Structural Analyses aiding Identification of Water Conductive Fracture Zones in Crystalline Rock

Kevin Morgan *
KH Morgan and Associates, Perth, Australia
Email: khmorgan@iinet.net.au

Abstract

Development of hydraulic conductive zones in crystalline rock can result from a wide range of geological conditions which include primary structures, post crystalline tectonics, fluid solution and movement within a developing and eroding regolith.

Crystalline rock areas mostly have low water resource potential due to inherent extremely low storage and water conductive properties. Therefore, fracture zones of high hydraulic conductivity have an important role in developing groundwater resources that may be distant or where it may be difficult to obtain alternative sources in these areas.

Mechanisms for development of open tension or pull-apart fractures in brittle rocks are similar to those involving development of mineralised veins. The same structural analytical techniques can be applied for water bearing structures.

Crystalline rock fracture zones can be amenable to rapid recharge through rainfall runoff. They are also significant in that they provide a mechanism for underdrainage through 'delayed yield' of surrounding or enclosing low conductive rocks such as saprock/saprolite, pelite and phyllite.

In addition to brittle rocks, open tension fracture zones of enhanced hydraulic conductivity may also occur in more fissile pelitic rocks such as slate and phyllite. These conductive zones are often associated with crestal zones of folds, strike deviations produced by conjugate shears and fracture zones discordant with layering and foliation. The development of conjugate joint sets in a region frequently provide a significant basis for this type of fracture analyses.

This presentation provides examples of water supplies developed from crystalline rock structures in a range of geological and earth environments.

Key words: **conjugate joints, wrench fault, saddle reef, stress, shear, hydraulic conductivity**

Introduction

Crystalline rock areas mostly have low groundwater resource potential due to extremely low water storage and water conductive properties. Therefore, the presence of fractured structures of high hydraulic conductivity and storage are important in extensive crystalline rock provinces for development of water supplies, particularly in arid and semiarid regions where it may be difficult to obtain an alternative water source. One positive property of a crystalline rock fracture system is that it can be amenable to rapid recharge by rainfall runoff. Another advantage of a crystalline rock fracture system is that it can provide underdrainage aiding in generation of delayed yield from overlying or enclosing low conductive saturated rock such as saprolite/saprock, siltstone, pelite, phyllite and other porous rocks of low hydraulic conductivity.

This paper presents examples where structural analyses has markedly assisted in identification of fractured rock structures in a range of earth environments from which industrial groundwater supplies have been developed.

Theory

Many examples of mineralised structures show that mineralisation has been enhanced through provision of space and zones of tension resultant from tectonic activity. Generation of these zones has particular association with brittle rocks being more amenable to fracturing rather than development of platy flow along multiple shears and other forms of ductile flow. The emplacement of dykes and veins are examples of emplacement along a tectonically prepared pathway. Less understood are post crystalline brittle rock fracture systems that have been enhanced through movement involved during development of the regolith, such as through erosion unloading and oxidation.

Three styles of fracture development are presented in this analysis:

1. joint and fractures developed during early stage open folding;
2. fracturing associated with shear stress in closer folded systems;
3. fracturing associated with shear and wrench faulting in advanced development stages of fold systems.

In early stages of open fold development two sets of conjugate joint/fractures develop at approximately 45 degrees to the fold axial plane (Billings 1946, page 108). In addition to joints, tension fractures develop at the fold crest. With ongoing development of closer folding, movement results along the duplex joint systems resulting in tension fracturing at join/fracture intersections. This type of fracturing is illustrated in borefield development at Bonikro, West Africa. Closer folding also increases development of crestal fracturing which has proven important in developing hydraulic conductivity in slates and phyllites. Good examples of water development in this style of fold crestal fracturing are found at Comos Howley in the Northern Territory Adelaide River System.

Crestal tension developed in similar style folding provides conditions for formation of saddle reefs between rock layers as exampled at Bendigo, Victoria (Spencer 1989, Figure 6.11) and at Bannockburn Mine in the Eastern Goldfield of Western Australia where this reef was developed as a water supply.

Shear movement subparallel to rock layering can result in kink folds. Significant boudinage development at these kinks has provided useful sites for mine dewatering bores.

In late stage tectonic development of a region in which rocks are highly lithified, shear stress results in wrench faulting subparallel to regional rock layering where part of the movement along these faults is transmitted to the duplex fracture systems. Sinistral or dextral movement along these faults determine the fracture set that results in shear and more ductile movement in the direction of maximum shear stress compared to the conjugate joint-fracture systems that lie in the direction of minimal stress and maximum tension. It is the tension systems that develop open fractures and brcome significant for development of increased hydraulic conductivity in the oxidation transition zone during regolith development. These systems are illustrated in establishment of Moolart Well Gold Mine and Thunderbox Gold Mine borefields.

Thunderbox Gold Mine

Thunderbox Gold Mine is located in a broad north-northwest trending Archean greenstone system in the Eastern Goldfield Province (Gee et al, 1979) of Western Australia. This greenstone system is bounded to the west by the Mt McClure Shear and to the east by the Mt Joel Shear (Figure 1). These ductile shears join the major northwest trending Perseverance Fault. Associated with the major northerly trending ductile shears are a conjugate set of brittle fractures, the northeast trending set being more dominant than the northwest trending set.

An initial conjugate joint set probably developed during regional D2 compression and open folding. The major north-northwest sub-strike ductile wrench faults, with a dominant dextral shear, developed during closer D3 folding.

Further shearing resulted in development of foliation in a direction subparallel to shear stress and was transferred to brittle fracturing along the early conjugate joint fracture sets, the northeast trending set taking up most of the movement under dextral shear along the main faults.

Extensive mineral exploration drilling along the main north-northwest shear hosting Thunderbox Gold Mine demonstrated that the main shears contain schistose rocks. Deep oxidation along these shears has produced a clayey regolith which has poor water transmitting properties. The principal water transmitting rocks are those subjected to late stage brittle fracturing mostly along the northeast trending fracture systems. It is to be noted that enhanced gold mineralisation in the main ore zone also occurs along northeast trending vein systems that were emplaced along structures initially prepared in an early stage of regional compression.

Sustainable water supplies in production bores in these brittle fracture sets has markedly been assisted through recharge from river systems which are also developed along shear and brittle cross fracture sets described above.

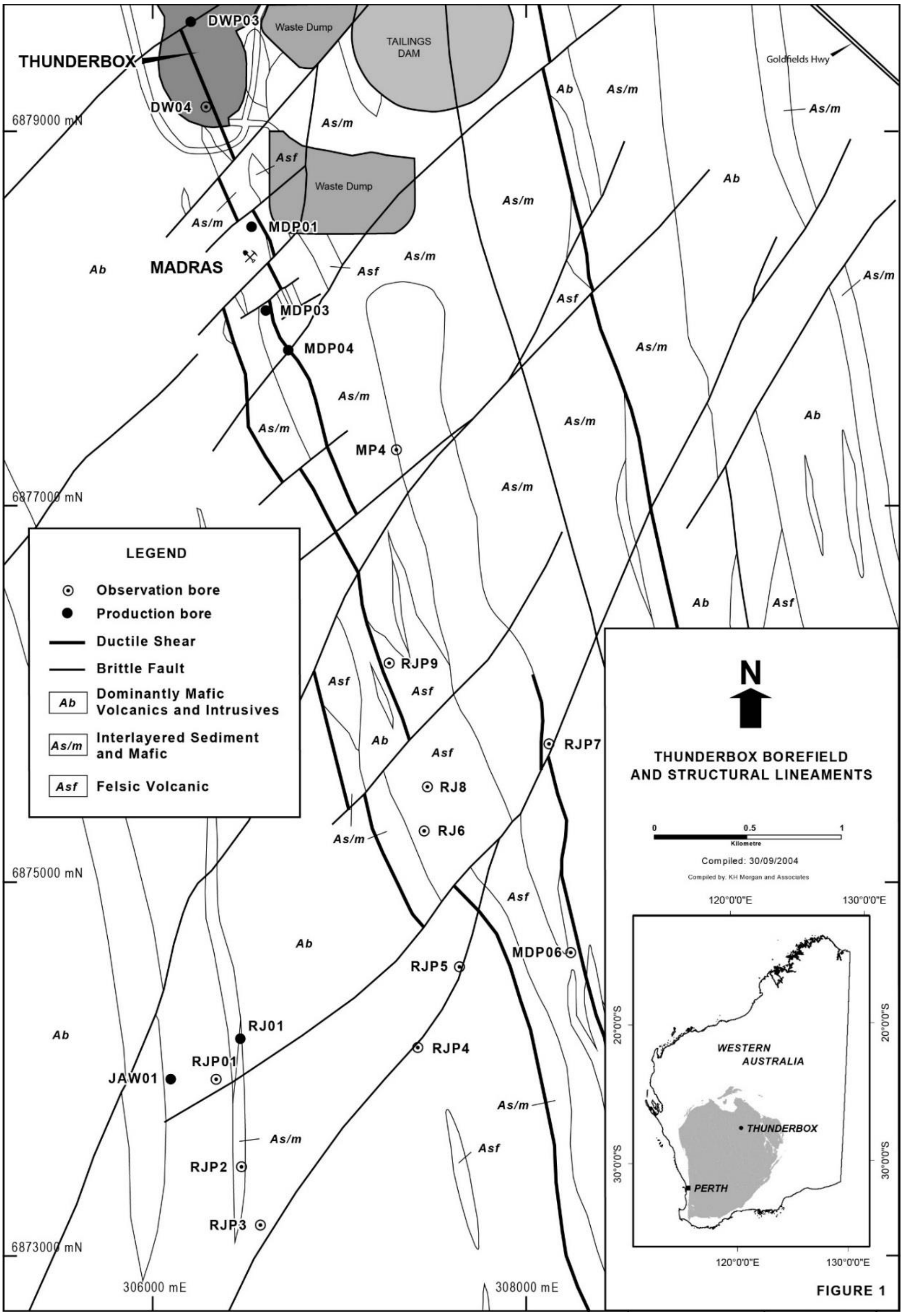

Figure One | Thunderbox Gold Mine, greenstone system

Moolart Well Gold Mine

Moolart Well Gold Mine (Figure 2) lies in the Duketon Greenstone Belt of the Eastern Goldfield Super Terrane of the Yilgarn Craton of Western Australia. This belt is a succession of metamorphosed Archean mafic/ultramafic and felsic volcanics associated with volcanogenic clastics, epiclastics and thin banded pelites, cherts and banded iron formation. Late stage high level felsic and intermediate sills and dykes and small plutons of granite intrude the sequence (Langford et al, 1993).

Metamorphism ranges from dominant green schist facies to amphibolite close to the margins of granite plutons.

The sequence is open folded along northerly and northeasterly trending axes. During this folding the initial conjugate northeast and northwest trending conjugate joint/fractures were established. In D3 to D4 tectonic development of the region, major north trending wrench faults developed. The westerly fault, with dextral shear, controls the main gold mineralisation. The easterly LuLu Fault follows the boundary of a granite pluton and has sinistral shear. These main faults control pathways of two northward flowing drainages. The distinct northeast and northwest conjugate fracture system controls pathways for the tributary drainages. Most of the dolerite dykes are emplaced along the northeast lineaments.

The conjugate fractures developed during early folding. Brittle fracturing along the conjugate system resulted through later movement on the main northerly trending faults.

Deep pervasive oxidation has produced extensive saprolite development with rock weathering up to a depth of 120 metres below ground level.

The principal water conducting zones are associated with brittle rocks impacted on by dextral movement on the westerly major fault (Figure 2). This dextral shear has generated brittle open fractures mainly along the northeast fracture set. The principal resultant water conductive lithologies are:

- silica caprock on ultramafic intrusions;
- stacked quartz vein systems along northeast shears;
- diorite intrusives, particularly those containing stacked quartz veinlets emplaced in early stage fracture system development;
- chert layers separating mafic flow.

A number of production bores established over a 15 kilometre strike length are mainly associated with structures associated with the main western fault system. These production bores range in yields of $5m^3d^{-1}$ to $100m^3d^{-1}$ and provide a water supply of $3.5MkLy^{-1}$ for ore processing and haul road maintenance. It is significant to note that drillholes away from these specific structural locations and in similar lithology rarely provide water yields of more than $3m^3h^{-1}$.

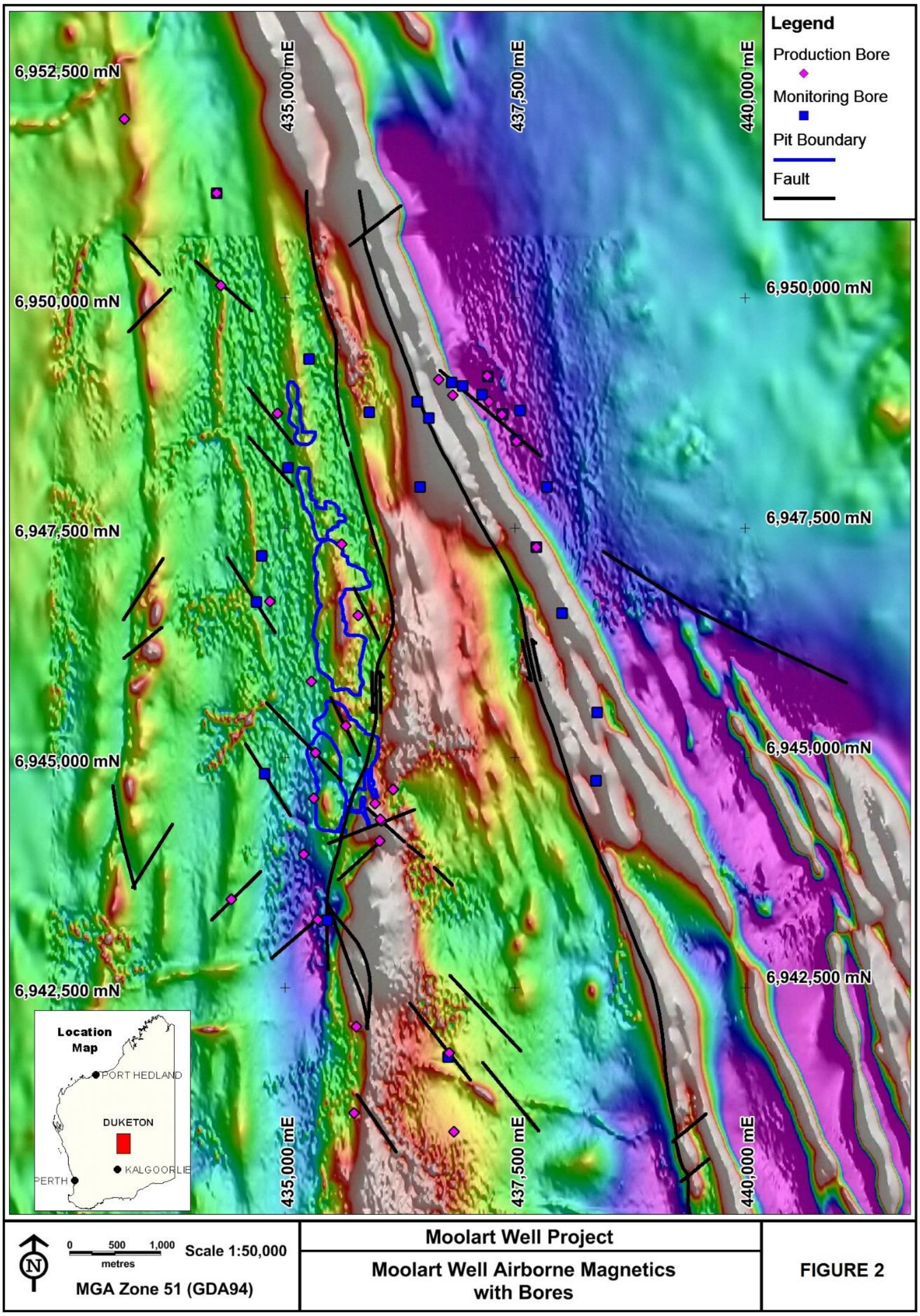

Figure Two | Moolart Well Location and Airborne Magnetics with Bores

Bonikro Gold Mine

Bonikro Gold Mine in West Africa lies in the Proterozoic Biriman Series of the Oumé-Fetékro Greenstone Belt, This Belt extends in a north-northeasterly orientation over a 300 kilometre strike length (Figure 3).

Gold mineralisation is in porphyry intruding basalt interlayered with a large thickness of felsic volcanic, mafic volcanics and volcanoclastics intruded by gabbro and diabase. The sequence is metamorphosed mainly to mid greenschist facies. Marginally higher metamorphic grades with development of feldspar, biotite, sericite and quartz stockwork occur near contacts with porphyry and at structurally complexed zones.

The region is oxidised to 50 metres below ground level. Deep erosion of the originally thick lateritic and saprolite profile has been overprinted in places by a younger lateritic development under influence of the present tropical climate.

The Oumé-Fetékro Greenstone Belt has a north-northeast regional structure. This trend is overprinted by strong north-northwest lineaments containing the gold mineralised structure. These two lineaments overlie a less prominent northeast striking system. Exploratory water drilling transects were directed towards intersection points of the major lineaments and also to cross the regional north-northeast rock layering where it contains the more brittle competent rocks.

Initial drillholes were declined 60 degrees to the west to obtain knowledge of structure and depth of the fractured oxidation transition zone. Vertical drillholes were then placed on successful sites to confirm exploration results and to provide data for design of production bores. Eight sites with reverse circulation water flows ranging $5m^3h^{-1}$ to $15m^3h^{-1}$ were identified for construction of 203 millimetre internal diameter production bores. These bores proved capable of delivering the required initial $256m^3h^{-1}$ supply for the mining and process operation.

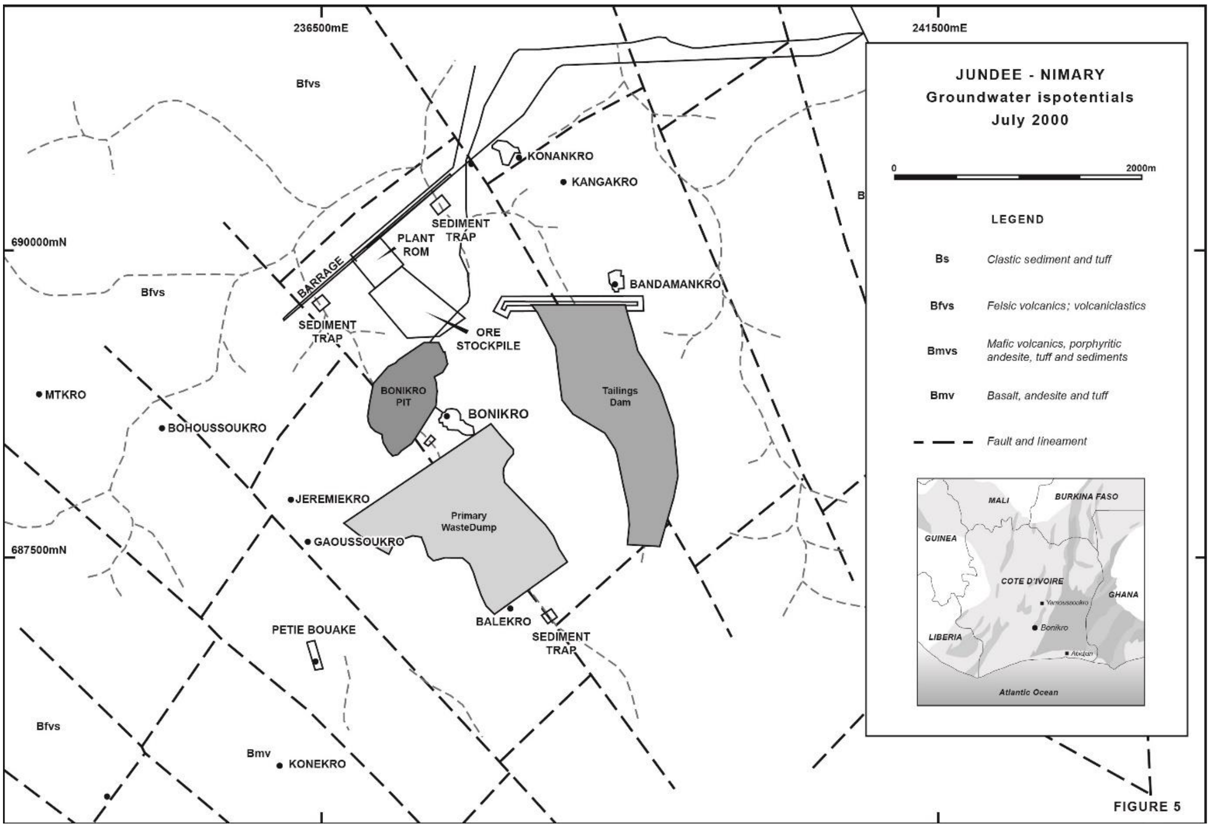

Figure Three | Bonikro Gold Mine, West Africa

Conclusions

The use of structural analysis has proven effective in increasing efficiency and reducing cost of development of water sources described in this paper. One significant factor has been a decrease in the number of exploration drillholes, the requirement for detailed mapping and geophysics that otherwise that may have been required for location of production bore sites. Four principal factors are to be considered when selecting a drill site in crystalline rock:

1. identification of the presence of brittle rocks that fracture rather than fail as ductile shear;
2. rock locations that have been under tension or pull-apart stress to provide the mechanism for open fractures;
3. lithologies that are more resistant to clay formation in the oxidation transition zone;
4. a location that may provide access to direct recharge or seepage recharge from an enclosing saturated regolith.

Selection of drill sites involves review of hydrogeological mapping, review of previous drilling and/or use of available regional geophysical mapping.

Detailed aeromagnetics have proven highly valuable for identification of lithology, structural configuration and depth of oxidation and/or cover rock. Air photography proved useful in identification of surface expression of these structures even under deep soil cover. In the examples provided for Thunderbox Gold Mine, Moolart Well Gold Mine and Bonikro Gold Mine the application of structural analyses proved highly successful in the location of tension structures for efficient development of these borefields.

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