RAB Drilling and RAB Geochemistry An Australian Perspective

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Introduction

For some 30 years, "Rotary Air Blast" (RAB) drilling has been a major tool for mineral exploration programs in Australia, particularly for gold in the Yilgarn Craton of Western Australia (WA). For example, in 1996 – 1997, a total of 5,000 *kilometers* of RAB drilling was reported in statutory activity statements by WA mineral explorers (later statistics do not distinguish between different drilling types but will be lower owing to a subsequent drop-off in "greenfields" exploration, in which RAB is most prevalent). The terms RAB drilling and RAB drill geochemistry are widely used and implicitly understood by Australian explorers, promoters, and financiers. In contrast, however, there appears to be a much lower awareness in other countries, where scout Reverse Circulation (RC) drilling through cover has become widely used but in the past the discovery process would have developed typically via prospecting, to soil sampling to trenching or pitting, then directly to diamond drilling or even trial mining.

In spite of its fundamental importance to the industry, RAB drilling has a very low literature profile, even in Australia. There are very few papers describing RAB equipment and methods, and even fewer on the geological and geochemical techniques that have evolved to extract maximum information from the drilling. For instance, the widely used field guide for Australian explorers, the *Field Geologists Manual* (Berkman 2001) - has no references to either RAB drilling or RAB drill geochemistry. Likewise,

Figure 1.
Photograph of typical Yilgarn weathering profile exposed in Darlot open pit (north-eastern Yilgarn). Note flat landscape. Benches height is 20 meters. Rock types are predominantly metadolerite. Profile shows thin "harpanized" soil cover (1-3 meters), mottled lake clays (only at far left in profile, thickening to about 40 meters out of field of view), residual upper saprolite (red and purple colours extending irregularly to about 30 meters, but much deeper on structures), lower saprolite (yellow and, grey-green colours, extending to about 60 meters), saprock transition (irregular zone about 5 meters wide just below 60 meter bench), and fresh rock at about 65 meters to base of pit at around 100 meters below surface.

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a recent book on drilling techniques (McGoggan, 1997) devotes just two paragraphs to RAB drilling. The few papers which directly address RAB drilling and sampling (e.g. Barnes, 1987; Marjoribanks, 1997) are mostly in conference proceedings, course notes or books which do not have wide international circulation.

This paper is written to begin to redress the lack of published information about RAB drilling, primarily for the edification of Explore's readers from outside Australia who may be unfamiliar with the scene “down under”. We review the development of RAB and speculate on why this is such a dominant aspect of Australian exploration. There is considerable variation as to how different companies apply the method, so we summarize typical procedures and attempt to identify modern “best practice”. A follow-up paper will provide a practical example of RAB geochemistry and perhaps also a summary of the Aircore technique, a more recent development that has further advanced reconnaissance drilling.

Background

Most of Australia's major gold-bearing regions, particularly those of the Yilgarn Craton of WA, occur within arid, generally low-relief, sparsely vegetated terrain that is characteristically deeply weathered (typically >40m to fresh rock, often >100m). The nature of Australian regolith, and its challenges and benefits for exploration, have been discussed thoroughly in many recent articles (e.g. Smith *et al*,1997; Butt *et al*., 1997; Anand,1995). Suffice to say here that Australia has an extended tectonic stability and a long history of episodic lateritic weathering perhaps extending back to the time when *T.Rex* and cohorts stalked the planet. More recently, a change to arid conditions has occurred in Australian climates, with lowering of water tables and development of saline groundwater systems in many areas. The resultant weathering profiles are deep, intense and complex (Figure 1 on front page).

As in other Australian goldfields, the first gold mining

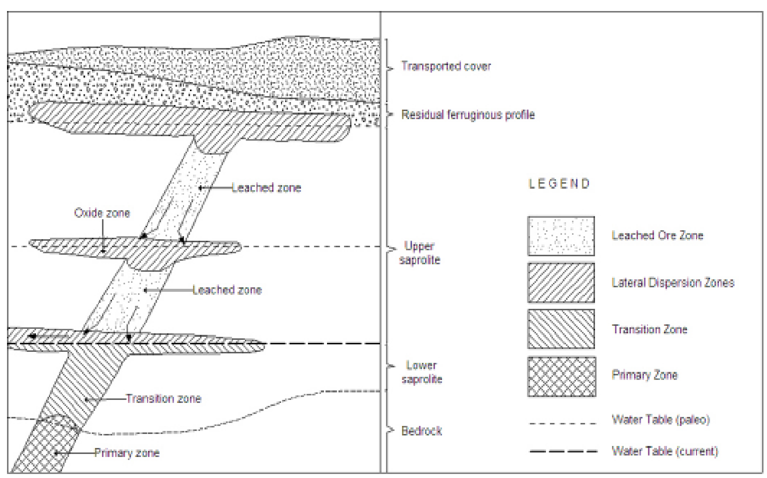

Figure 2: Schematic diagram of typical Yilgarn mineralised weathering zone showing distribution of supergene enrichment zones in relation to regolith units and hypogene ore shoots (modified after Mann, 1998). Profile is drawn as though buried without stripping. In practise, however, the first residual material below cover in a partially eroded and subsequently buried profile can be upper or lower saprolite, typically with sharp and unpredictable changes between adjacent drill holes. Dispersion zones related to palaeo-water tables may be stacked or absent.

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boom in the Yilgarn during the 1890s developed through discoveries by conventional prospecting – the visual detection of particulate gold in drainages, colluvium and outcrop. "Dry blowing" was particularly important owing to the arid environment (water was literally worth its weight in gold during the hot Australian summers). Most of the deposits exposed in outcrop, or with shallow residual soils, were readily located because they had visible gold. Incidentally, there is no record of the Australian aborigines having recognized or attributed any significance to gold during their 40,000 year plus occupation of the continent. Hence the first European prospectors took huge advantage of undisturbed residual surface enrichment of gold accumulated over perhaps millions of years.

The early miners and prospectors proceeded through trial and error in different gold camps to decipher and exploit the uneven distribution of gold within the profile. However, much of the surrounding terrain was covered by shallow alluvium, colluvium and sheet-wash deposits. Exploration of these overburden-covered areas could only proceed by slow and costly trenching or "wildcat" pitting. Some fortunes were certainly made by speculative shaft sinking along the "line of the lode" through shallow cover, but most of the deposits concealed under more than a few meters of overburden remained undiscovered during this phase.

Several periods of renewed prospecting occurred in the next 100 years (particularly during the depression of the early 1930s), generally spurred of course by higher gold prices. Techniques were largely the same as those employed during the 1890s, and significant new discoveries were rare. However, that situation changed dramatically during the modern gold boom from the early 1980s to the mid 1990s, when a spectacular period of gold discoveries more than doubled the known gold endowment of the Yilgarn. After a lull due to low gold prices, exploration activity has again surged since 2003 but few significant new discoveries have so far been made.

There were many reasons for the 1980s-1990s gold boom (e.g. high gold prices, improved processing particularly via CIP, better pit optimizations) but a major factor behind the improved exploration success was an enhanced understanding of the distribution and remobilisation of gold in the weathering profile. As new open-pits were developed, it became apparent that many mineralised structures exhibited both significant depletion and supergene enrichment zones within the regolith. Of critical importance was the realization that above many sub-economic hypogene gold occurrences there were extensive, mushroom-shaped, flat-lying lenses of gold enrichment at various levels in the weathering zone (Figure 2). These were highly economic on account of their free-digging nature and high-grade, high-fineness, readily cyanide-leachable gold.

These in-mine observations on gold distribution were supported and underpinned by a succession of highly

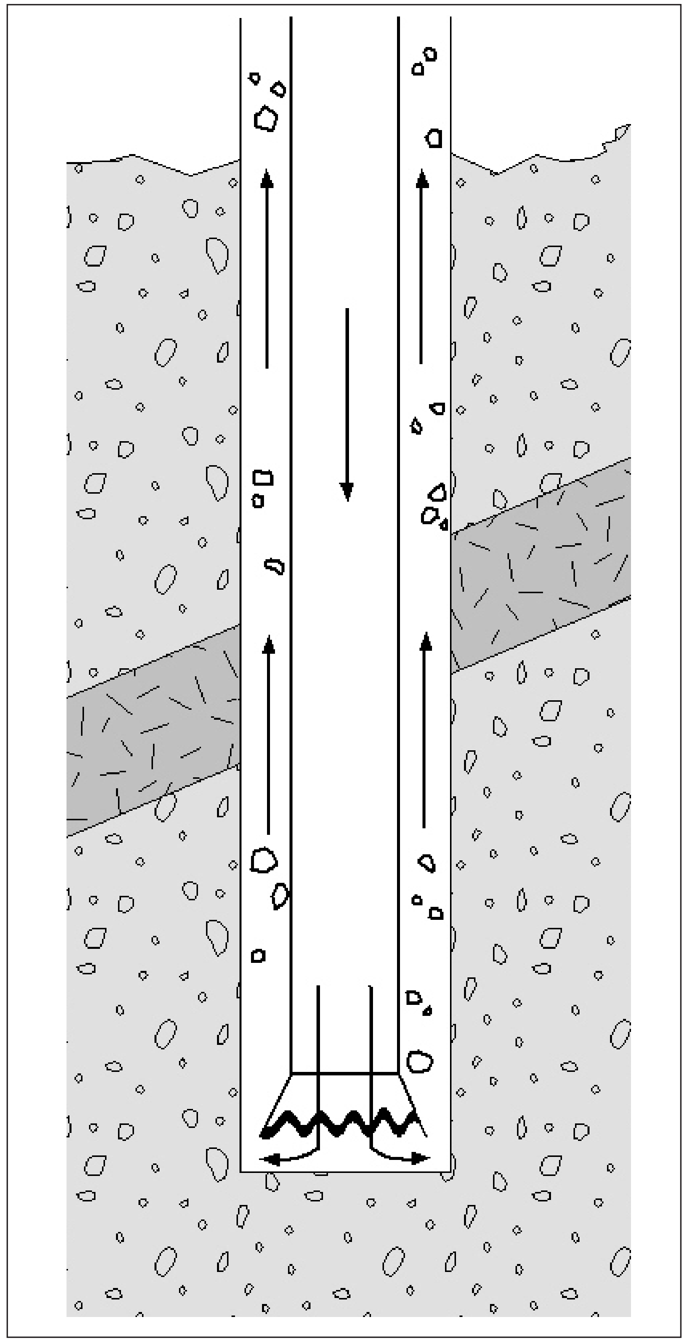

Figure 3: Schematic of RAB drilling and sample recovery. Compressed air forced down drill string results in cuttings blown to the surface for collection. Penetration is by rotation (blade) or impact (hammer).

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successful research projects conducted largely at the Commonwealth Scientific and Research Organization (CSIRO) and partly funded by the Australian Minerals Industry Research Association (AMIRA). The resulting insights into supergene gold re-distribution brought about significant change in the exploration process: close-spaced soil and trench sampling were abandoned in favour of early and extensive drilling.

RAB was the dominant reconnaissance drilling technique in gold exploration since 1980, and RAB geochemistry has been the key discovery technique in more than 90 percent of successful case-histories for modern gold discoveries in the Yilgarn. In looking for reasons why RAB is so widely used in Australia, yet relatively uncommon or even unknown elsewhere, several contributing factors stand out:

- The extensive shallow alluvial/colluvial cover overlying very deep weathering profiles, typical of much of the prospective terrains in Australia, makes for easy drill penetration through overburden and well into clay-rich oxidized bedrock.
- The current water table is commonly deep (typically 40-60m) meaning that sample recoveries are generally acceptable via RAB drilling.
- Relatively sparse vegetation and limited relief over much of the Yilgarn facilitates easy rig access to most sites.
- A well organized, highly mobile and professional drilling industry had already evolved, and readily adapted to provide contract RAB drilling services.
- RAB costs are much lower than for RC and diamond drilling; in addition, RAB rigs are far more mobile and require less support so that it is cost-effective to use RAB for initial testing then follow up with other drilling techniques.
- Unskilled labour costs in Australia are high relative to many other countries, so that manual pitting and costeaning (trenching) are not cost-effective options to penetrate shallow cover.

RAB Drills and Drilling

What is meant by "RAB drilling"? As the name implies RAB, or Rotary Air Blast drilling, is an open-hole technique in which compressed air is injected down the drill pipe in order to recover the cuttings up the outside of the drill stem to the surface (Figure 3). RAB is thus essentially similar to blast-hole drilling in open-pit mines, except that the rigs are commonly truck-, rather than track-mounted, and generally larger and more mobile (Figures 4 and 5). In addition, the cuttings are generally piped off and collected rather than being permitted to mound around the hole aperture. Both rotation (blade) and impact (hammer) drilling methods are employed.

RAB drill rigs evolved from the earlier wagon drills and rotary percussion drills during the early 1970s, as the WA nickel boom played itself out. Within a decade of their introduction, the highly mobile RAB rigs had largely replaced auger, air-track and rotary percussion rigs for first-pass exploration drilling, though "vacuum" rigs remain popular in some districts.

The all-up capital cost of current-generation of RAB rigs is of the order of $400,000 to $600,000, including support vehicles and mobile accommodation (these and all subsequent costs are quoted in US dollars, at current exchange rates of $1 AUD = $0.74 US). Most rigs are manufactured in WA. Typically, they are mounted on four or six-wheel-drive trucks for a total weight of 10 to 15 tonnes, and can to access sites with minimal disturbance of vegetation and topsoil. Hydraulics are used to drive the drill string and a compressor supplies high volume (500-

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Figure 4: Photograph of typical RAB rig (view from rear) showing sample delivery through "stuffing box" at collar along flexible tube under pressure to cyclone (at right) for collection. Note hard hats and safety boots for all personnel- a recent safety change to replace caps and thongs!

750 cfm), high pressure (250 – 350 psi) air for recovery of cuttings. Power for the hydraulics is provided by auxiliary diesel engines around 250 – 300 Horsepower. In modern rigs a single turbo-charged diesel drives both the compressor and hydraulic pump. Blade bits (tungsten carbide) with diameters of 9 to 11.5 cm (3.5 - 4.25 inches), account for 90 – 95% of meterage drilled, although down-the-hole hammers are used for unusually hard formations such as silcretes, quartz veins, cherts and banded iron formations.

Although a few exploration companies have used in-house drilling teams in the past, the vast bulk of RAB drilling is carried out by specialist drilling contractors. Base drilling charges are currently around $4.50 – 6.50 per meter for blade drilling, $8.50 – 12.50 per meter for hammer and $13 – 16.50 per meter for Aircore (a modification in which the cuttings recovery system is more akin to RC, with air blown down the outer tubes of the drill stem leading to "sticks" of semi-consolidated cuttings being delivered up the inner drill tube).

The Australian drilling industry is highly competitive and the actual dollar cost of RAB has remained remarkably stable over several decades. In fact, allowing for inflation, the cost of drilling in constant dollars has fallen by perhaps 15 - 20% over the last 15 - 20 years, assisted by continued developments in equipment and operating techniques. The major technological advance in this period has been improved air supply, which enables drillers to penetrate perched water tables with relative ease and often, while retaining essentially dry sample recoveries, to take blade holes to some 25m below the major water table (which is commonly on or around the weathered–unweathered bedrock interface).

Under "average conditions" a RAB crew – the driller and one or two assistants ("offsiders"), can drill about 300 - 500m in a single 10 –12 hour shift although up to 800m per day is not unheard of. Drill rates vary according to nature of cover and depth to water, with RAB blade to depths of 120m possible in some circumstances. Typically, the exploration companies are responsible for providing a geologist (colloquially known as a "RAB jockey") and a sampler, to composite and collect geochemical samples. The geologist has to oversee sampling, confirm hole locations, determine required drill depth, and log the hole by identifying the position of the overburden interface, nature of regolith units, and bedrock lithololigies (including of course visual signs of mineralization such as

Figure 5: RAB rig showing manual rod handling and minimal site preparation. The operator has switched to hammer drilling on account of quite fresh bedrock unexpectedly encountered beneath only shallow cover (1m) and minimal oxidized profile (2-3m). Photo courtesy of Leon Marsh.

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alteration, quartz veining and sulphides or their weathered products). Maintaining control of all these aspects is no small feat at high drilling rates.

RAB Drill Geochemical Surveys

RAB Drilling is used mostly in the early stages of exploration to:

- Provide a first-pass drill test of known surface (e.g. soil) geochemical anomalies;
- Probe for below-surface geochemical dispersion and, in particular, to collect preferred regolith sampling media such as pisolites and duricrust materials which can define extensive multi-element anomalies around supergene gold systems within intact laterite profiles or on "Redox" barriers in the profile (e.g., Smith *et al.,* 1997; Mann, 1998).
- Test the nature and prospectivity of structural, geophysical or geological targets beneath shallow cover- such as the continuation of known lodes, or interpreted mineralized shear zones evident in aeromagnetic imagery.
- Map the 3-D distribution of regolith and bedrock units where negligible outcrop otherwise precludes conventional mapping techniques (typically the RAB rig provides ground truth for an interpretative framework of lithotype distribution and location of major structures, built up from detailed aeromagnetic imagery)
- Prospect for concealed paleochannel-hosted placer and remobilised gold deposits within transported regolith.

Around 90% of holes in reconnaissance are drilled vertically. This is because the principal targets for the geochemical surveys are sub-horizontal zones of dispersed gold and pathfinder elements within the regolith profile. Vertical holes allow deeper penetration and more rapid site occupation, which are acceptable trade-offs against reduced coverage of bedrock features (in any case, the attitude of bedrock litho-structural trends, and hence optimum drilling direction, is often not known in covered areas). Sections or "drill fences" of overlapping angle holes (e.g. -60^{o}) are more common for follow-up programs or for testing specific targets whose orientation is known.

The unfocussed, broad-brush RAB geochemical surveys which were popular amongst the more speculative company directors and their brokers in the 1980s and early 1990s, are now rare. Today's RAB drill geochemical programs are generally tightly focussed on targets developed from prior geological, geophysical, and geochemical surveys. Drill spacing and grid patterns of reconnaissance RAB programs vary according to the definition and potential of target zones, or the explorer's perceived geological model. In first-pass programs over highly prospective structures, the initial pattern might be holes 100m apart along lines no more than 400 - 500m apart, though remote areas might be initially screened at 800 x 200m (or even 1600 x 400m), with immediate follow-up in anomalous or geologically prospective zones.

RAB drill holes (diameter 12 cm) are typically drilled uncased or with a temporary casing to prevent hole "bell-out". In the past, most holes were left open and unrehabilitated. However, environmental concerns (principally death of small marsupials seeking water) have resulted in directives from Government Mines Departments that all holes must now be plugged and sample spoils raked over or removed. While admirable from the environmental perspective, this latter requirement has caused concern due to the potential loss of valuable geological information. RAB spoil piles can remain intact for up to ten years after drilling, thus offering new generations of explorers access to bedrock and profile information during reconnaissance in areas where no trace of bedrock could otherwise be accessed without further drilling. There are even documented discovery histories from re-sampling of previous drilling where operators were focussed on different commodities. Bounty Gold Mine in the Southern Cross Belt (approximately 1Moz total mined resource) is the best known of these and resulted directly from gram-level assays in spoil taken from a 1970s nickel RAB hole which had not been analysed for gold (discovery history not well documented, but see for example, Lintern 2005). This loss of sub-surface information has been viewed by many experienced geologists as nothing short of "geological vandalism". However, there is little prospect for any revision of policy by Australian regulators.

In its initial usage during the 1970s and early 1980s, standard RAB drilling practise was to penetrate overburden then take a single "bottom-of-hole" sample in the first recognizable interval of *in situ* regolith. It is now clear that much of this exploration phase was highly ineffective. Even if the cover-bedrock interface was accurately identified (no small feat in many Australian profiles), resultant samples included lateritic duricrust (high multi-element and gold backgrounds), upper saprolite (normally severely leached), and lower saprolite or saprock. This was a classic case of comparing apples and oranges, and with lemons as well: In many cases, unrecognized older transported units were sampled by mistake!

In most exploration reports from the late 1980s to early 1990s, RAB holes are recorded to penetrate to 40 or 50m, commonly to a pre-set depth about "42m" (no doubt guided by Douglas Adams' answer to the ultimate question about life, the universe and everything in *The Hitch Hikers Guide to the Galaxy*). Of note, as recently as

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the late 1980s, one of Australia's largest company explorers undertook extensive geochemical surveys based on RAB holes drilled to a preset 18m depth, with a standard two 9m composite samples per hole. With hindsight, the effectiveness of this approach is highly questionable given variable depths of transported cover and variable stripping of the underlying residual regolith. In fact, much of the ground written off after 1980's style RAB drilling is now regarded as ineffectively tested and potentially still prospective.

With further insight into regolith processes, and with the advent of high volume, high pressure air systems, it became more common for RAB holes to be drilled to the limit of blade penetration – colloquially known as "blade refusal". This is typically well into lower saprolite and close to the base of weathering (i.e. fresh rock). Some holes may be abandoned at shallower depths because of excessive groundwater inflow, caving formations, plastic clay or hard layers such as silcrete. These "failed holes" need to be identified and flagged during interpretation because they may not constitute a satisfactory test for the presence of mineralisation. Where the weathering profile is deep, RAB rigs commonly penetrate to more than 100m and, exceptionally, to 140m. A variety of foams and additives can be used to facilitate sample recovery (geochemists beware!). However many, if not most, of the larger RAB rigs now carry the equipment, drill strings and bits to enable a switch to Aircore drilling when groundwater prevents dry open hole RAB drilling.

Sampling and Analysis

It is stressed that RAB drilling comes with a multitude of "challenges" from the perspectives of good geochemical sampling practise. It is prone to contamination from the hole walls or the surface, mineralized intercepts are commonly "smeared out", and sample recovery is problematic in poor ground conditions or where water inflow has occurred. For these reasons, RAB results should be considered as "indicative of mineralisation" only, and not a quantitative description of grade or width. In particular, RAB sampling is not a viable methodology for resource estimation. Should any

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Figure 6: Photograph of RAB spoil with geologist logging. Top of hole marked by stake at centre left. Spoil piles each representing 1 meter of drilling in rows of 10. Profile shows about 8 meters of cover underlain by leached upper saprolite (white, red and purple colours) then sharp change at 39-40 meters to lower saprolite (yellow-brown-green colours). Last sample at 41-42 meters is wet and contains some fresh mafic chips. A decision is required by the geologist on a switch to hammer drilling to penetrate fresh rock if water flow can be contained so as to ensure a sample of adequate quality.

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economic or sub-economic mineralisation be located, this should be immediately confirmed and defined using the more expensive but inherently superior reverse circulation (RC) and diamond drilling.

With these caveats in mind, we will outline the procedure involved in RAB sampling and highlight some of the pitfalls. As noted above, RAB holes are drilled dry wherever possible. High pressure/volume air is forced down the centre of the drill string in order to flush cuttings up the sides of the hole. The returned cuttings pass through a "stuffing box" at the collar which maintains air pressure within the holes and directs the cuttings via compressed air for collection at a cyclone in a bucket or plastic bag. Cuttings recovered from each 1m interval typically weigh about 15 - 20kg. These are laid out on nearby flat ground as separate piles in rows each representing 10 meters of drilling (Figure 6). Wet samples - usually a sludge, are poured into shallow shovel holes dug into the soil within their rows and allowed to drain. Recovery of wet samples into open-weave polypropylene bags or plastic "garbage bins" is becoming more common in order to minimize contamination from topsoil. However the water associated with wet samples is commonly allowed to drain away, along with much suspended clay, which potentially further compromises sample quality.

The dry (or air-dried) cutting piles for each 1m drilling return are usually sub-sampled by trowel or plastic "sampling spear" (a polythene tube with the sampling end cut obliquely, which is pushed through the spoil pile) to produce composites weighing 1.5 – 3.0 kg. Compositing is semi-quantitative, and the aim is to reduce analytical costs while still identifying any mineralized intervals for individual re-sampling. There are varying company procedures on composite lengths, but 4-5m is quite common, and up to 8 or even 10m composites may be used in leached upper saprolite. Increasingly, regolith and/or bedrock geological contacts are being used to determine variable-length composite sample boundaries. In this approach, important regolith units are identified and more closely sampled (e.g., 1-2m composites). Examples include lateritic duricrust, "Redox" boundaries (sharp changes from oxidized to reduced material, commonly recognized by iron precipitation even where the reduced zones have been subsequently oxidized), or suspected shear zones. By contrast, enclosing zones of cover or upper saprolite might be composited more widely.

In the past most companies did not sample transported overburden. However now most operators will composite and analyse overburden sequences, in order to identify possible dispersion trails including placer or hydromorphic mineralisation in palaeochannels, or plumes of geochemical dispersion extending upwards or laterally into old transported cover units.

After freighting to the laboratory, reconnaissance RAB samples are generally processed and analysed in dedicated "low-contamination" facilities used exclusively for exploration work. Each composite is dried then the entire sample is typically ground to a nominal 90% minus 75 micron by "SSMG" (Single Stage Mix and Grind) in a large diameter bowl pulverizer such as a Labtechnics LM5. A 250-300g pulp is then taken directly from the pulverizer bowl, the remainder being archived or discarded.

Gold analysis is generally by aqua regia digestion of 30-50g pulps, though some companies prefer fire assay collection (50-100g). In either case, the preferred analytical method is now direct aspiration of aqua regia into ICP-MS, this having replaced graphite furnace AAS after pre-concentration by solvent extraction into an organic phase. Realistic detection limits of 1 ppb can be achieved, though there can be digestion and/or analytical difficulties with high-Fe samples, or where graphite or charcoal is present.

The argument that Au is the best, and by inference, "the only useful" indicator of significant gold mineralization dies hard with some old-school exploration managers. However, attitudes are changing because there is now overwhelming evidence for gold leaching and a growing awareness that multi-element secondary dispersion haloes (e.g. Smith, *et al.,* 1997) can give a larger and more distinctive geochemical "footprint" than those defined by gold-alone assays. In some districts, there is a strong and direct association of Au and pathfinders (e.g. As, Sb, W). The common better preservation of pathfinders, in particular, W and As relative to gold in some regolith units, provides a means of identifying and mapping significant mineralized systems especially in upper saprolite from which gold has been substantially leached.

Although it is now quite common to analyse for pathfinders, the extent and nature of element suites varies widely between companies and regions. In notable contrast with geochemical surveys for gold-pathfinders elsewhere in the world, the alkali and alkaline earth elements are typically not analyzed, owing to their great mobility in the Australian regolith. However, Fe is widely analyzed as a pointer to regolith units. Elements most commonly analysed are As, Cu, Pb, Zn, and Ni (in part reflecting a subsidiary net cast for base metal occurrences as well as gold), together with a sub-set of other pathfinders like Sb, W, Co, Ag, Bi, Te and Mo. However, the use of W has to be reviewed critically because of the tungsten carbide tips on the drill blade. Other issues can arise from Mo in lubricants and Ag in solder.

It is quite common for the pathfinder suite to be determined from the same digest as the Au (i.e. on 30-50g samples) in order to save on analytical costs, even though results are substantially inferior to those obtainable through a re-digest using conventional higher acid: sample ratios or a separate mixed-acid digest. Analytical finish is typically by ICP-OES and/or ICP-MS depending on the analytical suite and required detection limits.

Selected samples (e.g., bottom of hole composites) may be further analysed by XRF, INAA or ICP-MS (after

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fusion or mixed acid digest) for "least mobile" elements like Ti, Zr, Cr, Sc and Nb. The purpose is to assist with rock-type identification (e.g. see Hallberg, 1984), which can be surprisingly difficult in many Yilgarn weathering profiles.

In terms of rig-site procedures, it is now widely acknowledged that close geological supervision is vital for successful RAB programs. Most companies instruct geologists to ensure that lowermost regolith has been intersected in all holes, generally with at least one in ten holes continued using a hammer bit well into fresh rock so as to ensure the profile and nature of bedrock is understood. Regolith materials are carefully logged, and the entire profile is sampled on fixed or (preferably) geologically-determined composites. The composite gold results are regarded as purely indicative: there will be immediate re-sampling of individual spoil piles for any intervals of anomalous gold.

Careful logging of regolith and bedrock is generally accepted as critical for both effective sampling and subsequent interpretation. The logging ideally takes place in real-time in order to control drilling depth and composite sampling strategy. It is based on the field geologist's observations with a hand lens or small binocular microscope of screened and washed cuttings. Both diligence and experience are required. Reference material is typically collected from representative regolith units and placed in plastic "chip trays" for later office reference. Geophysical logging is uncommon, other than the almost universal hand-held magnetic susceptibility readings from chip piles. Geologist's field logs are generally coded for later office entry into a digital database. On-site data entry tools (e.g. data loggers) are used by some companies but are not generally suited for reconnaissance programs.

The variable and often poor quality of RAB drill logs is a recognized problem in the industry. Leaving aside the obscuring effects of dust, mud, grease, blood, sweat, tears and squashed insects, terminology and logging codes are highly variable, and many important regolith features are cryptic and subjective. In addition, most first-pass logging is done by the least experienced geologists in the company, their lot being to manage the RAB rig. However, the 1980s – 1990s regolith studies by CSIRO and more recently by CRCLEME (Cooperative Research Centre for Landscape Evolution and Mineral Exploration), together with various Universities are now bearing fruit for the industry. There is a notable improvement of field interpretation and recording for RAB drill programs on account of increased graduation of "regolith-aware" young geoscientists, together with the participation of many experienced company geologists in short courses on regolith geology.

Interpretation of Surveys

Preliminary geochemical results usually become available 2 to 3 weeks after RAB drilling and sampling. Hence, plotting and interpretation of data is usually a post-campaign exercise because typical drill campaigns last only 2 to 4 weeks.

Theory and practice for data interpretation vary widely. However there is now widespread consensus that best practice requires careful evaluation of the analytical results in the context of the regolith. As mentioned above, the models of gold re-mobilization in the lateritic profile of the Yilgarn Shield that were developed in the late 1980s and 1990s are now well substantiated through numerous drilling campaigns and open-pit mining operations. The flat-lying dispersion plumes of Au and/or pathfinder elements are interpreted to reflect "redox" fronts or protracted still-stands in the water table (e.g. Mann, 1998), and they provide a broad geochemical footprint for locating primary and supergene deposits.

Data interpretation typically begins with interpretation of the regolith profile, initially from hand-drawn field sections, and continued on computer-generated drill sections. Anomalous gold values are plotted on the sections and interpreted in context of their position in the regolith profile, likely precursor rock type and proximity to interpreted structural features (e.g. shear zones). Stacked drill sections, showing assays, bedrock lithology interpretations and regolith units (including cover depth) are the most common and useful portrayal of first-pass RAB drilling data. In addition, summary plans of gold (highest composite value in each hole, or length-accumulated gold) are normally produced for comparison with regolith maps, magnetic images and interpreted bedrock geology. Imaging and GIS techniques are increasingly used for data integration. Hence, a well-structured and maintained, computerised geochemical database is essential.

Criteria for identifying and following up anomalous zones vary widely, depending on the area, the company and the individual. However, experienced campaigners will typically insist that any composites >100 ppb Au are re-sampled from the drill site, with all 1m chip piles within and adjacent to the anomalous interval, being submitted for individual assay. If the anomalous interval is repeated then the zone will be tested by both infill and step-out drilling, in which the type, spacing and orientation is determined by depth, geological knowledge and profile conditions. It should be re-stressed however, that the RAB drilling stage is for discovery, not measurement: Once the broad outlines of a mineralized zone have been established by the RAB rig, other drilling methods such as reverse circulation (RC) and diamond will be used to outline and quantify the resource and explore at depth.

In interpreting the significance of often spotty high Au values in an otherwise largely depleted profile, more weight is given to sections where the high values correspond with visual indications for mineralization (including quartz stringers, weathered sulphides or shearing textures). Specific regolith units such as lateritic duricrust, ferruginous clay "mottled" zones or "Redox" zones, or the transition zone from saprolite to bedrock (saprock) are also ranked higher. Length-weighted grade

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accumulations (grade x drill intercept) are commonly used as measures of significance, but it is important to bear in mind the inherent problems of sample recovery in RAB drilling. There is endemic contamination of the interval being drilled, by material higher in the hole. Although contamination can be substantially reduced by the skill of the driller, 'smearing' of high values down the hole is normal even in dry conditions, and almost inevitable in wet drilling conditions. There are many documented examples of RAB drilling producing false impressions of the width of mineralized intervals, but both high- and low-grade bias can be revealed after follow-up with RC or diamond core. Likewise, the sample collection and compositing operations are highly error-prone. Without doubt, the quality of laboratory operations viz. preparation, digestion, instrumental measurements, limits of detection etc and precision of determinations far exceeds the quality of the field sample recovery and sub-sampling.

Most explorers follow experience-based rules of thumb for determining significant gold "numbers" in RAB composites. Although levels vary between different geologists, companies and regions, most explorers would consider a gold value of 2 - 5 g-m/t (gram-meter/tonne) in one or two composites from a broad reconnaissance program as a significant result, and a 10 g-m/t interval as distinctly encouraging. Results of 100 g-m/t (e.g. 10m at 10 ppm, or 20m at 5 ppm) are exciting but not atypical within well-mineralised zones.

Outlook

Despite the relatively low per meter drilling charges, RAB drill geochemistry is a significant cost, often the largest single component, in most first-pass gold exploration programs in regolith-covered areas of the Yilgarn Shield. Even at a broad reconnaissance spacing, a RAB geochemical survey typically costs about AUD \$20,000/km^2, often almost an order of magnitude higher than the combined costs of the preceding phases of geological mapping, surface geochemical surveys and multi-client aeromagnetic interpretation. Hence, there is an incentive to improve the effectiveness of RAB geochemical surveys and/or to develop other techniques allowing better definition of drill targets. Some research and operational developments relevant to RAB drilling and RAB drill geochemistry are:

- Aeromagnetics – close spaced (down to 25m) and low level (15 m over salt lakes) surveys, particularly using helicopters, for more detailed "mapping" of cover and bedrock.
- Rigs - increased depth of penetration and improved dry sample recovery from deeper holes.
- Sampling - automatic sample splitting.
- Logging – more systematic and less individualistic geological and regolith codes, so that drill logs can be re-interpreted and used by others with greater confidence.
- Instrument logging e.g. using hand-held spectrometers like the "PIMA" (Portable Infa-red Mineral Analyser) for differentiation of clay minerals, and in future hopefully cheaper and more robust probes for down-the-hole logging - e.g. magnetic susceptibility, gamma calipers etc.
- Analysis – sub-ppb Au determinations and increased and more effective use of multi-element geochemistry.
- Improved data management and "visualisation" software for presenting and interpreting RAB geochemical data in context of regolith position and proximity to interpreted structures.

Most of these offer at best moderate improvements, albeit for only modest increases in costs. However, since most current RAB drilling programs proceed on a campaign basis with separate follow-up, a significant reduction in total survey costs could be achieved through a robust, cost effective system for in-field sample preparation and gold analysis at sub-ppb levels. This would allow drill patterns to be modified during the program, with immediate focus on any anomalous zones encountered. In spite of some promising developments, this goal of "real-time analysis" - where latest results drive on-going exploration, has not yet been achieved. It should also be noted that changes in the regulatory framework in WA now require submission of detailed drill programs for environmental approval. Sadly, this obstructs the geologist's ability to modify drilling patterns "on-the-fly", in order to follow up immediately on signs of mineralization. One of the key benefits of RAB drilling, namely its flexibility, is therefore becoming lost to the industry.

Will RAB drilling maintain its significance to the Australian exploration process, and will the procedure be adopted increasingly elsewhere? We believe so on both counts. Already in South America and Central and West Africa, some companies are adopting a RAB-focussed approach to exploring mineralised shear zones in regolith that has many similarities to parts of Australia.

Within the Australian scene, three different approaches have evolved over the past few years, namely:

- *Partial leach geochemistry;*
- *Selective sampling*; and,
- *Deep drilling*.

The ***Partial Leach Geochemistry*** adherents are using widespread near-surface, relatively cheap and non-invasive geochemical sampling combined with innovative partial and selective digestions (e.g. proprietary methods like MMI, Enzyme Leach, Regoleach, Deep Leach) to detect subtle geochemical dispersion even through transported cover. Their aim is to reduce significantly first-pass drill budgets and to achieve direct target drilling on discrete geochemical anomalies.

Working counter to this, however, is a growing realization that, under Yilgarn regolith conditions, it can be exceedingly difficult to identify the depth or complexity of transported cover without the benefit of drill profiles (thus raising questions about the effectiveness of near-surface sampling). Furthermore, it is now well

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documented that gold can be significantly leached from some parts of the bedrock profile, with lateral and vertical re-distribution.

Several minor successes have been reported, particularly in areas of shallow cover, and the potential is of course enormous. However, the jury is decidedly still out as to whether there are robust near-surface partial leach anomalies in areas of >10m cover in Yilgarn-type regolith environments.

The ***Selective Sampling*** approach is essentially a modification of the highly successful RAB-based approach of the last 5 or so years. Shallow drilling using a lightweight RAB or vacuum rig is used to specifically target and sample particular regolith materials such as ferruginous lateritic residuum or detritus, as well as base-of-hardpan (boh), base-of-cover (boc), or even upper saprolite. Drilling costs are perhaps only 25-30% of a conventional RAB geochemical survey, in which all holes penetrate to refusal and the entire profile is sampled by composite units.

There have been some notable successes using this approach, particularly in northern parts of the Yilgarn under cover thicknesses of 10-30m, though a serious question remains as to whether it constitutes an effective test in areas where lateritic profiles are largely stripped. Unfortunately, the widespread presence of stripped but buried profiles can normally be deduced only with hindsight- and the drilling budget cannot be refunded for a change in tactics!

The ***Deep Drilling*** approach is based on the belief that the only effective test of a potential gold system in the Yilgarn is to drill it systematically down to fresh rock, using RAB, Aircore or RC techniques as required by ground conditions. Within several Australian gold camps, some of today's most successful explorers have adopted this approach by negotiating access through Joint Venture or short-term Options to the most prospective terrain, then exploring the interpreted favorable sites for mineralisation by the use of intensive drill campaigns in which all holes penetrate through the regolith to fresh rock.

There have been some notable successes, but only time will tell if the skill of target generation and quality of resources justifies the rate of expenditure that such deep systematic drilling requires. A graphic recent example is provided by the Mt Pleasant area, NW of Kalgoorlie. Previous exploration generated several moderate-to-small gold resources (Mazzuchelli, 1996) using a conservative surface geochemical approach amounting to some 40,000 samples. However, the group who took control of the properties in late 1995 favoured an aggressive deep drilling approach. Focussing on interpreted geological features from magnetic interpretations and essentially ignoring the previous surface geochemistry, they reportedly located and defined in excess of 2.5 Moz of new gold resources within a twelve month period (Forster *et al.,* 1997). However, it should be noted that the conversion of these "resources" to reserves by subsequent operators was substantially less than expectations.

We cannot identify any technological change that offers significant improvement to current RAB drilling practises, but any development would be rapidly taken up by the industry owing to the potential for huge savings. The advent of Aircore drilling has provided a significant benefit particularly in areas of thick and clay-rich cover, so perhaps a follow-up article on this technique is warranted at some point. Australia's exploration drilling industry has shown itself to be innovative and quick to take up new technologies (e.g. reverse circulation, face sampling bits). For geochemists, challenges remain to extract maximum benefit from RAB drill samples that are relatively cheap, but often with problematic quality. Much remains to be done in this area.

Clearly, great savings are possible if we can confidently screen out much of the non-prospective "kangaroo pasture" and thus focus on prospective target zones without having to resort to grid-style RAB drilling. Improved techniques in geochemistry, geophysics and geology can all play a part here. In particular, near-surface geochemical methods (e.g. partial extractions and biogeochemistry) offer some promise, but many pragmatic explorers are not yet convinced of the reliability of these techniques as "area sterilisation tools", in new areas with poorly constrained regolith depth and profile. By contrast, the RAB rig is seen as a reliable, or even diagnostic, first-pass confirmation, be that positive or negative.

The immediate proximity of a RAB rig is not a pleasant working environment: it is typically hot or chilly, dusty and/or muddy, noisy and invariably hectic. However, this is the place where the geologist's knowledge of regolith materials and processes is put to its most severe test, and it will remain the place to be for Australian explorers who want to experience the adrenalin rush that comes from discovering new ore bodies.

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Alan Marshall
Xplore Pty Ltd,
21 Viewway, Nedlands WA 6009, Australia
E-mail: qestore@it.net.au

Leigh Bettenay
Sipa Resources Limited, L2,
87 Colin St, West Perth WA 6005, Australia
E-mail: leigh@sipa.com.au