The Pilbara Gold Rush

Abstract

During the last few weeks I have spent most of my time digging deeper into why there seems to be so much gold conglomerate gold in Pilbara, especially the central- to western parts, which is highlighted by Novo's staking activity. This journey of due diligence took me through hundreds of research papers and graphic illustrations covering meteor impacts, subduction zones, cyanobacteria, gravity profiles and magmatism during the Archean.   Since there are so many different theories about how and why the majority of the currently known gold deposits in the world were created on earth during the Archean, I was pleasantly surprised to find that it seems that substantial parts of the ancient Pilbara Craton potentially experienced many if not all of the events behind the different theories that has been put forth to explain the extremely gold rich Witwatersrand gold fields. It is my belief that subduction zone activities and an ancient meteor impact located near Karratha have had great influence in shaping the Pilbara Craton we see today. West and Central Pilbara seems to be the place to be, so choose your junior holdings wisely.

The Main Theories

Let's just quickly go over the theories, including the ones that led Quinton to believe that Pilbara has "Wits type" gold potential, and how the Witwatersrand gold fields came to be:

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ABSTRACT: The Witwatersrand (WWR) ores contain more gold than could have been derived in particulate form by erosion from any conceivable type of source area as proposed by the modified placer hypothesis. In contrast to this, syngenesis goes further to explain a host of observations from those Late Archean Au-U ores. Although recycling, placer processes, and processes of hydrothermal (diagenetic/authigenic) mobilization all contributed, syngenesis was a major factor contributing to ore genesis in this huge metallogenic province. Over 80% of the gold occurs in the Main Reef and Bird Reef of the Johannesburg Subgroup in the Central Rand Group, and about half of this gold is closely associated with carbon derived from microbial remains. In the principal deposits within the WWR basin, the ore is disposed in thin carbonaceous horizons of extensive lateral continuity upon chronostratigraphic unconformities in otherwise unmineralized siliciclastic metasediments. The ore-bearing horizons are not themselves part of the erosion cycle that gave rise to those paleosurfaces but were generated during the initial phase of renewed cycles of deposition after long intervals of nondeposition. They bear little resemblance to placers, their alluvial character seemingly inherited from reworking in fluvial environments.

Most of the gold and probably also part of the uranium were made available for transport in solution under relatively low-temperature, chemically aggressive environmental conditions, a situation favored on the emerging Kaapvaal Craton. Intense chemical weathering was made possible by the influence of the same ionizable gases as occur in geothermal systems, and this was a crucial factor leading to metallization. These elements, together with a host of other heavy metals, were then transported to the edge of the depository. A key confluence of conditions was completed with the blooming of microbial communities during hiatuses in sedimentation. Over large areas, microbial mats developed directly on paleosurfaces upon which the goldfields occupy slight depressions, bounded on either side by clean quartz arenites. The resulting metallization was a complex chemical and biochemical precipitation of gold, uranium, pyrite, and associated Co, Ni, Cu, Pb, and As in thin, areally extensive deposits. Metallization was focused at several carbonaceous horizons along the north and northwestern margins of the WWR basin, depending on the availability of metal-rich aqueous fluids coincident with the stillstand of land surface degradation and the consequent proliferation of microbial mats. Biochemical processes supplemented low-temperature geochemistry of the fluids in helping to concentrate a substantial portion of WWR gold in larger particles, which were transported further downslope and then subjected locally to fluvial processes. Gold precipitated outside of the preserved basin by these processes likewise will have undergone alluvial reworking prior to deposition in the conglomerates without the originally associated carbon; recognition of this feature diminishes the source rock problem. Minor remobilization of metals occurred during diagenesis and metamorphism.

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Abstract

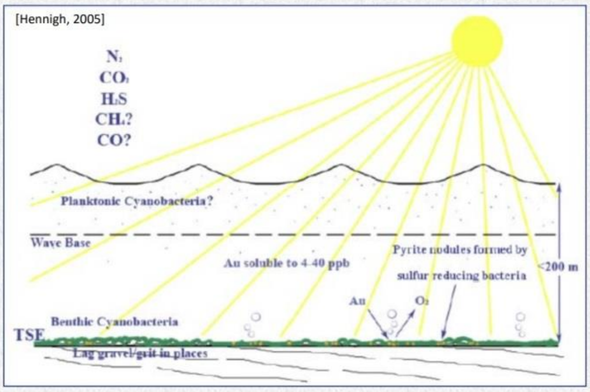
The analysis of the temporal distribution of gold deposits, combined with gold production data as well as reserve and resource estimates for different genetic types of gold deposit, revealed that the bulk of the gold known to be concentrated in ore bodies was added to the continental crust during a giant Mesoarchaean gold event at a time (3 Ga) when the mantle temperature reached a maximum and the dominant style of tectonic movement changed from vertical, plume-related to subhorizontal plate tectonic. A magmatic derivation of the first generation of crustal gold from a relatively hot mantle that was characterized by a high degree of partial melting is inferred from the gold chemistry, specifically high Os contents. While a large proportion of that gold is still present in only marginally modified palaeoplacer deposits of the Mesoarchaean Witwatersrand Basin in South Africa, accounting for about 40% of all known gold, the remainder has been recycled repeatedly on a lithospheric scale, predominantly by plate-tectonically induced magmatic and hydrothermal fluid circulation, to produce the current variety of gold deposit types. Post-Archaean juvenile gold addition to the continental crust has been limited, but a mantle contribution to some of the largest orogenic or intrusion-related gold deposits is indicated, notably for the Late Palaeozoic Tien Shan gold province. Magmatic fluids in active plate margins seem to be the most effective transport medium for gold mobilization, giving rise to a large proportion of volcanic-arc related gold deposits. Due to their generally shallow crustal level of formation, they have a low preservation potential. In contrast, those gold deposits that form at greater depth are more widespread also in older rocks. This explains the high proportion of orogenic (including intrusion-related) gold (32%) amongst all known gold deposits.

The overall proportion of gold concentrated in known ore bodies is only 7×10^{-7} of the estimated total amount of gold available in the continental crust. This is less than the solubility of Au in common crustal fluids. A high potential for the existence of voluminous, hitherto undiscovered, gold resources may thus be inferred.

2001), almost all of the known placer deposits (91%) are located in a single gold province, the Witwatersrand Basin. This Mesoarchaean sedimentary basin accounts for about 40% of all known gold and thus represents the by far largest known gold depository. Most of the pre-modern gold production, notably from the Arabian–Nubian Shield, the European Variscan belts and the Yilgarn Craton, was probably derived from orogenic gold deposits, but no precise production data are available. For this study, the minimum estimates for past production until 2000 are taken from Goldfarb et al. (2001) and complemented with available data for the past six years. Note that the genesis of some examples that are assigned here to the orogenic type is debatable (e.g., Sukhoi Log).

Deposits hosted by both oceanic and continental volcanic arcs are the next most important hosts of gold (Fig. 2). These include porphyry Cu deposits, often associated with Mo when located in a continental arc, some intrusion-related and skarn deposits and, more distal, sediment-hosted deposits. Although highly variable in the style of mineralization, this type of gold is sourced in magma and related magmatic fluids that are typically derived from the partial melting of lithospheric mantle above subduction zones.

Seawater provides an effectively limitless supply of soluble gold. One cubic km of seawater holds 4-40 tonnes gold at a concentration of 4-40 ppb.

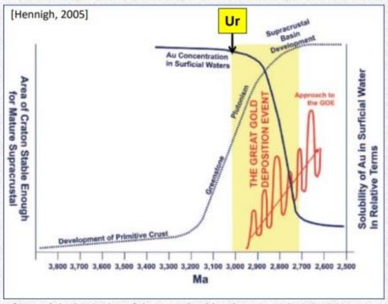


The continent of Ur and the beginning of the crustal gold cycle – Hennigh, Q.T., IGC35, September 1, 2016

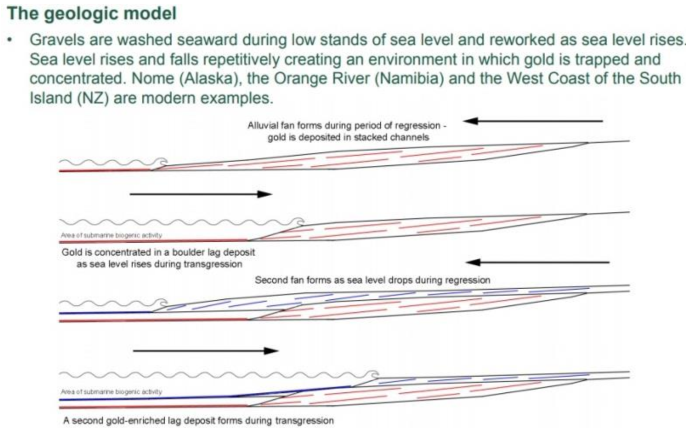
Ur provided the stage for the evolution of photosynthetic life.

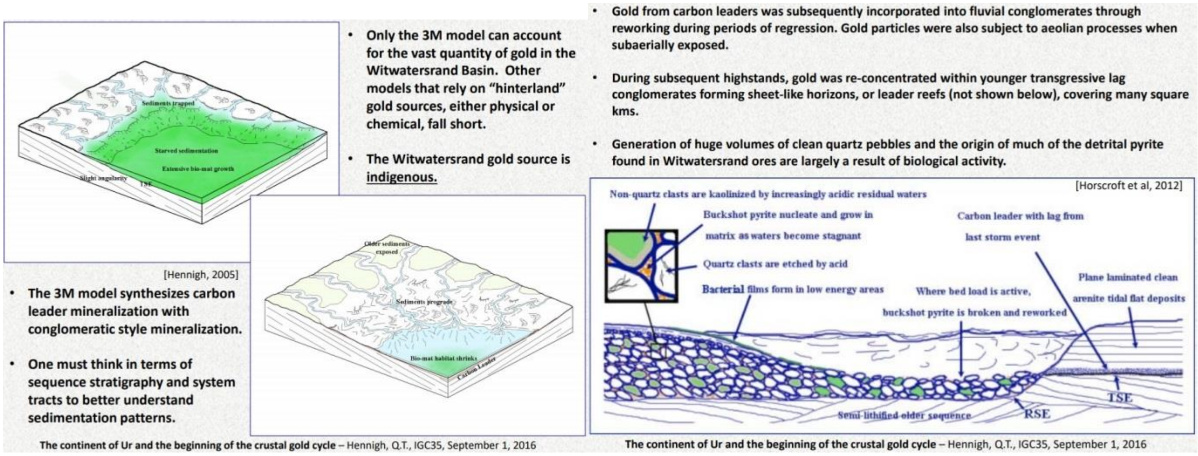
The first whiffs of oxygen triggered the Great Gold Depositional Event.

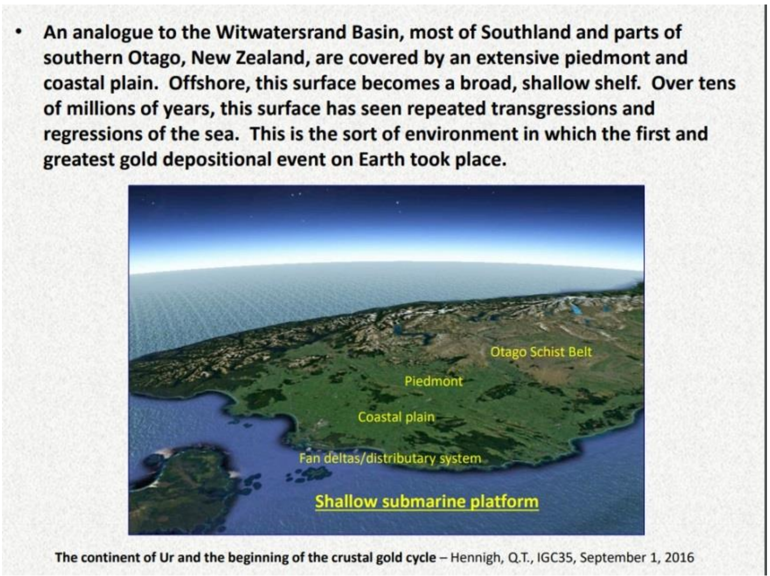
Huge quantities of gold were scavenged out of seawater by microbial mats starting at around 3.0-2.9 Ga thus initiating the crustal gold cycle.



The continent of Ur and the beginning of the crustal gold cycle – Hennigh, Q.T., IGC35, September 1, 2016







In simple terms we basically need cyanobacteria in shallow water to trap gold and then have it wash up and be deposited into conglomerates. Intact, gold rich algal mats, is also something we hope to find. Lastly, magmatism and hydrothermal fluids should be able to boost this whole process.

Subduction zones

This topic became interesting after I stumbled upon this interesting presentation named "Did Plate Tectonic Begin in Early Archean Times?": http://slideplayer.com/slide/4753542/

First things first, what are subduction zones?

(Warning: This first part might be a bit boring)

Definition from Wikipedia:

Subduction

From Wikipedia, the free encyclopedia

Subduction is a geological process that takes place at convergent boundaries of tectonic plates where one plate moves under another and is forced or sinks due to gravity into the mantle. Regions where this process occurs are known as *subduction zones*. Rates of subduction are typically in centimeters per year, with the average rate of convergence being approximately two to eight centimeters per year along most plate boundaries.[1]

Plates include both oceanic crust and continental crust. Stable subduction zones involve the oceanic lithosphere of one plate sliding beneath the continental or oceanic lithosphere of another plate due to the higher density of the oceanic lithosphere. That is, the subducted lithosphere is always oceanic while the overriding lithosphere may or may not be oceanic. Subduction zones are sites that usually have a high rate of volcanism and earthquakes.[2] Additionally, subduction zones develop belts of deformation[3][*better source needed*] in the overriding plate's crust in a processes called orogeny part of which leads to mountain building.

Illustrations:

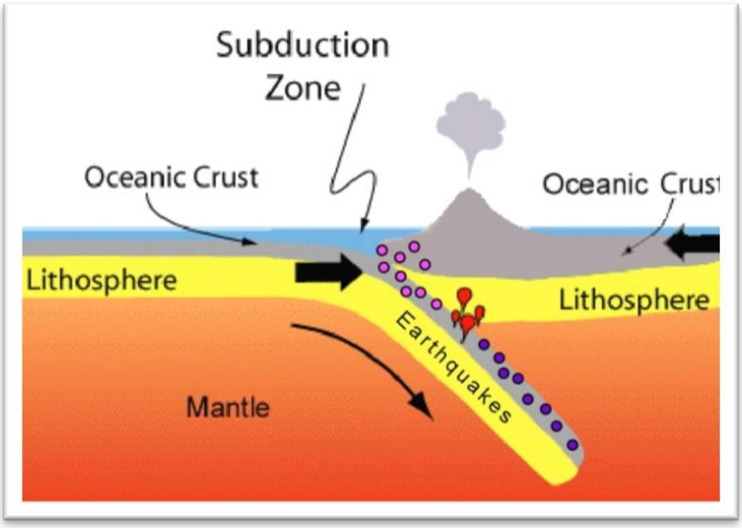


Figure 1

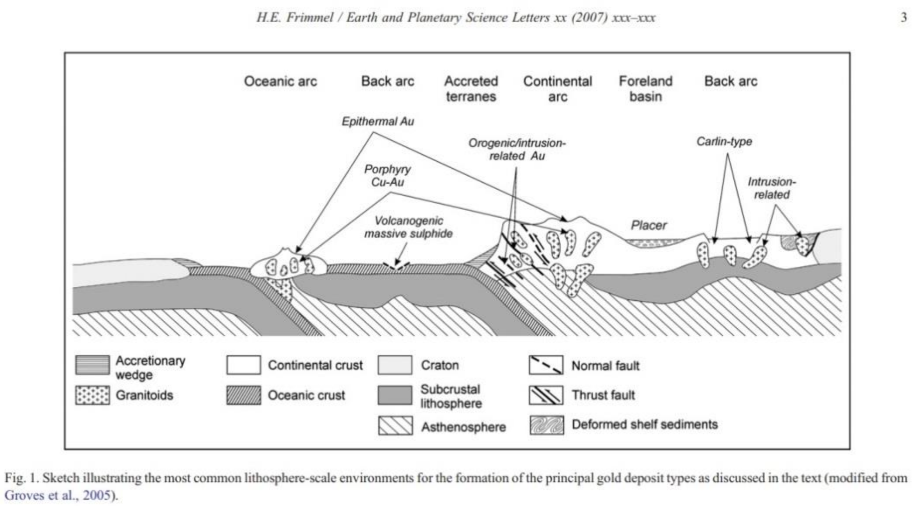


Figure 2

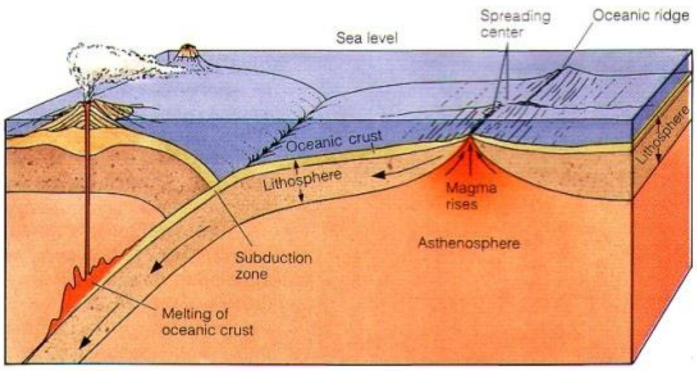


Figure 3

An animation of the subduction process:

http://www.cet.edu.au/projects/intra-cratonic-geodynamics/subduction-zone-evolution-and-interaction-with-an-intracratonic-suture

So what does subduction zones have to do with Pilbara?

I will start by some information found in this article: http://www.geo.uu.nl/~kikeb/thesis/thesis/Ch8/8_frame.html

That presentation laid out a case for there to have been subduction style magmatism and hydrothermal activity in the west part of Pilbara during the Archean:

Abstract

The mid-Archaean granite-greenstone terrain in the Pilbara Craton in Western Australia consists of several elongate domains. It has been previously suggested that this 'domainal' architecture reflects a history of accretion. Models have been proposed in which the western margin of the Pilbara was interpreted to be an accreted island arc. However, no evidence for island arc accretion in the presently exposed granite-greenstone terrain was found. In this paper an alternative model is proposed, where the West and Central Pilbara represent a small part of an Andean type active continental margin associated with at least two episodes of subduction beneath the West Pilbara from the northwest. The continental margin was subsequently affected by several phases of transpression and transtension involving major crustal scale structures, resulting in the formation and deformation of the intracontinental Mallina Basin.

The components of the West Pilbara were formed over a history spanning more than 300 million years between ca 3270 Ma and 2930 Ma. The 'island-arc' components of the West Pilbara are at least 100 million years older than the 'extensional back-arc' components of the Central Pilbara, making a genetic link unlikely. Further more, extensional back arc basins form only when the subducting plate goes down at a sufficiently high angle to cause extension in the overriding plate. This can only occur when the downgoing plate has a negative buoyancy, which was believed to be unlikely in the early Archaean because of the higher mantle temperatures and associated thicker and more buoyant basaltic oceanic crust. However, geochemical data confirm that subduction may have occurred in the mid to late Archaean. It is proposed that this occurred at a low angle, beneath an convergent continental margin.

A geological map of Pilbara to give some context:

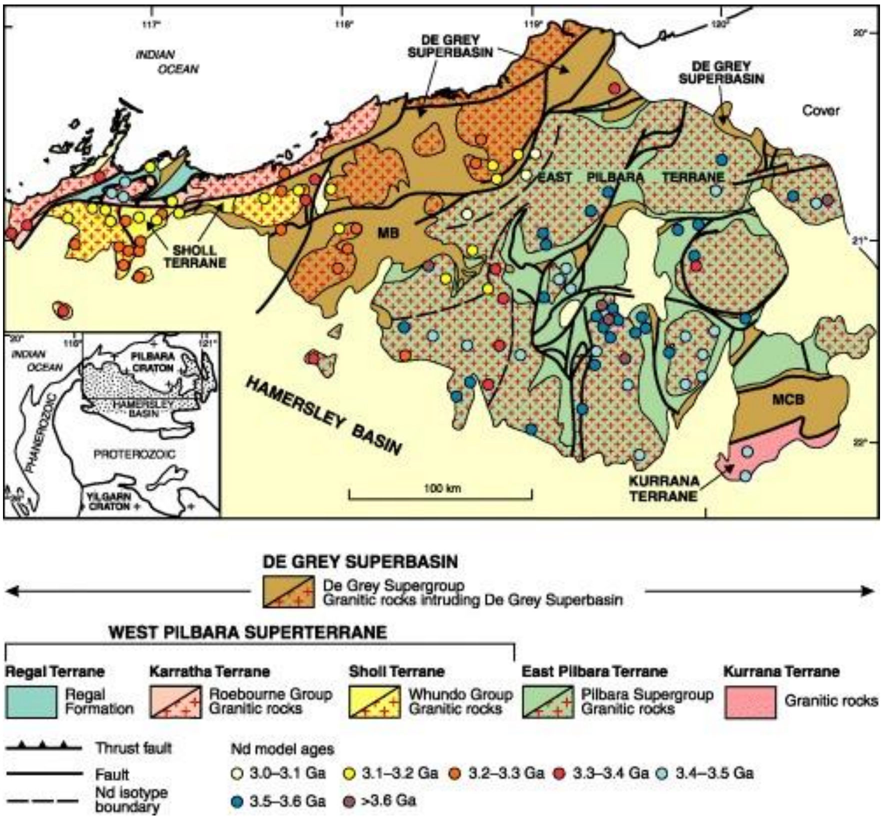


Figure 4

… Notice the major faults and the different terranes.

structure separating the West Pilbara from the Central Pilbara in this scenario. In this paper the Sholl Shear Zone will be regarded as the boundary between the Central and West Pilbara, because it is a major crustal scale structure separating significantly different domains, in accordance with Blewett (2002). The Tabba Tabba Shear Zone will be regarded as the boundary between the East and Central Pilbara (Figure 8.1).

Archean subduction has been a highly debated phenomenon but as seen above, this paper argues that West- and Central Pilbara saw at least two episodes of subduction and that these episodes resulted in the formation and deformation of the "intracontintental" Mallina Basin.

More from the same paper:

8.2.3 Subduction-related magmatism

In a 'normal' Phanerozoic subduction regime (Figure 8.3.c), fluids are produced as a result of slab dehydration. Depending on the geometry, the fluids are mostly generated where the slab reaches a depth of about 110 kilometers (Tatsumi and Eggins, 1995). Interaction of these slab fluids with the overlying mantle wedge results in calc-alkaline basaltic and andesitic volcanism (Schmidt and Poli, 1998) which occurs in a relatively narrow zone (Figure 8.3.c). Subduction of young and hot oceanic lithosphere results in dehydration of the downgoing slab at much shallower levels. Because magma genesis occurs at deeper levels, the melt generation in the then dry slab will involve lower degrees of partial melting and there will be less metasomatism in the mantle wedge (Harry and Green, 1999). This shows that even in Phanerozoic subduction systems many variables are present which hamper a simple and conclusive interpretation of the geochemistry of subduction-related magmatism.

During flat subduction, which may have occurred in the Archaean, there exists no material between the subducting slab and the bottom of the overriding lithospheric plate (Figure 8.3.a). As a consequence, the slab melts do not interact with mantle material. The hydrated mafic crust may still contain amphibole and the melting occurs below the plagioclase stability depth and in the presence of garnet. The resulting magmas are adakitic (Drummond and Defant, 1990). Smithies (2000) found that TTG's are distinct from adakites, as they show no evidence for interaction with mantle material. Martin and Moyen (2002) noticed that the composition of TTG from the early Archaean through to the Proterozoic reflected a gradual change towards higher Mg, reflecting more interaction with a mantle wedge. These data may suggest that during the early Archaean only flat subduction occurred.

During the mid and late Archaean the mantle temperature became progressively lower, consequently a thinner oceanic crust would have been produced (Davies, 1992). General consensus in the recent literature is that subduction at a small to medium angle may have become possible in the Late Archaean. This is also illustrated in Figure 8.3.b.

An illustration of the events:

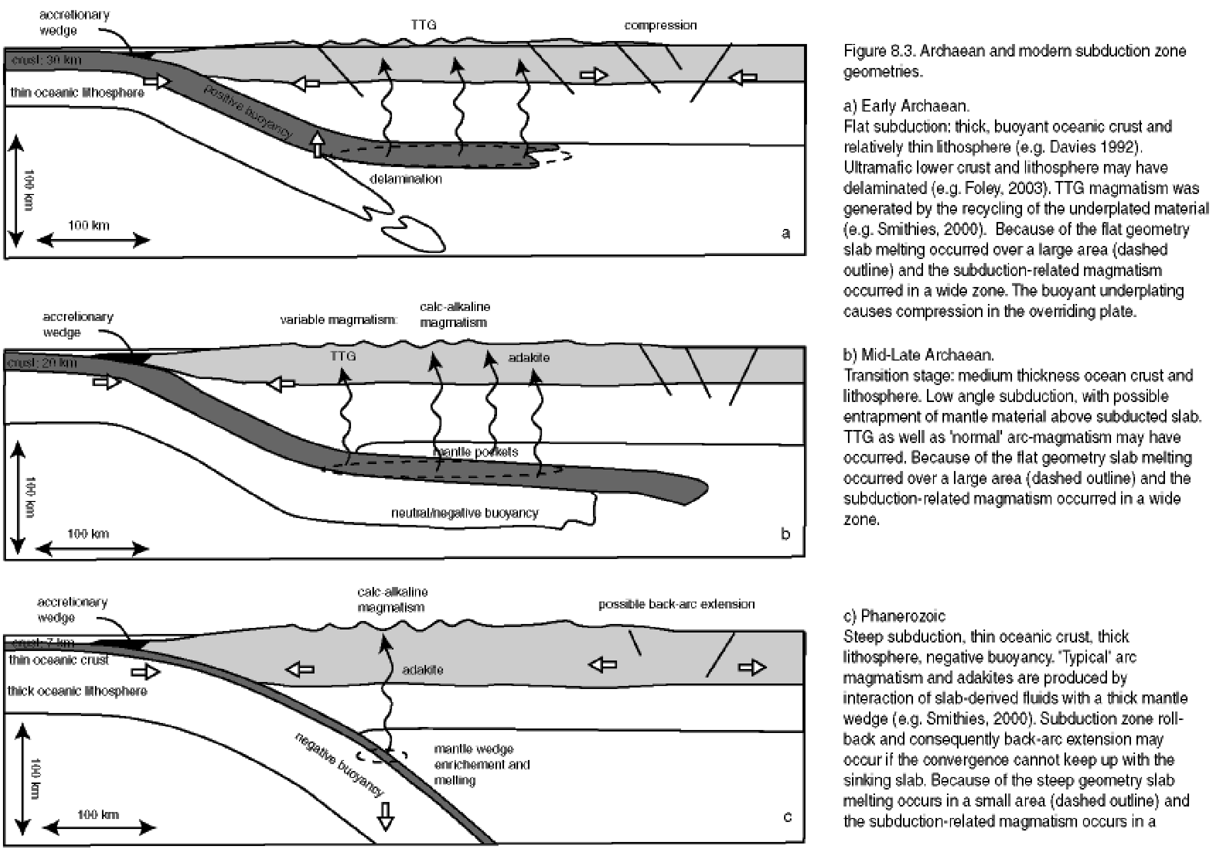


Figure 5

Notice the different stages and characteristics of the magmatism that results from Archean subduction episodes. Also, this paper argues that flat and then small to medium angle subduction might have taken place during this time. Steep style subduction is not considered to have taken place until the Phanerozoic era. All this will be important to keep in mind for the rest of this document.

8.3.2 Lithology and stratigraphy

A tabular stratigraphy for the greenstone successions in the Pilbara was originally proposed (Hickman, 1983; Horwitz, 1990), but with the recognition of the domain boundary structures and new precise geochronological constraints, this interpretation has been revised (e.g. Van Kranendonk et al., 2002). The greenstone successions of the different domains cannot or only partially be correlated across domain boundaries.

The East Pilbara is characterized by the 'typical' ovoid granitoid complexes surrounded by greenstone belts. The greenstone succession comprises the ca 3.51 Ga Coonterunah Group, the ca 3.47-3.43 Ga Warrawoona Group, the ca 3.23 Ga Sulphur Springs Group, the un-dated Gorge Creek Group and the ca 2.95 Ga De Grey Group. A detailed overview of the most recently published East Pilbara stratigraphy is given in Table 8.1. The Central Pilbara is made up of the 3.12 Ga volcanics in the Sholl Belt, a ca 3.01-2.97 Ga volcano-sedimentary succession in the Whim Creek Belt, ca 2.97 Ga continental sediments in the Mallina Basin and several granitoid complexes. The West Pilbara is an elongate domain on the western margin of the Pilbara Craton, comprising a ca 3.265 Ga supracrustal succession and granitoids, and an undated mafic sequence of possibly oceanic origin. A detailed overview of the most recently published West and Central Pilbara stratigraphy is given in Table 8.2. The distribution and timing of granitoids and also volcanic rocks can be seen in Figure 8.2. This thesis is mainly concerned with the post 3.25 Ga history of the West- and Central Pilbara.

After stabilization of the Pilbara Craton and slow uplift and erosion, the ca 2.77 - 2.45 Ga volcano-sedimentary succession of the Hamersley Basin was deposited over a large part of the craton. This was the result of a complex event that involved breakup through rifting of a continental plate which contained the Pilbara Craton (Blake and Barley, 1992; Blake, 2001).

The deep structure of the Pilbara has remained enigmatic. Drummond (1979; 1981) found that the crustal thickness in the Pilbara is 28-33 kilometers. The base of the greenstone belts is inferred to occur at 14 kilometers, and a similar average thickness was modeled for the granitoid complexes with an inferred shape of a vertical cylinder (Drummond, 1979; Wellman, 1999).

Notice the mention of sediments and the Mallina Basin (Central Pilbara) around 3.0 Ga. Also notice the West Pilbara and "undated mafic sequence of possibly oceanic origin". These rocks were present before the Hamersley basin was deposited over most parts of the whole Pilbara Craton.

8.3.3 Geochronology

The rocks of the Pilbara Craton have been the subject of numerous geochronological studies. Most of these dates have been discussed in previous chapters in their regional context. In a joint effort with A. Kloppenburg, a large number of published and unpublished dates have been collected in a database. The database has been analyzed statistically, on age distribution and geographical distribution. A diagram showing the spatial and temporal distribution of zircons in intrusive and volcanics rocks and zircon xenocrysts (SHRIMP ages), Argon cooling ages, and limited Sm-Nd model ages, can be found in Figure 8.2.

It is clear that the age distribution is unique for every domain, and this has been used as evidence for terrane accretion models in the past. However, there are also distinct similarities. The three East Pilbara domains have common peaks around 3450 Ma, 3300 Ma, 3240 Ma and 3100 Ma (Figure 8.2). Because they only occur to the east of the Tabba Tabba Shear Zone, this structure is interpreted as an important boundary. The oldest peak in the West Pilbara lies at ca 3260 Ma, followed by ca 3150 Ma and 3020 Ma. From about 2950 all domains have a similar history.

As the ca 3260 peak only occurs to the north of the Sholl Shear Zone, this structure represents a major break and was interpreted as an important boundary. Alternatively, the 3260 Ma peak in the West Pilbara and the 3230 Ma peak in the East Pilbara could represent a diachronous event affecting the whole craton.

The striking age 'gap' in the Central Pilbara (it contains no rocks older than ca 2970 Ma, see Figure 8.2) occurs due to the development of the Whim Creek-Mallina Basin, covering older basement. In this scenario the Pilbara may have been a single unit throughout the Archaean. These ideas will be discussed below in the context of newly acquired geochronological, geochemical and structural data.

Additional information regarding the different characteristics of West, Central and East Pilbara. Note the suggested importance of major structural breaks such as the Sholl Shear Zone and the Tabba Tabba Shear Zone.

The major and trace element geochemistry of the pre-3150 Ma Regal Formation in the Roebourne Group suggest it may represent Archaean ocean floor; however, it differs from Phanerozoic MORB in its higher Fe and REE content, and lower Ti. This might be explained by a higher fertility of the mantle, and a higher degree of partial melting which started at greater depth than at present (see also Ohta et al., 1996), and is exactly what would be expected in the Archaean at a higher potential mantle temperature. The fact that these rocks occur as a thrust sheet in the Roebourne Domain suggests that they may have been emplaced as part of an ophiolite (Chapter 5). The rocks have not been dated and currently it is interpreted that they were emplaced in the convergent regime loosely dated at ca 3150 Ma (Chapter 5). Precise dating is necessary to confirm this. In Figure 5.25 in Chapter 5 is illustrated that if the arc-setting is correct, most likely the West Pilbara was an active continental margin with subduction towards the south, at ca 3265 Ma. This is also suggested by Smith (2003).

The Ruth Well, Nickol River and Regal Formations were metamorphosed to amphibolite grade during a northwest directed phase of thrusting and crustal thickening at about 3150 Ma (R-d1, Table 8.4). This event corresponds to the D3a deformation event of Blewett (2002). All lithological contacts became sheared at this time. As discussed before, the Regal Formation may have been emplaced in the Roebourne Domain at this time. Alternatively, the Regal Formation was emplaced earlier, during the ca 3265 Ma subduction event. In that case the Regal Formation must be older than ca 3265 Ma. Absolute dating could possibly resolve this issue. There are no known extrusive or sedimentary rocks of ca 3150 Ma or older, south of the Sholl Shear Zone. It is possible that they are not exposed to due to down-dropping of the area south of the Sholl Shear Zone, during sinistral transtensional (R-d2, Table 8.4) basin formation in the Central Pilbara (see below).

There are no known extrusive or sedimentary rocks of ca 3150 Ma or older, south of the Sholl Shear Zone. It is possible that they are not exposed to due to down-dropping of the area south of the Sholl Shear Zone, during sinistral transtensional (R-d2, Table 8.4) basin formation in the Central Pilbara (see below).

The ca 3020 Ma Cleaverville Formation was deposited over a large area spanning the West and Central Pilbara. It occurs in the western part of the Whim Creek Belt at Mount Ada, and forms the youngest stratigraphic unit in the Roebourne Domain. Granites of similar age are abundant on either side of the Sholl Shear Zone, and have also intruded into the shear. The nature of this rock-forming event remains enigmatic, as on the one hand the cherts of Cleaverville Formation seems to suggest a period of quiescence across a large area, and on the other hand the area is intruded by granites. This is interpreted to point towards an extensional setting at that time. The rocks have Sm-Nd model ages of 3110-3210 Ma (Sun and Hickman, 1998).

The whole of the Central and West Pilbara were affected by a major northwest-southeast directed compressional event at about 2930 Ma (R-d3, Table 8.4). In the early stages this caused north-side up reverse movement on the Sholl Shear Zone, juxtaposing amphibolite grade units of the Roebourne Domain to low greenschist grade units of the Sholl Belt. In the Whim Creek area there is no evidence for reverse movement on the Sholl Shear Zone. It is interpreted that the Roebourne Domain was slightly tilted such that only the southwestern section was uplifted, causing the decreasing metamorphic grade in the Regal Formation towards the northeast, at the present erosional level.

A lot is happening here in Western and Central Pilbara. **Sholl Shear Zone (SS)** and **Tabba Tabba Shear zone (TT)** seem very important and is congruent with Novo's staking. My understanding is that West Pilbara saw subduction zone episodes that started very early on (3265 Ma) and after that SS possibly TT were formed. Continental arc volcanism occurred again ca 3010 Ma that was possibly related to another subduction episode. The area south of SS possibly got "down-dropped" after ca 3150 and the now growing Central Pilbara area (between SS and TT) that was also subsiding saw extensive deposition. The evolution of Pilbara in graphic form:

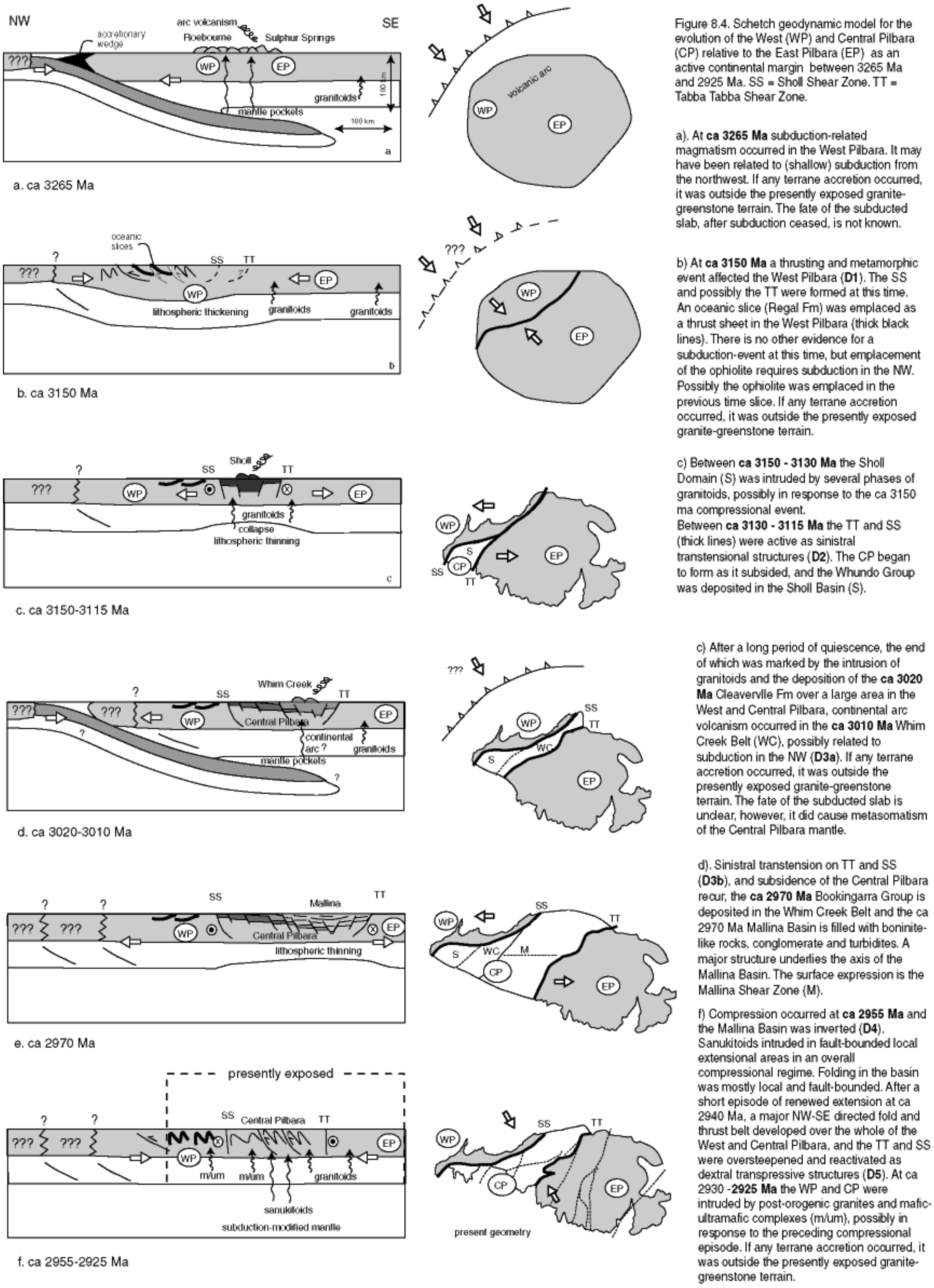


Figure 6

I guess why all of this might be important is because lower elevation would increase the time window and likelihood that the areas could be submerged under water and therefore exposed to "precipitation events" and sediment deposition for a longer period of time. The suggested subduction events would also lead to magmatism and hydrothermal activity, which could be favorable in terms of both enriching the water in the area as well as help sustain microbial life. These should all be positive factors for gold deposition in accordance with the precipitation theory.

An illustration of the events from another angle:

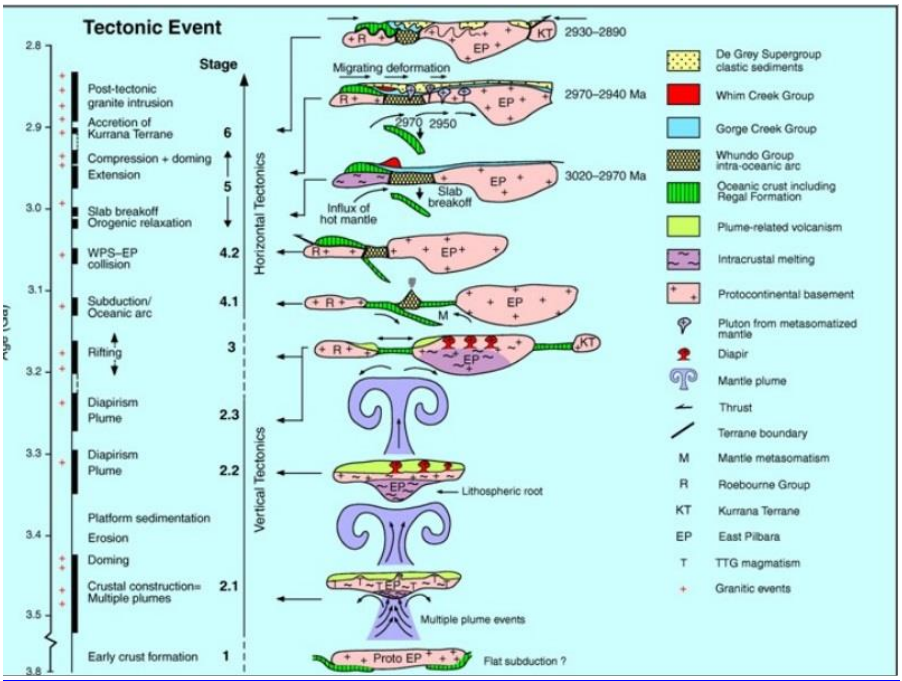


Figure 7

… Most of the juicy action does seem to have happened in the West and Central Pilbara (in accordance with Novo's staking activites).

Now, on to some more research on the subject:

Abstract

Intra-oceanic arcs are the simplest type of subduction systems in that they occur where overridding plates of subduction zones consist of oceanic rocks, contrasting with arcs built on continental margins. They comprise some 40% of the subduction margins of the Earth. The better-known examples include the Izu-Bonin-Mariana arc, the Tonga-Kermadec arc, the Vanuatu arc, the Solomon arc, the New Britain arc, the western part of the Aleutian arc, the South Sandwich arc and the Lesser Antilles arc. They are thought to represent the first stage in the generation of continental crust from oceanic materials. They are generally more inaccessible than continental arcs, but, for a variety of reasons, provide insights into processes in subduction zones that are impossible or difficult to glean from the better-studied continental arcs. Intra-oceanic arcs typically have a simpler crustal structure than arcs built on continental crust, although there are significant differences between examples. Geochemically, magmas erupted in intra-oceanic arcs are not contaminated by ancient sialic crust, and their compositions more accurately record partial melting processes in the mantle wedge. They are also the sites of generation of intermediate-silicic middle crust and volcanic rocks, probably representing the earliest stage of generation of andesitic continental crust by partial melting of basaltic lower crust. They are the best locations in which to study mantle flow in the vicinity of subducting slabs using both geophysical and geochemical methods. They are the sites of significant hydrothermal activity and metallogenesis. The fact that their hydrothermal discharges typically occur shallower in the ocean than those from mid-ocean ridge vents means that they have the potential for greater environmental impact.

… "Sites of significant hydrothermal activity and metallogenesis"

Orogenic gold deposits: A proposed classification in the context of their crustal distribution and relationship to other gold deposit types

D.I Grovesa, R.J Goldfarbb, M Gebre-Mariamac, S.G Hagemanna, F Robertd

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Abstract

The so-called `mesothermal' gold deposits are associated with regionally metamorphosed terranes of all ages. Ores were formed during compressional to transpressional deformation processes at convergent plate margins in accretionary and collisional orogens. In both types of orogen, hydrated marine sedimentary and volcanic rocks have been added to continental margins during tens to some 100 million years of collision. Subduction-related thermal events, episodically raising geothermal gradients within the hydrated accretionary sequences, initiate and drive long-distance hydrothermal fluid migration. The resulting gold-bearing quartz veins are emplaced over a unique depth range for hydrothermal ore deposits, with gold deposition from 15–20 km to the near surface environment.

… "long-distance hydrothermal fluid migration"

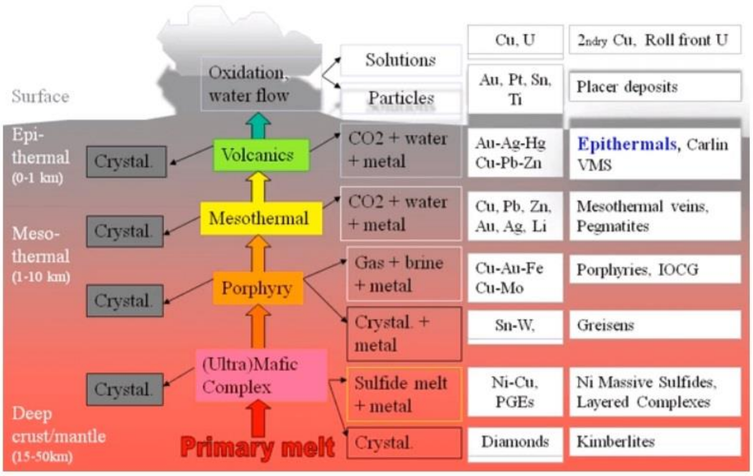

Figure 8

… (Ultra)Mafic Complexes are sources from the deep crust/mantle, so Pilbara potentially ticked every box in that slide according to:

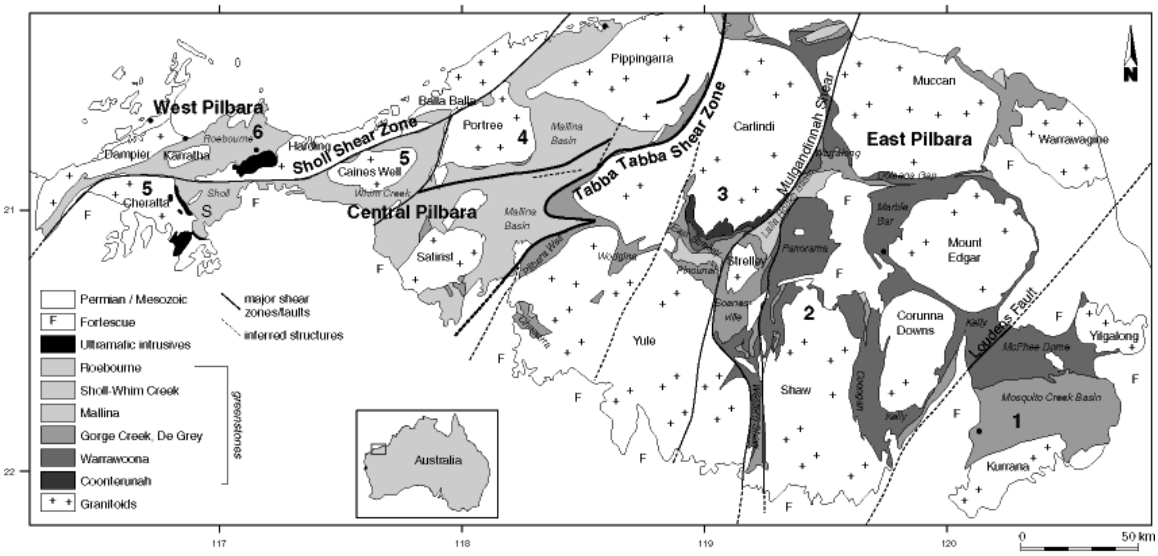

Figure 8.1. The Pilbara Craton in North Western Australia. The main supracrustal groups, granitoid complexes and major structures are shown. The six domains of Krapez and Eisenlohr (1998) are also indicated: 1 = Nullagine Domain, 2 = Marble Bar Domain, 3 = Pilgangoora Domain, 4 = Mallina Domain, 5 = Sholl-Whim Creek Domain. 6 = Roebourne Domain. Van Kranendonk et al. (2002) include the Sholl Belt (S) in the West Pilbara. Blewett (2002) and this study consider the Sholl Shear Zone to be the boundary between the West and Central Pilbara. The Tabba Tabba Shear Zone is the boundary between the Central and East Pilbara. Names in small regular font are granitoid complexes. Names in small italic font are greenstone belts.

Figure 9

… We also have diamond prospects in West Pilbara, which also happens to be found in Witwatersrand.

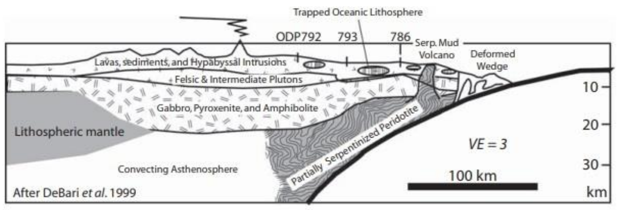

Fig. 5. Interpretation of the seismic structure of the crust and upper mantle of a typical intra-oceanic arc, modified after DeBari *et al.* (1999). This section is interpreted from the seismic refraction study of Suyehiro *et al.* (1996) for the Izu arc. The presence of a mid-crustal 'tonalite' layer should be noted.

Sediments are a relatively unimportant part of the forearc, but there are some. The relatively stable inner forearc may host a thin forearc basin, with a few hundred metres to few kilometres of sediment thickness. This paucity of sediment in IOAS forearcs is consistent with the fact that IOAS trenches are empty, and contrasts with the robust accretionary prisms and thick forearc basins characteristic of many Andean forearcs.

Volcanic–magmatic arc

The locus of continuing igneous activity in a mature IOAS defines the magmatic arc. This is recognized in modern IOASs as a linear or arcuate array of volcanoes that parallel the trench (England *et al.* 2004; Syracuse & Abers 2006). These are the largest and most productive volcanoes in a mature IOAS and are often the only feature that rises above sea level. These volcanoes are underlain by plutons and hypabyssal intrusions exposed by erosion in ancient, fossil IOASs. The trenchward limit of young igneous activity is referred to as the 'volcanic front' or 'magmatic front', and marks a steep gradient in heat flow, which is low towards the trench and high towards the back-arc region. The style of IOAS volcanism is fundamentally different from that of the other two great classes of oceanic volcanism, mid-ocean ridges and hotspots. Mid-ocean ridge volcanism is entirely volatile-poor tholeiitic basalt, which produces crust of nearly constant thickness (5–7 km) when magma fills the gap between two plates being pulled apart. Hotspot volcanism typically builds a linear chain of tholeii-

trench, so that the crust thickens at a rate of several hundred metres per million years as a result of the cumulative effects of magmatic addition at essentially the same place. Furthermore, IOAS magmas are relatively rich in silica and in volatiles, especially water, so that these eruptions are more violent and lavas are dominated by fragmental material, except in deep water, where the pressure suppresses violent degassing of magmas. This can sometimes be seen in the deposits of a growing IOAS volcano, as it grows from a base at 2–4 km below sea level to shallower water and then becomes an island. Eruptions from such a volcano are likely to change progressively with time from more effusive flows to increasingly fragmental as eruptions occur at increasingly lower *P* environments over time.

Hydrothermal activity and ore deposits associated with IOASs are also distinct from those associated with other oceanic igneous settings. Hydrothermal mineralization at mid-ocean ridges is controlled by the heating of seawater by hot rocks, which sets up a hydrothermal circulation that also leaches metals from the fractured basalts as it passes through these; these dissolved metals precipitate when hydrothermal fluids vent on the sea floor. Such circulation and leaching also occurs in association with IOAS submarine volcanoes, but in addition, the volatile-rich nature of IOAS magmas contributes directly to mineralization when these magmas degas (de Ronde *et al.* 2003; Baker *et al.* 2005). There are thus fundamental differences expected for mineral deposits that are related to mid-ocean ridges and IOASs.

Figure 10

… I simply included this slide because I found this “degassing”, as an additional enrichment source, quite interesting.

IOAS sediments

As mentioned before, IOASs are characterized by slow sedimentation rates and relatively thin sediments. Unless an IOAS lies near a continent, its trench will be empty and it will not have an accretionary prism. Significant sediment accumulations in IOASs occur only near the volcanic front, both on the back-arc side and forearc side. Sedimentation rates here will also reflect prevailing wind directions, which control the direction of volcanic ash dispersal and which flanks of subaerial volcanoes will be preferentially eroded by waves. Larger volcanoes are increasingly affected by flank collapse, which episodically sends tremendous volumes of sediment downslope.

… “Significant sediment accumulations” and “both on the back-arc side and forearc side”. Hmm, if the Sholl Shear Zone (SSZ) is a proxy for the “volcanic front” then I guess it makes sense why Novo staked some unusual ground to the north of the SSZ.

An interesting paper on the conditions for generation of calc-alkaline complexes:

Introduction

BOTH PRECAMBRIAN tectonics and Archean environmental setting are elusive subjects, and as James (1966) once wisely stated for the origin of the banded iron formations (BIF), the suggestions for the evolution of this scenario must be taken for what they are, that is, plausible speculations more than final answers. However, one thing we know for certain is that the transition from the Archean to the Proterozoic separated worlds apart (Taylor and McLennan, 1995, 1996), and involved major changes in the environmental conditions, sedimentation, subduction style, and magmatism (Fig. 1). For example, Archean magmatic complexes yield intrinsically low fO_2 values, and there are good arguments to support that the Earth’s upper mantle was originally more reduced (Kasting et al., 1993). Thus, a good question regards the conditions that brought oxidizing conditions to this realm, ultimately allowing the generation of calc-alkaline complexes. As we argue in this work, the onset of photosynthetic life (cyanobacteria) and the subsequent oxidation of the oceans (leading to massive deposition of iron oxide–rich sediments), may be the missing links of a story involving the subduction of these chemical sediments, the rise of oxygen fugacity, and formation of calc-alkaline magmas.

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It seems to me that the author argues that the presence of cyanobacteria and thus “oxidizing conditions” was a prerequisite for generating the “Whundo calc-alkaline basalts” that are found to the north-east of Purdy’s Reward:

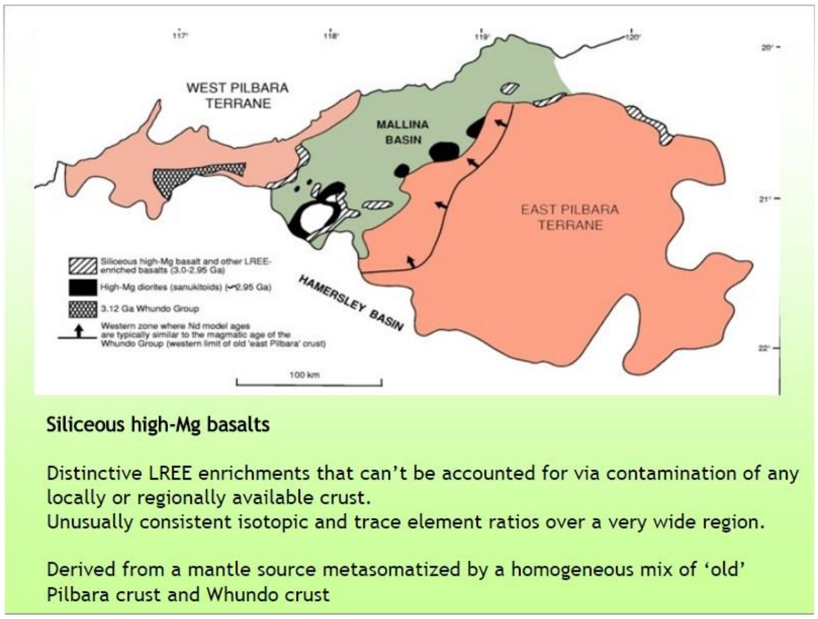


Figure 11

Note that according to the slide above, the Whundo Group was deposited around **3.12 Ga**. I guess that (if true) points to Karratha already having a fully functioning photosynthetic life already at that point in time. Now it's starting to make even more sense as to why more targets may be live (which I will cover later in the document) in Pilbara than just the sequences found directly beneath Mt Roe Basalt as per Novo's staking.

Another illustration:

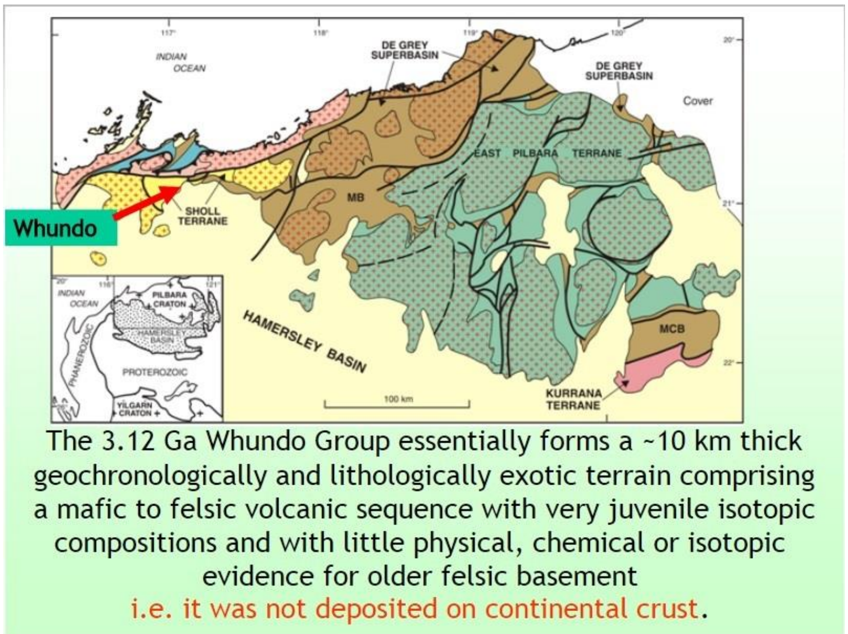
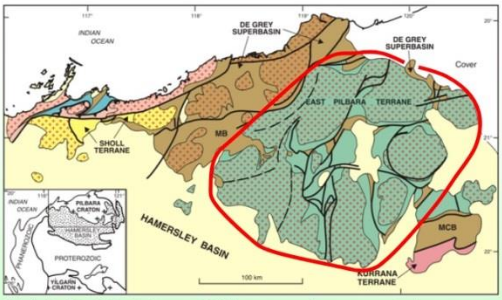
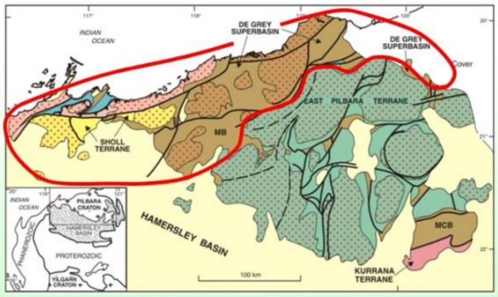


Figure 12

The paper's final conclusions:



Old (3.53-3.2 Ga) east Pilbara nucleus - contains no clear evidence for modern-style plate tectonics. This thick crustal block most likely began as some form of oceanic plateau type crust.



The West Pilbara Superterrane

A younger (3.3 - 3.05 Ga) amalgamation of terranes - contains extensive set of features that collectively present a compelling case for modern steep-style subduction at ~3.2 Ga. This represents accretion peripheral to the East Pilbara nucleus.

Figure 13

West Pilbara Superterrane

THE COMPLETE PACKAGE

We have several lines of evidence that combine to present a compelling case that modern-style subduction occurred at least by 3.2 Ga.

- an overall linear architecture with distinct terrains and boundaries that include strike-slip shears that account for 100's km movement – Exotic terrains.
- isotopically juvenile crust
- a 3.12 Ga volcanic sequence free of any exotic continental material
- Whundo calc-alkaline basalts which require an enriched mantle source
- Whundo calc-alkaline basalts which reflect flux-melting
- Whundo boninites
- Whundo adakite/NEB association
- Whundo volcanic/geochemical association/architecture
- Later basalts independently derived from a modified mantle source, flanking the East Pilbara

… While we are on the topic of "juvenile crust" (mentioned top right):

The formation of juvenile crust has been recognized as a first-order control on the likelihood of developing giant orogenic gold systems based on the global distribution of such deposits (Bierlein et al., 2006), whereby hydrated mafic crust is interpreted as the best available source of both the mineralizing fluids and the gold. Giant orogenic gold provinces seem to occur preferentially in orogens with subducted oceanic crust or only thin continental lithosphere, where the pre-mineralization crustal history had been short. The significance of oceanic crust as potential gold source for orogenic gold deposits is highlighted by the Au-enrichment of hydrothermal fluids on the ocean floor (Hannington et al., 2005). An apparent exception to the postulated relationship between giant orogenic gold deposits and lithospheric thinning, expressed by the short duration of pre-mineralization crustal history, is the giant Muruntau (>6100 t Au) and related deposits in the Tien Shan orogen. There mineralization was coeval with a Variscan orogenic event that followed an earlier Caledonian orogeny, thus reflecting a long pre-mineralization crustal history. Relatively unradiogenic initial Os isotope ratios and elevated $^3He/^4He$ ratios (Graupner et al., 2006; Morelli et al., 2007) indicate a mantle-derived component in the ore fluid there, thus pointing to a significant phase of extension, which made it possible for post-respectively). As the large proportion of Cenozoic deposits is an artifact of the much higher preservation potential of younger deposits, the actual temporal distribution of gold deposits is strongly biased towards the Archaean. Most of the crustal gold was sequestered from the mantle already by the Mesoarchaean, probably by H_2O-rich melts as typically found in active plate margins. Subsequently, that gold was recycled repeatedly on a lithospheric scale by a variety of crustal fluids, predominantly of magmatic origin. Remarkably variable but overall very high Os concentrations and unradiogenic Os isotope ratios in the Witwatersrand gold highlight its relatively juvenile character with only some remobilization by crustal fluids prior to deposition as placer deposits. In contrast, most of the younger gold has been recycled extensively, thus loosing most of its original Os. An example of post-Archaean mineralizing fluids that emanated from the mantle may be found in the Tien Shan gold province, notably the giant Muruntau deposit. It remains to be tested, whether other giant orogenic or intrusion-related gold deposits also contain a mantle component. Even if they did, it would not change the fact that the overwhelming part of all continental crustal gold was extracted from the mantle as early as in the Archaean. !

The actual cause for the very high rates of gold addition to the continental crust in Archaean times remains open to debate. It may be a question of juvenile crust formation rate — in itself

… That does sound very promising for West and Central Pilbara, especially if we did indeed had precipitation mechanics active already, 3.1 billion years ago. Keep all this in mind for the rest of the article.

Potential gravity traces from an Archean subduction zone in West Pilbara?

Background:

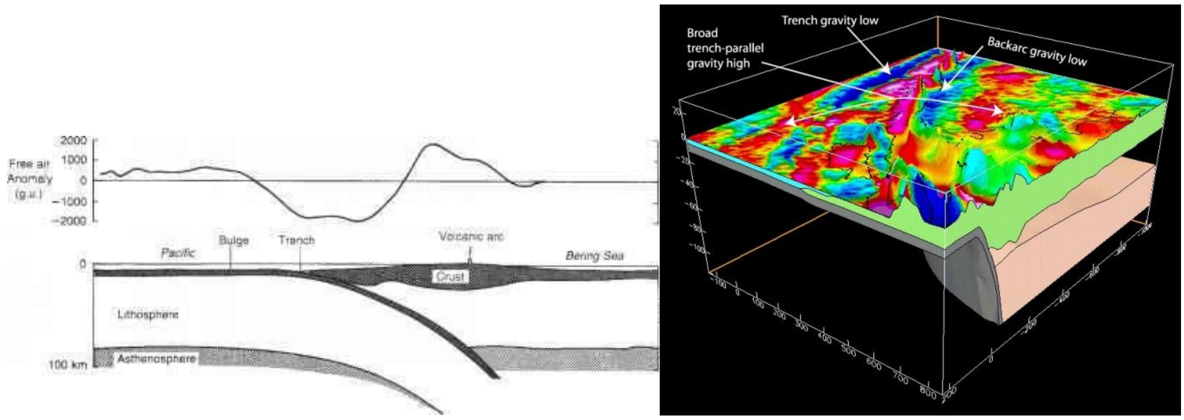


Figure 14

Summary
Gravitational signatures of subduction are a major feature of the Earth's gravity pattern, being visible as lineaments parallel to the arc-trench systems. The

Pilbara:

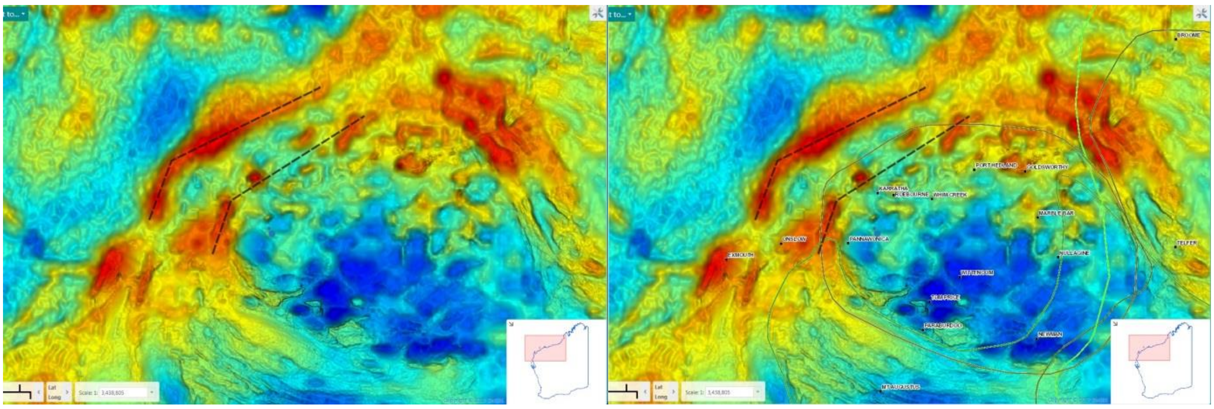


Figure 15

There are also magnetic anomalies at and near the two major shear zones in West and Central Pilbara:

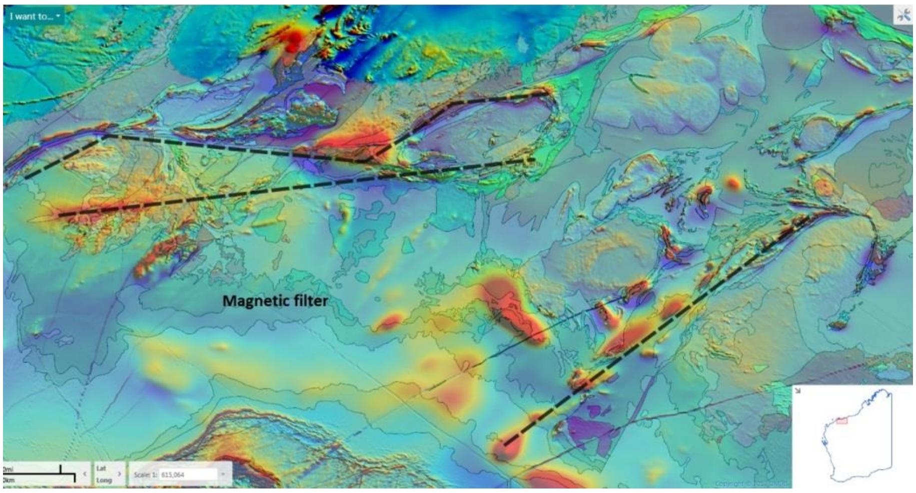


Figure 16

… I would guess these can be seen as magmatic hot spots and thus potential feeder zones. I would say Novo has staked 90% of the claims on top and around those magnetic highs, between the two shear zones (Sholl is far left line and Tabba Tabba is the line to the right), with the appropriate rock formations. With that said, I don't know how important (if at all) this is in terms of the conglomerate targets. What makes me think it might play a part is the fact that Novo staked some "weird" claims north of the Sholl Shear Zone and a large part of the Constantine Sandstones next to De grey, both areas which should have no or very little Mt Roe Basalts present.

It does paint an interesting (theoretical) picture:

Imagine the area between the shear zones being subdued/submerged, with periodically heavy magmatic and hydrothermal activity going on, along the sides, acting as feeders(!).

Meteor Impact

This article argues that Karratha lies near the edge of an impact structure that formed when the area got hit by a meteor sometime in the Archean era:

https://geotreks.com.au/work/giant-ring-structures/archaean-impact-structure-mt-flora-pilbara/

The author's take:

Archaean Impact Structure? Size, origin and age of the Mt Flora giant ring structure.

The Mt Flora GRS has many of the features of an impact structure. There are numerous concentric circles, albeit segmented. There is a strong 200km diameter ring observed in gravity, magnetic, radiometric, Landsat and geology data images. There is a 30km central high in gravity. The annulus between the centre and the outer ring is of lower gravity and magnetics than the regional data intensity. There are many segments of the farfield rings up to 600km from the centre suggesting an original diameter of 1200km.

The concentric nature and the morphology (Grieve and Pilkington 1996) of these rings suggest that the Mt Flora GRS may be an impact structure.

The age of the Mt Flora GRS is older than the base of the 2.775–2.630 Ga volcano-sedimentary Fortescue Group (Thorn and Kendall 2001) and may be as old as the age of the older 3.47 Ga spherulite beds in the East Pilbara (Glikson and Allen 2004).

Evidence in the Archaean Pilbara and adjoining Kaapvaal Cratons of several impact spherulite ejecta horizons confirm that large impacts occurred around 2.48, 2.63, 2.7 2.9? and 3.47 Ga (Simonson et al 2004, Hassler and Simonson 2001, Bryerly et al 2002, Glikson 2004, Glikson and Allen 2004, Glikson and Tonguç Uysal, 2013, Glikson et al. 2016).

The following gravity image is provided:

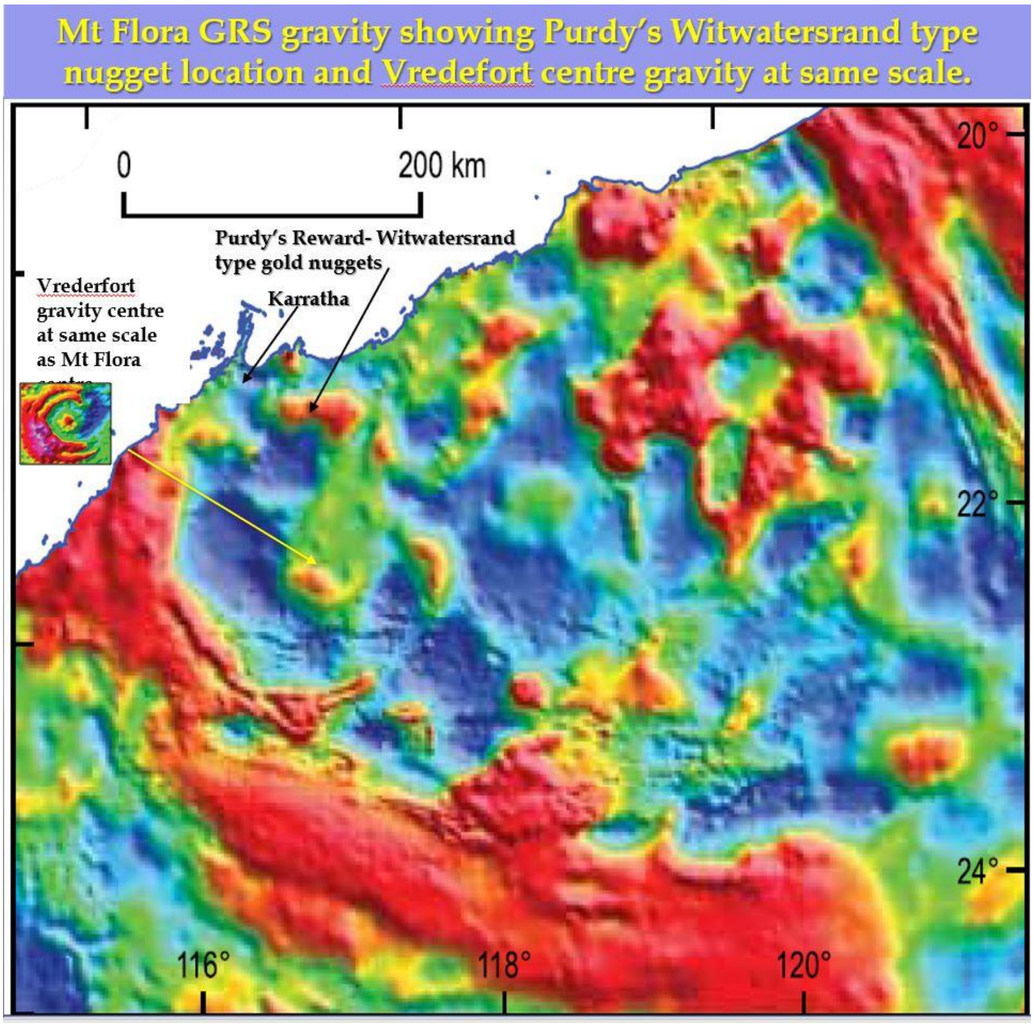


Figure 17

Another gravity filter that also includes Novo's claims:

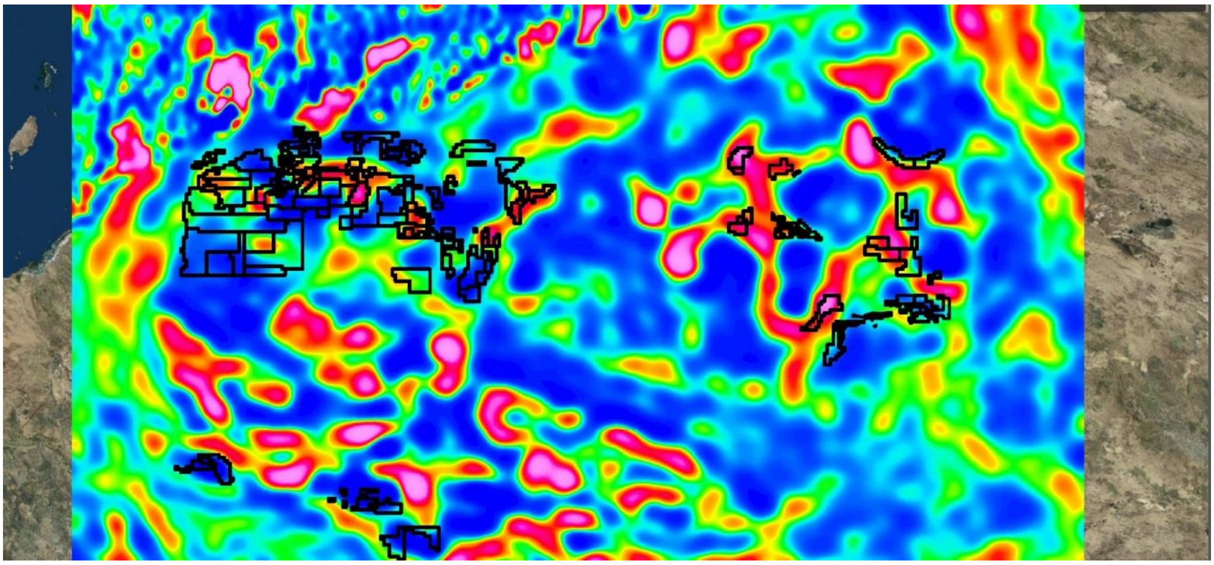


Figure 18

Suffice it to say, 80% or more of Novo's newly staked claims in Western Pilbara are located around the edge of the gravity ring highs. When we are talking "down dip", we are most likely talking down dip into an Archean impact crater. I would also argue that what I believe are some newly staked claims in the east are primarily focused around gravity highs and not at the gravity high centers.

A closer look on the west part of the area depicted above through a different gravity tool:

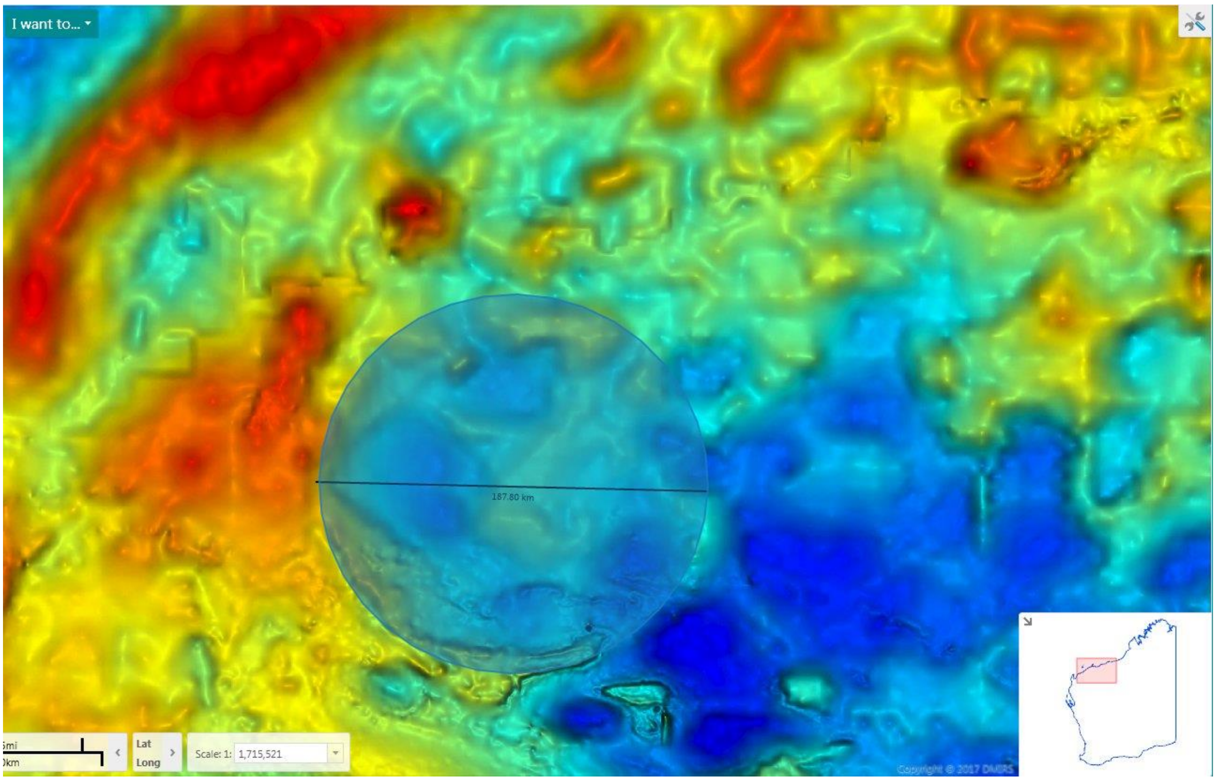


Figure 19

Same area with geological units:

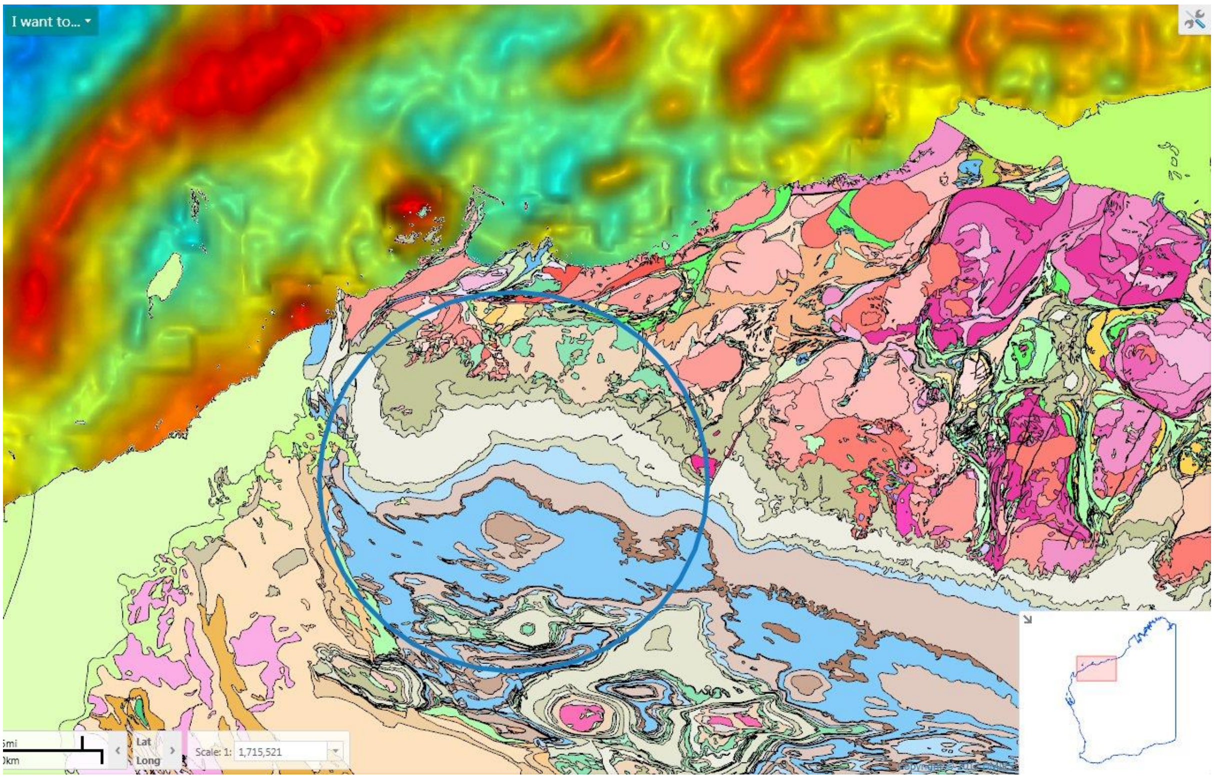


Figure 20

I will personally argue that both the gravity and bedrock units do suggest that some kind of spherical deformation did happen in this area.

Different illustrations showing how a meteor impact could have changed the land in West Pilbara (Karratha):

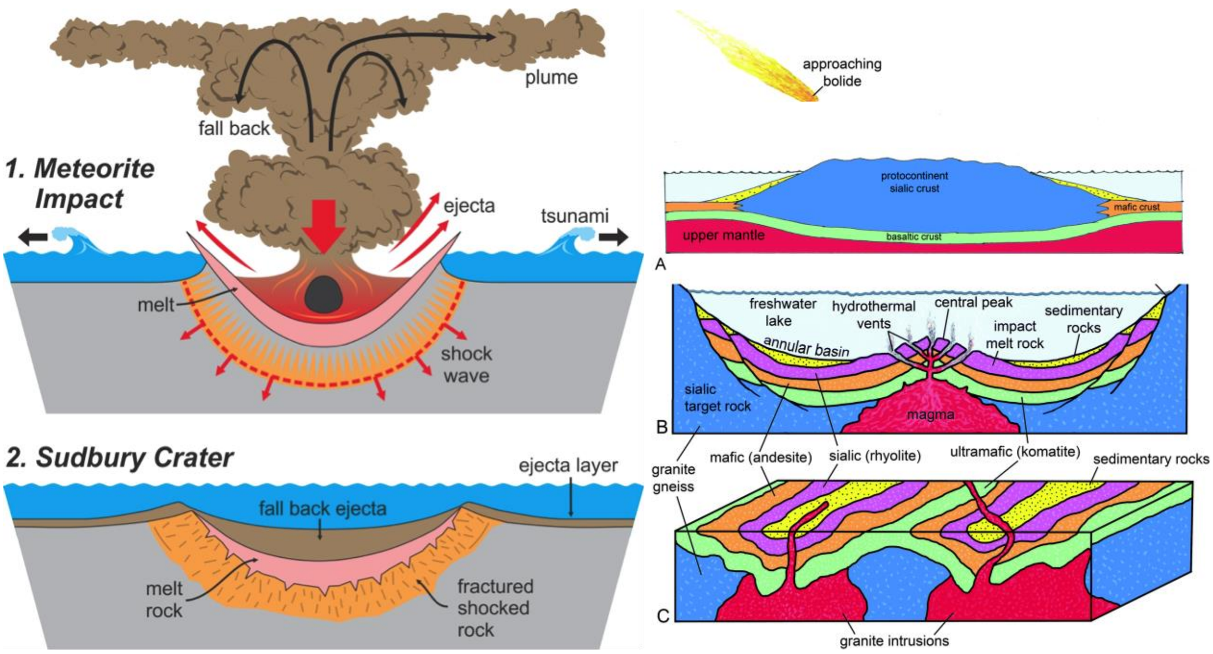


Figure 21

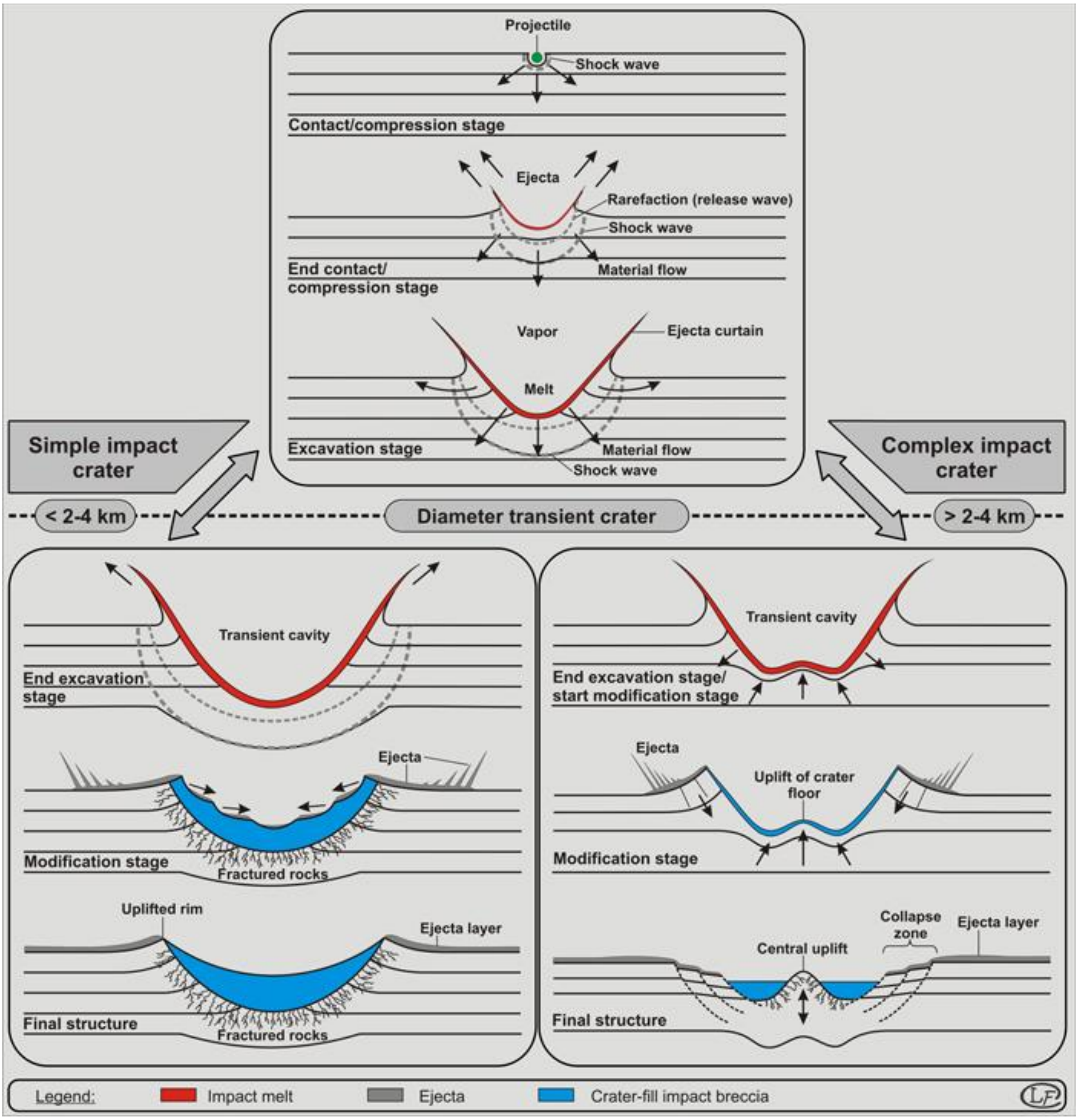


Figure 22

A pre-Fortescue (Mount Roe Basalt) meteoric impact in the western Pilbara could thus have provided a basin or a sub-basin ideal for water concentration and sediment accumulation. More than that, the impact could have led to magmatism and major long lasting hydrothermal activity in the basin which will be covered in the next section. This could mean that the basin saw rich hydrothermal systems working for a long time that nurtured microbial life and transported gold rich fluids. As far as I know this kind of impact crater environment was not present when the Witswatersrand gold was deposited. The Vredefort impact crater in South Africa was created AFTER the conglomerates were laid down as seen in this next picture:

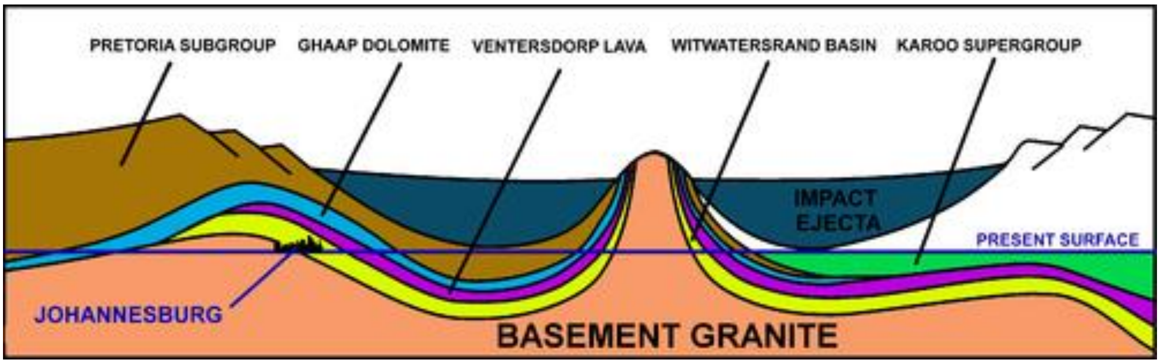


Figure 23

I would also like to show this next illustration of an impact structure before we move on:

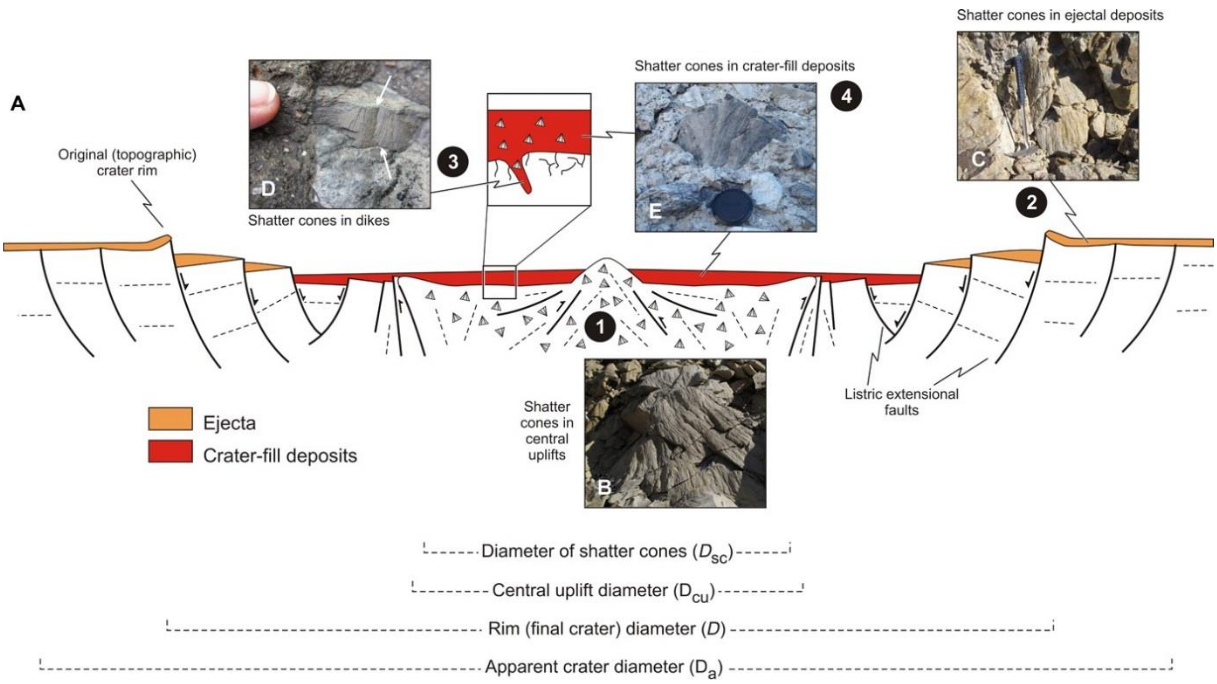


Figure 24

A couple of speculative things spring to mind when I go back and re-read Novo’s News Releases:

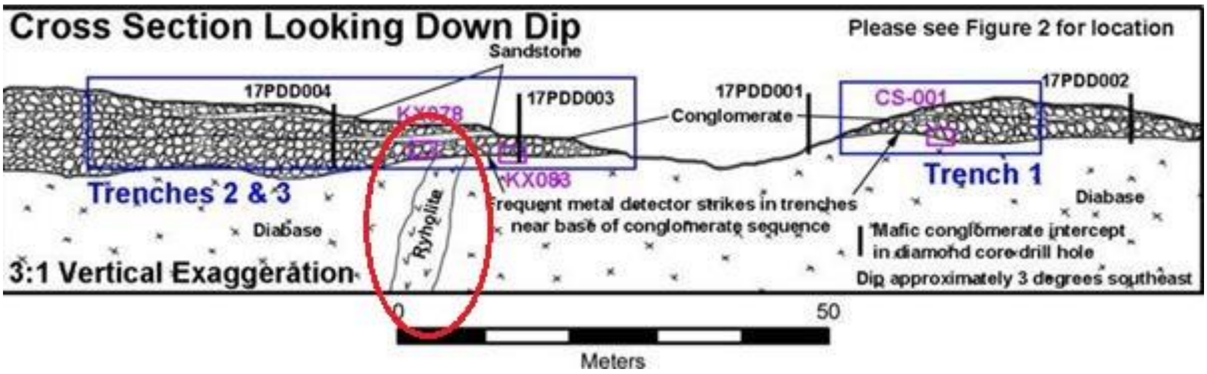


Figure 25

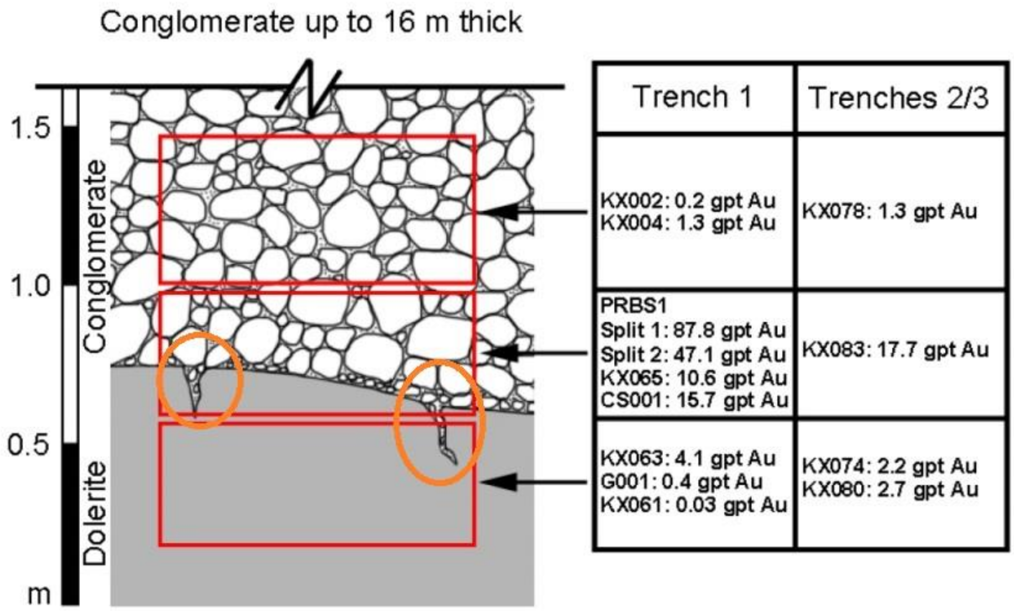


Figure 26

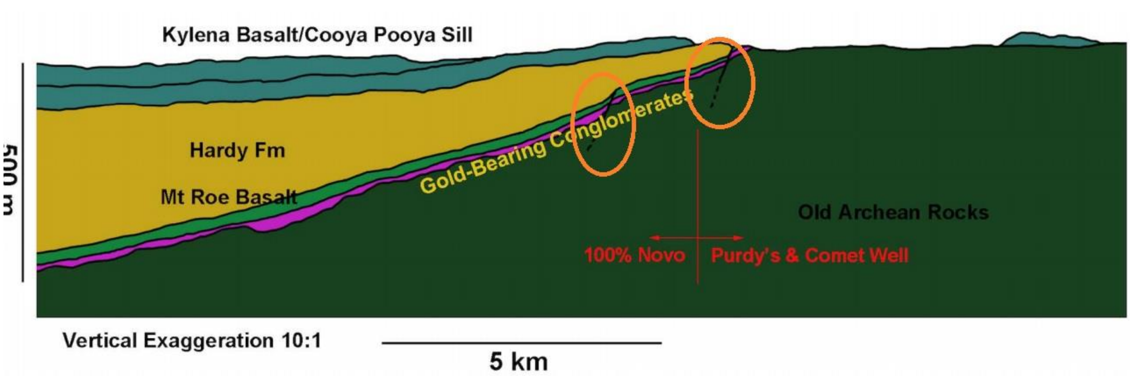


Figure 27

… I just found it interesting.

Impact Structures and Gold

Now, let’s move on to why having an impact structure present might be more beneficial than simply creating an ideal basin for sedimentation and water storage.

First, an image from geotreks.com.au depicting gold mineralization (yellow dots) and inferred ring structures near Kalgoorlie, Western Australia:

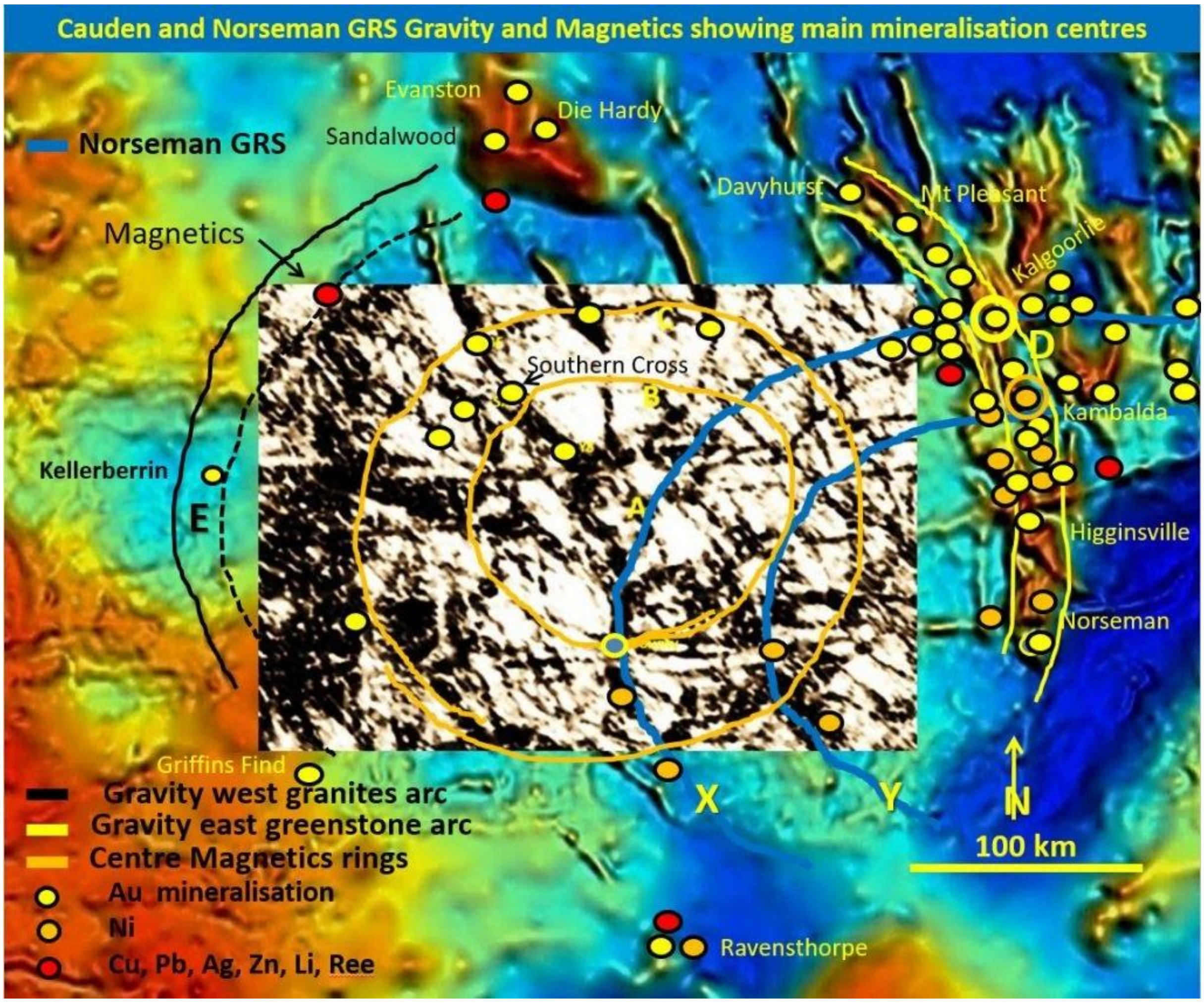


Figure 28

A close up on the Kalgoorlie area (right side in the top picture) with linear structures mapped:

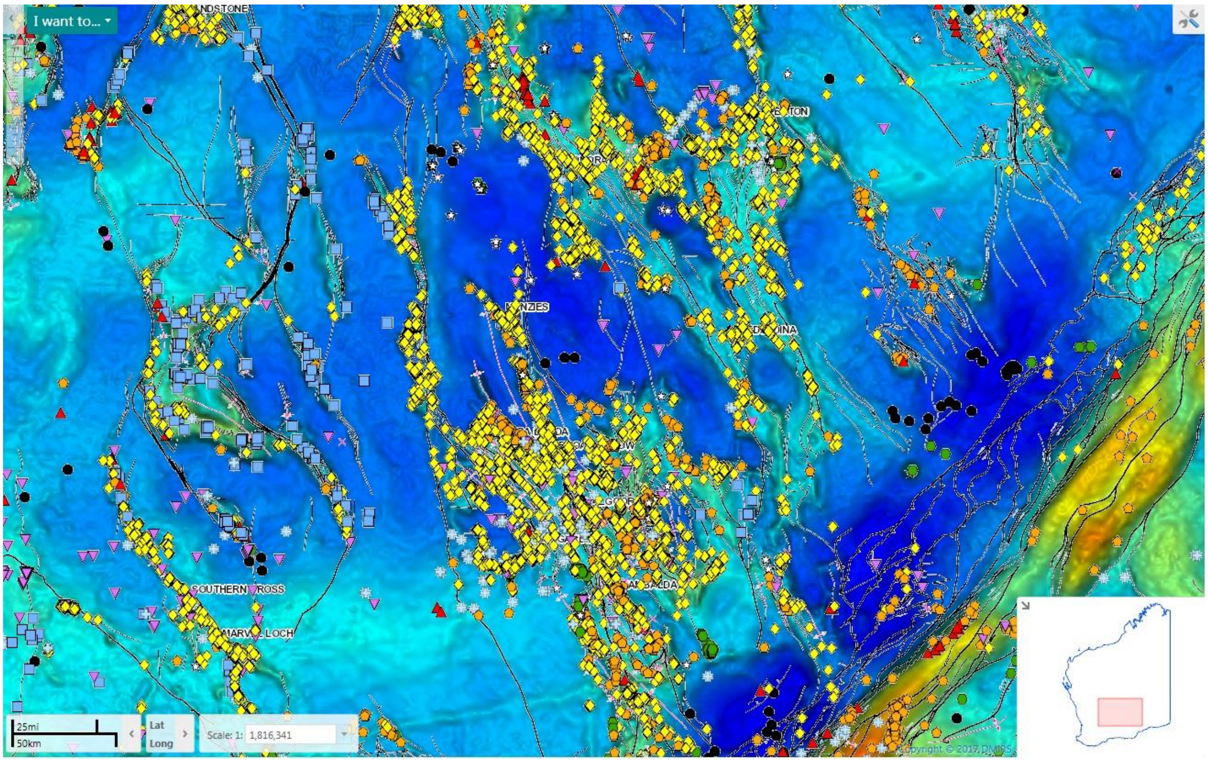


Figure 29

The obvious observation is that gold occurrences seem to be located near faults (expected) and around gravity lows.

Snippets from an article about the "Watchorn Impact Structure" in the eastern Yilgarn, West Australia:

> He says the link between mineral deposits and the rings of the WIS could impact mineral exploration in WA.
>
> "I plotted all the gold and nickel mines [in the Eastern Goldfields] onto the Western Mining database," he says.
>
> "All of the big gold mines—I mean every single mine that was over one million ounces fell on the rings.
>
> "If you're going to go looking for deposits you should be looking in an entirely different location than what you would have before."

> "I could see many concentric circular structures... at different levels of the lithosphere and then check them against seismic traverses that had been done.
>
> "Eventually I was able to correlate different depth plans of the gravity data with the seismic data and noticed concentric bowl and dome shaped structures which correlated to the impact structures."
>
> He says the location of gold and nickel deposits on the rings are indicative of its significance to the makeup of the Eastern Goldfields.
>
> "I know the gold deposits are 2.6 to 2.64 billion years old and they've actually formed on the rings," he says.
>
> "However the nickel formed 2.67 to 2.72 billion years ago and as most of the big nickel mines are on the rings there are still unanswered questions.
>
> "It's a paradigm-shifting discovery."

Gravity profile for the Marble Bar area (East Pilbara) with mapped mineral occurrences:

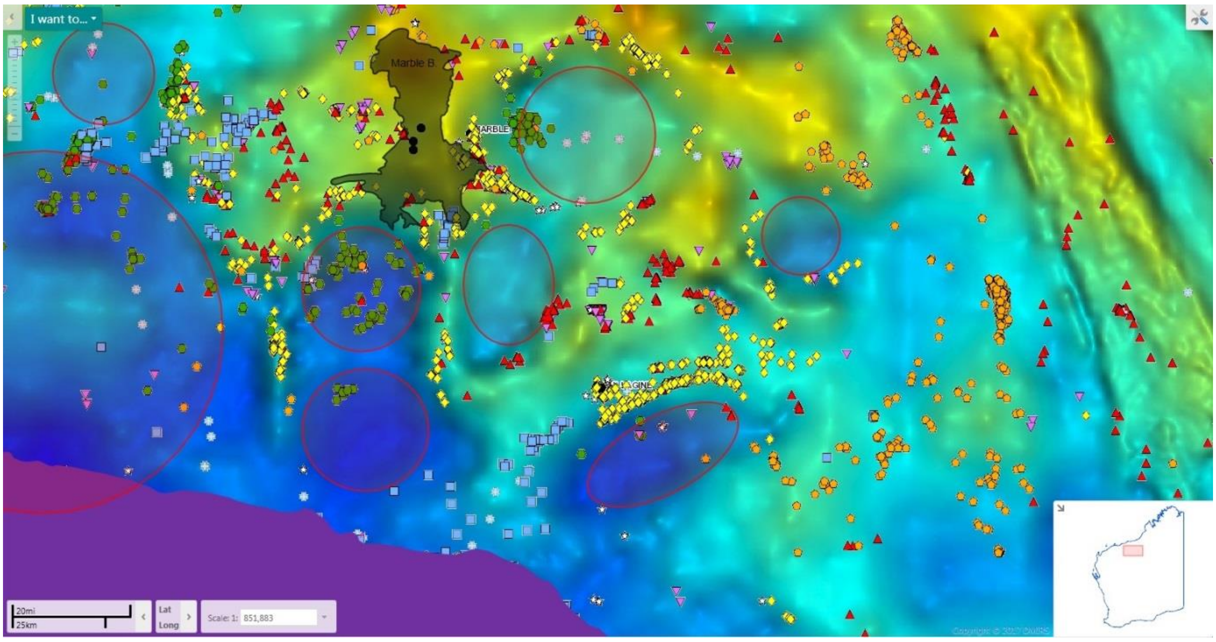


Figure 30

Same area but with Fortescue cover rock blackened out:

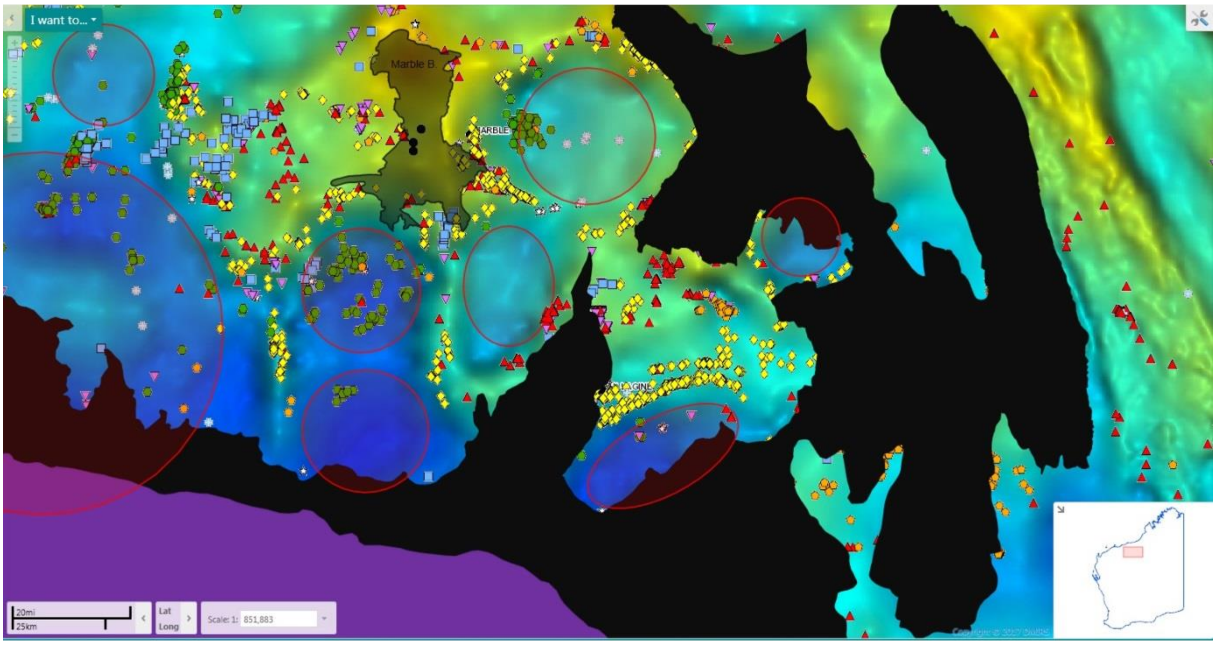


Figure 31

Same area with mapped linear structures:

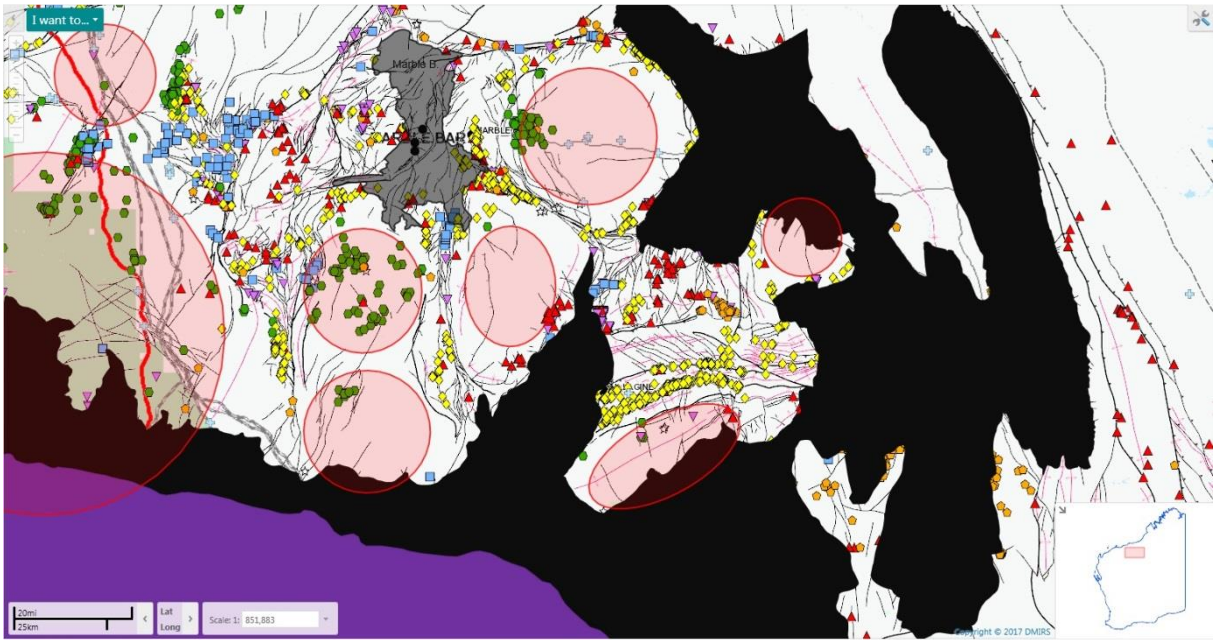


Figure 32

Suffice it to say, gravity "bowls" seem to be surrounded with gold occurrences, which we also happen to have inside our Karratha claims (mostly covered by Fortescue cover rock though):

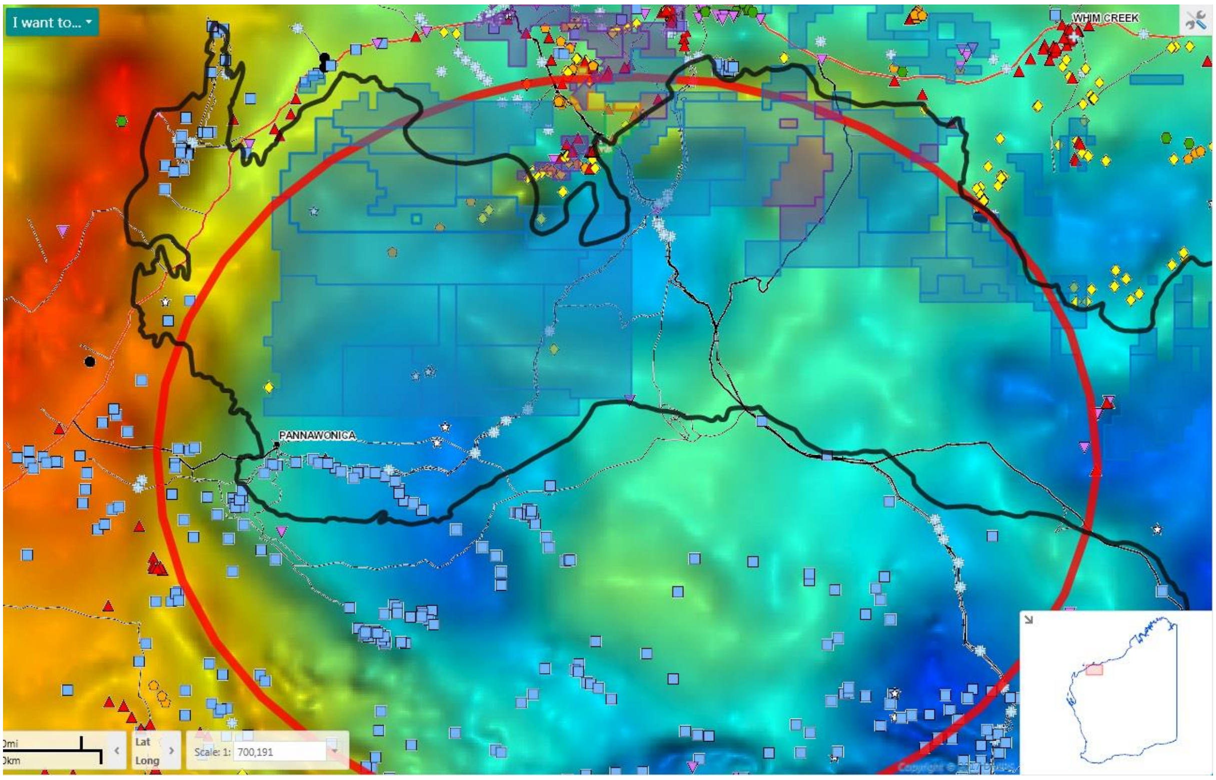


Figure 33

The gravity lows in the impact structure are hopefully also indicative of major sediment (and conglomerate) accumulation, basically where "down dip" is:

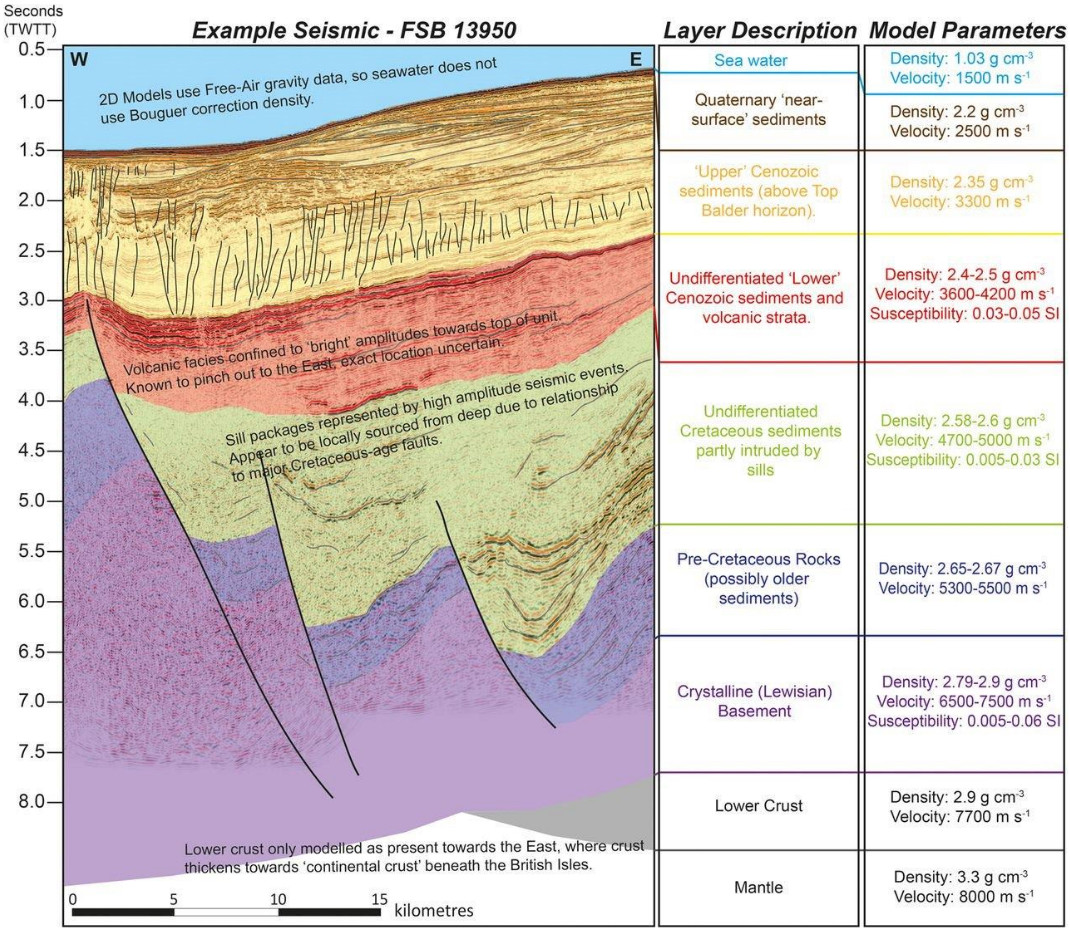


Figure 34

Lastly, I would like to show the following slide regarding “impact units”. Especially the description regarding the impact units that were attributed to a meteoric that hit the “top Jeerinah Formation, Fortescue Group, Hamersley Basin”:

Table 8.5-1. Archaean and early Proterozoic asteroid impact fallout units and associated ferruginous sediments, Pilbara Craton, Western Australia, and Kaapvaal Craton (Barberton greenstone belt – BGB), South Africa

Age/stratigraphy	Impact unit/s	Overlying ferruginous sediments	Reference
3470.1 ± 1.9 Ma: ACM-1, Antarctic Creek Member, Mount Ada Basalt, Warrawoona Group, Pilbara Craton	Silica-sericite spherules in ~1 m thick chert breccia/conglomerate	Overlain by felsic hypabyssal/volcanics	A
3470.1 ± 1.9 Ma: ACM-2, Antarctic Creek Member, Mount Ada Basalt, Warrawoona Group, Pilbara Craton	Silica-sericite spherules within ~14 m thick chert, arenite and jaspilite	~10 m thick jaspilite overlying spherule unit ACM-1	A
3470.4 ± 2.3 Ma: BGB–S1A and BGB-S1B, upper Hooggenoeg Formation, Onverwacht Group, Kaapvaal Craton	Two units of silica-chert spherules within 30–300 cm thick unit of chert and arenite	–	B
3258 ± 3 Ma: BGB–S_2, base of the Mapepe Formation, Fig Tree Group, Kaapvaal Craton	<310 cm thick silica–sericite spherules	MJM (Manzimnyama Jaspilite Member): BIF + jaspilite + ferruginous shale (<20 m) and shale common above BGB–S_2	B
3243 ± 4 Ma to 3225 ± 3 Ma: BGB–S_3 and BGB-4, lower Mapepe Formation, Fig Tree Group, Kaapvaal, Craton	S_3 – 10–15 cm-thick to locally 2–3 m thick silica-Cr sericite-chlorite spherules S_4 – 15 cm thick arenite with chlorite-rich spherules	BGB–S_3 is overlain by ferruginous sediments of the Ulundi Formation in the northern part of the BGB	B
2629 ± 5 Ma: JIL, top Jeerinah Formation, Fortescue Group, Hamersley Basin.	Hesta – 80 cm thick carbonate-chlorite spherules and spherule-bearing breccia; 60 cm thick overlying debris flow	Marra Mamba iron-formation, immediately above ~60 cm thick shale unit overlying JIL	D
?2.63 Ga: Monteville Formation, West Griqualand Basin, west Kaapvaal Craton	5 cm thick spherule layer	Carbonate hosted	E

… *"Carbonate-chlorite spherules… overlying debris flow".*

I remember Cook stating that what he saw at Purdy's and/or Comet Well looked like "debris flow" if I remember correctly. The following slide is from a Novo NR, describing the base of the Purdy's Reward sequence, where most of the gold is located:

conglomerate sequence. Recent observations in trenches continue to confirm this pattern. Novo personnel have noted metal detector strikes throughout this lower conglomerate sequence, however most occur near its base. Interestingly, black chlorite-rich shale fragments are commonly observed in areas with abundant visible nuggets. Such shale fragments are seen in proximity to gold nuggets in the second video linked to Novo's July 12, 2017 news release announcing the discovery of gold nuggets at Purdy's Reward. The geologic reason for the association between these shale fragments and gold nuggets has not yet been determined.

Black shale description form Wikipedia:

Composition and color

Shales are typically composed of variable amounts of clay minerals and quartz grains and the typical color is gray. Addition of variable amounts of minor constituents alters the color of the rock. Black shale results from the presence of greater than one percent carbonaceous material and indicates a reducing environment.[1] Black shale can also be referred to as black metal.[3] Red, brown and green colors are indicative of ferric oxide (hematite – reds), iron hydroxide (goethite – browns and limonite – yellow), or micaceous minerals (chlorite, biotite and illite – greens).[1]

… These last slides were basically included as trivia and nothing I would consider that important.

Impact Structures and Life

First, let's start with some research on this topic:

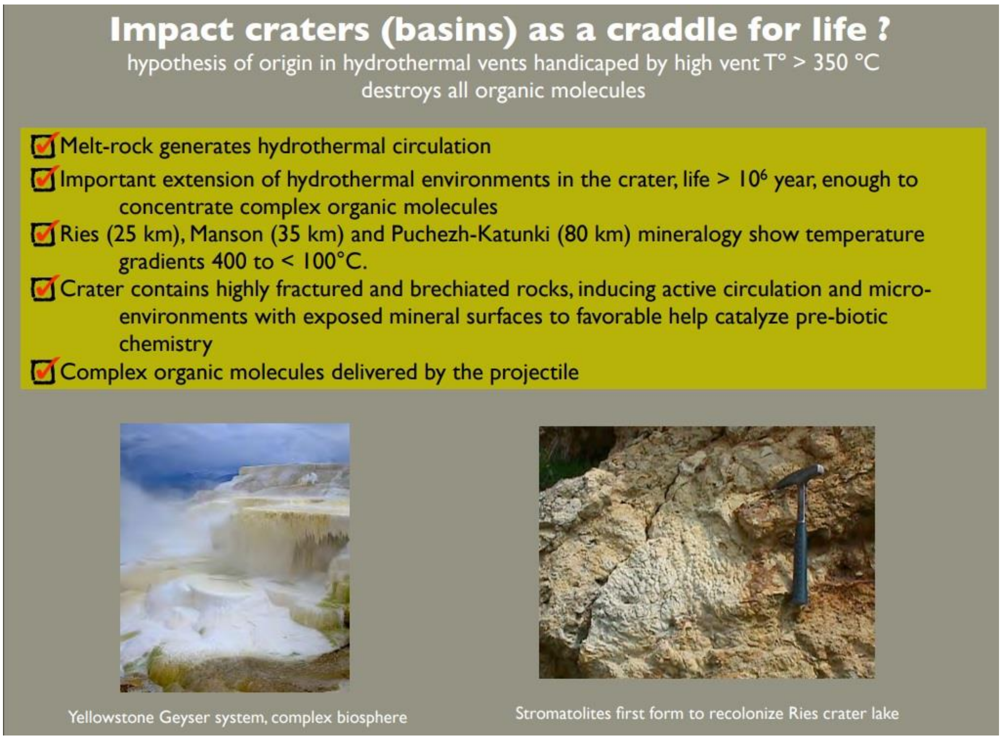


Figure 35

Abstract

Submarine hydrothermal vents are generally considered as the likely habitats for the origin and evolution of early life on Earth. The theory suffers from the 'concentration problem' of cosmic and terrestrial biomolecules because of the vastness of the Eoarchean global ocean. An attractive alternative site would be highly sequestered, small, hydrothermal crater-lakes that might have cradled life on early Earth. A new symbiotic model for the origin of life at hydrothermal crater-lakes is proposed here. Meteoritic impacts on the Eoarchean crust at the tail end of the Heavy Bombardment period might have played important roles in the origin of life. Impacts and collisions that created hydrothermal crater lakes on the Eoarchean crust inadvertently became the perfect crucibles for prebiotic chemistry with building blocks of life, which ultimately led to the first organisms by prebiotic synthesis. In this scenario, life arose through four hierarchical stages of increasing molecular complexity in multiple niches of crater basins. In the cosmic stage (≥4.6 Ga), the building blocks of life had their beginnings in the interstellar space during the explosion of a nearby star. Both comets and carbonaceous chondrites delivered building blocks of life and ice to early Earth, which were accumulated in hydrothermal impact crater-lakes. In the geologic stage (~4 Ga), crater basins contained an assortment of cosmic and terrestrial organic compounds, powered by hydrothermal, solar, tidal, and chemical energies, which drove the prebiotic synthesis. At the water surface, self-assembled primitive lipid membranes floated as a thick oil slick. Archean Greenstone belts in Greenland, Australia, and South Africa possibly represent the relics of these Archean craters, where the oldest fossils of thermophilic life (~3.5 Ga) have been detected. In the chemical stage, monomers such as nucleotides and amino acids were selected from random assemblies of the prebiotic soup; they were polymerized at pores of mineral surfaces with the coevolution of RNA and protein molecules to form the 'RNA/protein world'. Lipid membranes randomly encapsulated these RNA and protein molecules to

Fungal colonization of an Ordovician impact-induced hydrothermal system

Magnus Ivarsson[1], Curt Broman[2], Erik Sturkell[3], Jens Ormö[4], Sandra Siljeström[5,6], Mark van Zuilen[7] & Stefan Bengtson[1]

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Impacts are common geologic features on the terrestrial planets throughout the solar system, and on at least Earth and Mars impacts have induced hydrothermal convection. Impact-generated hydrothermal systems have been suggested to possess the same life supporting capability as hydrothermal systems associated with volcanic activity. However, evidence of fossil microbial colonization in impact-generated hydrothermal systems is scarce in the literature. Here we report of fossilized microorganisms in association with cavity-grown hydrothermal minerals from the 458 Ma Lockne impact structure, Sweden. Based on morphological characteristics the fossilized microorganisms are interpreted as fungi. We further infer the kerogenization of the microfossils, and thus the life span of the fungi, to be contemporaneous with the hydrothermal activity and migration of hydrocarbons in the system. Our results from the Lockne impact structure show that hydrothermal systems associated with impact structures can support colonization by microbial life.

While giant asteroid impacts would spell doom for many species today, they may have played an important role in helping jumpstart the first life billions years ago, when life's toehold on Earth was still very tenuous. Impact sites could have been especially crucial for life during a period about four billion years ago, known as the Late Heavy Bombardment, when the newly-formed Earth was hammered by swarms of asteroids and comets.

Not only would shocked rocks have offered shelter against harmful ultraviolet light at time when Earth still lacked a protective atmosphere, asteroid and comet impacts would have created hydrothermal systems that could have helped sustain life by providing sources of heat, water, and nutrients, Osinski said.

"Because of the huge amount of energy from impacts, you can create kilometers of liquid molten magma that can take a long time to cool down. And these hot rocks can heat up water, and as the water warms and cools, you can get a circulation going," he added.

"Until about a decade ago, the only way to generate hydrothermal systems that we knew of was in volcanic settings. But we've since been able to show that impacts also generate hydrothermal systems."

Abstract

Research within the last decade has revealed that meteorite impacts on our planet have the potential to create transient hydrothermal environments that are conducive to the development of extremophile microbial communities. Impact products also record the hydrologic and environmental history of a terrestrial body's surface, making them attractive targets in the search for water and exolife on other planets and satellites. The interpretation of geologic and surface processes observed on other terrestrial bodies is based on ground-truths we recognize on Earth. Due to the recycling of crust and an active surface environment, the direct study of hydrothermal activity in craters on our planet is often obscured by pre-impact fluid episodes and non-preservation at ambient surface conditions. As a result, detailed studies focusing on water-rock interactions during the post-impact cooling period are lacking. Many mysteries still surround the development and sustainability of impact-hydrothermal activity, such as the role of target composition and paleofluid reservoirs. This study investigates post-impact hydrothermal activity within the complex, 23km diameter, marginal marine, late Triassic Rochechouart impact structure located in west-central France. Previous studies have noted a pervasive K-metasomatic overprint attributed to post-impact hydrothermal circulation; however, Rochechouart is highly weathered, and the target consists primarily of Variscan quartzofeldspathic igneous and amphibolite facies metamorphic rocks which show evidence for aqueous alteration during pre-impact events. This thesis aims to overcome the complications arising from multiple fluid event overprinting in Rochechouart by documenting secondary alteration throughout all impactites using detailed petrography, scanning electron microscopy, energy dispersive X-ray and Raman analysis combined with carbon, oxygen and sulphur stable isotope techniques to place temperature and fluid constraints on secondary carbonate and sulphide minerals within lithic impactites. Results from this study reveal that the intensity of alkali metasomatism directly correlates with host rock melt content; relatively impermeable melt rocks and melt-bearing breccias show evidence for pervasive K-metasomatism, with late-stage carbonate-sulphide mineralization concentrated in lithic breccias and autochthonous impact fractures. No pre-impact hydrothermal carbonates were detected isotopically. Isotopic data also supports the hypothesis that seawater, and possibly meteoric water, mixed with metamorphic fluids, were the contributing fluid reservoirs fuelling hydrothermal circulation within the structure; this conclusion is further supported by the strongly biological signatures of secondary sulphide minerals and the structure's marginal marine paleogeography. The sequence of hydrothermal alteration within Rochechouart follows the following scheme; early stage alkali-saturated waters sourced from the quartzofeldspathic, impermeable melt rocks were responsible for the pervasive K-metasomatic overprint in all lithologies; intermediate stage alteration was dominated by chlorite-smectite assemblages with continued K-metasomatism, which decreases in intensity in melt-poor rocks; and relatively cool carbonate-sulphide assemblages dominate lithic impactites and basement fractures where hydrothermal fluid flow is concentrated well into the late stages of cooling. Results also reveal that the porous network of parautochthonous breccias and autochthonous impact fractures within the sub-crater environment of complex craters with a majority-crystalline target may host hydrothermal fluid circulation for relatively long periods of time. These sites may also provide an environment conducive to the development of thermophilic microbial communities.

Basically I think it's safe to say that this basin or sub-basin could have been a real cradle for life in Pilbara during the time that the conglomerates were laid down and gold deposition took place. This next slide is also interesting:

or asteroid crashing into Earth between 23 to 39 million years ago. The team found that, in general, rock samples that were exposed to higher pressures during the impact contained more microscopic pores and harbored higher numbers of photosynthetic cyanobacteria that had evolved to colonize the tiny rock crevices.

"We speculated that this was the case in the past, but we've never had the hard data before," Osinski said.

Using a spectrometer, the team also showed that shocked rocks were better at blocking biologically damaging ultraviolet rays while still allowing enough light through to sustain the microbes, which rely on sunlight to survive.

"When you shock the rock, you fracture its crystal structure so that [ultraviolet] light ends up bouncing all around the rock and less of it gets transmitted through the rock," said study first author Alexandra Pontefract, a researcher in Osinski's lab.

As far as scientists know, impact craters are the only environments that can transform rocks in this way.

"This is a unique process," Osinski said. "Even the most violent volcanic eruptions you can think of don't come anywhere near generating the pressures that you get during these impact events."

… Coupled with this:

Cyanobacterial Inhabitation on Archean Rock Surfaces in the Pilbara Craton, Western Australia.

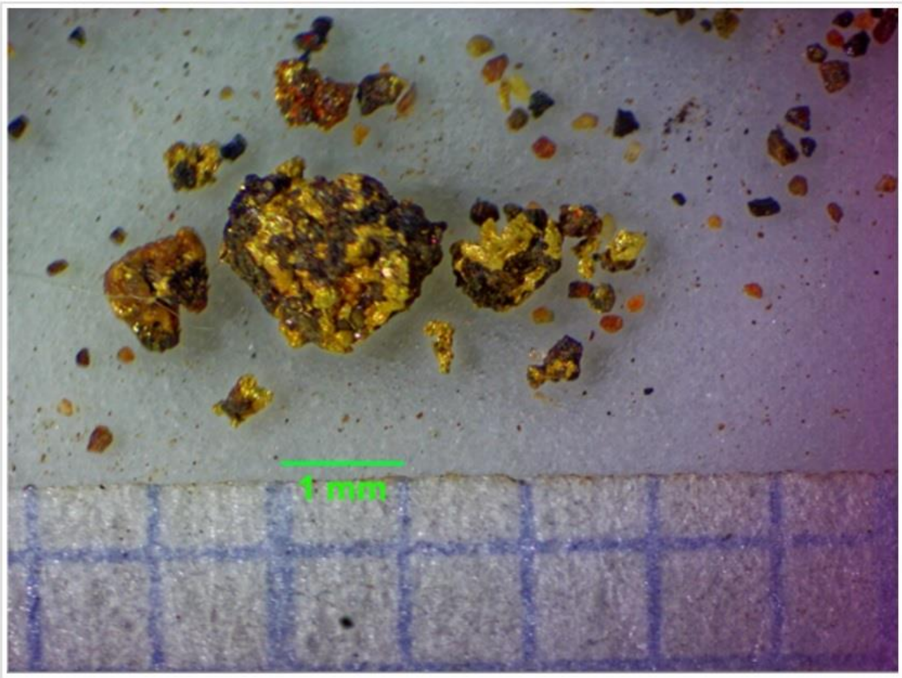
Hoshino Y[1,2,3], George SC[1,2].

⊕ Author information

Abstract

High abundances of 7- and 6-monomethylalkanes as well as C17 n-alkane, indicative of cyanobacteria, have been discovered near the surfaces of Archean carbonate rocks of the Fortescue Group in the Pilbara region, Western Australia. The presence of cyanobacterial biomarkers is mostly limited to the surface layer (<1 cm thickness) of the rocks, indicating that the cyanobacteria are an endolithic species. Biomarkers are found in bitumen I (solvent-extracted rock) and also in bitumen II (solvent-extracted decarbonated rock). The abundance of biomarkers is generally the same between both bitumen fractions in the surface layer, which suggests that the cyanobacteria penetrated into the carbonate minerals. Trace amounts of the biomarkers have also diffused into a deeper part of the rocks, but this influence is only seen in bitumen I. This implies that hydrocarbons moved toward the inside of the rock through pores and fissures in the rock fabric. In contrast, hydrocarbons in bitumen II, which mainly come from within the carbonate minerals, are isolated from the hydrocarbon migration from the outside of the rock and may be ancient indigenous organic matter. To the best of our knowledge, this is the first report of the past or modern inhabitation of cyanobacteria on Archean rocks in the Pilbara region for which hydrocarbon biomarker analyses was used.

… Don't know why, but it made me think about this from a Novo NR:



Gold particles recovered from panning of a grab sample from the lowest most conglomerate exposed in trench 2. Although the center nugget is about 2 mm across, the rest are smaller than 1 mm across. Note that most gold particles have minor dark brown rock matrix attached.

Figure 36

- A slide visualizing how of the insides of an impact structure could have eventually looked like:

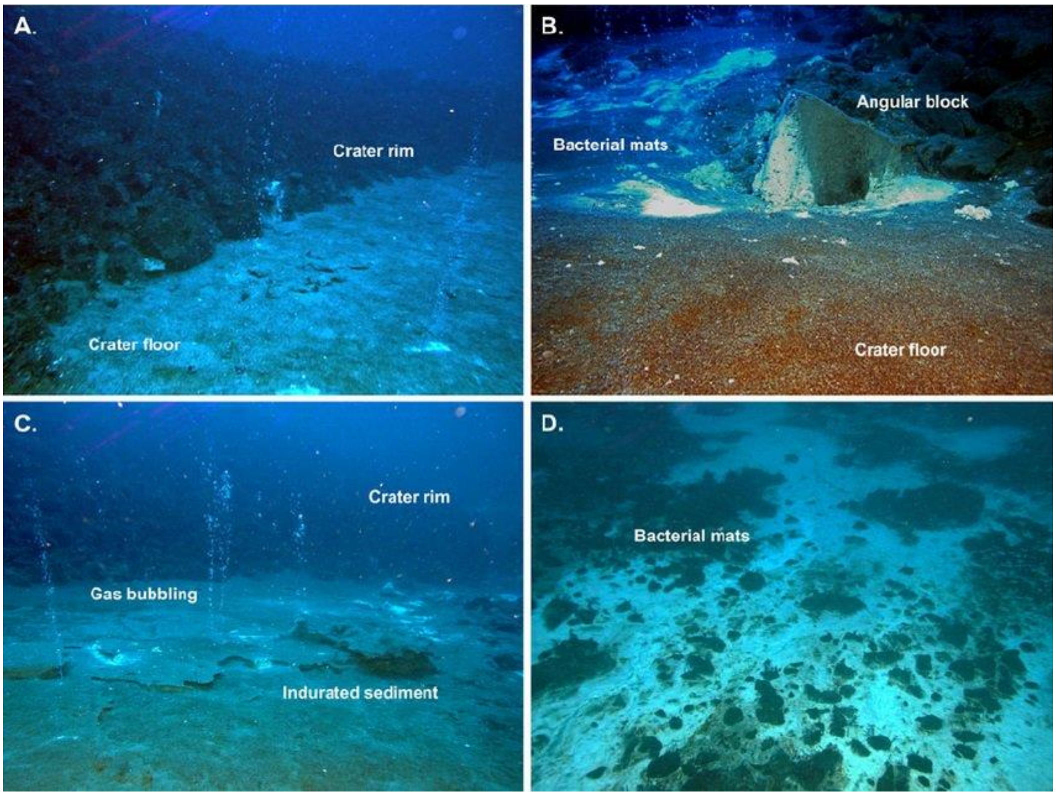


Figure 37

- **An illustration of "microbes in aquatic marine ecosystems":**

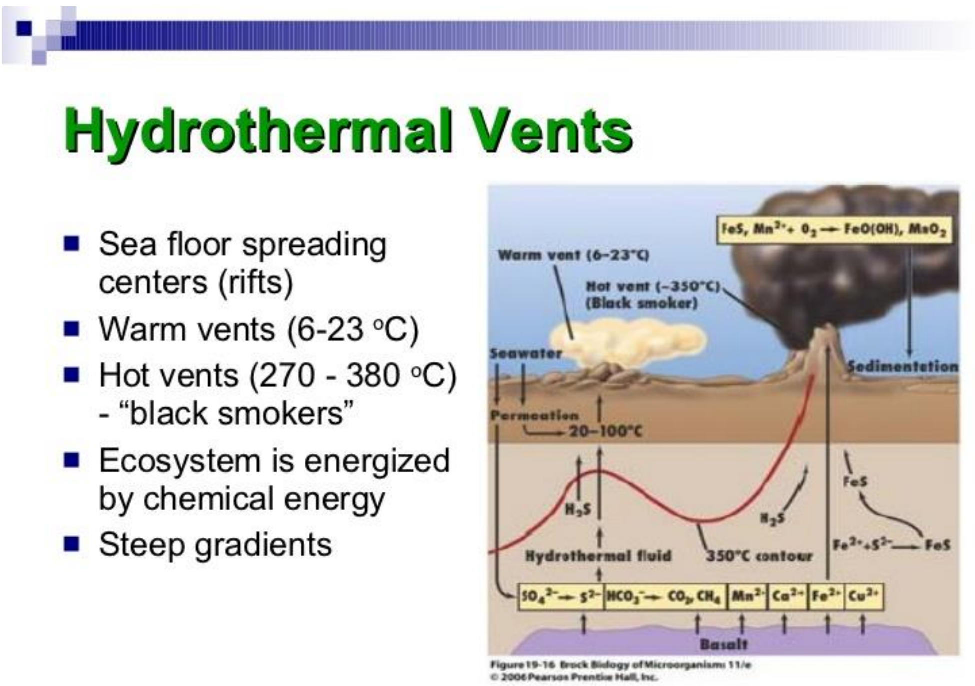


Figure 38

Before I leave this section I will at least mention that there is of course a possibility that the meteor was also auferious (gold bearing).

What's Down Dip?

What we know so far is that the conglomerates are getting thicker and that we encountered a new sequence, the Comet Well sequence, underneath the Purdy's Reward sequence. We also know that we are encountering large boulders in the Powerline area.

- Are we currently at a boulder front/debris flow that will subside?

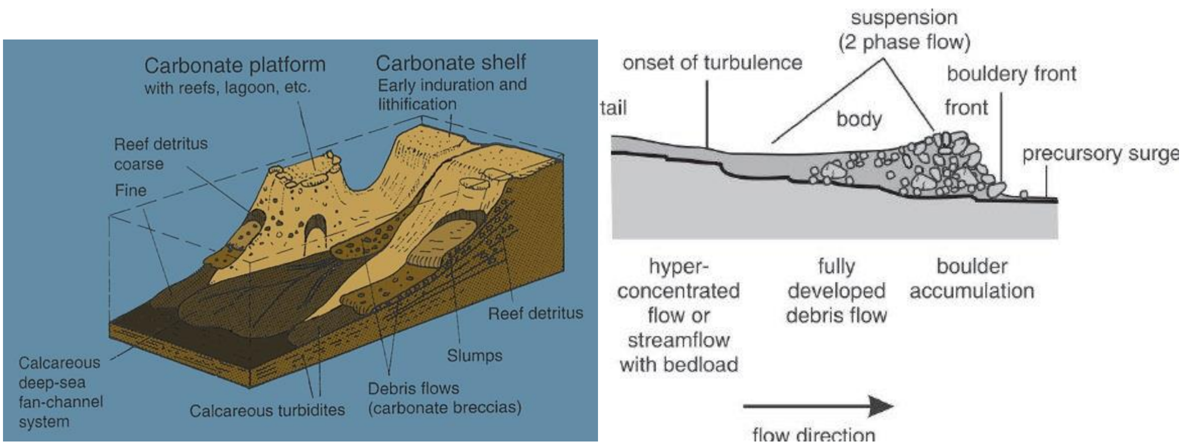


Figure 39

- Will we see finer gold in the upper parts of the Powerline conglomerates?

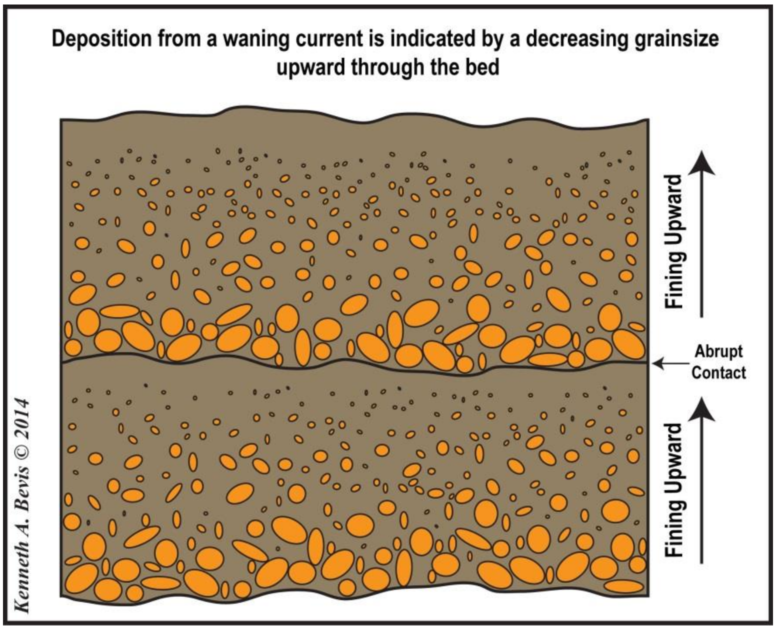


Figure 40

- Will it evolve and grow even thicker? More layers?

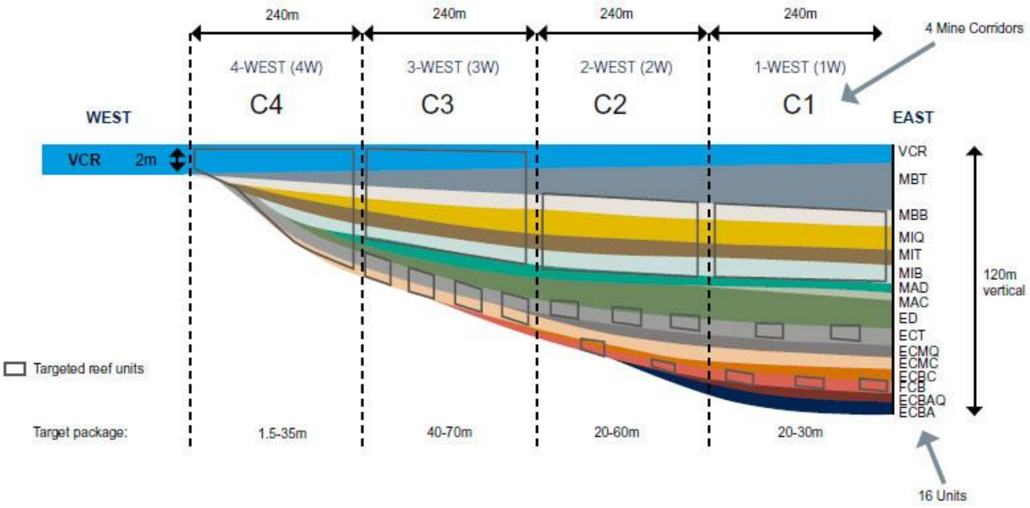


Figure 41

What did the meteor hit?

I'm open to the idea that there is at least a possibility that the meteor struck an area that was already submerged and under water as per the "Sholl subduction", and thus might have already been experiencing gold deposition (through precipitation). Whatever the meteor hit should still be down there since it has been shielded form erosion ever since. If this basin is as rich and extensive as it looks, it would probably just be considered potential icing on the cake though. With that said, Artemis recently stated they are going to drill a very deep hole down dip.

I also found an interesting paper regarding the mineralization in Witwatersrand and how the underlying gold deposits could have been altered:

Abstract

The Witwatersrand 'basin' is the largest known gold province in the world. The gold deposits have been worked for moren than 100 years but there is still controversy about the ore forming process. Detailed petrographic studies often reveal that the gold is late in the paragenetic sequence, which has led many researchers to propose a hydrothermal origin for the gold. However, observations, such as the occurrence of rounded, disc-like gold particles next to irregularly shaped or idiomorphic secondary gold particles in the same sample, suggest an initial detrital gold source within the Witwatersrand strata. Mineral chemical and isotopic data, together with SEM cathodoluminescence imaging and fluid inclusion studies, provide evidence for small-scale variations in the fluid chemistry – a requirement for the short-range mobilization of the gold. The existing data and observations on the Witwatersrand rocks support a model of hydrothermally altered, metamorphosed placer deposits, with at least two subsequent gold mobilization events: hydrothermal infiltration in early Transvaal time (2.6–2.5 Ga) and during the 2.020 Ga Vredefort impact event.

Meteor discussion

First of all it seems obvious that Novo has staked the edges (thus closest to surface) of what looks to be a basin or sub-basin made of an impact structure that was created during the Archean era, pre Mount Roe (Fortescue) depositon. Literature on the subject suggests that meteoric impacts have been known to produce hydrothermal systems and volcanism, inside and around the structure. Potential cracks in the underlying rocks may also help to keep the area well circulated and provide "housing" for different kinds of microbial life. All this should be positives in terms of both providing rich hydrothermal sources as well as nurturing primitive life.

I could also see this "artificial" basin being a positive in terms of the odds for this gold system to be relatively symmetrical. This isn't an ordinary basin (or sub-basin) that was created "willy-nilly" by earthly processes; this was a meteoric impact that affected all areas around the impact spot in a ring pattern. It could have plugged holes and lows and leveled highs, thus creating a more homogenous "bowl" in the crust. This makes (at least) me think that the odds are better in terms of potential for whatever mechanisms that deposited gold at Purdy's and Comet Well to be present in many more places in this basin.

Also, who knows, maybe a meteor impact could have "re-activated" the Sholl Shear Zone and adjacent faults?

Western Australia Department of Mines Presentation

The Department of Mines, Industry Regulation and Safety (DMIRS) has recently come out with a juicy presentation that sums up a lot of geological info regarding the Pilbara play:

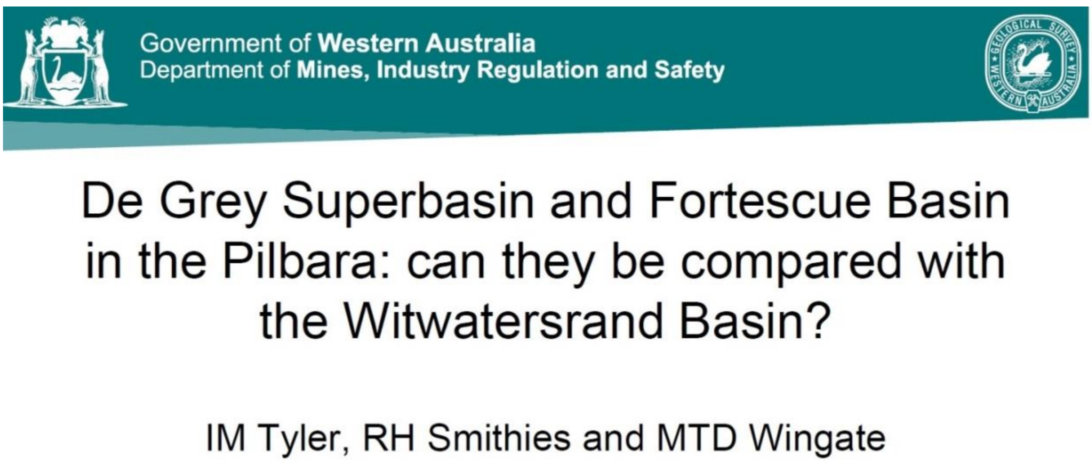


Figure 42

First thing to notice is that it doesn't only states the question if the Fortescue Basin can be compared to the Witwatersrand Basin, but also the De Grey Superbasin.

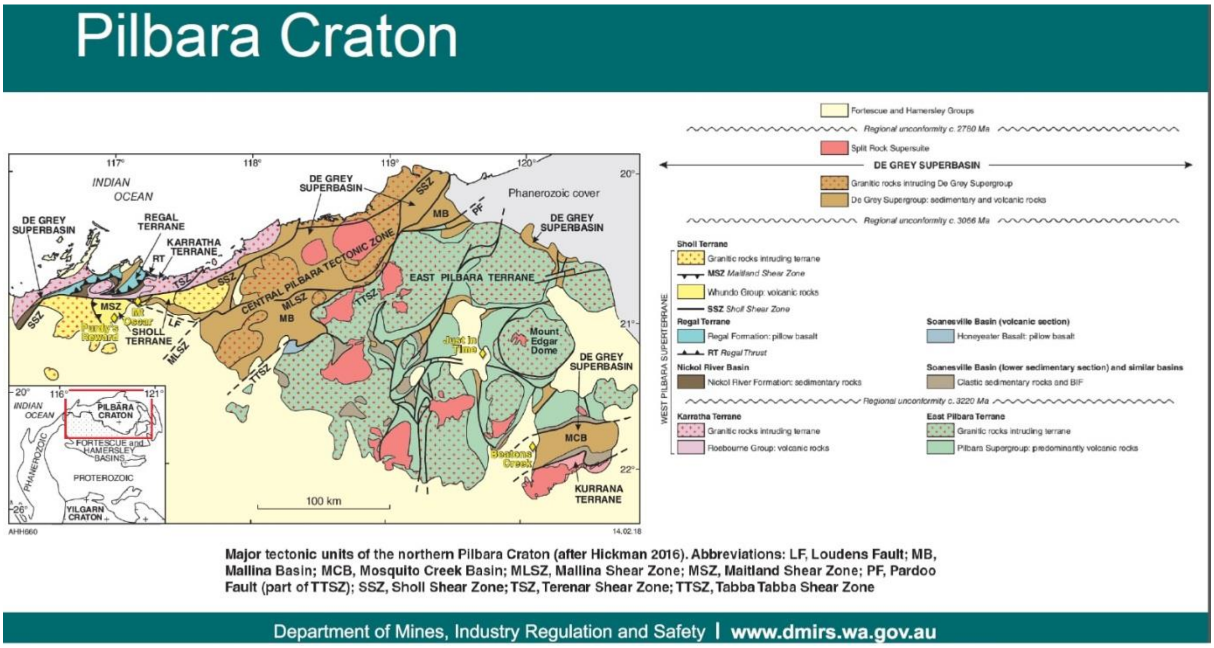


Figure 43

This is the same geological map that was shown earlier but with more detail in terms of dating and when where regional unconformities, three in total, are present in the Pilbara Craton. According to Quinton the "Great Gold Deposition Event" started around 3.0 Ga, which perhaps leaves especially the oldest unconformity, less prospective. Unconformities are breaks in sedimentary geological records and should be prime targets in the hunt for gold bearing "Wits like" conglomerates as per the West African producer Goldfields:

The reefs, which are generally less than 2 metres thick, are widely considered to represent extensive fluvial fans. Deposition took place along the interface between a fluvial system that brought the sediments and heavy minerals from an elevated source-area and a lacustrine littoral system that reworked the material and redistributed the finer sediments along the shoreline of an intracratonic lake or shallow water inland sea. The gold is mainly of detrital origin, deposited syngenetically with the conglomerates and interrelated with sedimentary features such as unconformities and fluvial channels.

There are different types, but the next picture illustrating a "Nonconformity", might be an example of how the sedimentation looks like inside Novo's (potential) impact structure setting:

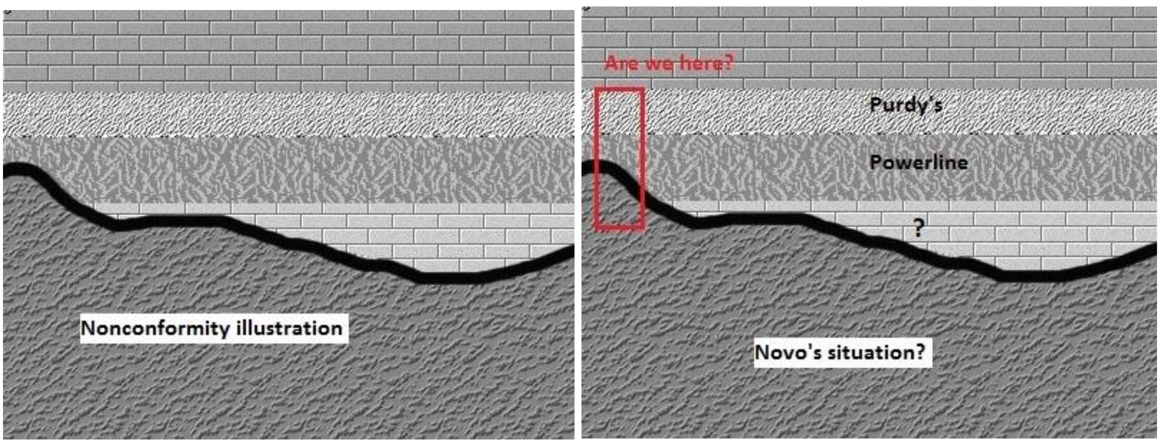


Figure 44

It certainly rhymes with the fact that as we go down dip, we are finding that the Purdy's Reward sequence sits on top of the new Powerline (Comet Well) sequence, which also seems to get thicker. The sequences are probably steeper than in the picture above though, ie not sitting perfectly horizontal.

Now, back to the DMIRS presentation:

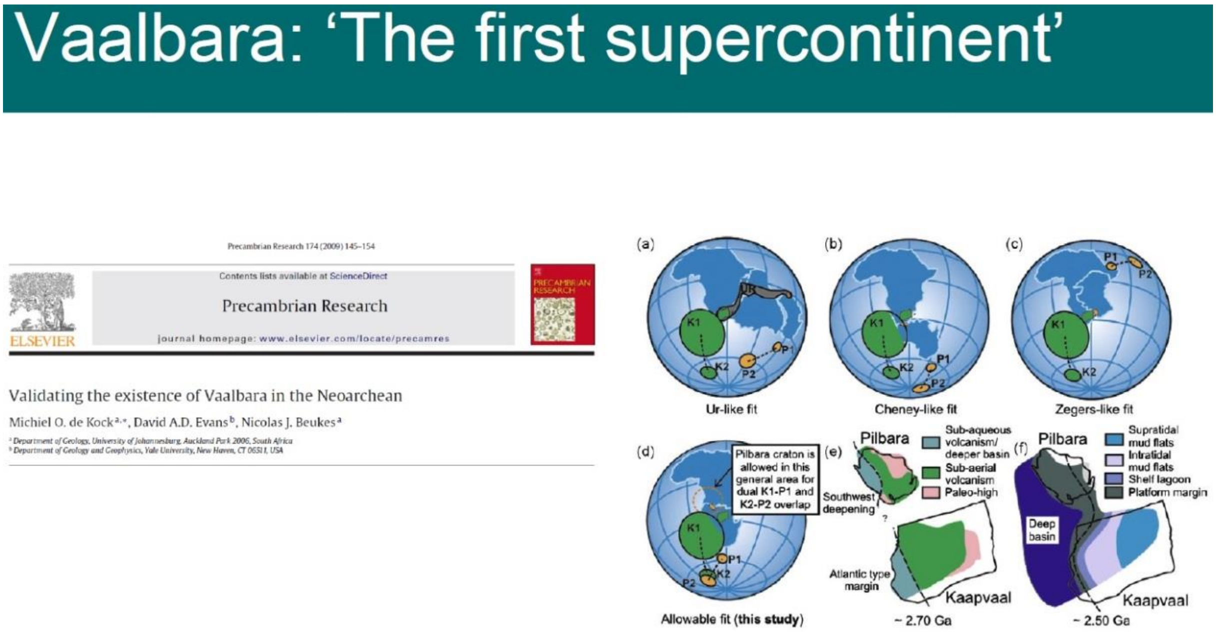


Figure 45

If the schematic above is correct, then south-west and south Pilbara was still fully submerged under water around the time that Mount Roe Basalt flooded the Pilbara Craton as per the "sub-aqueous/deeper basin". Thus, one can assume that these areas had more "time under water" than the other parts of Pilbara during this time, not to mention the time equivalent Ventersdorp Contact Reef in the Witwatersrand Basin. Also note the "Paleo-high" located around the northern rim, basically along the periodically active Sholl Shear Zone where many magmatic events etc took place. As for the impact structure near Karratha, that potential "bowl" was approximately centered at the "Southwest deepening" line. If that is the case, then that would mean that the northern rim (which Novo staked) might have been kind of a "shielded" lagoon, bay or inland basin setting:

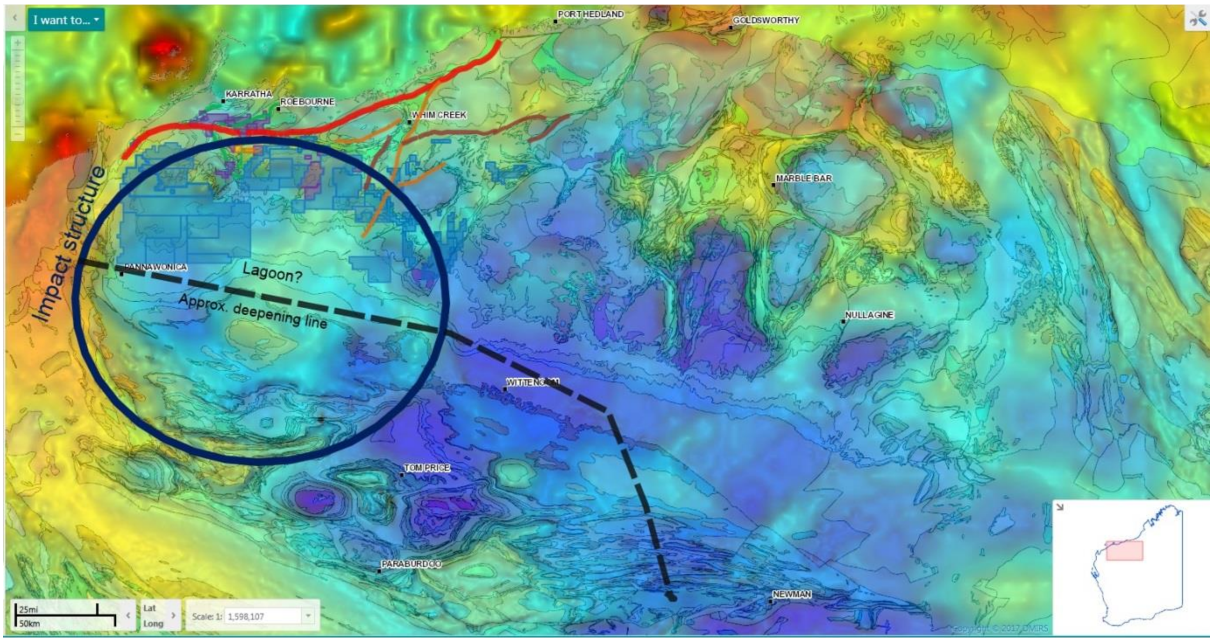


Figure 46

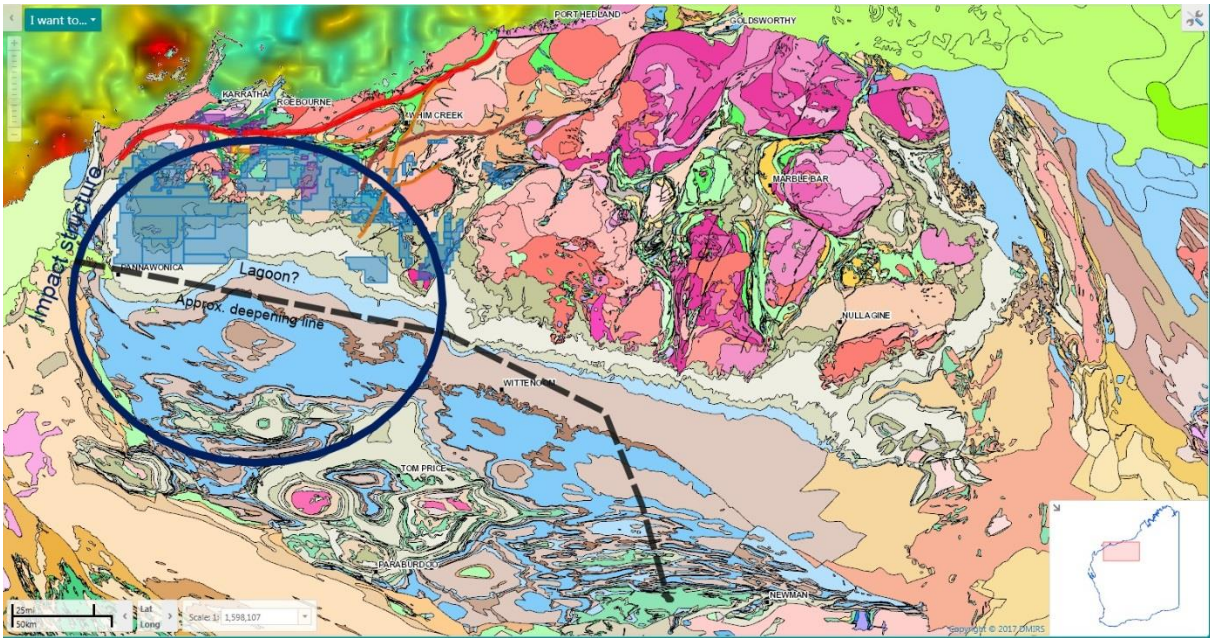


Figure 47

Keep in mind that the line I drew is just an approximation (and not all Novo's claims are mapped out), but the line sort of fits with the Hardey Formation "erosion front" as well. The top half of that impact structure might have been a near shore marine bay or lagoon just up until the Mt Roe Basalts flooded the area that was located between the "deepening line" and a "Paleo-high". This bay/lagoon might have been "well fed", in terms of rich hydrothermal fluids, magmatism, meteoric water and microbial life, with the help of gravity, subduction zone activity and impact structure dynamics. The bottom half of that circle, south of the "deepening line", probably has very thick sedimentation. In that area, any potential Mt Roe conglomerates might be located extremely deep. Thus I am starting to believe that Novo and Artemis own most of this "crown jewel" in Pilbara.

Note that the slide showing the “deepening line” was an illustration of how Pilbara might have looked 2.7 billion years ago, possibly pre-Fortescue deposition, thus we cannot know exactly what Pilbara looked like when these gold bearing conglomerates first started to be laid down. All I know is that an impact structure seem to have formed pre-Fortescue depositon and that this area could have seen a bay, lagoon or basin setting. It is also possible that the setting changed back and forth over millions of years, and thus any gold bearing conglomerates might have different deposition mechanics.

Another visual with linear structures, mineral occurrences and the “Paleo-high” mapped:

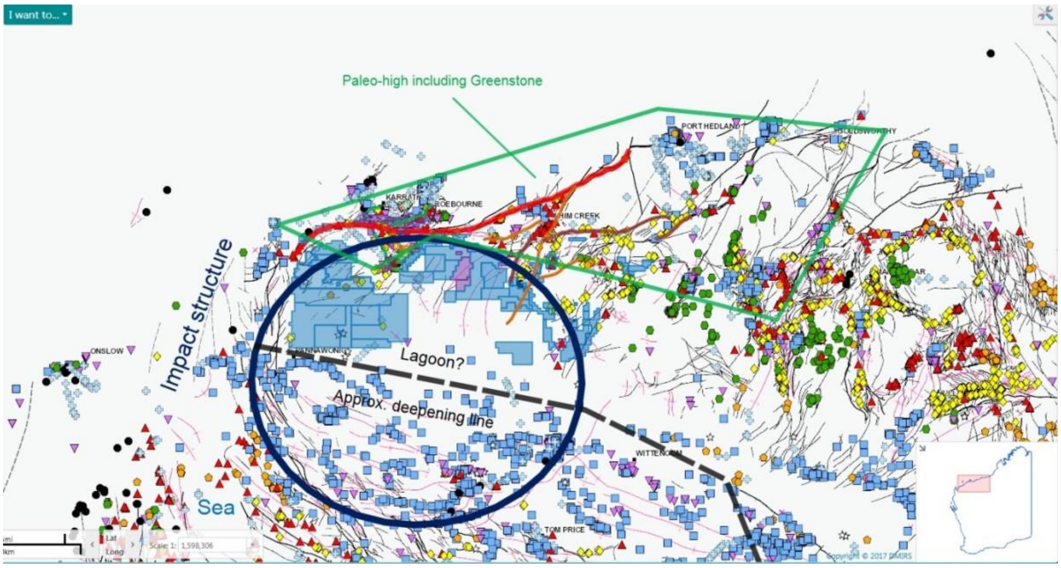


Figure 48

Now, let’s go back to the presentation:

Additonal prospects

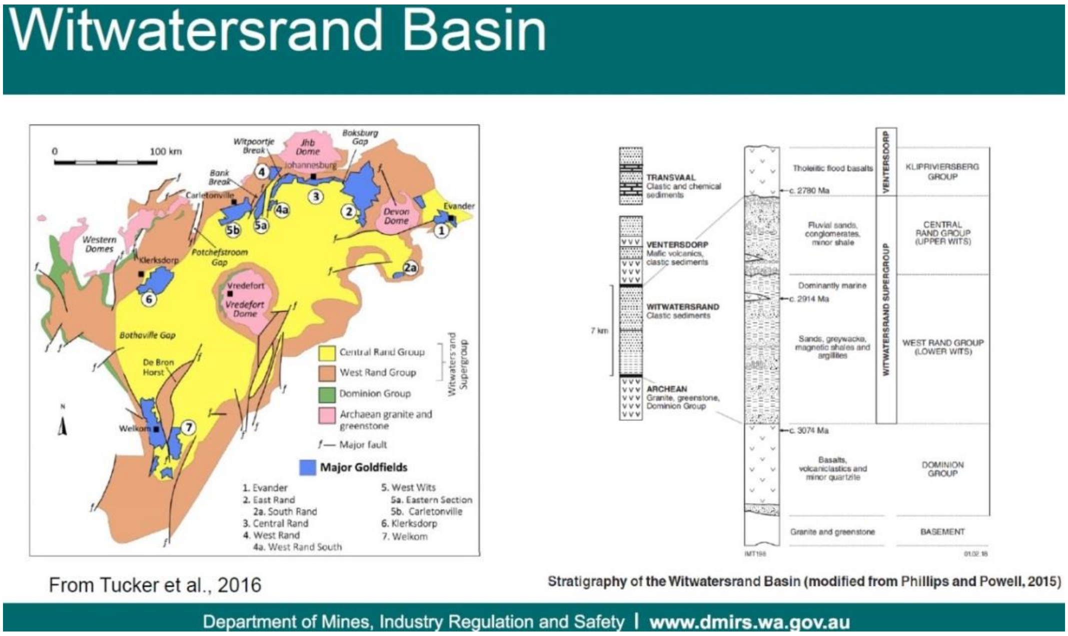


Figure 49

This slide includes mapping of the different gold bearing sequences in the Witswatersrand Basin as well as the chronological profile of the strata. Some of the gold bearing conglomerates in Witswatersrand is 3 billion years old, which should be a big positive in terms of the potential for finding gold bearing conglomerates in the De Grey Superbasin that is widespread in Central Pilbara (mainly between the Sholl Shear Zone and the Tabba Tabba Shear Zone):

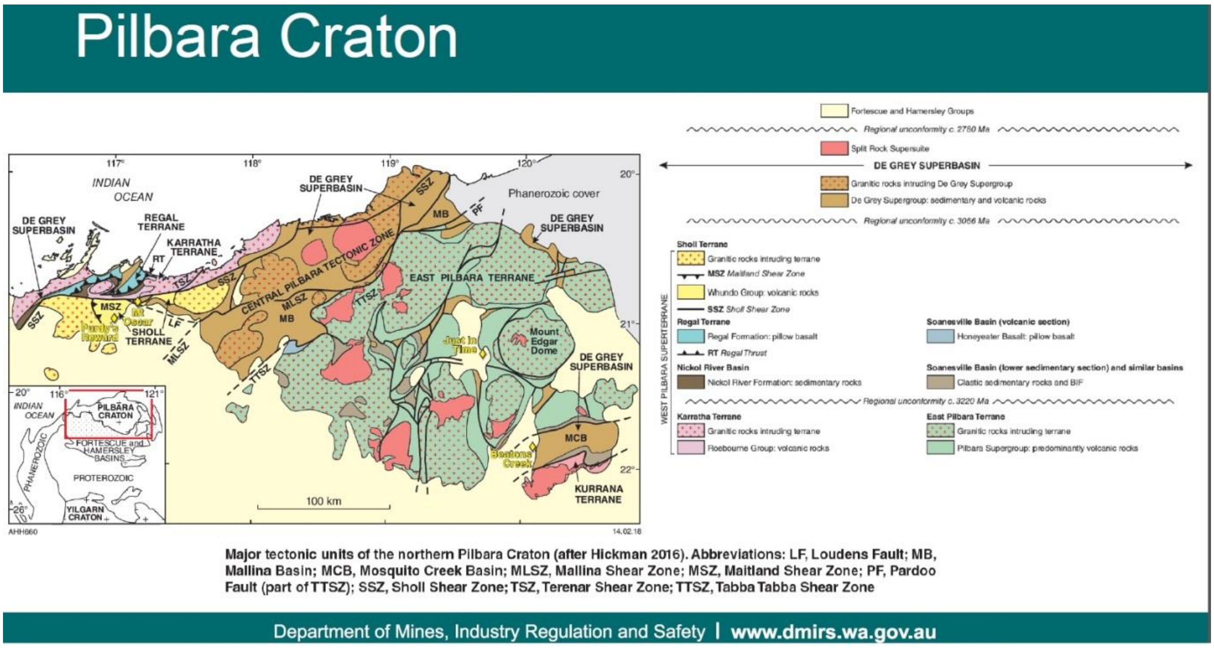


Figure 50

The potential for even older gold bearing horizons within the De Grey Superbasin is the only rationale I can find in order to explain some of Novo's staking in Central Pilbara. The strata under the Constantine Sandstones seem to be the main (widespread) target:

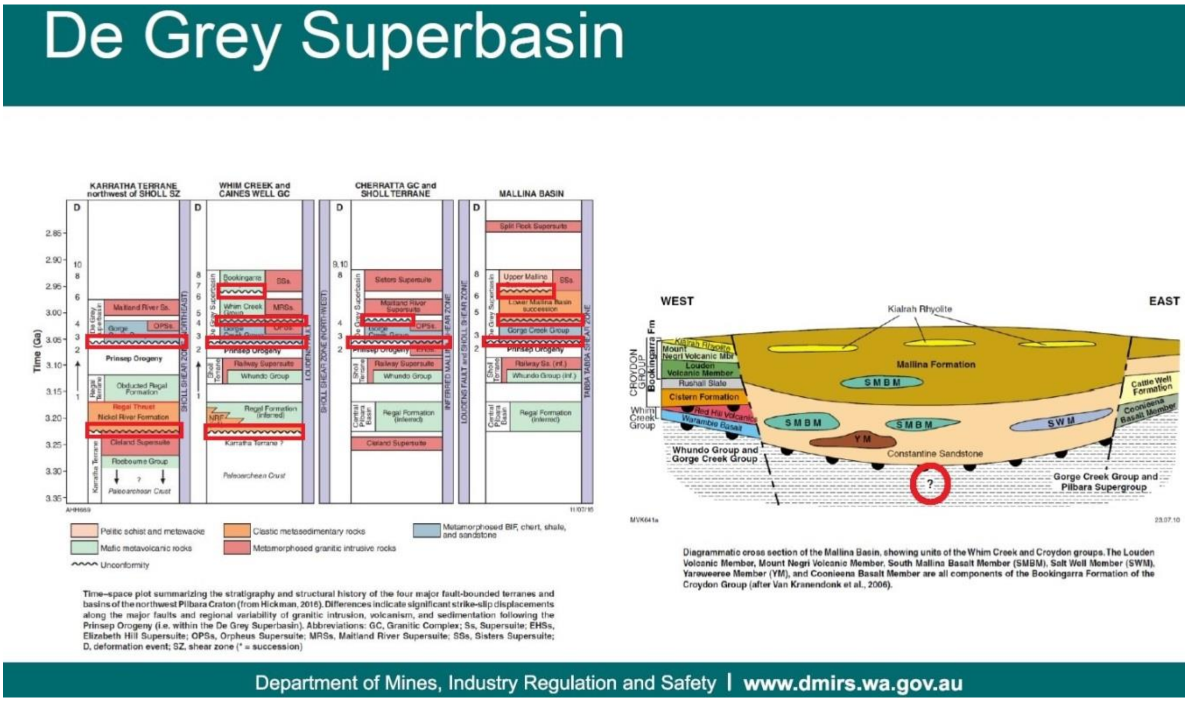


Figure 51

As you can see in the slide above, there are a number of unconformities mapped in the De grey Superbasin with different profiles in terms of location, extent and age. With some of the staking we have seen, coupled with mineral occurrences in West and Central Pilbara, it does seem that the conglomerates sitting directly under Mt Roe Basalt might not be the only gold bearing horizons.

Novo's staking in the Central Pilbara:

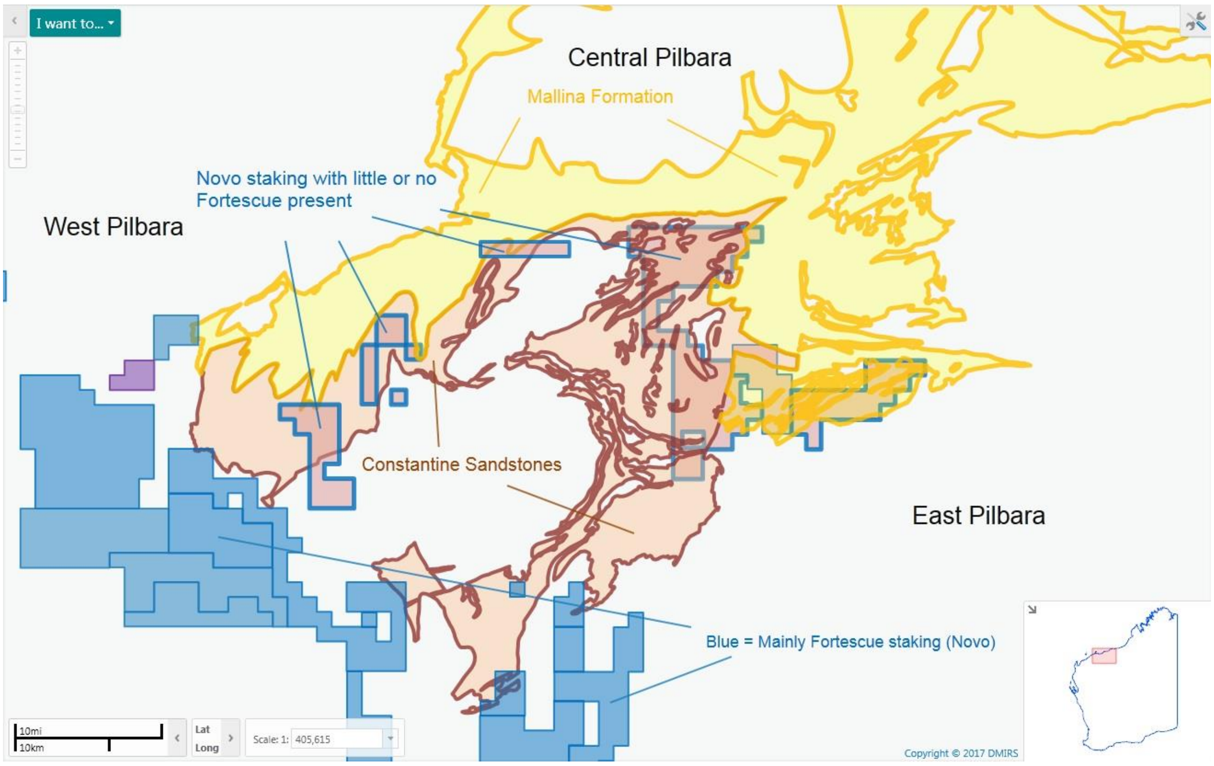


Figure 52

Same area with mapped mineral occurrences:

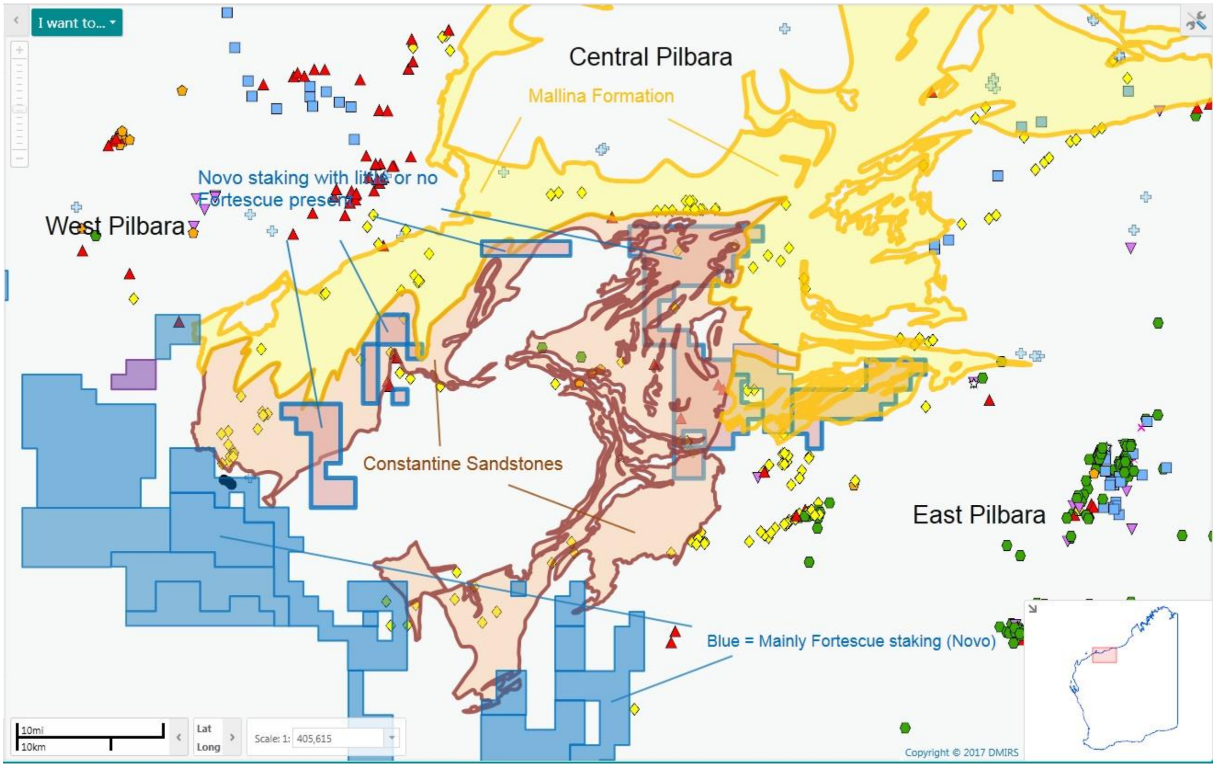


Figure 53

It's probably worth pointing out that some of those gold prospects located on mapped Constantine Sandstones mentions "scraping", "gravel" and even "gold nuggets reported for area". Also, Novo staked some ground (not shown in the picture above) that is located north of the Sholl Shear Zone that has no Fortescue or Mallina Formation etc mapped in the area.

What does it all mean?

Well, I think that the Pilbara Gold Rush will transform in the not too distant future and will start to include "Wits type" gold targets from older sequences, older than the conglomerates sitting directly under Mount Roe that is, thus not only being limited to the Fortescue Group (Mt Roe).

CRA's drill holes from the 1980s when they hunted for "Wits gold" in the Pilbara:

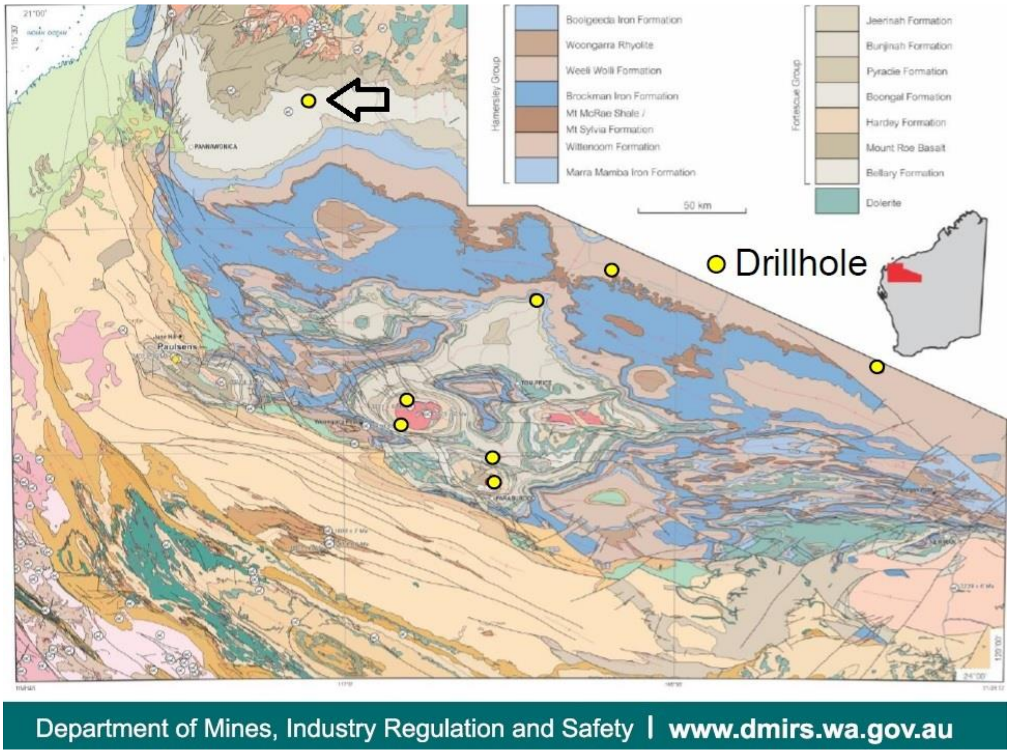


Figure 54

For starters, every single hole seen in the picture above was drilled outside the impact structure, except the one that is marked with an arrow. That hole started drilling on what is mapped as Maddina Basalt, and that's a whole lot of rock to drill through, to hit the potential pay zone under Mt Roe:

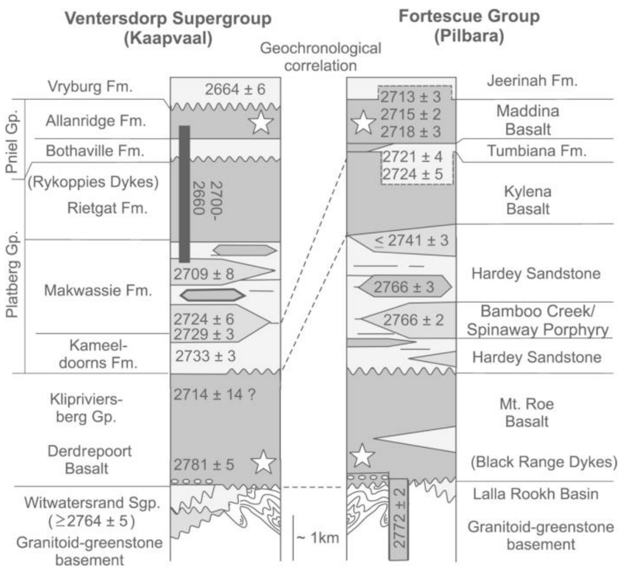


Figure 55

No wonder that hole wasn't drilled deep enough to hit what is the main target today.

Another interesting slide from the DMIRS presentation showing Hardey Formation "palaeocurrent trends":

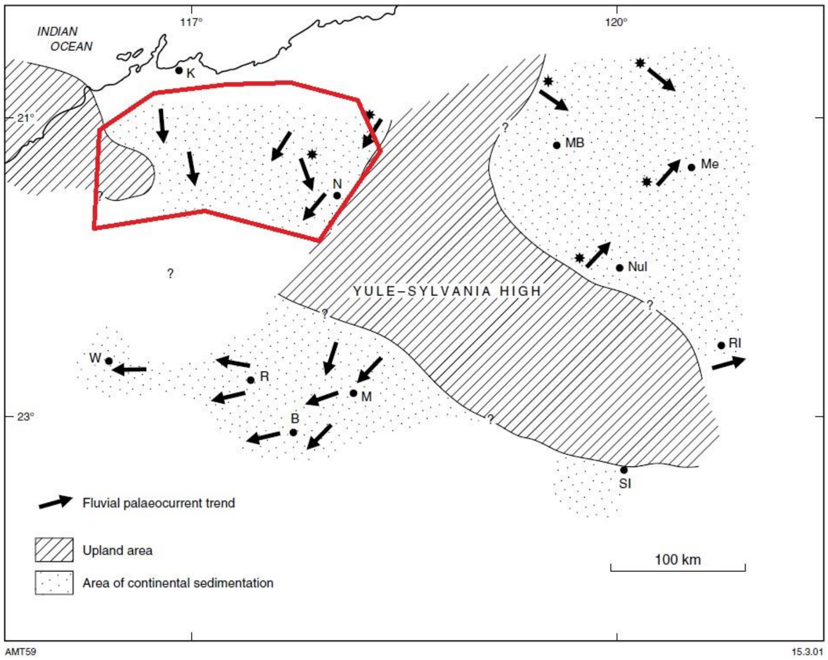


Figure 56

Inside the area marked in red is where most of the claims that Novo has staked are located. So, at least Hardey Formation's fluvial palaecurrents mainly trended south from the Sholl Shear Zone and somewhat parallel to the Tabba Tabba Shear Zone onto Novo's (and Artemis's) lands. At least into the claims of the Pilbara juniors who are located in the West and Central Pilbara. This paper I found seems to agree:

Rocklea Dome are generally weakly reflective, although a number of prominent southwest-dipping to flat-lying reflections are recorded at depth. These reflections are interpreted as discontinuous greenstone sheets within the granitic crust.

The Fortescue Group is most prominent in the north-eastern part of the section (Figures 6, 9) where it dips gently to the southwest, and is imaged as a series of weak to strong, layered reflections. Based on their seismic reflectivity, three units can be recognised within the Fortescue Group: a lower layer of weak reflections 0.25 s TWT (~0.8 km) thick that possibly corresponds to sedimentary rocks of the Hardey Formation; a middle layer of strong reflections 0.7 s TWT (~2.2 km) thick that equates to the mostly basaltic rocks of the Boongal, Pyradie and lower Bunjinah formations; and an upper layer of weak reflections 0.5 s TWT (~1.4 km) thick, which includes the upper Bunjinah Formation and Jeerinah Formation. Although the seismic reflections lose some of their definition beneath the Turner Syncline, they suggest a southwesterly thickening of the Fortescue Group from about 1.5 s TWT (~4.5 km) to about 2 s TWT (~6 km) approaching the Moona Fault. The seismic data also suggest that a section of the Hamersley Group about 1 s TWT (~3 km) thick is preserved in the Turner Syncline.

A thick, almost complete, succession of the Fortescue Group crops out on the southwestern limb of the Rocklea

I also found an interesting paper that said this about the younger "Tumbiana Formation":

Highlights

- The 2.72 Ga Tumbiana Formation was deposited in fluvial and lacustrine environments.
- Deposition may have been in an inward-draining continental basin.
- Conical stromatolite morphologies are anomalously little depleted in ^{13}C.
- Contribution of organic matter from phototrophic versus methane cycling metabolisms.

Abstract

The 2.72 Ga Tumbiana Formation is a succession of clastic and carbonate rocks outcropping along the southern margin of the Pilbara Craton in Western Australia. It hosts abundant, diverse and exceptionally well-preserved stromatolites and has provided the setting for numerous investigations focussing on the Archaean biosphere. Despite its palaeobiological significance, the overall depositional setting of the Tumbiana Formation remains unclear. Here we present the results of stratigraphic, sedimentological and geochemical investigation of the Tumbiana Formation in the well-known Redmont/“Knossos” area and at several localities in the northwestern Pilbara sub-basin. We suggest these data are best explained by deposition in fluvial and lacustrine environments of an inward-draining continental basin. $\delta^{13}C_{org}$ values vary from −49.9‰ to −15.0‰. Conical stromatolite morphologies, commonly attributed to cyanobacteria, are anomalously little depleted in $^{13}C_{org}$, implying a higher relative contribution of organic matter from phototrophic versus methane cycling metabolisms.

The Tumbiana Formation is a bit younger than the Mt Roe Basalts but it may still be a good sign as to what kind of environment was present in the area around 2.7 billion years ago. This next slide shows where we have Tumbiana outcropping today:

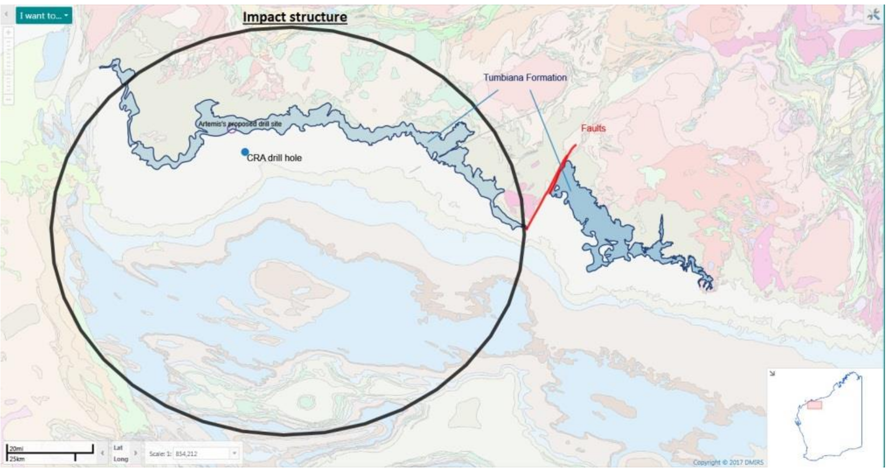


Figure 57

… It does seem to fit with the impact structure and Novo’s staking. Novo has staked pretty much all of the area in the top half of that impact structure, up until the red fault lines. Might the eastern part have been included in the “inward-draining contintental basin”? We don’t know, but Novo has not staked any ground east of that line. It rhymes with the notion of West and Central Pilbara having been "subdued" (Basically the area between the Sholl Shear Zone and the Tabba Tabba Shear Zone).

Now back to the DMIRS presentation and what it has to say about the Sholl Shear Zone:

Sholl Shear Zone

- Crustal-scale structure
- Reactivated suture (Prinsep Orogeny/North Pilbara Orogeny)
- Pathway for volcanism and mineralization from underlying subduction-modified mantle
- 250 m.y. history
  - basin formation, volcanism, mineralization, metamorphism, fluid flow, and folding and faulting

… All that activity and over such a long time period (250 million years!) is something I would think could be VERY beneficial, especially for an impact structure that lies down dip from the Sholl Shear Zone, and seems to have fluvial palaeocurrents heading down into the structure (basin/bay/lagoon).

More "West is best" Signs

Novo's Marble Bar JV claims in 2015:

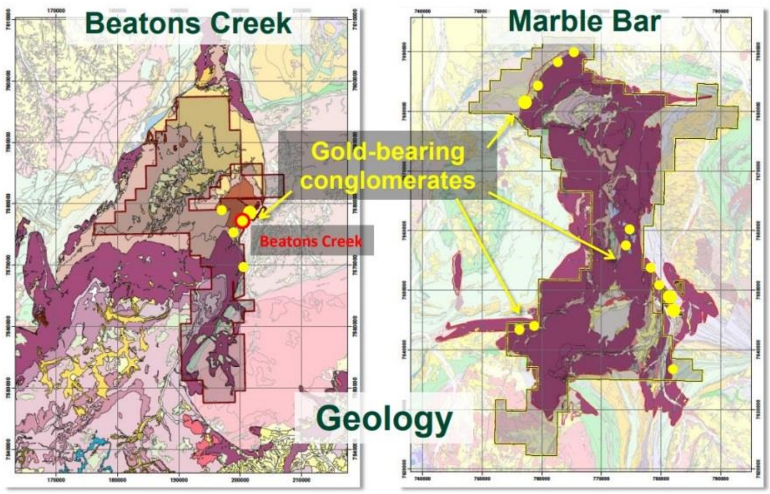


Figure 58

Novo's Marble Bar claims today:

Figure 59

… If there is no particular explanation that I'm not aware of I guess these slides would further cement the notion that "West is best". Also, if you remember the first gravity slide, it showed that the center of the Marble Bar Fortescue Group was located at the highest gravity peaks. This it seems that Novo "kept" the claims where the gravity readings were decreasing, possibly due to the possibility for thicker sediments and conglomerates being present.

- **How the geology under the Mt Roe Basalts differs between Marble Bar (East) and the Bellary Formation in the south-west Pilbara:**

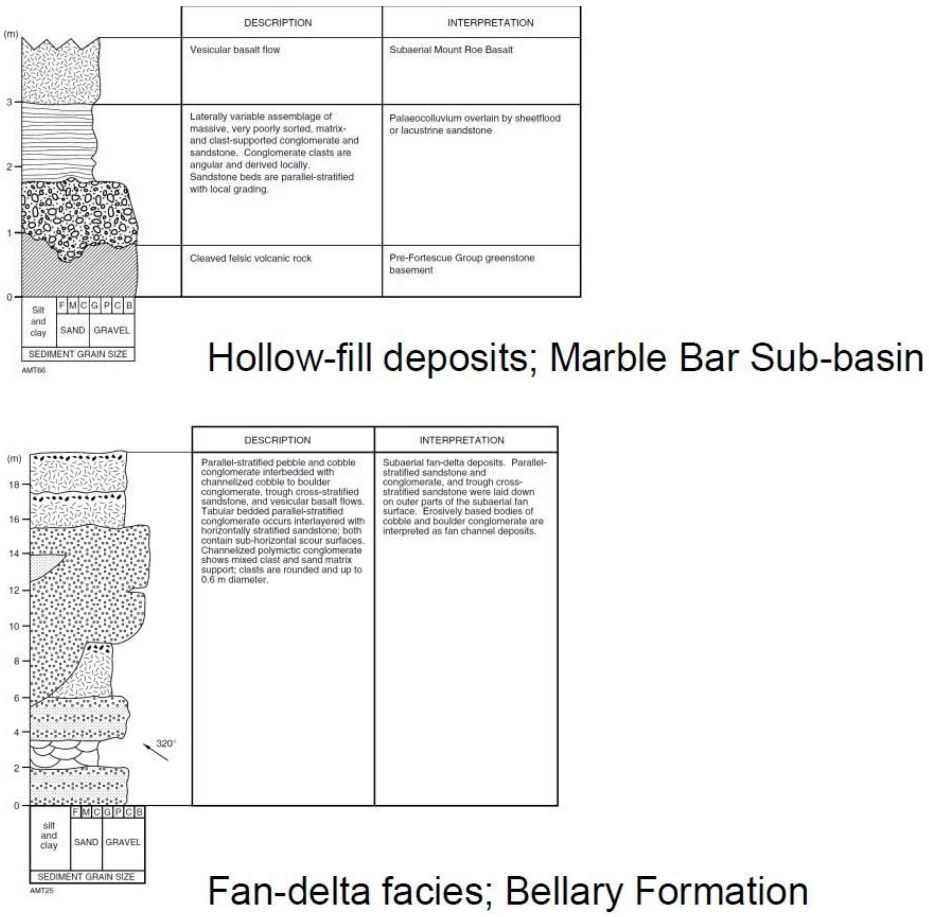


Figure 60

- **An illustration:**

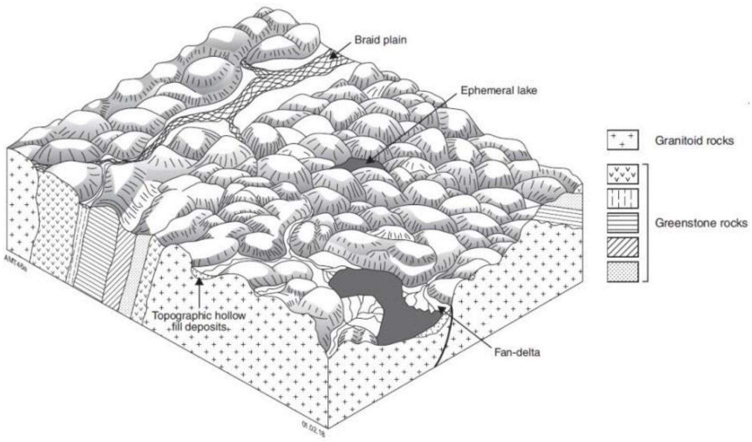


Figure 61

More "West is best" lingo (south west to be exact):

Hyaloclastite flow tops are common. These features, together with the nature of intercalated sedimentary units, provide evidence that most of the Warrawoona and Whim Creek Groups erupted in subaqueous, probably submarine, conditions. Possible exceptions are some basalts from the Warambie unit, which are amygdaloidal and rarely pillowed and appear to have erupted subaerially or in shallow waters.

The Fortescue volcanic rocks are mainly subaerial. In the northern part of the Pilbara craton, rare pillowed flows and interlayered tuffs and clastic sedimentary rocks provide evidence for the local presence of shallow water, but the great majority of the flows are thick and massive, in places columnar jointed, and commonly highly amygdaloidal. The presence of paleoregoliths within the Mount Roe Basalt provides additional evidence of subaerial eruption. In the southern part of the Pilbara craton, however, stratigraphically equivalent units such as the Mount Jope sequence appear to have erupted subaqueously.

As in other Archean greenstone belts, the distinction between tholeiites and komatiitic basalts is often arbitrary, because the two types of basalt have similar mineral and major element compositions. To achieve a distinction requires the use

Surprisingly little has been published on the petrology and chemical compositions of komatiites from the Pilbara craton. The only adequately documented examples of true ultramafic lavas are the ultramafic flows and pyroclastic rocks from the Ruth Well Formation in the western part of the Pilbara craton. Nisbet and Chinner (1981) briefly described these rocks and presented some chemical diagrams as well as an interesting petrogenetic model. Unpublished information from G.A. Chinner and E.G. Nisbet (personal commun. 1984) and our own descriptions and analyses reveal that the komatiites differentiated after eruption into upper sections of olivine spinifex rocks and lower sections of olivine cumulate rocks. Although many of these rocks are altered to the extent that no primary minerals are preserved, the shape and distribution of relict grains clearly indicate that olivine was the principal mineral in both spinifex and cumulate lavas.

The overall abundance of komatiite in the eastern Pilbara sequences is unclear. Barley (1993, p. 52) stated that "no well-developed komatiitic successions have been recognized" in the Warrawoona Group and that "aphanitic or sparsely phyric lavas

Artemis Resources Deep Drill Hole

Artemis recently came out with a news release that stated:

Gold Target

11km to the south-east of the proposed ASD-1 hole, CRA Exploration Pty Ltd drilled a 2,269.95 metre diamond drill hole DDH84MF#1 in 1984/85 and intersected 0.5 metres grading 10.67 g/t Au from 1,756m[1]. Artemis has inspected the core from this drill hole at the GSWA Core Library, and believes the hole needs to be drilled deeper.

David Lenigas, Artemis's Executive Chairman, commented;

"This is a very exciting super-deep hole for Artemis and the drilling of this hole should help answer many questions surrounding the geology and rock sequences in the Pilbara Basin. The Pilbara Region of Western Australia is one of the most resource rich areas in Australia and there has been very little exploration at depth. In essence, Western Australia has been spoilt for choice for shallow mineral wealth. It's time that someone started looking for the source of a lot of mineralisation in the Western Pilbara that has fed the many surface deposits of Cobalt, Nickel, Copper, Zinc, Gold and PGE's, within Artemis' extensive tenement package south of Karratha."

"It will also be very interesting to see if we can find continuity of the gold recorded at around 1,756m in the nearby CRA hole[1] that was drilled back in 1984/85 as we drill this hole to test for the potential of base metals, gold and diamonds."

… So they are set to drill deeper than the Hardey Formation, into and potentially past, the Mt Roe Basalt conglomerates. If the conglomerates are there, then we might get some sense of thickness and also find out if we are getting some fine gold help at that location, which should be many kilometers down dip. An obvious bonus would of course be if we either, a) found some kind of algal mats and/or, b) found some finer mineralization and/or c) found say some kind of big orogenic gold deposit that acted as a feeder for the bay/lagoon/basin.

Let's take a closer look on the area where they are drilling and how it relates to the old CRA drill hole:

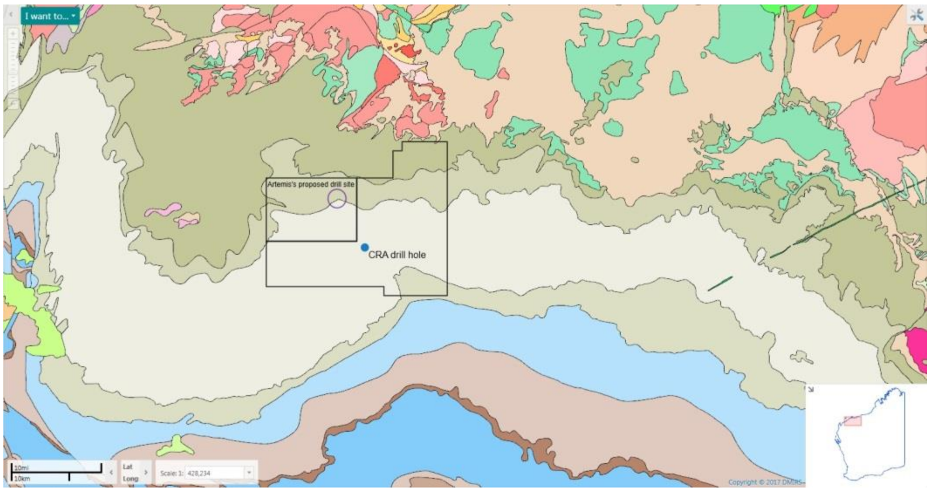


Figure 62

… The drill should start at an area where the Maddina Basalts (light grey) have practically eroded away already, and still they have decided to drill much deeper, which is very interesting.

How it looks when we apply a gravity filter:

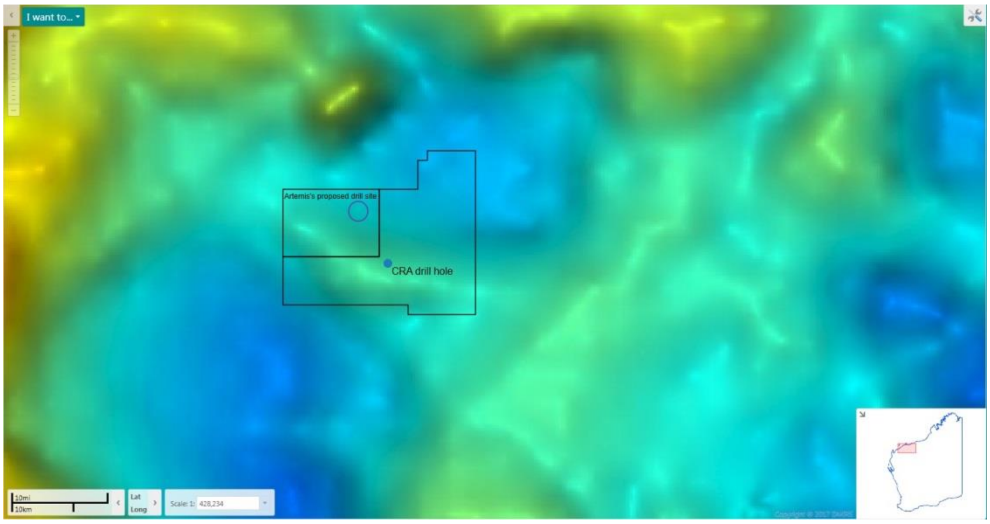


Figure 63

… And close up:

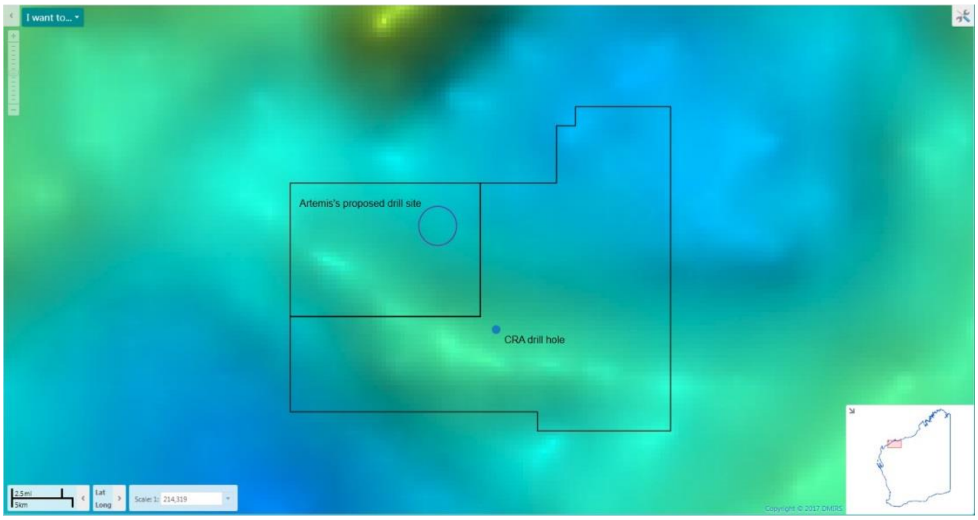


Figure 64

Now it starts to look really interesting. It seems the CRA hole was drilled pretty much over a gravity high "ridge" of sorts. Not only that, but Artemis is now set to drill even deeper where a) There should be less covering rock with due to heavier Maddina erosion, b) we have a lower gravity signature. All this taken together tells me that Artemis is drilling a spot that looks to potentially host much thicker sedimentation and potentially conglomerates. Why else would they start at a lower stratigraphic level AND drill more than 1km deeper than CRA did in the 1980s? It is also worth mentioning that Artemis believes that the CRA hole did not reach basement.

Seems Artemis is swinging big with a high cost/high reward hole. If they would hit the gold bearing conglomerates down there on the first try then our inferred down dip strike would jump to tens of kilometers all of a sudden.

One last highly speculative thought on the matter: I wonder if they will even try to test what might be below the "basement". I mean, we still have no idea what the meteor hit since the area south of the Sholl Shear Zone got “subsided” during the pre-Fortescue subduction episodes which was described in the subduction section earlier.

Discussion

Pilbara seem to have all the ingredients for a gold precipitation event…

What we know:

1. Right time:
    a. Deposited during the great gold deposition time window (Around 3.0 – 2.7 Ga)
2. Right place
    a. Some of the earliest signs of life have been found in Pilbara
    b. Cyanobacteria and stromatolites
    c. Was part of the continent of Ur
3. Been tectonically dead for a long time

Additional potentially positive factors concerning mainly West and Central Pilbara:

1. **Meteor impact (Karratha)**
    a. Potentially created cracks and hydrothermal vents that also sustained early life.
    b. Potentially created a homogenous basin that sustained early life and sediment concentration.
    c. The meteor was potentially endowed with metals and minerals.
    d. The meteor impact could have set off magmatism sourced from the mantle.

2. **Subduction zones (West and Central Pilbara)**
    a. Potential for magmatism.
    b. Potential for hydrothermal activity.
    c. Potentially made this part of Pilbara more of a bay/lagoon environment with insitu- or close by, enriching gold sources.
    d. Potentially created a Paleo-high including Greenstone etc.

How Novo’s (and Artemis’s) main areas differs from the Wits:

1. A meteor impact probably hit the western Pilbara Craton and created a basin or a sub-basin.
    a. An impact structure is a unique setting for multiple reasons.
2. The Witwatersrand basin got hit with a meteor AFTER the gold rich Archean conglomerates had already been laid down.
3. The Witwatersrand basin had no apparent subduction zones in or very near the gold fields.
    a. West- and Central Pilbara had a periodically active major shear zone directly “up dip” (SSZ) and more major shear zones to the east (TTSZ etc) along with related faults etc.

All this makes me at least entertain the thought that Pilbara could be a Witwatersrand type gold field, but on steroids, due to potentially several factors having provided Pilbara with nearby gold rich sources. We potentially have a “shielded” bay/lagoon/basin setting inside the impact structure that might be biologically richer due to; 1) impact fractures creating a well circulated hydrothermal systems and possibly magmatism, 2) that is located between the sea and a nearby Paleo-high (greenstone etc), 3) that possibly came to be via intra-oceanic volcanism that resulted from multiple periods of subduction eposides, and also spurred hydrothermal activity and volcanism, 4) This Paleo-high made up of greenstones etc would probably have seen meteoric water trickling down into the bay/lagoon/basin as well, 5) has the potential for orogenic gold sources located near and/or inside the basin.

To sum up I basically think we may very well have some, if not all, theories (hydrothermal, placer & precipitation) as to why the Witwatersrand is loaded with gold covered in Pilbara, especially in the Karratha area:

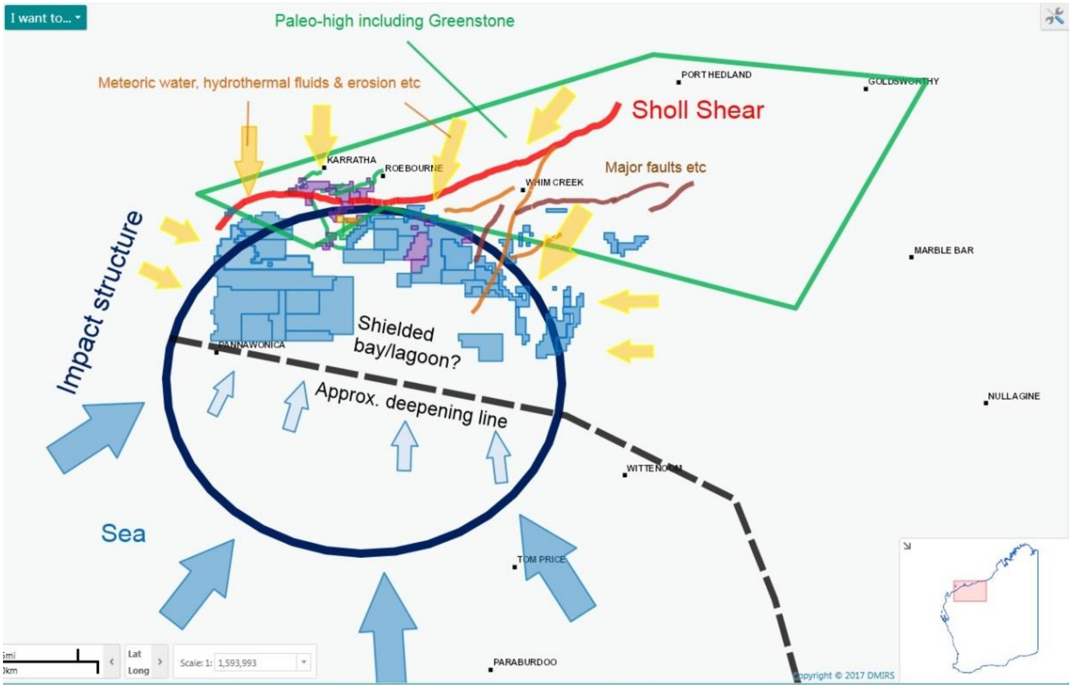


Figure 65

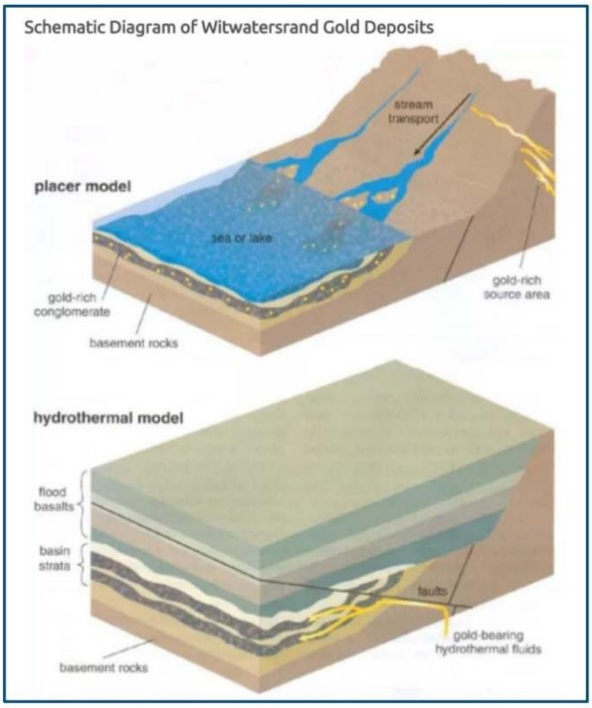
(Note that not all of Novo’s/Artemis’s claims are mapped in the image above)

I recommend everyone to watch this presentation from Impact Minerals:

https://www.finnewsnetwork.com.au/Presentations/PMIS/2017/ImpactMinerals_IPT/index.html

… Especially at 03:20, when Dr. Mike Jones talks about faults and hydrothermal fluids.

Conventional theories as to why the Witswatersrand Basin is extremely gold rich:



Kirk et al. in American Scientist "The Origin of Gold in South Africa" Nov 2003

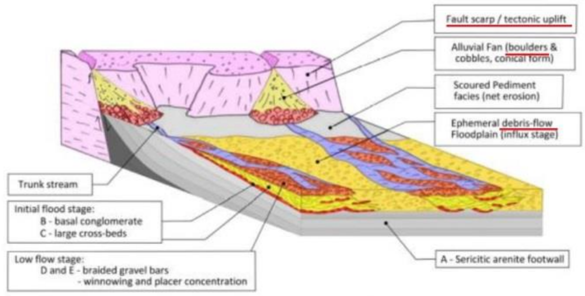


Figure 8: Model showing the main architectural elements of the multistage development of Witwatersrand palaeoplacers (R.F. Tucker, 1980).

What we have in Karratha:

1. Periodic subduction zone activity (Hydrothermal fluids, magmatism, recycling, uplifting)
2. Greenstone belts at "paleo-highs" to the north (Meteoric water, erosion etc)
3. Potential near shore impact structure (Well circulated hydrothermal system, magmatism)
4. Shear zones and faults near and inside the basin

If I were to rank the areas in Pilbara based on what we know at the moment and Novo's staking activity, it would be something like this:

1. **Lower Fortescue in the Karratha impact structure (The bay/lagoon/basin)**
2. Lower Fortescue in West and Central Pilbara outside of the impact structure
3. Intrusive rocks in West Pilbara that are younger than 3 Ga
4. Constantine Sandstones and other young intrusives in Central Pilbara
5. Lower Fortescue and other intrusives in East Pilbara

The juniors:

In terms of companies with the biggest area of potentially prospective ground I would say that Novo is the hands down winner by an order of magnitude. After that it gets trickier but if I had to choose a few other juniors for speculation it would probably be Artemis, De Grey, Kairos and a few other that have big chunks of Mallina Formation and Constantine Sandstones in Central Pilbara like Coziron, DGO and Segue Resources. VXR could also be interesting since they have a few younger intrusives.

The main point is to stay inside West and Central Pilbara, between the Sholl Shear Zone and the Tabba Tabba Shear Zone if you want to speculate in the juniors, judging by what we know so far and keep in mind that the Mt Roe Target is the only target that has been officially "proven". Next potential target seems to be the Constantine Sandstones and then potentially the Mallina

Formation. With that said, there are probably some prospective targets in East Pilbara, but why gamble at this point when pretty much every Pilbara junior has had a big correction?

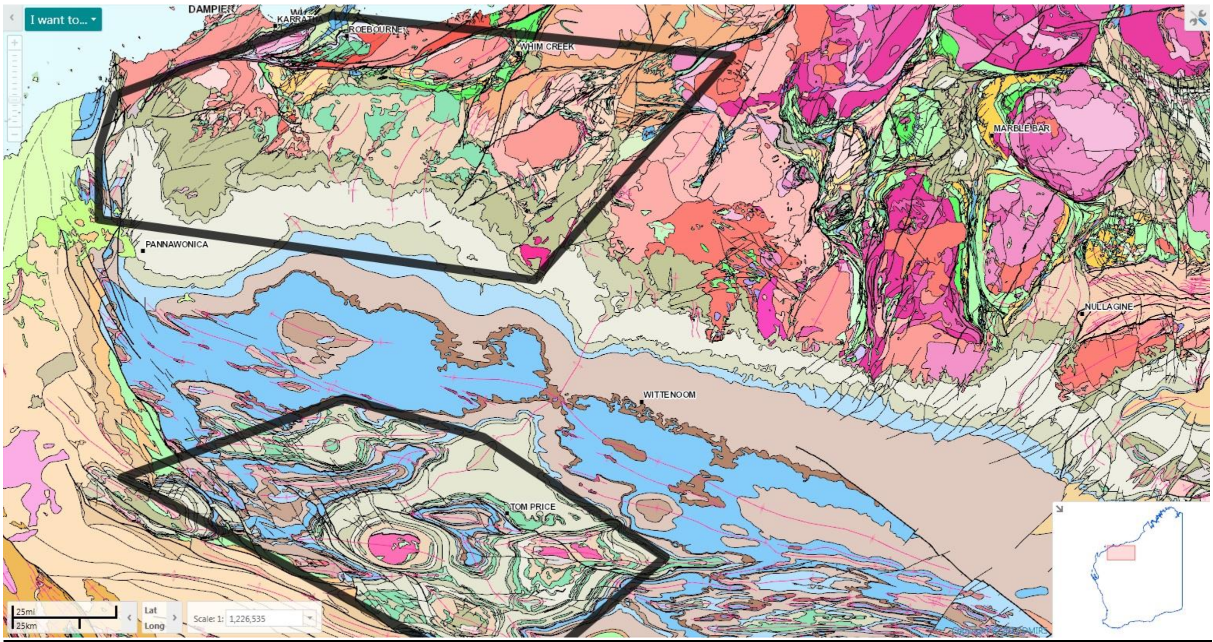


Figure 66

I would personally pick companies that have the right geology inside the areas you see marked in black above. Preferably the top area. (#1) Mount Roe Basalts, (#2) Constantine Sandstones (#3) Young intrusives and Mallina Formation.

Everyone should do their own due diligence!

Closing Thoughts

I expect Novo and Artemis's impact structure area to be the crown jewel in Pilbara. I do expect the geology to evolve even more down dip (which Quinton has already stated is happening). I think the Purdy's Reward Pay Zone that is located at the basal contact and is basically purely nugget mineralization is a unique sequence and that Powerline at Comet Well looks more like "regular" conglomerates, thus I have hopes of us finding a little bit of fine gold there. If it turns out to be no finer gold at Powerline, I do expect us to find it further down dip. One thing to keep in mind is that if Quinton's theory is correct, and given how rich Powerline looks, one could only wonder what we will find down dip. I mean, the gold was sourced from somewhere, and what we are seeing at Powerline at the moment is 3-4m of "nugget abundance". If a large part of that came from cyanobacteria down dip, then what kind of potential algal mat scale are we talking about? Are there orogenic gold sources? Either way I am excited in regards to what insights Artemis's deep drill hole might produce.

It also seems to be more of a high energy environment compared to Witwatersrand and there is still a possibility that we might have extensively more "nuggety" mineralization.

Lastly I would say that I am pretty sure the Pilbara Gold Rush will turn out to be a massive area play, with extensive mineralization, and with gold found in more sequences than only the strata located directly under Mt Roe Basalt.

Ending trivia: Gold's solubility in the Archean made it possible for sea water to contain as much as about 4 ppM of gold vs today's 12 ppT according to John Kaiser in one of his presentations.

Disclaimer: Novo Resources has been my biggest stock position for the last two years and I am thus biased. I have not received compensation from any party to write this document. This article is highly speculative in nature and there is no guarantee as to how accurate the thesis is (if at all). Always do your own due diligence. This is a volatile and risky exploration story across the board. If you found this article valuable, then please feel free to let others know about it!

Best regards,

Erik Wetterling / The Hedgeless Horseman

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