Geophysics at the Hawsons Iron Project, NSW – Eastern Australia's new magnetite resource

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SUMMARY

A JORC inferred resource of 1.4 billion tonnes at a magnetite Davis Tube Recovered Grade of 15.5% was defined at The Hawsons Iron Project near Broken Hill in western New South Wales making it the largest magnetite iron ore resource identified to date in eastern Australia.

Reconnaissance surface exploration in 2009 identified the area's potential for magnetite iron ore fifty years after it was last considered an iron ore play prior to the discovery of Mt Tom Price.

Neoproterozoic Braemar Ironstone Facies sediments host the magnetite mineralisation which generates aeromagnetic anomaly amplitudes greater than 6000 nT. Five target areas for magnetite iron ore were identified from the open-file aeromagnetics.

A realistic Exploration Target was estimated from selective 2.5D magnetic modelling and image processing of the airborne aeromagnetic data. The inferred resource was established within 18 months of commencing the exploration program drilling 72 holes into the five aeromagnetic targets.

The monotonous sedimentary host sequence of siltstones and sandstones with few marker beds makes detailed geological interpretation extremely difficult. A magnetic stratigraphy was constructed from recognizable patterns in wireline magnetic susceptibility traces and correlations of the mineralisation could then be established down dip and across strike.

Key words: Broken Hill, Neoproterozoic, Braemar Ironstone, magnetic susceptibility, Davis tube recovery, tilt derivative.

INTRODUCTION

The Hawsons Iron Project is located approximately 60 km south of Broken Hill in far western New South Wales at 32° 25'S, 141° 08' on the Menindee (SI54-3) 1:250 000 scale map sheet (Figure 1). Carpentaria Exploration Ltd (CAP), a Brisbane-based exploration company, and registered holder of the exploration licence for the Hawsons Prospect, began investigating the area for iron potential in 2009. In December 2010 Carpentaria, with joint venture partner Bonython Metals Group (BMG), announced a Inferred Resource of 1.4 billion tonnes at a Davis Tube[1] Recovered (DTR) Grade of 15.5% making it the largest magnetite iron ore resource identified to date in eastern Australia.

The Hawsons Iron Project is hosted by the NeoProterozoic Braemar Iron Formation, a geological unit within the Nackara Arc, which extends 250 km to the west-southwest from Hawsons, along which other companies are now exploring for magnetite iron ore.

This paper describes how various types of magnetic data collection and processing was used to optimise exploration, develop an Exploration Target, assist geological interpretation and augment resource modelling. The types of data discussed are airborne, and down-hole data: processing methods include image processing and 2.5D magnetic modelling.

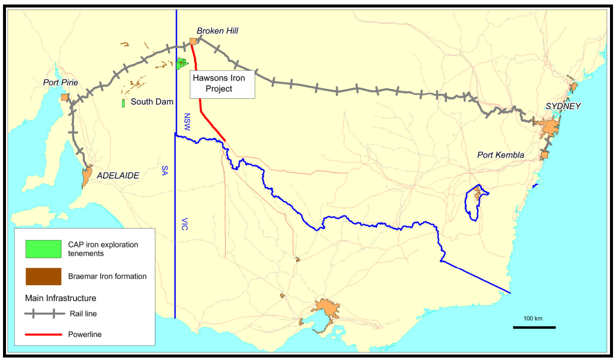

Figure 1. Location of the Hawsons Iron Project, western New South Wales (NSW)

GEOLOGY

The Hawsons Project area lies over folded Neoproterozoic sediments of the Nackara Arc of the Adelaide Fold Belt.

The Neoproterozoic rocks exposed at the Hawsons Prospect are part of the Yudnamutana Sub-Group (Umberatana Group) which contains diamictitic siltstones (tillites), quartz sandstones, calcareous siltstones, dolomite and magnetic ironstone units of the Braemar Ironstone Facies or Formation. The Braemar ironstones are examples of glaciomarine

[1]Davis Tube Recovery is a standard analytical test where a sample goes through a staged grinding process, in this case at 38 microns, followed by wet magnetic separation to produce a magnetic concentrate. The amount of concentrate is the DTR% expressed as a weight percent.

Raptian-Sturtian sedimentary iron-formation type which has a world-wide occurrence in the Neoproterozoic (Klein & Beukes, 1993 and Lottermoser & Ashley, 2000).

The Hawsons Prospect is pronounced in regional aeromagnetic data as a large, curvilinear, high amplitude magnetic anomaly caused by regionally folded magnetite rich Braemar Iron Formation. The Prospect is subdivided into target areas defined on the aeromagnetic anomalies and structure. The *Core* and *Fold* anomalies host the inferred resource. (Figure 2).

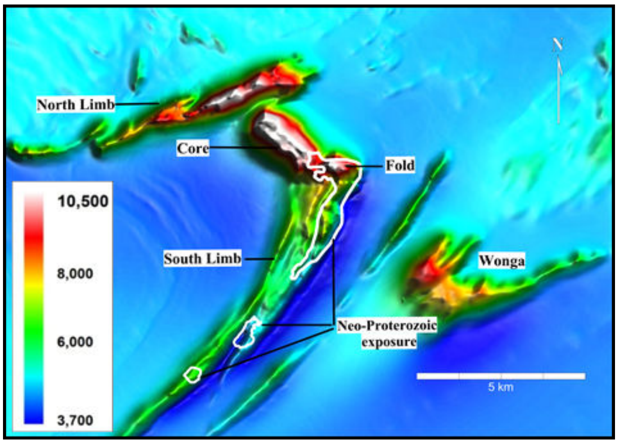

Figure 2. Total magnetic intensity image of the Hawsons Iron Project showing Neo-Proterozoic outcrop extent and target areas.

Outcrop at Hawsons is limited to a window of folded, greenschist metamorphosed Neoproterozoic strata located on the *Fold* and *South Limb* of the Hawsons' aeromagnetic anomaly (Figure 2). The *Fold* is an irregularly exposed sequence of steep, west-northwest to south dipping strata that kinks in strike about a fold structure in the northern part of the Neo-proterozoic exposure window (Brewster 2009).

Where exposed, ironstone units are numerous and form protruding, track like exposures up to 10 m wide striking for many hundreds of metres, inter-bedded with recessive siltstone. The number and thickness of ironstone units increase up section and northward along strike until exposure is obscured by post mineral ferruginous duricrust and recent sheet wash/aeolian sand.

At the *Core*, and elsewhere, preferentially developed preserved ferruginous regolith and recent unconsolidated sheet-wash and aeolian sands entirely conceal the higher magnetite content Neoproterozoic ironstone units that produce the peak aeromagnetic amplitudes.

Mesoscopic fold geometry and stereographic analysis of bedding orientations, coupled with drill core observed way-up structures, demonstrate the regional curvilinear Hawsons' magnetic anomaly is a southwest plunging syncline.

EXPLORATION HISTORY

The Hawsons Prospect area attracted only modest mineral exploration activity prior to Carpentaria's program.

In 1960, Enterprise Exploration outlined a number of track-like Neoproterozoic magnetite ironstone (+/- hematite) exposures with a maximum iron concentration result from surface rock channel sampling of six metres at 49.1% Fe. Small, probable nineteenth century pits, made in ferruginous duricrust were also noted. Enterpise concluded the Hawsons' area had little potential for giant high-grade, direct shipping hematite deposits and in 1962 they ultimately discovered one of the world's major high-grade, hematite iron-ore deposits in Western Australia at Mt. Tom Price.

Prior to Carpentaria's exploration program at Hawsons the magnetite ironstone exposures and small prospecting pits were not recorded in the Geological Survey of New South Wales metallic mineral occurrence (METMIN) database or other recently published mineral occurrence compendiums (e.g. Brownlow *et al*, 2007).

Following completion of high-resolution airborne magnetic surveys in the Broken Hill district commencing in the 1980's the fold-like, high-amplitude magnetic features at the Hawsons Prospect attracted several explorers specifically seeking precious and base metal mineralisation including CRAE (now Rio Tinto) and Placer (now Barrick).

CRAE, targeting gold mineralisation, drilled five holes between 1986 and 1988 into a second-order linear magnetic low interpreted to be a concealed faulted iron formation adjacent to the then untested peak of the highest amplitude of the Hawsons aeromagnetic anomaly (the *Core*). CRAE's program failed to locate significant gold or base metal mineralisation but drilling intersected relatively broad magnetite ironstone units interbedded with diamictite.

In the 1990's Placer completed a cored drill-hole testing for a conceptual iron oxide copper gold (IOCG) target on the *Wonga* Anomaly. The drill-hole intersected a substantial thickness of sulfide barren magnetite siltstone that was not geochemically analysed but reported magnetic susceptibilities averaging over 0.2 SI units for intervals up to 10 m (Hoskins, 1993).

Carpentaria, recognised that the ironstone exposures and associated large, high amplitude aeromagnetic anomaly at Hawsons had potential for bulk tonnage magnetite mineralisation and in early 2009 commenced an exploration program directed to magnetite iron-ore exploration that confirmed the presence of large tonnages of magnetite ironstone at Hawsons. In December 2010, Carpentaria with its JV partner publically released an inferred magnetite resource within the *Core* and *Fold* targets.

DEVELOPING AN EXPLORATION TARGET

An initial Exploration target of 2.5 to 4.5 billion tonnes (Bt) magnetite at 18-20% DTR magnetite was estimated for the Hawsons Prospect using limited drilling results, image processing and 2.5D modelling of aeromagnetic data.

The Hawsons Prospect is covered by 100 m line spaced, 60 m terrain clearance, aeromagnetic survey flown by Geoscience Australia in 1995. The magnetite siltstones of the Braemar Iron Formation cause magnetic anomalies 3,000 to 7,000 nanoTeslas (nT) above background that dominate the aeromagnetic data. Total magnetic intensity (TMI) amplitudes are strongest at the *Core*, *Fold*, and *North Limb*. The *Core* is a 2.5 x 1.5 km elliptical shaped anomaly located on the hinge of the regional fold where thick ironstone units are present concealed by post mineral cover. The *Core* anomaly is the highest aeromagnetic amplitude (+6000 nT) of the Hawsons' Prospect.

Two traverses of hand-held GPS controlled ground magnetic data across the *Core* and *South Limb* confirmed that the aeromagnetic data was well located and suitable for targeting reconnaissance exploration drilling. Surface rock geochemical and magnetic susceptibility measurements in the areas of outcrop (Figure 2) confirmed the source of the magnetic anomalies as magnetite siltstone/ironstone and the high aeromagnetic amplitude of the *Core* suggested potential for significant volumes of post mineral cover concealed magnetite mineralisation.

Following interpretation of the aeromagnetic data and 2.5D magnetic modelling of a single profile, a fence of three reverse circulation percussion (RC) drill-holes was drilled across the peak aeromagnetic response at the *Core*. The second hole (RC09BRP002), inclined at 60 degrees, intersected 32 m of transported post mineral cover and 67 m of oxidised target strata before encountering 115 m (to bottom of hole) of magnetite-bearing siltstone with a 18.0 % DTR grade, including 14 m at 21.9% DTR. The quality of the DTR concentrate from the intersection was of high commercial quaility with approximately 70% iron and 2.5% SiO_2. The predicted depth to top of the magnetite unit from the 2.5D model was 70 m vertical – a reasonable match to the drill-hole observed oxidation base.

After 72 drill holes the thickness and grade of magnetite in RC09BRP002 remains one of the best drill intersections encountered at Hawsons.

Image Processing for the Exploration target

There are many options for filtering magnetic data to enhance features of interest; vertical and horizontal derivative filters are commonly used. The tilt derivative (Miller and Singh, 1994) of the reduced-to-pole (RTP) TMI aeromagnetic data was used extensively during the exploration and early resource definition stages at Hawsons.

The tilt derivative is the arctangent of the ratio of the vertical derivative to the total horizontal derivative:

$$\text{Tilt} = \tan^{-1}\left(\frac{\text{vertical derivative}}{\text{absolute total horizontal derivative}}\right)$$

At Hawsons, high frequency noise effects from the surficial lag and preferentially developed ferruginous regolith are less pronounced in the tilt derivative image than in vertical and horizontal filtered images. Further, the arctan operator behaves as an automatic gain control filter, restricting all values to $\pm\pi/2$ enhancing small-amplitude basement anomalies that would be otherwise masked by the very high aeromagnetic amplitudes while maintaining the resolution of a derivative filter. Multiple magnetic horizons defined by the tilt image supported the surface exploration conclusion that Hawsons contained multiple iron formations with large strike lengths and continuity..

Below the recent cover at the *Core*, five magnetite horizons are interpreted from the tilt image (Figure 3). Unit 1 is the stratigraphic bottom and RC09BRP002 intersected Unit 3. The boundaries of Unit 2 and Unit 3, subsequently defined by resource drilling at 100 m below surface, correlate exceptionally well with the structure realised by the tilt image of the RTP aeromagnetics.

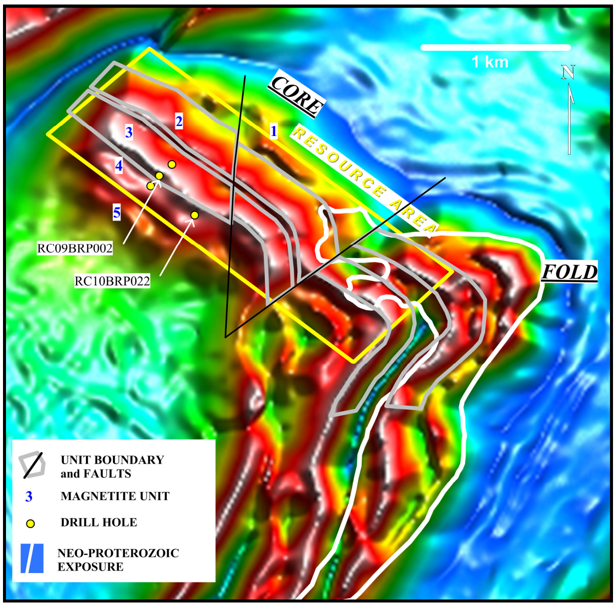

Figure 3. Boundaries of Unit 2 and Unit 3 defined from drilling 100 mbs for the *Core* and *Fold* on the tilt derivative image of the RTP aeromagnetic data.

2.5D Modelling for the Exploration target

The thickness and DTR grade intersected in RC09BRP002 (Unit 3) at the Core, and the dimensions and continuity of the magnetic units mapped in the tilt image suggested very large tonnages of low-grade magnetite mineralization were present at Hawsons

Profiles of gridded and located first vertical derivative aeromagnetic data across all the major anomalies were 2.5D modelled using dipping tabular prisms to simulate the thick magnetite units. The first vertical derivative data provides better resolution of closely spaced magnetic sources, improves depth to source interpretation and is less influenced by regional effects than modelling TMI profiles. A self-demagnetisation approximation was available but not used.

2.5D models across the Core demonstrated Unit 3 continued as a thick magnetite bearing horizon along strike for approximately 1500 m with similar model properties to the magnetite mineralisation in RC09BRP002. The interpretation of five magnetic horizons at the Core from the tilt image with comparable strike length and geometries was also verified by the 2.5D modelling. A cumulative strike length of 7 – 8 km for the five magnetite bearing units was estimated for the Core.

Additional 2.5D magnetic modelling showed thick magnetic units similar to Unit 3 present at the North Limb, Fold, South Limb and Wonga anomalies (Figure 2).

An Exploration Target of 0.8 to 1.6 billion tonnes (Bt) for the Core and Fold Targets (Table 1) was estimated interpreting the tilt image. Each of the 5 units was assumed to have an average true thickness of 100 m and grade of 18% DTR based on drilling and 2.5D magnetic models.

Target Area	No of Bands	Cumulative Strike (km)	Thickness (m)	Volume (Mill m^3)	Tonnage (Bt)
Core	5	7.5 to 8.0	80-120	0.15 to 0.20	0.4 to 0.8
Fold	5	7.0 to 7.5	80-120	0.15 to 0.20	0.4 to 0.8
North Limb	1	14.0 to 16.0	80-120	0.30 to 0.40	1.0 to 1.4
South Limb	1 to 4	6.3 to 6.9	80-120	0.15 to 0.20	0.3 to 0.7
Wonga	?3	7.5 to 8.0	80-120	0.15 to 0.20	0.4 to 0.8
	Totals	**42.8 to 46.4**	**80-120**	**0.9 to 1.2**	**2.5 to 4.5**

Table 1. Exploration Target estimates[2]

DETERMINING THE INFERRED RESOURCE

2.5D Modelling

Following definition of the Exploration Target, a two stage drill program was initiated. A 26 hole scout drilling phase established the depth of cover, thickness of mineralisation and DTR grade characteristics of all the anomalies. The scout drilling identified the contiguous Core and Fold anomalies as potentially the most favourable for any mining operation due to lesser cover (~80m) and consistent thickness of the magnetite mineralised units.

Resource drilling of 51 mixed RC and diamond holes at the Core and Fold anomalies commencing mid 2010 along nominal 400 m sections with inclined holes spaced at a nominal 100 m along section was completed and established an inferred resource comprising mostly Unit 2 and Unit 3 to a depth of 500 m below surface. The inferred resource was announced in December 2010.

Drilling established Unit 2 and Unit 3 were 50 m to 100 m thicker but lower grade than assumed in the Exploration Target magnetic model. Unit 1 is approximately 50 m thick and comparable in grade to Units 2 and 3, and Units 4 and 5 are much lower thickness and grade than assumed for the Exploration Target.

The inferred resource includes the entire *Core* and approximately half of the strike extent assumed in the Exploration Target estimate for the *Fold* (Figure 3). The Exploration Target estimate for this reduced area of 0.6 to 1.2 Bt at 18% DTR to a depth of 250 m compares favourably with the drilling defined inferred resource of 1.4 Bt at 15.5% DTR to a depth of 500 m.

Hole design for the scout and resource drilling was based on the 2.5D magnetic models of TMI first vertical derivative profiles. Key to the project's early momentum was the consistency with which the magnetic models provided reliable estimates for depth, location and orientation of the cover-concealed magnetite bearing units, below a highly variable base of oxidation (40 m to 115 m). This confidence enabled hole locations and orientations to be optimised, eliminating costly surprises. An average koenisberger (Q) ratio of 0.175 from four drill core samples verified the magnetization direction is not rotated appreciably by remanent magnetisation oblique to the present field direction.

At the *Fold* and *South Limb*, where ironstones outcrop, model predicted source depths 50 m vertically below surface were met with scepticism that was dispelled after drilling which confirmed the oxidation base of the models.

Wireline magnetic susceptibility logging

Drilling at the *Core* intersected a very monotonous, greenschist facies metamorphosed, sedimentary sequence of diffusely laminated and bedded siltstone, fine sandstone and relatively low fragment content diamictitic siltstone consistent with the regionally known glaciogene origin (Figure 4). The lack of clear marker horizons made even moderate resolution geological correlations difficult.

Wireline magnetic susceptibility data provided high resolution magnetic stratigraphy that could be correlated within this monotonous geological sequence of siltstones. The characteristic patterns of the magnetic stratigraphy could be traced down dip and up to 5 km along strike. For hole RC10BRP022, a repeat in the wireline magnetic susceptibility trace pattern at 423 m down-hole, coincident with an observed fracture, confirms the presence of a fault and fault thickening of Unit 2 intercept encountered in this hole (Figure 4).

Geological logging, geochemical data and the wireline logging established a stratigraphic column of three recognisable Units within the magnetite inferred resource at the *Core*:

1. Unit 2 is a magnetite bearing siltstone unit with several recognisable diamictite beds averaging 150 to 200 m in true thickness with an average DTR grade of 15-17%.

2. The Interbed is a dominantly fine grained magnetite quartz-rich sandstone unit with no distinct diamictite units. This unit averages between 30 and 60 m in true thickness with an average grade of 9-11% DTR.

3. Unit 3 is a massive, dolomite bearing,magnetite-bearing siltstone dominant unit with no diamictite units. The unit averages 150 to 200 m in true thickness with an average grade of 15-17% DTR.

CONCLUSIONS

Surface magnetic susceptibility measurements, image processing and profile modelling of magnetic data all contributed to the exploration and resource definition stages at the Hawsons Magnetite Prospect. Wireline magnetic susceptibility data was used during the resource definition and geological modelling stage.

[2] Assumes density of 3.2t/m^3, and vertical depth to 250m

Open-file aeromagnetic data, complementing the surface geochemical and mapping effort, directed exploration for magnetite iron ore towards the concealed *Core* anomaly. Drill testing a 2.5D model of the peak aeromagnetic amplitude returned one of the best mineralised intersections of the project.

An Exploration Target that compares favourably with the inferred resource can be estimated by calibrating a 2.5D magnetic model with limited drill results and interpreting structure and continuity between 2.5D models using the tilt image of the RTP aeromagnetics.

Within a monotonous geological sedimentary sequence, wireline magnetic susceptibility data was used to develop a magnetic stratigraphy for the mineralisation and able to be correlated over large distances across the resource .

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REFERENCES

Brewster, D.C., Hill, Q. S., and Donohue, J. G., 2009, The forgotton Hawsons iron prospect – Is there significant magnetite iron-ore mineralisation in the Neoproterozoic at Broken Hill. Broken Hill Exploration initiative: Abstracts for the 2009 Conference 28, 12-21: Geoscience Australia: Canberra).

Brownlow, J.W., Burton, G. R., Ferguson, A.C., Glen, R.A., Lishmund, S.R., MacRae, G.P., Malloch, K.R., Oakes, G.M., Paterson, I.B.L., Pienmunne, J.T., Ray, H.N., Watkins, J.J. & Whitehouse, J., 2007. Industrial mineral opportunities in New South Wales. Geological Survey of New South Wales, Bulletin, 33.

Hoskins, W.L., 1993, Placer Exploration Limited. Exploration Licence 3983 Hawson's Knob, New South Wales. Final and Annual Report for 12 months ended 24 July 1993. Geological Survey of New South Wales, Report, GS1992/290 (unpublished).

Klein, C. & Beukes, J. 1993, Sedimentology and Geochemistry of the Glaciogene Late Proterozoic Raptian Iron-Formation in Canada. *Economic Geology*. **88**, 542-565.

Lottermoser, B.G. & Ashley P. M., 2000, Geochemistry, petrology and origin of Neoproterozoic ironstones in the eastern part of the Adelaide Geosyncline, South Australia. *Precambrian Research*. **101**, 49-67.

Miller, H. G. and Singh, V., 1994, Potential field tilt – a new concept for location of potential field sources: J. Appl. Geophys., 32, 213-17.

Rose, G., 1967. *Menindee 1:250 000 Geological Sheet, SI54-03*. Geological Survey of New South Wales.

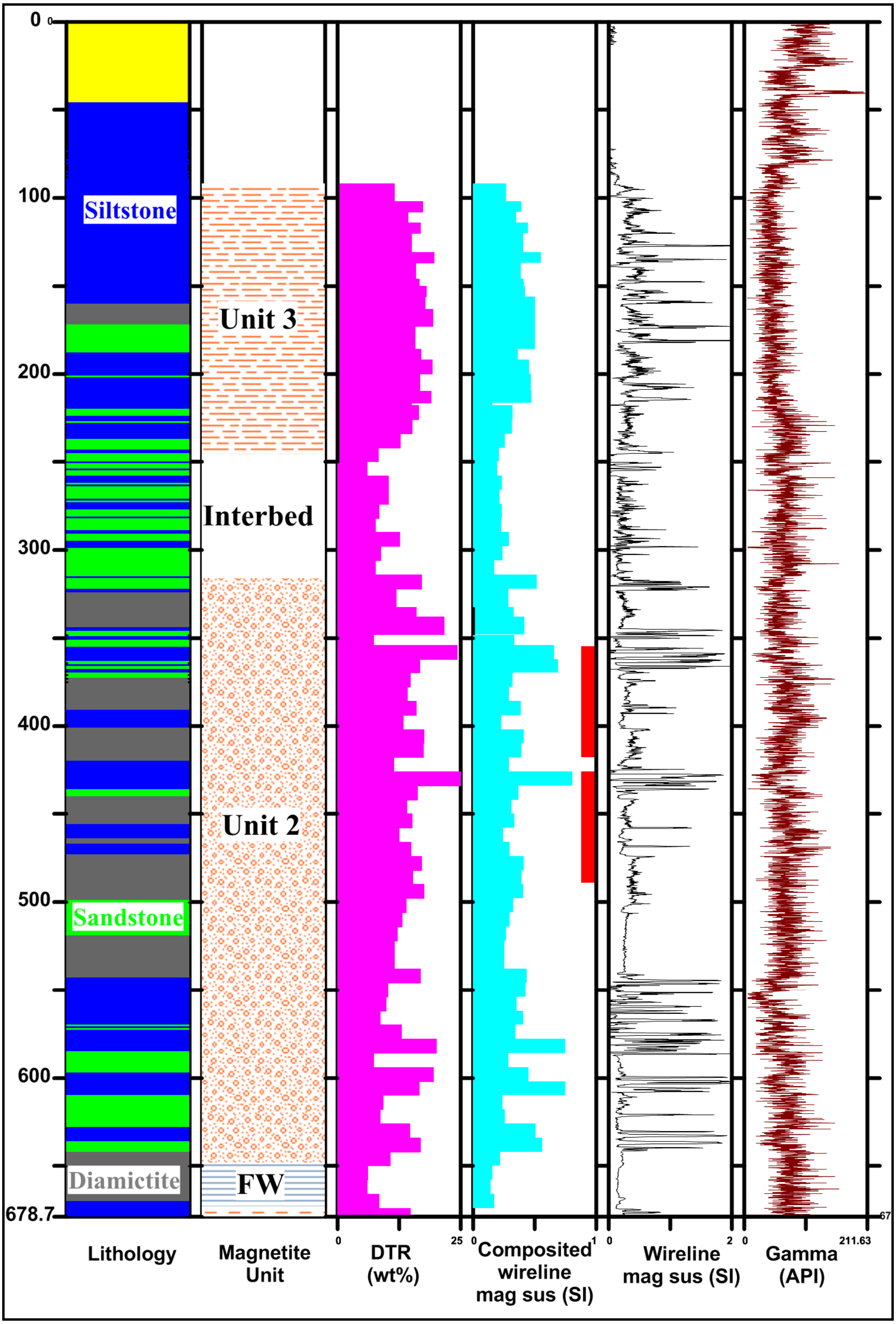

Figure 4. Geological and geophysical log plot for drillhole RC10BRP022. Red bars above and below 423 m down hole show faulted repeat of Unit 2.