Quest for the Holy Grail; BHP's Geophysical Research Program 1985-2005

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SUMMARY

Over the period from 1985 to 2005, BHP carried out three major geophysical research projects that were intended to significantly enhance the ability to find new ore deposits. This involved major activities internally as well as external components that involved complex multi-year programs involving large expenditures. In all cases, major efforts were made to deploy the outcomes in BHP's minerals exploration programs. While the technologies developed could be considered as successful in having met or exceeded the original development goals, in no case did the outcomes of these efforts contribute materially to the discovery of significant new mineral resources. This suggests that the technical objectives for a new technology can be comparatively straight-forward to define, but the subsequent implementation path, once the technological goals are achieved, were poorly conceived.

BHP's experience is much like the exploration industry as a whole over the same period. While much appears to have been developed which has added significantly to the technical capabilities of the industry, it has been less apparent that these developments have been able to contribute significantly to an improved discovery record.

Considerable effort is now being directed towards bringing on new geophysical technologies in programs such as *Uncover* in Australia and CMIC's *Footprint* in Canada. Past experience suggests, however, that better technology alone can't be expected to achieve the sought after goal of improved discovery success.

Key words: Geophysical research, BHP, minerals exploration, discovery

INTRODUCTION

The purpose of minerals exploration is to identify new economic mineral deposits. While there are a wide range of approaches to this task, major mining companies have often undertaken research to improve technical aspects of the exploration process in order to enhance their competitive advantage in discovery of new deposits.

Geophysical research has been a popular topic since the beginning of modern minerals exploration in the post-world war two (WW2) era (e.g. Wait (1959) and Nelson (1997)). In the mid-1980s, BHP[1] had expanded its corporate vision with the purchase from GE of Utah International, a mining company with significant Australian and off-shore assets. Exploration was viewed as an important means for further growth and the company began exploration programs that expanded at all levels until the late 1990s. During this time, three major technology development (R&D) efforts were undertaken by the exploration group; a program to expand BHP's use of aeromagnetic data; a program to develop new airborne EM technology and a program to develop an airborne gravity gradiometer system. Only the later program had a designated project name, Falcon. All three programs achieved the technical goals initially defined and all three resulted in significant intellectual property being developed which entered into general commercial practice and are still in use. None of these developments however, delivered a significant exploration outcome to BHP. These outcomes seem, however, to be characteristic of much of the mineral company sponsored R&D (e.g.Witherly 2000) which largely have failed to provide a significant return on investment.

As the industry enters into an era with even more expected challenges for geophysics as exploration goes increasingly undercover, it is seen as important to have a better understanding of what determines the success or failure of new technology in generating the outcomes that would justify the original expenditure.

BACKGROUND

In the early stages of exploration following WW2, mining companies began the development of geophysical technologies to aid in the discovery of mineral resources. Some of this work was an outgrowth of techniques first developed prior to the war such as electromagnetic (EM) prospecting and magnetometry. EM techniques were in common usage but were all ground based systems and

[1] The company went through a variety of names changes during the study period, so for purposes of this review the company will simply be referred to as 'BHP'.

it was not until the late 1940s that airborne systems were developed. While airborne magnetometers were being trialed prior to WW2, the US Navy significantly advanced the technology for submarine location and this technology became available for civilian applications following the war. Major companies such as Newmont (Wait, 1959) and INCO (Fraser, 1985) began the development of geophysical technology during the 1950s and many followed suite in the 1960s and 1970s. Service companies also contributed to the development of new technologies, some of which were made available from the original developers and in some cases, developed internally. The McPhar organization was an earlier pioneer of new geophysical systems (Fraser, 1985). Two companies arose which were collaborations between mining companies and developers; Barringer and Selection Trust (commercialized by Questor) and Fraser and Teck (commercialized by DIGHEM). In both cases, supporting companies wanted access to good technology but did not feel that they needed to have this as an exclusive arrangement. As a result, new service companies arose whose technologies were funded at the early stages by mining companies. During this time a number of American mining companies undertook considerable research into the development of IP technology, primarily aimed at helping to locate porphyry copper deposits (Halverson et. al. 1989, Nelson 1997; Kingman 2014).

While the formal record of these projects is thin, the record of discovery outcomes that could be attributed to these efforts is even thinner. Overall, it seemed that 'close followers' or groups who were not the initial developers of the technology. but were able to adapt the concepts or technologies after the initial players had brought the technology into existence, seemed to fair better in terms of discovery outcomes. However, the desire to 'be first' has been and remains a strong motivator to undertake geophysical research.

BHP'S R&D PROGRAMS

Background: While some of the work discussed was started in the 1980s, much of the work was undertaken in the 1990s when John Prescott was managing director (MD) of BHP (1991-1998). Prescott was the first MD to be in charge of the merged BHP-Utah entity and he viewed it as important to grow the company at a level not previously undertaken. Corporate R&D was seen as part of a strategic component for sustained growth and this had a direct impact on the funds available to exploration. With the almost simultaneous discovery of the Cannington silver-zinc-lead and Ekati diamond deposits in the early 1990s and the start of production of the major Escondida copper deposit in Chile, discovered in the early 1980s, exploration was seen as an important means for future growth. This high level support was particularly important for geophysical R&D projects which required a large fiscal commitment over a number of years. Following Prescott's resignation in 1998, the company's approach to growth and risk changed significantly and much of the R&D supported in the 1990s throughout the company was terminated and BHP abandoned corporate R&D at all levels. The role of exploration (seen as a form of R&D) as a result changed as well and the style of approach to exploration became very different from the 1990s when the various R&D programs were conceived and initiated.

Aeromagnetics Initiative: In the 1980s, BHP was engaged in a number of major exploration programs in Australia including exploration for Broken Hill type (BHT) lead-zinc deposits, Olympic Dam copper-gold style and orogenic gold. Aeromagnetic data was seen as a key geoscience layer in these efforts and BHP began to assess the use of new mini-computer systems such as those produced by VAX and Data General to provide a new level of value-added processing that was not possible with mainframes. A software package called Processing Imaging Technology (aka **P**ie **i**n the **S**ky or PITS) was developed that allowed for far more sophisticated processing to be undertaken that was previously possible with main frame systems. In the mid to late 1980s, a major exploration program was initiated to explore for BHT deposits in the Eastern Succession of the Mt. Isa terrain of Queensland. Due to the extensive cover, this program relied heavily upon the use of aeromagnetic data and in 1990, the Cannington deposit was discovery when drilling a distinctive aeromagnetic feature. Almost concurrent to this, aeromagnetic data were playing a key role in the then unfolding Ekati kimberlite (diamond) field in northern Canada. Aeromagnetics was in ascendency.

In 1992, a global exploration group was formed from the two legacy exploration groups supporting the BHP and Utah companies. This new group made securing global aeromagnetic coverage as an exploration priority. A major effort to secure the best global coverage was initiated. An instruction course in aeromagnetic interpretation was designed for the exploration staff and in groups of 20-30 staff at a time, week long workshops were run which provided a hands-on assessment on how to use aeromagnetic data for exploration. A compilation of the aeromagnetic signatures for major deposit types from around the world was assembled.

BHP had a major internal R&D group with centers in Melbourne and Wollongong. In the mid-1980s, a group began working on exploration issues and in the early 1990s, senior scientists were hired to work on EM and potential fields related problems.

Airborne EM Initiative: Following the discovery of Cannington in 1990, an assessment was made of best means to screen the many magnetic anomalies which were defined in the course of the exploration program. Ground EM (Witherly and Mackee 2015) showed that parts of the Cannington deposit were conductive but this could not be reproduced using existing airborne EM systems due to the high conductance of surface materials. In 1992, BHP and Aberfoyle co-funded a proposal put up by Geoterrex Pty Ltd., the international licensee for the INPUT/Geotem EM system, to undertake a program of R&D intended to modify the existing technology by reducing the base operating frequency and increasing the output power. Concurrent with this project, BHP entered into a collaborative R&D program with CSIRO to assess and potentially develop ground and airborne EM sensors based around CSIRO's work with high temperature SQUID sensors. In expectation of a significant amount of EM data to be generated with the new systems, BHP undertook a major expansion of its internal R&D related to the processing and analysis of EM data, particularly in the amounts expected to be generated from airborne surveys.

The Aberfoyle-Geoterrex program was termed the ***25 Hz Project*** and this was advanced over a number of years with the base frequency decreasing from 150 Hz to 75 Hz and then 25 Hz concurrent with increases in the output power. As the Geotem technology improved, BHP undertook a major program of application which saw the systems being applied around the world on projects in Africa, North America, Europe, Chile and of course Australia. BHP was commissioning so much flying that for several years, BHP was employing two of Geoterrex's three Geotem equipped aircraft on more or less a full time basis. One of the programs was the porphyry copper exploration project undertaken in Chile. The first phase was carried out in 1993 using Geoterrex's then standard CASA twin-engine platform. When BHP wanted to undertake a second phase in 1996, the aircraft operational safety regulations had changed such that the CASA could no longer be used. This resulted in BHP committing to a program with Geoterrex whereby Geoterrex undertook to migrate the Geotem technology onto a Dash-7 four engine airliner. This was termed the MegaTEM technology and it first flew in Chile in 1997.

The SQUID program advanced concurrently, with successful ground tests carried out over Cannington in 1994. As BHP lacked the technical means to operate an aircraft EM system, a separate contract to the 25 Hz project with Geoterrex was created by BHP to gain access to parts of Geoterrex's technology, specifically the container (called a 'bird' in the business) that was towed behind the aircraft and contained the EM coils. BHP engineers installed their SQUID sensor system in the bird (designated Big Bird as it was a large yellow fiberglass shell) and used the Geoterrex on-board DAS (data acquisition system) to record the data. Three airborne trials were carried out, two in Australia and the last one near Timmins in November 1997 (Lee et. al. 2002).

With the cessation of the SQUID project in 1997, BHP offered the intellectual property it had developed to Geoterrex as a means to further enhance their Geotem technology. While Geoterrex was interested in the SQUID system and its ability to measure a B-field component, it chose not to adopt this technology directly but rather derive the B-field via an integration approach first used Indian researchers in the 1970s (Sarma et. al., 1976). Other parts of the BHP technology were however, used by Geoterrex.

Airborne Gravity Gradiometry (Falcon): Prior to the BHP Australian and Utah entities being merged into BHP Minerals in 1992, both exploration groups were investigating the technical feasibility of acquiring airborne gravity data at a resolution of ground based systems. This essentially required the use of a gravity gradiometer system, which at the time had only been built by Bell Aerospace for the American Navy to be used to guide ballistic missiles being launched from submarines. The Utah group examined a proposal from Noranda Exploration that involved a Canadian inventor. The BHP group was concurrently investigating the Bell technology, which was in the process of being demilitarized following the dissolution of the USSR. A joint technology team was formed when the two groups were merged and they established that the Bell option was the best approach. Following a series of innovative dynamic testing trials of the existing airborne gravity gradiometer (AGG) technology in 1993, a series of changes were designed to produce a system optimized for use in a small aircraft. Two years later BHP Corporate approved a development budget for the technology and in early 1998 the system became operational and production flying was initiated in October 1999. The program and instrument were designated Falcon.

Concurrent with the building of the Falcon AGG, which was undertaken by Lockheed-Martin (who had purchased Bell Aerospace from Textron), BHP undertook an internal R&D program to design software to process and analyse the AGG data that would be produced by the Falcon system. The Falcon project overall was likely the largest geophysical R&D project ever undertaken by a mining company, with close to $US50 million being spent on the building of systems, software and the initial field trials.

Once delivered, BHP began a series of extensive field trials over projects in Canada (Ekati), Australia; Cannington and Pilbara (FeO) and South America (Escondida). By 2004, there were three systems and by 2007, there were over 1,500,000 lkm flown on five continents (Whiting 2004, Harman 2004). This flying and follow-up work likely represented a total expenditure in excess of $US200 million dollars. In late 2007, BHP sold their technology to Fugro Airborne Surveys (now CGG MultiPhysics) but continued to use it on a commercial basis.

OUTCOMES

The major R&D initiatives undertaken by BHP in the 1990s failed to deliver any significant economic outcomes. The strong focus on Broken Hill-style deposits where BHP felt they had a strong competitive advantage yielded no new deposits or even 'interesting systems' following years of intense effort on a global basis. The PITS software, while deemed a competitive advantage in the 1980s, was recognized as being difficult to maintain internally in the emerging world of PCs. Therefore a decision was made to outsource PITS to a Desmond Fitzgerald and Associates (DFA) who would produce a PC compatible version which BHP could distribute internally to its world-wide exploration group. DFA re-branded this as *Intrepid*, a software package still in commercial use today.

With regard to the airborne EM initiatives, the MegaTEM system was attributed with the discovery of the Perseverance deposit (Canada) by Noranda Exploration in 1999 (Gingerich and Allard 2001). The ground SQUID system is still in commercial use and was attributed with playing a key role in discoveries for Falconbridge Nickel at the Raglan Nickel Camp, in northern Quebec (Osmond et al., 2002 and Hughes 2006). BHP's software for airborne EM processing, GEMEX, was outsourced to Encom Technologies Pty. which used the concepts to develop their *Profile Analyst* application, a derivative of which is still in commercial use today. From the major airborne EM programs in Chile and Peru, a number of prospects were developed but no significant mineral systems were located.

The Falcon system was applied aggressively in the search for kimberlites (diamonds) in Canada, Africa and Australia but no significant deposits were found. At Ekati, Falcon was used in two programs; first the fixed wing technology in 1999-2000 and then the improved HeliFalcon in 2005 (Dransfield, 2007). While Falcon showed it could map many of the kimberlites at Ekati, it arrived 'too late' as basically all the economic deposits had been found years earlier using a combination of airborne EM and magnetics. The Falcon system played a role the discovery of the Santo Domingo IOCG deposit in Chile in 2003-04 (Dransfield 2007) but while a significant resource of copper has been defined, its development remains problematic in current economic conditions. The Falcon system and its sister technologies commonly termed 'FTG' for full tensor gravity, are in common use today and these original systems from Lockheed Martin still remain the only functional AGG systems in use by the natural resources industry.

DISCUSSION

The geophysical R&D conducted by BHP during 1985-2005 was well conceived and executed and essentially achieved all defined technical goals. In all cases, the developed technologies were then aggressively employed and supported over reasonable periods of time. No one deployment model was defined and adhered to but rather each technology was matched what was seen as the best model at the time.

For the aeromagnetic effort, there was a major focus on training staff in how to use aeromagnetic data. Case studies and tutorials were produced for a broad range of deposit styles in a variety of terrains. Large sums were spent to acquire the 'best available' data on a global basis. A large number of technical staff were assigned and trained in the processing of aeromagnetic data using the commercialized (formerly in-house) software. While many explorers acquired exposure to data that they previously were unfamiliar with, the time to move from novice to expert interpreter was longer than anticipated. In the end, a small number of "gifted" geoscientists undertook much of the analysis. While most explorers grasped the concept of using aeromagnetic data for targeting, much of the outcomes from working with aeromagnetic data were better geology maps. This result while useful, took much more time to assess and feed back into exploration programs. With the amounts of data BHP was acquiring, the task was huge and many projects had to 'move on' before the regional data sets could be properly assessed.

For the EM effort, a broad range of deposit styles and terrains were pursued; porphyry copper deposits in Chile and Arizona, massive sulphides in North America and Australia, BHT in Scandinavia and southern Africa and magmatic nickel in Africa. Likely far too much data in too many diverse locations was being acquired to allow for a proper assimilation and analysis. The BHP teams were using technology no one else has ever had access to and were generating vast amounts of data that no group ever before had to deal with; this could be aptly described as 'information overload'.

From the time Falcon was conceived in the early 1990s to when it was deployed a decade later, the BHP exploration group was transformed from a 'risk taking' organization to a 'risk minimizing' one. When originally conceived, the AGG technology was to serve the needs of BHP's explorers on an exclusive basis. When the technology was rolled out however, BHP had gone through a traumatic episode of internal purgatory and as an outcome, had decided to minimize business and fiscal risk wherever possible. The exploration group had to follow this new company ethos. On more of a technical front, as with the massive amount of airborne EM undertaken in 1990s, the feed-back loops required to calibrate and educate the Exploration group in the best use of the new AGG technology were hard to recognize and support properly. As well, the 'visionaries' who at the start of the journey saw Falcon as a powerful discovery tool for BHP were replaced with people whose first task was to manage risk; the two approaches were basically incompatible.

The programs outlined above were individually major efforts but collectively, they amount to what has to be considered the largest program of R&D a mining company has undertaken. The projects all achieved what could only be called exceptional technical success and enjoyed some commercial success as well. However, all failed to deliver what could be considered the primary goal for all of them, new major minerals discoveries for BHP. Nevertheless, when several of the technologies became commercially available, their application resulted in discoveries for the companies involved.

WAY FORWARD

The story thus far would seem to be a fairly depressing if not a puzzling unfolding of events. How is that when a major mining company with extensive resources, commits to undertake a series of major R&D efforts, achieves technical success with all programs and yet does not see one of them deliver a significant return to its' bottom line?

In an exploration industry-wide context however, this appears to be a similar outcome for much of the geophysical R&D efforts undertaken in the last three decades. Major advancements have been achieved in virtually every aspect of the exploration technology (e.g. Nabighian and Asten 2002) but the declining discovery record fails to show any significant impact that these technological improvements have on identifying new mineral resources (Schodde 2014).

The focus area where this does not appear to be as much of a problem pertains to brownfields exploration, where geophysics seems to be more consistently able to deliver economically significant results (e.g. Hughes 2006 and Vowles 2014).

In the present, major exploration R&D programs are being undertaken or proposed for programs such as the CMIC Footprints initiative in Canada (Galley et. al. 2014) and the Uncover initiative in Australia (High Flyers Think Tank 2010). In both programs, geophysical R&D is a key component and yet there appears to be little awareness that the new programs have anticipated, let alone solved, the "R&D curse" that has vexed basically all R&D efforts in the past several decades.

If there is any cause for this conundrum, it is felt that the following passage made by one of the geophysical industry's greatest geophysical contributors and academics presented at a ASEG conference in 1999 touches on the key issue that has likely been overlooked by the proponents and implementers of new technology:

But there is one vital field for mining geophysics that may easily get lost in the rush for higher tech geophysical systems. It is understanding the relationship between the geological characteristics of earth materials and the physical properties that can be remotely sensed. This can only be improved by organized, systematic feed-back from geologists who can measure the geological effectiveness (or ineffectiveness) of geophysical products to geophysicists who design the geophysical methods and surveys and (hopefully) understand the physics involved. West 1997

This issue (and maybe its solution) can be likened to the incredible power that medical imaging provides to the health industry. This capability however, did not arise simply because Rontgen in 1895 pointed his newly discovered X-ray machine at his arm and saw an image he knew had to be his bone on the screen. Rather, the usefulness was a result of the huge knowledge of anatomy that had been gained over literally millennium as physicians cut open people either to help them or address their basic curiosity. With this knowledge in hand, the X-ray device could be seen as a means to map something which was already very well studied.

In the case of geophysical imaging of the earth, our subsurface knowledge in many respects, still very basic and there are few deposits, let along terrains, where there is enough petrophysical knowledge to build a proper 3D model of the subsurface. Without that understanding and linkages between geology and geophysics, much of what geophysics 'sees' are shadows we simply can't interpret in a meaningful way.

Going forward, geophysical conferences will likely remain places where people gather to hear about new technology and similarly, at geological conferences, the latest in geological models will be espoused. But if the task of improving the discovery rate is to be addressed, then these two groups must develop a passion about the problem, a respect for each other's contributions to addressing it and then work together to build the science around the issue, such that we truly will be able to say we have produced the Holy Grail for ore deposit discovery that has be goal of so many for so long.

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