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

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1. Introduction

This brief history of data processing in exploration geophysics in Australia has been compiled from contributions from computer software developers and users of the software. It is not intended to be a complete description of all developments in data processing over recent decades, but rather to record the history of the major stages in the foundational developments and the principal achievements. It is also to recognize those people primarily responsible for the various industry contributions.

The history focuses on data processing for hard-rock geophysics, an indication of the shortage of the required software for this application in the 1960's, the early period of the geophysical surveying industry. In stark contrast was the continually evolving range of software then available for processing of soft-rock geophysical data to meet the requirements of the much larger petroleum-driven seismic industry, viz. seismic section processing and presentation plus well log and velocity analyses etc. Most of this software was at the time sourced from North America and Europe. Several locally operated data processing facilities for soft-rock data analyses existed in Australia in the 1960's and 1970's, e.g. Geophysical Services Incorporated (GSI) who predominantly used overseas-developed software.

In Australia, the geological environment focused exploration activity chiefly towards minerals, so there has been and continues to be a strong emphasis on airborne acquisition of data. This drove the need to acquire and process the large volumes of data that began to flow from what were then unique types of airborne geophysical surveying. These involved low-level flying, close line spacing, and surveying the vast area of the Australian continent. Much of this

was undertaken by Governments with survey programs that required more than five decades to complete the first regional continental coverage, and in so doing spanned several transformations in acquisition and processing technologies. This not only produced new data processing challenges, but also produced processing challenges in the merging of the data from the very large number of individual survey areas, and of differing quality.

The rapidly increasing availability of this new class of exploration data, notably that in digital form, produced the requirement from the end-users to maximise resolution of the data for subtle responses of the geology. The geophysical industry responded to become an earlier adapter of the then rapidly evolving new science of digital signal processing (DSP).

2. Overview

Before the advent of computers in the late 1960's, survey acquisition systems produced data in the form of mechanically plotted analogue charts, the data being digitised from the charts post survey. The X values were recorded at constant intervals, usually a measure of along-line distance or time, and the Z value, the measured geophysical parameter, read from the chart by the operator and manually entered into a card punch machine. For the case of ground surveys, the data were manually recorded into field notebooks at the time of acquisition. Reduction of the data, i.e. corrections such as instrument drift, diurnal variations, height and Bouguer corrections in gravity etc, were then done by hand with the aid of a mechanical calculator. Contouring of the values along the survey/flight lines was also undertaken by hand, and so evolved 'the art of hand contouring'.

Until digital techniques became available, processing of geophysical data into a map was done using analogue devices. Aero Service Corp in 1962 had photogrammetric flat-bed plotters used with a Wild A8 photogrammetry stereo plotter. Calculations were done on a Monroe 6N calculating machine (see 'Doug Morrison's Story' as Attachment 1). To convert analogue charts to maps, Aero Service used 'human' transcribers, also called 'graph rectifiers'. In the 1950's through to the 1960's, Adastra Aerial Surveys/ Adastra Hunting Geophysics had an analogue data processing section, as did the Australian Bureau of Mineral Resources (BMR), the South Australian Mines Department and Geosurveys in South Australia.

An early photo of Doug Morrison, circa 1963-64, transcribing analogue data to maps at Aero Service Corp. On the desk at the back is an aerial photographic slotted template cutter for producing basemaps.

A breakthrough came in the early 1970's with the advent of the digitizer. Analogue charts could then be placed on a digitizing table and a 'cursor' passed along the chart with the operator clicking the 'Enter' button at required intervals to 'capture' the data values and their locations in digital, electronic form. The captured X and Y values were stored on punch cards or paper tape which could then be sent to a processing centre. Data reduction software were created next along with contouring software to display the data, such as developed by Briggs (1974). Data interpretation required numerical enhancements of the data with applications of digital signal process operators, such as reduction-to-the-pole, continuation and other forms of digital filtering. Modelling tools were also required to aid the work of interpreters, and so followed development of interactive forward modelling on main frame computers. Output was plotted on flat-bed plotters.

The development and availability of computers during the late 1960's, especially with the emergence of numerically powerful desktop machines in the 1970's, and availability of interactive colour display systems in the 1980's, determined the timing and efforts of many developers. Associated with this, was the accompanying continued development of computer operating systems and languages (e.g. Pascal, Basic, Fortran and C) that provided the tools to allow coding developers to implement mathematical theory as algorithms and develop computer code into useable data processing programs. McLean (1979) gives a description of the wide variety of graphics hardware available in Australia at that time.

With the continued increase in power of computers, the 1990's saw the commercial availability of data reduction, processing, display and modelling software systems. Many of these systems were interconnected to streamline the

whole ‘data to earth-model’ process, essential for the geophysical industry to meet the nation’s requirement to process and interpret large volumes of data quickly in order to identify earth resources. In addition, super-computing facilities, accessible through universities and government agencies, began to make hugely powerful computing resources available to the geophysical industry at affordable cost. They provided the computing resources necessary to numerically process nationwide datasets and compute large and mathematically complex models from these.

To best illustrate the advancement of computer processing of geophysical data within Australia, a timeline of the various personnel and companies with their achievements is provided below. Since the early 1990’s, the proliferation of computing skills amongst geoscientists and specialist computer scientists working in the geophysical industry has meant that many more people and development groups, in both industry and in academic institutions, have contributed to and continue to develop software systems. They are too numerous to mention in this historical account that focuses on the earlier formational period of computing in mineral geophysics.

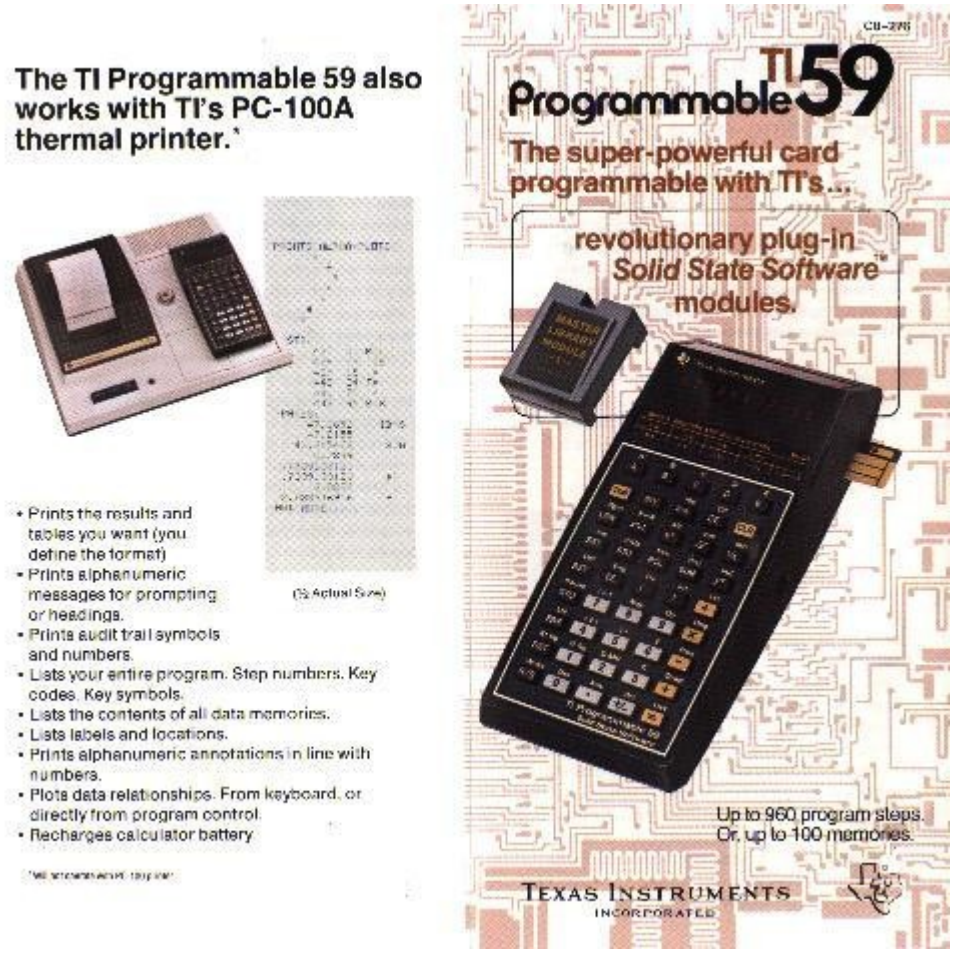
3. Pre 1967

Before about 1965, the only computing tools were sliderules, mechanical hand calculator machines and published mathematical tables. Calculations using hand calculators and mathematical tables were slow and tedious. For example, within the BMR during 1963, gravity reductions were done using Swedish Facit calculators, as illustrated below. Numbers were manually entered via the keyboard and by winding a handle, the result of predetermined mathematical operations were obtained. In 1966, Facit calculators were replaced by a digital computer located at ANU in Canberra.

The Swedish Facit manual calculator.

4. Mid to late 1960's

The arrival of electronic calculators with memory in the late 1960's was the beginning of the long road of computing hardware development to the present. Hewlett-Packard (with its Reverse Polish Notation - RPN) and Texas Instruments calculators were the most commonly used. Although these early calculators had storage memory or magnetic recording card capability, it was not until the early 1970's that storable programmable steps and operations were implemented. The portability of these machines allowed easy field use for newly acquired data and even basic interpretation was possible using simple forward geophysical models. The concept of inversion was only just beginning to emerge, but theoretical algorithmic development was still to be refined.



Advertising for the TI-59 programmable calculator with printer.

The first computer-based digital processing was carried out in the **1960's.** From that time processing was developed either by individuals or small companies and by a few mining companies. The computers used were a mixture of large mainframes with limited memory and basic operating systems plus some early, hobbyist computers of limited functionality. The emergence of more capable CPUs and PCs available for companies and individuals was about to start even though certain languages such as Fortran were developed much earlier (1954). UNIX systems were developed in 1969 and became the operating system of choice among mainframes (including DEC (Digital Equipment Corporation) and later, SGI (Silicon Graphics).

L. A. Richardson (LAR) (See the LAR background "Sliderule to PC" as Attachment 2).

During the early to mid 1960's using only sliderules and logarithm tables, Lew Richardson, a consultant geophysicist working with Geopeko, in conjunction with mathematician Bruce Kirkpatrick from the University of New South Wales, developed a rigorous mathematical process to calculate the magnetic (and gravity) anomaly responses due to an ellipsoidal body with any orientation and taking demagnetisation into account. The developments were applied in the analysis of magnetic data from the Tennant Creek gold field, NT, in the early

1960's, and led to the discovery of a number of new mineral deposits over the following decades.

LAR 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. Roger Deakin joined LAR in 1972 when they used BASIC source code via punched tape and a telephone line connection to Computer Science of Australia (CSA).

Later, in 1973, LAR purchased a WANG 2200B desk-top computer, hard-wired in BASIC and able to be connected to a flat-bed plotter. The WANG was replaced in 1976 with a Hewlett-Packard HP 9825 desktop computer.

5. Late 1960's to early 1970's

In arranging the various data processing developments and companies into time periods it becomes evident that the most active period of data processing achievements was in the late 1960's to early 1970's. During this period Pittman Data and Engineering Computer Services (ECS) were prominent. The BMR was also active in developing inhouse processing facilities for their rapidly growing national gravity and airborne survey programmes.

Pittman Data

John Pitt was employed at Broken Hill South in about 1960. He was the first person to introduce computers into mining in Australia for mine planning. He couldn't buy plotters then, so John built his own flat-bed plotter (designing and building the electronics and servo motors to drive the pens, paper etc.) to plot mine plans. The standard and well understood Fortran language was used for the source code generation. About 1965, John employed Ian Campbell from Sydney University to assist with software development. Combined, they operated one of the first mainframe computers in Australia for the Zinc Corporation at Broken Hill. In the early 1970's they moved to Sydney and operated as Pittman Data processing exploration and geophysical data. They formed a Joint Venture with Austirex Aerial Surveys to process data from a large airborne surveying contract in Iran, and following this, continued as Pitt Research until 1991.

A visitor to John Pitt's offices in those days was obliged to put on some red/green, 3D glasses to view his contour maps! John was experimenting with edge enhancement filtering at the time and generated some spectacular 3D products and all before good image processing with sun angle enhancement was available. Ivan Zadoroznyj (later to join BMR) was running the digitisation process at that time.

John Pitt was always innovative in computing terms, developing a useful regolith enhancement filter in 1990 and Fourier transform-based filtering of magnetic data. He moved to Adelaide and continued with Mark Deuter and an ex-architect, Geoff Young in 1990. John Pitt died in 1991.

Australian Mining Exploration Geophysics (AMEG)

According to John Newman, Australia's first successful computer automated data acquisition and processing of airborne geophysical data began in about 1968 by AMEG. AMEG was originally 100% owned by Lindsay Ingall and subsequently, with the participation by Barringer Research Australia (BRA) of whom John Newman was Executive Director.

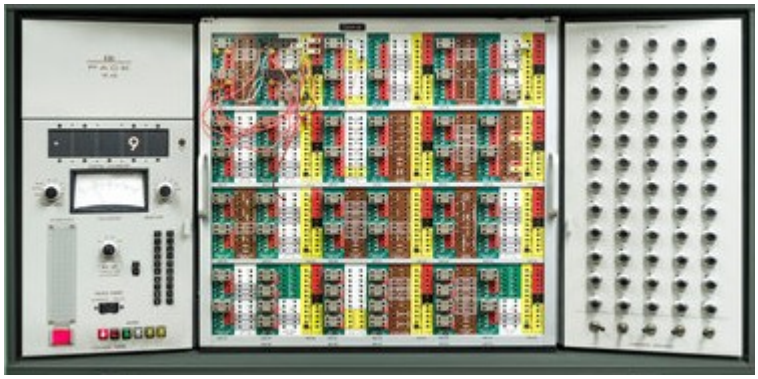
There were no compact airborne magnetic tape drive systems available during the 1960's. Data capture typically used 8 and 16mm camera photography with side-lit numerical indicators of total magnetic field readings and fiducial times updated every second. These film records were converted to punch cards for input to an IBM 1630 computer. Punch cards and paper tape were standard computer input in those days. Punch card operators were cost effective and efficient at converting the film records. Approaches to IBM and various universities for software to convert the airborne magnetic profile data into contour maps proved unsuccessful. This was regarded as beyond the current state-of-the-art.

Engineering Computer Services (ECS) (Also see 'The ECS Story' as Attachment 3).

Tony Cram of ECS saw an industry need for computing services and in 1969 began generating acceptable magnetic contour maps for clients on a large in-house flatbed plotter with proprietary software developed for topographic mapping.

ECS was formed in 1966 from an office in St Leonards, in Sydney, where Tony wrote software for the dress making industry. This industry required efficient laying-out of dress patterns on rolls of fabric so as to minimise wastage when cutting the fabric. Tony saw the opportunity of using similar tools and he extended the software to suit the exploration application of geophysical processing.

Tony Cram also owned an analogue as well as a digital computer and a large Gerber flat bed plotter. In 1969, this plotter drew the most elegant contour maps in real time whereas previously these maps were hand drawn and drafted. Also in 1969, Tony and ECS Research won a contract with the United States Geological Survey (USGS), which in turn applied that work to a study it was undertaking in Saudi Arabia.



A Gerber flatbed plotter and computer.

Tony was given a 9-track tape of digital aeromagnetic data which captured his interest. He then developed efficient software with the capability for contouring and levelling, using an in-house developed software package (Airborne Geophysical Processing - AGP) for processing airborne geophysical data. In 1973, during the then mining boom, ECS developed MINEX software including extensions to the package which allowed map production by third parties using definable scales, annotations, projections, labelling and titles etc. Operating with DEC VAX computers, this package was sold to a number of mining and coal companies and was ultimately exported around the globe. In 1975, ECS moved to Bowral, south of Sydney, and provided services directly to local coal mines and industries in the region. Pat Hillsdon joined ECS to successfully assist in contract processing, marketing and promotion of the software. From the early 1980's Pat digitised BMR analogue records at ECS in Bowral and produced small-scale computer drawn contour maps of the data to reveal the immense detail contained in the original line data, which had been hand-contoured at regional scale.

Also, at ECS in the mid 1970's were John Marnoch (ex Digitech) and Martin Schneider (who later became head of data processing at Geoterrex). Bob Kretchmer also worked at ECS after 1972 and assisted Tony in code development. In 1971, a paper co-authored by A. A. Cram and J. A. Corbyn and published in '*Geoexploration*', described the use of the 2D Strakhov filter for removing noise in magnetic data (refer *Corbyn and Cramm, 1971*). Chris Martin (ex Geosearch) joined ECS in Kalgoorlie in 1979, relocating the office to Perth in

1980 and providing data processing services to the airborne survey industry and for in-house software development.

John Duke also joined ECS in 1985, and worked mainly on the ECS specialized coal software, MINEX, and the metals data processing software. This product was later renamed MINEX3D. Both packages offered optional reserve estimation, kriging, volumetrics and mine planning. Later the ECS offices moved from Bong Bong Street to ECS House on Moss Vale Rd, Bowral to provide more space for staff and large flat bed plotters. Additional capabilities of the coal mining software during the 1980's were released as the MINEX Eclipse package.

Tony retired in 1997 and in1998, ECSI was 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. Tony stayed on to continue to create for another five years, when ECS was sold to SURPAC. Surpac purchased ECSI and created the Surpac Minex Group which in turn in 2006 was acquired by Gemcom Software International Inc. In 2012 Gemcom Software was acquired by the European-based Dassault Systèmes and the GEOVIA brand was created, targeting the Natural Resources industry.

A copy of the AGP software was purchased by Hunting Geology and Geophysics in the UK in about 1982 and was used by Paul Wilkes to process airborne and marine geophysical data from international projects. Paul (originally with BMR in the late 1970's) helped start the computing group in Hunting Geology and Geophysics. Paul returned to Australia in 1986 and joined Chris Martin as manager of ECS in Perth until about 1990. Paul then joined CSIRO in Perth while Chris remained with ECS until 1995.

Geophysical Resources Development (GRD)

Originally at Chatswood in Sydney, GRD used 7-track tapes copied from profiles generated in the late 1960's. At the time, 38 drafting staff were employed to work with the analogue data. The profiles were mostly aeromagnetic data but also gravity and radiometric data. Led by Brian Lenon, GRD later moved to Ramsgate where Doug Morrison and Jack Templin hand contoured the GRD surveys until John Pitt started machine contouring around 1970.

John Pitt, Ian Campbell and Bob McKenzie had a loose arrangement with GRD with their first contour map being produced over a test area flown by GRD near Kambalda. Roger Deakin used GRD for all the jobs he had in the early 1970's that used airborne magnetics. Brian Lenon advised that they had developed a 'herringbone filter' for noise reduction and improved line levelling.

Scintrex

Both Sydney-based (in the 1960's), Tony Howland-Rose and Linda Kichno compiled data for Lindsay Ingall/AMEG/GRD and Scintrex. GRD and Scintrex shared premises at Ramsgate during the late 1960's to early 1970's. Linda had punch card experience and compiled the original Ok Tedi helicopter magnetics

which pioneered proton magnetic data acquisition in the industry (using almost unreadable analogue charts). All data were transferred onto punch cards which were read by GRD at Ramsgate for processing.

Computer Science of Australia ("CSA")

During 1970, CSA located at St Leonards in Sydney, offered a time-sharing service to clients at a reasonable cost via a dedicated phone line. L. A. Richardson (LAR) became one of its first customers and were set up with a teletype terminal in their Killara office. Programs could be written off-line and stored as paper tape. The entire calculations for a magnetic body of one ellipsoid case took about 3-4 seconds on the CSA Univac 1108 machine with about 20 minutes terminal connection time. Through the CSA facility, LAR set about developing a range of software programs using the BASIC language

Digitech

In 1970 at Digitech in Sydney with CEO Ross Crain, David Pratt set up a processing bureau service for non-seismic data processing and enhancement of magnetic and gravity data using a software package known as SACM (Surface Approximation and Contour Mapping). It was developed in 1968 by Ed Assiter from ACI, Houston and was widely used in the petroleum industry in the seventies. They processed McPhar's first digital survey which consisted of an 8 mm movie film photographing a Nixie tube display at 1 second intervals. The readings were transcribed to punch cards by data processing staff. Other surveys were digitized from analogue charts on a digitizer table. The big challenge was competing with geologically realistic hand contouring of widely spaced line data. The Australian operation folded at the end of 1971.

Data Analysis

About 1970, Mike Gahn and Henry Irrgang provided data processing and geostatistics services software for processing of aeromagnetic data, contour mapping plus interpretation of Dipmeter data, open cut mine optimisation and digitising, editing and display of seismic interpretation data. Their main competitors were ECS, Digitech and later Pittman Data.

QASCO

Under CEO Lee Furlong in 1971, David Pratt joined QASCO in Sydney for a short time as they moved into aeromagnetic surveying using a Varian magnetometer to acquire data and an 8K word Varian minicomputer for processing, gridding and contouring. This processing used software developed in the USA by Sheldon Breiner of subsequent Geometrics fame. This computer not only ran the software but also ran an electrostatic plotter.

Bureau of Mineral Resources (BMR)

Within the BMR in Canberra during the early 1970's, programs were written largely using Fortran source code in-house and run on a CSIRO mainframe computer via tapes. John Rees was the main geophysical programmer of the original code. The resulting group of programs was called the ARGUS package which began its development in 1973. Much of the development and data entry (such as diurnal magnetic data) was undertaken using punch cards. Bruce Wyatt was one of the managers within the Airborne Group of the BMR in the late 1970's and Tony Luyendyk was then in charge of programming and processing with Ivan Zadoroznyj.

In 1980 the BMR became the Australian Geological Survey Organisation (AGSO). AGSO gradually migrated away from reliance on the CSIRO mainframes to operate with in-house computers including PCs. David Collins and Peter Milligan (joining AGSO in 1986) undertook converting the Fortran programs to run on the PCs. Later, the decision was made, with heavy involvement from Phil McFadden, that the program development should be outsourced to make it more sustainable in the long term. This would later form the basis of the Intrepid processing system. Also in those early years, until 1999, BMR/AGSO was acquiring regional airborne magnetics and radiometrics with its own staff and aircraft, an Aero Commander and a Twin Otter. The real-time acquisition systems in these aircraft were developed in-house by David Downey. Navigation picks used aerial photography until a brief use of Syledis radio navigation in the late 1980's was replaced later by GPS in the early 1990's.

Alice Murray developed an accurate and complete gravity processing system in BMR/AGSO and eventually it ended up using the Oracle language.

The Magnetic Map of Australia was conceived by Geoff Young in the early 1980's when he led the Airborne Division. A major part of this development was the digitization and reprocessing of the existing analogue recorded aeromagnetic data. Much of this work was done by contract services; the resultant digital levelled point line data being further leveled, gridded, merged, contoured and imaged by AGSO using their in-house ARGUS/Intrepid facilities. The first edition of the map was released in 1993, with several later updated editions following. (See more on Argus and Magnetic Map of Australia by Ian Hone as Attachment 4).

6. Mid to late 1970's

Geospex Associates

In 1975, Bob Whiteley, Barry Long and David Pratt formed Geopspex Associates in Sydney and focussed on processing and interpretation of airborne magnetic data for mineral and petroleum exploration. Barry wrote a lot of the processing software and Bob and Dave focussed on interpretation. In 1979, Barry Long moved into seismics and went on to start Velocity Data and later Velseis, while Bob Whiteley focussed on building an engineering geophysics business. David Pratt continued with the Geospex company and developed computer processing

and modelling software for the interpretation of magnetic, gravity, remote sensing and seismic interpretation as part of a consulting service. Minicomputers such as the PDP-11 were initially used but were being replaced by micro-computers like the DEC LSI 11 and portable PCs with floppy disk drives beginning to appear and running the CP-M and later, Microsoft DOS operating system.

Earth Science Computer Services (ESCS)

In the late 1970's in Rockdale, Sydney, Bob Johnson, competed with ECS offering data processing and map-making services. Randall "Randy" Smallwood started working at ESCS before he joined Geometrics with Ian Lilly in Arncliffe. ESCS undertook a significant amount of the contract processing of airborne surveys flown by GeoMetrics.

Bob White at Getty Oil, started to use Bob Johnson and his computer in the late 1970's, both to run his contouring package and other software, but also for ore reserve work on the Jabiluka uranium deposit. Kriging software was created and a lot of other developed code needed a computer and someone who knew a bit more about the mathematics behind disjunctive kriging. Bob's then wife, Dr Sue Johnson, was a mathematician and the software was modified and made operational with her assistance. It was largely from this that Bob Johnson progressed from geophysical data processing and sold ESCS to CSA. He then formed Maptek and was inducted into the International Mining Technology Hall of Fame for providing vital services to the global mining industry. Maptek's primary software package was called Vulcan which has since been sold and used in mining with various companies globally.

EG&G Geometrics

Original program code developed in the USA by Doug O'Brien and Alan Edberg with contributions by Bob Fowler and Bob Graf were implemented within GeoMetrics in Australia. The original software was written for UNIVAC 1100 series mainframe with pre-processing (field tapes) done on a Perkin-Elmer (nee Interdata) 8/32. In 1978, the system was converted to Prime 550 minicomputers, in Sydney. The code was substantially rewritten during conversion to Prime, with work done principally by Alan Edberg and Jim Eshelman.

In Sydney, in 1980-83, Ian Lilly and Randall Smallwood modified the code operating at GeoMetrics and changed the workflow with the processing becoming more 'map based'. Once data reading locations were verified and merged with fiducial-based sensor data, the system referenced all data/plots etc. to map sheets defined by AMG coordinates or latitudes and longitude. This enabled easy overlay of different data types.

Gridding was done by minimum curvature (using the Briggs algorithm developed in 1974) with some modifications by Rich Hansen. Rich Hansen later developed interpretation algorithms (Curie point depth estimation) and filtering

algorithms. Randall Smallwood was relocated to GeoMetrics, Sunnyvale USA when the Sydney processing centre shut down (in 1983) and worked on code development there.

GEOEX

During the late 1970's Geoex in Adelaide, under the leadership of John Haigh, developed a number of digital multi-parameter borehole logging trucks. Software was developed on HP9800 series desktop computers for the acquisition, processing, interpretation and plotting of the logs. From the logs physical properties could be obtained along with a variety of computed parameters, such as ore-grades, coal ash content, rock strength index etc.

Geological Survey of NSW

From the mid 1970's the geophysical group at the NSW Geological Survey were users of a PDP11/45 computer and later the Hewlett-Packard HP9800 series desktop computers. Upon these, they implemented a variety of processing and forward modelling algorithms for gravity, magnetics and resistivity/IP data, initially in Fortran and later in HP Basic. In addition, Peter Hatherly developed software for seismic methods.

A particularly novel development during the early 1980's was a downhole resistivity/IP logging vehicle with industry support through AMIRA (Australian Mining Industry Research Association). Under the leadership of Ted Tyne, the project involved a computer-driven wire-line logger and software development in Fortran of all the programs necessary to acquire, process, display and model the multi-parameter logs. The logging truck housed a Hewlett-Packard HP1000 minicomputer (the size of a domestic refrigerator) and an A0-size HP plotter.

7. Early 1980's

During this period, computer processing and computer modelling of data had become an integral part of most geophysicists work programmes. Apart from gridding and contouring, there were no other geophysical software products commercially available for purchase at that time for mineral geophysics. So explorers either used consulting and bureau services, accessed university developed software or, in some cases, did their own inhouse developments of the required software.

Geophysical Research Institute (GRI) (See 'The GRI Story' as Attachment 5).

Located within the University of New England (UNE), Armidale, NSW, researchers John Stanley and Malcolm Cattach developed specialities in highly sampled ground magnetometer data. This work presented unique characteristics for processing and presentation and in 1982 Isoplot was developed for stacking line data to form an isometric image. It was first run on a mainframe DEC 20 and had particular attributes for discreet dipolar sources such as UXO (UneXploded Ordinance). In 1986 Malcolm Cattach developed a suite of software programs to

run on a Z-80 based PC platform. Malcolm also developed MAGIC for automating the acquisition of data from within an irregular grid boundary and Colmap, a colour imaging program. In 1988, Stephen Lee within the same GRI group, developed MagSys, a PC-based program specifically for UXO detection. In 1989, MAGIC was upgraded for fully automatic tracking of the planned survey coverage.

Tesla-10

Tesla-10 was formed in 1982 with Noel Mattocks as GM, Rod Pullin, Dave Abbott and Helen Tuckett. Work undertaken included the digitising of analogue profiles from AGSO and airborne data acquisition and processing. Brendan Jagoe-Banks wrote and developed all of the initial data processing code and programs used in-house in the late 1980's. Ed Reeves also created a lot of data processing code and programs for Tesla-10 in the early-late 1990's. Tesla-10 under ambitious leadership by Noel Mattocks, attempted to set up in Toronto, Canada offering the same services as in Australia but were unsuccessful in the Canadian market.

Southlands Geophysical Services (See 'Doug Morrison's Story' as Attachment 1).

In the early 1980's Bob White of Getty Oil had Doug Morrison digitize old BMR airborne data using John Pitt's Sydney facilities. Doug then continued digitising for others including the BMR until he got priced out by ECS, Bruce Wyatt and others. Doug started getting $1.50/km for digitising profile data and contours but by the mid 1980's the price was down to $0.25/km. The first 1:250,000 scale map digitised was the Cobar sheet with excellent results and SGS ended up doing many regional BMR sheets over the following few years.

Encom Technology

Commencing in 1984 and continuing to 2007, David Pratt and Ian Grierson started Encom Technology to develop software for the first generation of Microsoft MS-DOS based personal computers. In this era Digital Equipment VAX and Prime computers were the dominant systems, but the PC era had just begun. Initially DEC minicomputers, inherited from David's Geospex consultancy were used but both Ian and Dave could see the future and rise of the PC for field and wider industry use.

Some of the early DOS processing and interpretation systems developed for the minerals industry included XLMAP (for PC-based gridding, contouring, filtering, data processing and plotting), INFIELD (G-856 magnetometer drift correction and geocoding), TOOKLKIT 2.5D (gravity and magnetic modelling and inversion), RESINV (electrical sounding inversion) and a few others.

The development of Microsoft Windows in the late 1980's provided an acceleration of user-friendly software with user interfaces being simplified and made more efficient. Within Encom, the various software packages were made user-friendly by Steve Mann, Peter Gidley, Tony White, Sam Roberts and others.

In the late 1980's, companies employing geophysicists such as CSR, MIM, WMC, BHP and CRAE began doing their own in-house imaging of potential field and radiometric data.

CSIRO

Software development was a major component of geophysical research projects at CSIRO during this period, and usually with industry support through AMIRA (Australian Mining Industry Research Association).

Art Raiche led the mathematical group in association with other research institutions around the world, and developed a range of mathematically complex algorithms to model the electromagnetic (EM) and resistivity/IP responses of a wide range of earth models. The software was developed in Fortran on a DEC-VAX mainframe computer. By the mid 1990's the large number of programs were largely transferred to PC (the most mathematically complex requiring greater computing resources than available then on PCs) and made commercially available to the industry as EM Vision by Encom Technology.

At the same time, a group led by Andy Green developed image processing algorithms and made these available to corporate sponsors as the DISIMP package, again for DEC-VAX computers. Developed for mini-computers and originally for Barrier Reef Image Analysis, (BRIAN), David Jupp of CSIRO, developed a second image processing system called microBrian which offered a full suite of image processing software adaptable for use in image processing of geophysical data.

BHP

Throughout the 1980's, BHP developed its own in-house processing system called PITS ('Pie In The Sky'). PITS was developed by a small team including Ray Seikel who was one of the principal developers. The system initially ran on UNIX-based Silicon Graphics workstations and comprised a complete processing system for airborne magnetics and radiometrics data with sophisticated display and image processing capabilities. BHP was expanding outside Australia and, particularly after the purchase of Utah Minerals in 1984, becoming a worldwide exploration company using regional magnetic data extensively for project generation, so PITS played a major role during this period.

Through on-going collaboration between Des Fitzgerald & Associates (DFA), and following the decision by BMR to outsource its software development, in 1990 PITS was merged with the BMR ARGUS software to form the Intrepid Geophysical system. Ray Seikel moved to DFA and participated in the development of Intrepid.

Renison Goldfields Consolidated (RGC)

After joining Renison Goldfields Consolidated (RGC) in 1981 Steve Mudge spent a lot of time in the 1980's writing modelling software for magnetics, gravity, SP,

resistivity, IP and some basic EM. By 1986 Steve had every published algorithm for computation of various model shapes in gravity and magnetics (including Dave Clarke's ellipsoid model) programmed for an HP9836 desktop computer. The HP Basic language was used with full graphics and the software had the capability of combining responses of any number of models, as well as calculating gradients and downhole responses, and fitting the forward model responses to field data. By 1988 it was all transferred to Fortran 77 on a Prime 750 minicomputer at RGC. There were a number of other software developments for data reductions, filtering survey data, and geodetic computations and map projections as required by RGC's international exploration activities. During the 1990's all of the software was gradually upgraded to Fortran 95 and transferred to Windows-based PCs.

In the mid to late 1990's, with the involvement of Sam Roberts, the gravity and magnetic modelling software evolved further to include the capability of building models from drillhole information, developed in PowerBasic on a PC. This was used to compute the composite magnetic response (in Fortran 95) of the Renison tin-bearing magnetic pyrrhotite bodies (known from drilling) in Tasmania. The responses of intersections from more than 3,000 drillholes were computed at the same measurement locations of a high-resolution helicopter magnetic survey allowing the two to be integrated in order to identify hitherto unknown pyrrhotite bodies. Noteably, the enormous computing requirement was satisfied by harnessing about half-a-dozen office PC's for overnight 'crunching' over several months.

Consultants

Individual consultants and survey contractors were also active during this period developing software to fulfill their own processing requirements. This was usually on desktop computers, typically the Hewlett-Packard HP9800 series scientific computers and the portable but less powerful HP85 computer. By the mid 1980's Apple and DOS-based IBM PC's were being used. All of these systems used a version of the BASIC computer language for code development and did not support interactive colour graphics.

The availability of PC-based Fortran compilers in the mid 1980's allowed for existing Fortran software to be ported to the PC environment. This combined with the increasing power of PC hardware and more affordable colour graphics hardware, led the move away from mainframes, minicomputers and expensive work stations to the more-affordable PC environment for all but the most mathematically complex operations. This opened the way for consultants and survey contractors to do a greater range of computer processing and modelling inhouse.

8. Mid to Late 1980's

GeoImage

In Brisbane in 1985, Bob Walker and Sylvia Michael established Geoimage in MIM's office, behind a black curtain to partition them from the other MIM staff. GeoImage offered a commercial imaging service, of which RGC was one of the first and regular customers for processing aeromagnetic data into images where a 35mm camera was used to photograph the screen. Bob and Sylvia initially used the CSIRO DISIMP software running on two Apollo Computers but later, in the mid-1990's GeoImage became resellers of the ER Mapper image processing system which they used internally.

CSR Minerals

At CSR, in Sydney in the mid 1980's, Peter Gidley and Ian Lilly, developed software to display ECS grids on CSIRO's DISIMP software using a COMTAL Vision 1 image processing system linked to a DEC VAX mainframe. Use of the ECS AGP software package also provided a complete exploration mapping system.

Southern Geoscience Consultants

In 1987, John Ashley and Bill Peters at Southern Geoscience Consultants in Perth began offering image processing services using the CSIRO microBrian system running on a PC with ink-jet printers for hard copy images. They grew to become a user of a wide variety of industry available software for data processing, modelling and display.

Geophysical Software Solutions

Richard Almond started developing his POTENT potential field modelling software for use on IBM PC's after leaving the BMR in 1987. The initial version of POTENT was written in Borland's Turbo Pascal language then was further developed using Microsoft's Visual C++.

Geosolutions

In 1988, Graham Boyd developed existing presentation software using an IBM 1130 mainframe, and modified it to run on a PC using an Imagraph graphics card of 32-bit resolution. Routines were written specifically for potential field data including the application of shaded relief which by then was an industry standard.

9. 1990's and Later

With the advent of the personal PC in the early 1990's, a variety of geophysical modelling, mapping and imaging software making full use of the new operating systems and hardware became commercially available. Organisations generally acquired multiple copies of these for use by each member of their geophysical teams. These included many of the products mentioned previously.

This period also saw the rise of the Internet, in the context of geophysics specifically as a source of data transfer and in later years as an online data

processing tool. In this role, highly specialised computing resources can be accessed from anywhere in the world at affordable cost. Typical applications include super computer-based modelling of large datasets by simply uploading the survey data and running the software on the data according to some straight forward instructions.

Intrepid Geophysics (See 'Intrepid Overview' as Attachment 6).

Des Fitzgerald founded Des Fitzgerald & Associates (DFA) in Melbourne in 1978. He led the development of the Intrepid Potential Fields Geophysical Processing System, which began in1992 with the combined support of Pasminco, Stockdale Prospecting (the late Frank Arnott) and Geoscience Australia (GA, previously AGSO/BMR).

Following the decision by BMR to outsource its software development, the BMR-developed ARGUS system (see BMR) and the BHP-developed PITS system (see BHP) were merged into a single comprehensive processing system called Intrepid. It was available through DFA for bureau processing services and offered for sale as well, with DFA adapting the merged package to PCs for wider distribution and increased sales.

The BMR Airborne Group continued in-house to research and develop new and better methods of processing, which were then incorporated into the new Intrepid package. Under Des's leadership this grew into a world class, flexible system to allow both GUI-based interactive and batch processing of potential field and radiometric data processing. By 1999, together with Brian Minty and Tony Luyendyk, GridMerge was added to Intrepid allowing advanced radiometric data reduction and processing of full 256 channel spectrometer data.

In addition, the Geomodeller software, initially developed by the BRGM, in France, (GeoFrance3D) over 10 years from 1995, was integrated and significantly enhanced under Des's direction. This software allowed inversion of geological field measurements to produce a geological model.

AGSO (originally BMR and now Geoscience Australia) as the national centre of regional geophysical data requested DFA to assist in developing the Geophysical Archive Data Delivery System (GADDS) to provide general on-line access to publicly-funded government datasets. This system used the Jetstream process and became available for public data distribution in 2004.

Other advanced and tailored developments by DFA included software support for processing of the SPECTREM/AngloAmerican project for magnetic tensor data, gravity gradiometry processing of Lockheed-Martin instrument data and Micro G LaCoste Sea-G marine gravity hardware interface developments.

Chris Martin

Chris Martin started work with Kevin Radford's Geosearch in Perth in 1975 responsible for processing of airborne survey data. The ECS AGP software was

used to process and contour the data with map plotting done through a bureau service offered by the State Energy Commission on their IBM360 mainframe computer. Later the software was installed onto an in-house DEC PDP/11 minicomputer with map plotting done at ICL's bureau service in Perth.

In 1979 Chris joined ECS's Perth office and after leaving in 1995 he worked with several airborne survey companies managing their data processing. At the same time he commenced development of a comprehensive geophysical data processing and imaging package called ChrisDBf. It is written in PowerBasic to suit the PC environment and is used by a large number of exploration companies, survey contractors and consultants.

Encom Technology (See 'Dave Pratt's story' as Attachment 7).

In 1994, Encom transferred and extended much of the functionality of the earlier released TOOLKIT product to the ModelVision Pro program. It was developed for both Unix and Microsoft Windows because Earth Resource Mapping had built a strong Unix following with their ER Mapper image processing system. ModelVision Pro began as a full 2D and 3D modelling and inversion application and continued to grow with the addition of advanced processing techniques, forward modelling for all magnetic and gravity systems including gradiometers and tensor systems. Joint inversion was introduced around 2005 to cater for the next generation of squid full tensor magnetometers.

Other Windows products for the minerals industry from Encom included EM Vision which used some of the Art Raiche AMIRA-CSIRO research algorithms for EM modelling, EM Flow (CRC-AMET research by James Macnae's team) for EM conductivity-depth imaging, IP Vision for modelling resistivity/IP data, and QuickMag for fast magnetic modelling.

To provide a competitive alternative to the developing DFA Intrepid product and using some open source database-access routines, Encom Technology also released the Profile Analyst line, map and 3D display and processing system in the 1990's.

Earth Resource Mapping (ERM)

ERM (Earth Resource Mapping) was formed by David Hayward and Stuart Nixon during the late 1980's with a beta release of their ER Mapper product in 1990. This product offered image and data processing of satellite and gridded geophysical datasets using Sun, Unix-based workstations but with the highly efficient Dynamic Algorithm Compiler to compute and display imagery extremely rapidly. Later innovations including ortho-rectification, image compression, real-time roaming and zooming and 3D displays which set the standard for image display into the future. Not until 2002 was a PC-version of ER Mapper available commercially, but this software found its way into a large number of exploration industry companies both within Australia and around the world. In 2007, the ER Mapper Ltd company was acquired by Leica Geosystems (aka ERDAS).

Baigent Geosciences

Mark Baigent created Baigent Geosciences Pty Ltd in 1995. Originally based in NSW, the company then moved to Perth in 2003. Within the company, the Terrasense software which originated from Geometrics in the early 1980's, was adapted for PC use. The code was originally running on Prime minicomputers and was written by Jim Eshelman, Doug O'Brian and Richard Hansen. Judy Doedens a programmer at Kevron also joined Baigent Geosciences in 1997 before moving on to Fugro and CGG. Judy was responsible for writing and rewriting all the software at BGS and developed one the first commercial version of the NASVD technique in 1997. The NASVD technique or Noise Adjusted Single Value Decomposition was developed by Jens Hovgaard and Bob Grasty to vastly improve the quality of radiometric data. BGS was one of the few companies that also offered gradient enhancement of the total field magnetic data. This vastly improved data resolution and attempted to move the magnetic anomalies into their correct position by incorporating the horizontal gradient measurement into the interpolation process.

Scientific Computing and Applications

John Paine, based in Adelaide has developed PC-based geophysical software for several decades. The WinDisp package includes 3DModeller for 3D modelling and 3DViewer for visualization of 3D models. Other programs include TQIPdb for quality control of IP data and MGinv3D for 3D inversion modelling of gravity and magnetic data.

10. Summary

Geophysical data processing described here, has focused primarily on the mining industry and only within Australia. Although a number of predominantly US and Canadian computing tools were used and introduced into Australia during the period, Australia was a centre of innovative geophysical processing development over a large number of early years. This innovation was borne of a lack of available overseas products in the 1960's -1990's and from the difficult and unique geophysical environment with which the industry had to contend.

Software development continued until the present with refinements to standard systems, as described. The Australian exploration industry in the late 1980's also saw the introduction of overseas-created PC-based packages such as Geosoft, GeoPak (marketed by Encom Technology) and Charlie Stoyer's Interpex. However, at that time, many of these programs were simply not well adapted for Australian exploration challenges. Many of the entrepreneurial developments seen in the early years of geophysical processing in Australia were born of necessity, but also by the emergence and evolution of computers. This commenced with limited and expensive access to mainframes and then to minicomputers and, ultimately, to the lower cost, more highly developed, more versatile and widely available PCs within the industry.

Throughout this period there has been a continually escalating increase in the volume of digital data generated by the industry and computing resources have correspondingly risen to meet this new challenge. Software has evolved to encompass user-friendly graphical interfaces allowing for its more routine use by those with limited technical skills.

At the time of writing this historical account, early 2020, the Internet has become a key component of every aspect of mineral exploration offering the storage and transfer of large datasets, and access to online super-computing resources. Underlying this is the World's insatiable demand for mineral resources in an environment of limited, and diminishing, ore resources. This is driving an increasing need for automated systems to manage and analyse the ever-increasing volumes of geoscience data. It is in this context that the concept of 'big data', large-scale inversion modelling and the advent of artificial intelligence systems are now capturing the interest of the exploration industry. Developments in data processing for these new sciences will involve a wider range of technical skills than those required for the innovative developments made over the last 55 years, and that have successfully brought us to the start of this new era in geophysical data processing.

As for the various people mentioned here, the two significant initial players, John Pitt and Tony Cram, have now passed on, but the younger generations of geophysicists and developers whom they influenced moved forward with the same drive and sense of scientific enquiry for new processing and modelling tools as they did. Many of these are still around today having embraced the challenges presented by the rapidly changing technological environment throughout this period, and this was despite the numerous economic ups and downs of the exploration industry. For today's generation of developers, the new era of 'big data' and what the industry must demand from it to deliver future new mineral resources presents these new players with many new and complex challenges.

11. Acknowledgements

A large number of software developers and workers in the geophysical data processing software and application fields have contributed to this paper. The content has been principally compiled by Roger Henderson, Peter Gidley and Stephen Mudge with constant input by many of the names appearing herein. The passage of time has seen a number of the mentioned software developers and industry leaders pass on, and while this is sad, their passing and the legacy they have left in their life's work, has prompted the need for documenting here the advancements and contributions they made.

12. References

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13. Attachments

Refer to *Attachments* as a separate document.

1. Doug Morrison's Story.
2. "Sliderule to PC" by Bob Richardson.
3. The ECS story - Tony Cram 1939-2014.
4. Ian Hone on ARGUS and Magnetic Map of Australia (MMA).
5. The GRI Story.
6. Intrepid Overview.
7. Dave Pratt's Story.
8. Abstracts of papers published in 'Geoexploration' in 1971.