 based platform that was the heart of the TM-3 magnetometer which in 1988 received the first Grahame Sands Award of the ASEG for Innovation in Applied Geoscience. The unique feature of the TM-3 was its ability to acquire automatically positioned magnetic data at a very high sample rate so long as survey lines were straight. To take advantage of this feature, Mal developed his **MAG**netometer **I**nterface **C**ontrol (MAGIC) software for automating the acquisition of data within an irregular grid boundary. This software was the precursor to that now commonly used with GPS technology for applications in farming as well as geophysical mapping.

In meeting the RAAF requirement for PC-based software to deliver an auditable data processing, signal enhancement and interpretation trail, Mal had to convert Isoplot to run on a PC. He also developed of a suite of facilities for reading the raw data from the magnetometer, rejecting outlying data, providing base station correction for diurnal variations, appending data from different survey sessions, applying Fourier Transform filtering along line and finally preparing an ASCII grid file. This file was able to be filtered to produce interpretive enhancements using gradients or reduction to the pole. The ASCII grid file was the input for a program to visually preview the data in plan form on a 640 x 350 resolution colour monitor (Apricot ZEN). This previewing facility became the colour imaging program called "Colmap". A rainbow spectrum of colour was assigned to the potential field amplitude, first in a linear scale and then histogram equalised around the median. While this program was initially focussed upon UXO detection requirements, its application to magnetic geological, archaeological and industrial site mapping was always recognised.

In what may have been a first, magnetic survey data acquired in 1986 during the day, in a remote location off the Gunbarrel Highway in central WA, were presented as an isometric image the following morning, the plotter and PC having been working away all night while the field crew slept under the stars.

In 1988 Stephen Lee joined the GRI as part of the team developing the next generation magnetometer, the TM-4. Stephen developed a new PC based program MagSys", specifically for the UXO detection application. MagSys extended the capability of Colmap adding the ability to interactively or automatically recognise localised dipolar source anomalies from magnetic data. MagSys then fitted a dipolar model to this data for the purpose of defining position and estimating size and depth of potential UXO targets. A project was immediately commenced to statistically quantify the characteristics of the magnetic dipole of ordnance of different types and orientations so that an estimate of depth to which the detection of ordnance of a particular type might be assured. Mal and Steve's software for delivering an audit trail in UXO remediation for the RAAF was a world first in what has become a legally sensitive industry.

In 1989 the ASEG Conference was held in Melbourne. At the trade exhibition, two companies presented their software for processing potential field data on a PC. They were GeoPak and GeoSoft. The software offered by these companies was no further developed than Mal's Colmap and it lacked the interpretive modelling of Steve's MagSys. Unlike the GRI who were writing software to fill their own needs, Geosoft was established to commercialise their product and since 1989 they have done this extremely well.

Also at the ASEG Conference in 1989 was the sponsor of Mal Cattach's Masters research and later PhD, Graham Boyd of Newmont Exploration. Graham invited special friends to his hotel room to see what he was working on. His package was called "Geosolutions" and this was well advanced and clearly the world leading software of its type at this time. The structure of Geosolutions was conceived as a flexible database from which layers of data could be combined. These layers may include non-geophysical information such as base maps and photography and it may include a range of geophysical data such as radiometric and potential field. But also, layers could be generated by applying signal processing to raw data. Geosolutions was a very well-designed concept.

The precursor to the Geosolutions development was a numerical services database developed in the early 1970's by IBM for its small, IBM 1130 mainframe. In the early 1980's, Newmont exploration commenced development of a geophysical data presentation application using this package with a 512x512, 16 bit graphics card. Graham Boyd, working for Newmont, recognised the limitations of the IBM software and in 1988 commenced the development from scratch of the Geosolutions software, now to run on a PC. At the heart was a binary database. In order to make full advantage of this on a PC, Graham installed an Imagraph graphics card of 1024 x 1024, 32 bit resolution.

With the database and high-resolution graphics card, the next stage was to install image processing routines most applicable to potential field data and to overlay these with other geophysical and topographic information. As a significant first, Graham recognised that the mathematics behind a just declassified feature of terrain following radar used on the F111 fighter aircraft could be beneficial to the enhancement of geophysical data. The result was the application of shaded relief to potential field data. This has since become an industry standard in image enhancement. Geosolutions software went into use by Newmont in 1988.

!988 was also the year when the concept of Sub Audio Magnetic (SAM) was recognised and when signal from a nearby CSAMT transmitter was detected with a TM-3 magnetometer giving confidence that SAM was feasible. In 1988, the upgraded TM-4 was produced, now running a Motorola 68030 processor with 68881 co-processor and delivering 400 measurements to 0.1 nT resolution per second. SAM was a radically new innovation in the application of potential field measurement and processing, and it was only made practical by the development of the TM-4 magnetometer. In 1989 the TM-4 was interfaced with differential GPS and the original MAGIC data acquisition software developed by Mal was upgraded to facilitate fully automatic tracking of a planned survey coverage. Survey aides such as an off-line indicator became available.

With this technology, in 1991 Mal commenced a PhD program, sponsored by Graham Boyd through Newmont Exploration, into the development of SAM. Mal's first priority was to separate the spatially varying magnetic field (TMI) from the magnetic field associated with a time-varying electromagnetic field. Initially this electromagnetic field was measured during the on-time of a square wave current introduced to the ground through distant electrodes. From knowledge of the position of the electrodes and the position of the wire feeding them, models had to be developed and run to calculate the primary field (from the wires), the Normal field (from current flowing through a homogeneous earth) and to subtract these from the measured on-time field to give the anomalous response (TFMMR). These programs were all developed in 1990 and the output integrated as layers in the Geosolutions database.

In 1995 David Boggs joined the GRI team as a PhD student and commenced a feasibility study into the extraction of transient electromagnetic and induced polarisation information from SAM data. In doing this, David prototyped some specialised data processing applications. From 1998, Mal integrated David's results and to this day has continued to develop and refine the whole package of SAM processing, including its spin-off SAMSON for acquiring total field EM data of the highest sensitivity. (The TM-4 and its application to SAM received the Grahame Sands Award in 1995).

6. The Intrepid Story - Des Fitzgerald and Associates (DFA)

Software Products

1. **INTREPID** potential fields geophysical processing system (software)
    a. A mature comprehensive implementation of all established methods required for observations of Geomagnetism, Gravity, Gamma-Ray spectroscopy.
    b. Reduction of this data to a uniform best representation of the field on a continental scale.
    c. Standard and novel methods for extracting geological information from such data
    d. initially supported by BHP, Pasminco, Stockdale Prospecting and Geoscience Australia (GA); This started in 1992 with a consortium that went for 3 years, and ended with an extension from AGSO, to cover a make-over of managing continental scale gravity acquisition, levelling and deployment. By 1999, Intrepid and AGSO had released the GridMerge capability, that Brian Minty and Tony Luyendyk had conceived of. This remains the dominant tool for conditioning the survey data to grids, and then making a best fit continental composite, more or less on demand.
    e. Extensions to large scale Airborne Electrical Magnetic surveys, Full tensor Gravity Gradiometry, with an "object oriented" way to treat any geophysics signal. So, extension to vector components and gradients also supported.
    f. Clean and clear systematic code base with integrated testing and training material
2. **GEOMODELLER**
    a. Geological editor based upon the principals of structural geology and field observations
    b. Geostastisically based implicit function technology is used to interpolate the geology formation volumes, and a Geological pile provides the rules for resolving a unique prediction at each point in 3D.
    c. Originally derived from GeoFrance3D over 10 years from 1995
    d. Commercialized from 2004, in partnership with Australian Geological surveys and the French Geological Survey
    e. 3D software integrated with potential field geophysics, was introduced in 2006 to 2009.
    f. Geological uncertainty via a high level API that includes error terms for any of the field observation terms, has been added in 2017.
3. **JETSTREAM**

a. The Australian GADDS product for on-line delivery of geophysical data from Geoscience Australia – duplicated for PIRSA. This was first developed in 2004
b. Tullow Oil seismic data web query and delivery of seismic data
c. Namibian Geological Survey data repository, query and delivery system
d. Geological survey of Ireland bathymetry data query/delivery

4. Custom Off-The-Shelf software

a. The SPECTREM/AngloAmerican magnetic tensor project started in 2005 and has now reached the stage of a full processing stream for mag tensor signals, ie filtering, levelling, decorrugation, micro-levelling, tensor gridding.
b. Lockheed Martin new developments for gravity gradiometry. This also started around 2004, with tensor gridding, SLERP patent, MITRE as a successor to Minimum Curvature and Full tensor Noise Reduction filters, using truncated Fourier series in 3D.
c. Micro G Lacoste marine gravity bespoke hardware interface, Sea-G, developed first in 2013

5. 2.5D AEM forward and inversion capability, to create sections, predict the response from expected geology etc. This effort started with Arjuna , AMIRA P233, then morphed into MOKSHA (' Lifting the fog of ignorance'). This work started at Intrepid in 2015 and is on-going. The important breakthroughs include

a. Removing any limitation on size of inversions, so any size survey is OK
b. Finishing the initial implementation and testing of the 2.5D forward model
c. Optimizing the solver and changing the convergence strategy.
d. Investing in software engineering to handle the complexity and position the technology for further improvements and integration with 3D geology modelling.

DFA Services

Services offered by DFA include:

a. A complete compilation of Australian regional geophysical maps (both on shore and offshore) for magnetics, gravity, and bathymetry in partnership with Geoscience Australia (GA); Intrepid provided the starting examples for most of these products.
b. Independent Quality control and interpretation of airborne gravity, magnetics and tensor gradients for exploration companies
c. Integration of geology and geophysics to create 3D brown fields models around operations to identify other opportunities to exploit.
d. Sensitivity studies for original instrument manufacturers, to aid the specification and testing novel geophysical instruments.

e. A 2.5D AEM inversion and reporting fee for service. This uses as much of the measured signal as possible to produce "geo-electric " sections which look geological.

Performance and Growth

The DFA company has been deliberately kept below a head count of 20 people, to keep the focus on innovation and improved productivity in the systems used to conduct the business and manage complexity. An extra layer of agents and close associates expands and contracts depending upon demand and market conditions.

The company has undertaken a few larger R&D efforts, (order of 3 years+), and a commitment to continuous R&D on smaller projects at other times. The outcomes are almost always incorporated into the products for sale.

The company has had the approach of seeking external funding from interested parties for most of the higher risk activities, so that the main risk the company faces at any one time is technical, not financial. The company turnover typically sits in the A$1.6m to $2.2m bracket, with the odd year well above due to grant requirements for expenditure.

The company has cash reserves and has not used an overdraft in more than 20 years.

Company Culture

The company exhibits an ability to change and adapt to emerging new methods and practises.

The company has considerable sunk costs into the engineering and maintainability of mature commercial software products.

The growth is best measured not just financially, but in terms of product maturity and responsiveness to the market forces.

There is a continuous demand for better integration, reliability and packaging of geoscientific knowledge, to enable new generation workers to be more productive and to not make simple mistakes due to ignorance. The company resources have evolved to a point where it delivers this solution already, and for interested parties, can also continue to add value when sitting beside other sophisticated and well-engineered solutions.

History

Many people have contributed to the evolution over the years.

Peter Dart, John Sumpton, Frank Arnott, Richard Smith, Ray Seikel, Phil McFaddern, Shaun Whittaker, Asbjorn Christensen, Phil McInerney, Antonio Guillen, Gaby Corrieux, Dave Pratt, Dick Irvine, Tom Whiting, Rainer Wackele, Dave Hutchins, James Heywood, Martin Schneider, Reece Davies.

The current team includes Greg Walker, Rod Peterson, Jovan Silic, Difu Wang, Jason Williams , George Cottew, Matthew Roth

From the AGSO/GA side of things - Richard Lane, Tony Luyendyk, Peter Milligan, Brian Minty, Ian Hine, Murray Richardson, Ross Brodie, Michael Morse, Alice Murray, Ray Tracey, Phil Wynn, Mario Bachin, Peter Petkovich, Ron Hackney.

The switch to broad scale, systematic processing and repeatable processes, with audit trails and no major limitations on dataset sizes, while respecting the underlying physics, has created a revolution in free, available pre-competitive data for Australia, which is the envy of the rest of the world.

In no small part, is this due to the Intrepid 20 years+ of efforts.

7. Dave Pratt's Story

Dave became interested in computing in the 1960s while doing honours in geophysics. He had a problem to solve doing electrical soundings on the Kurnell sand dunes where he found the European depth sounding curves were inadequate to handle four decades of contrast in electrical properties. He wrote a forward modelling program for Schlumberger and Wenner soundings and created a new set of charts. Without it he could not resolve the soundings or finish his field work. The fact that he solved the problem using software led to a life-long interest in geological modelling of geophysical responses. Dave went on to 3D resistivity and IP forward modelling for his MSc and remote sensing thermal property modelling for his PhD.

Dave Pratt left the NSW Geological Survey at the beginning of 1970 towards the end of the Poseidon boom to join the seismic processing company Digitech, where Ross Crain was Managing Director and a foundation member of the ASEG and Editor for the first edition of the ASEG Bulletin. Dave joined to set up a group for non-seismic geophysical processing with a focus on magnetic and gravity methods. Digitech had acquired the SACM (Surface Approximation & Contour Mapping) processing software that was developed commercially in the sixties and used by a number of oil companies and geological surveys.

Machine contouring of aeromagnetic and gravity data was the major market at the time which was competing with conventional hand-contouring undertaken by GRD. The contour quality of the GRD procedures was excellent as cited by Doug Morrison. There were no bicycle chain anomalies along obvious acute angled linear geological features.

Dave had no prior experience at the time with airborne data and the very first survey submitted to Digitech was flown by a company called Air Research. Instead of nice straight lines recovered onto aerial photos, they had used a topographic map to locate the aircraft. When they had to climb a hill, they applied a circular flight path. Was this to be the industry standard? The experts at the BMR soon pointed me in the right direction.

Most surveys were recorded on charts that had to be digitized before they could be processed, so when the very first digital survey was offered by McPhar Geophysics I was excited. This survey was recorded on an 8mm movie film strip of the readout of 5 Nixie tubes with fiducial synchronisation.

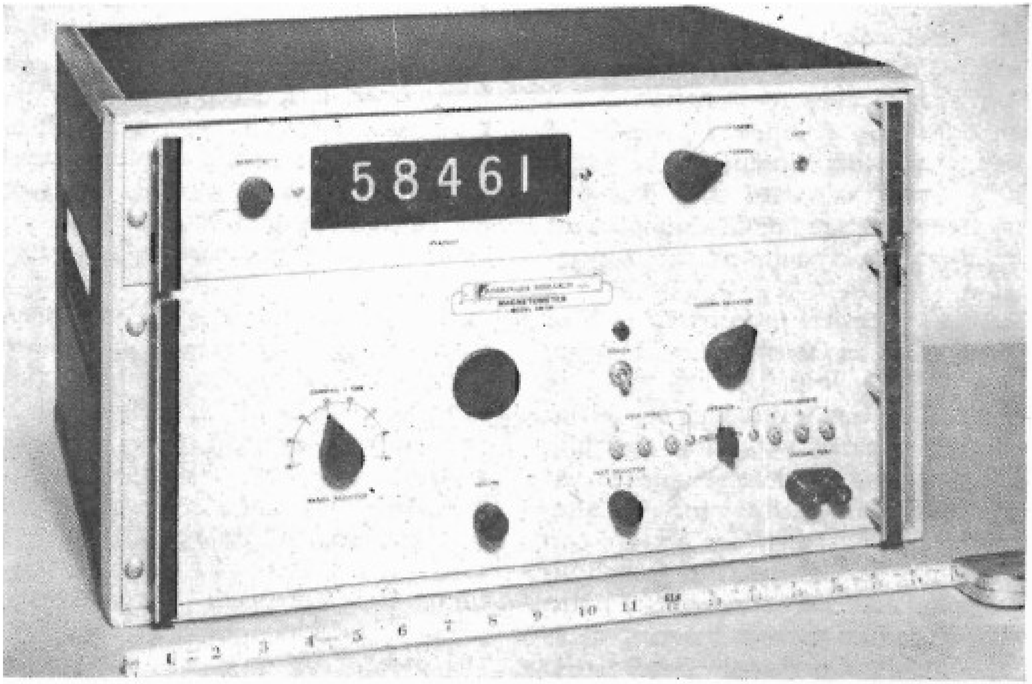

Figure 1. AM 101-A direct reading proton free-precession airborne magnetometer, Barrington Research Ltd.

Maybe it was the first hybrid of analog and digital recording. Unfortunately, the Poseidon boom came to an end just 12 months after joining this innovative group. This was followed by a brief stint with Lee Furlong at QASCO who wanted to extend their photogrammetry survey work into airborne geophysics. They had signed on with Sheldon Breiner at Varian Instruments to purchase a magnetometer, digital acquisition system and Varian computer. The whole system ran in 8K (words, 18bits) of memory including driving an electrostatic plotter for contour production. QASCO pulled the plug on this initiative because they also understood the impact of the end of the Poseidon boom and did not want to follow in the footsteps of Digitech.

After a period consulting with Layton & Associates, Dave went to Newcastle University to do a PhD in remote sensing and started up Geospex Associates with Bob Whiteley and Barry Long. Barry wrote a lot of airborne processing and modelling software and Dave developed some early interpretation tools, but the group split up and went in different directions with Barry specialising in seismic acquisition and processing. Bob specialised in engineering geophysics and Dave in consulting and interpretation tool development.

In 1984, Dave and Ian Grierson started Encom Technology to take advantage of the beginning of the PC era and develop software and services for the PC generation. Dave focused on potential fields interpretation, processing and visualisation tools while Ian focused on the petroleum geophysics opportunities. In the minerals DOS-era Encom developed forward and inverse modelling software for magnetic, gravity and mapping with products such as MAGSIM, GRAVSIM, RESINV, INFIELD, TOOLKIT and XLMAP.

When Microsoft Windows began to emerge, there was a big contest between Unix and Windows for the hearts and minds of minerals geophysicists, largely driven by ER Mapper which became a disruptive technology by integrating conventional remote sensing technology with the need for geologists and geophysicists to visualise geophysical datasets with much larger dynamic ranges.

In this era, Encom went on to develop minerals software for MS Windows including ModelVision, EM Vision, IP Vision, QuickMag and Profile Analyst. Encom was sold to Pitney Bowes Software in 2007 and Tensor Research took over the ongoing development of ModelVision. In 2017, Datamine purchased the remaining Encom software assets from Pitney Bowes but has dropped support for the geophysical products.

8. Abstract of paper published in '*Geoexploration*' in 1971.

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Abstracts Session 10: Computer Applications

A TECHNIQUE FOR AUTOMATIC CONTOURING FIELD SURVEY DATA

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(Received February 9, 1971)

This paper describes a technique which has been developed to contour field survey data using a digital computer. With irregularly spaced data the method has the advantage that the original observations are contoured rather than the calculated values of a regular grid. Each contour is created in discrete steps with each successive step being positioned by use of calculated values at two points on either side of the projection of the previous step. For each point the value is obtained by fitting a surface to the nearest observations and using the value of the surface at that point. Theoretically, the surfaces considered may be of any degree, though in practice use of weighted planes has been found to combine necessary accuracy with speed. By suitable selection of the number of observations used in the evaluation at a point, contours can be made to agree closely with those drawn by established hand techniques. Use of an overlaying mesh facilitates the commencement and termination of contours. The programs are written in Fortran and are in use on a CDC3200 computer, utilising a CALCOMP 30 inch off-line plotter. Experience has shown that the production of maps by this technique is efficient and economic in relation to other methods, the principle advantage being in the speed with which quite complex maps can be prepared.

APPLICATION OF MACHINE PROCESSING TECHNIQUES TO THE TREATMENT OF MAGNETIC SURVEY DATA FROM THE WEST AUSTRALIAN SHIELD

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Methods are described for the automatic handling and reduction of magnetic survey data, particular attention being given to the removal of depth controlled noise by one and two dimensional Strakhov filtering techniques. Simulation procedures for ground and aerial survey results are given and their usefulness in connection with survey design discussed.

Geoexploration, 9 (1971) 167–168

Abstract of Lodwick and Whittle (1971) and Corbyn and Cram (1971).