The continent of Ur and the beginning of the crustal gold cycle

Dr. Quinton Hennigh

quinton@novoresources.com

IGC35

Gold Mineralizing Systems SEG/SGA

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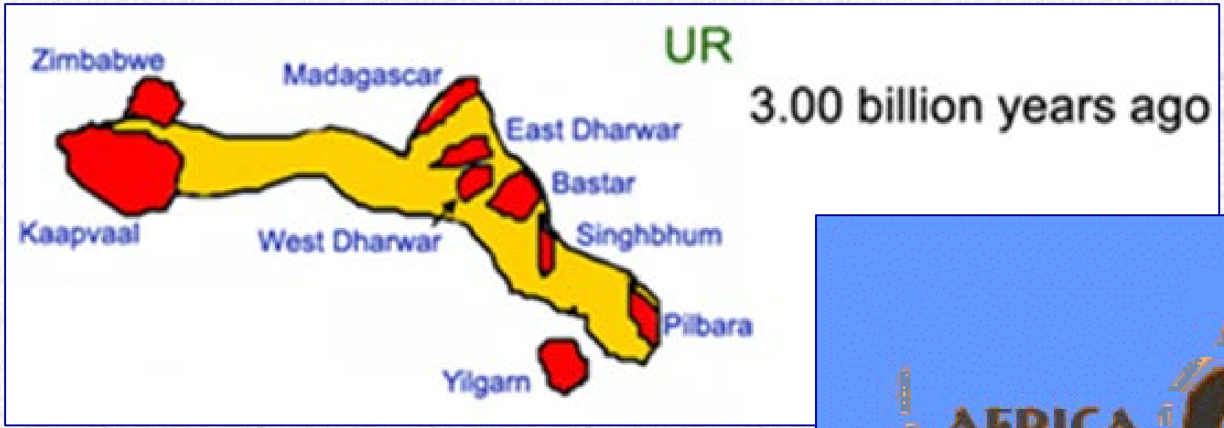
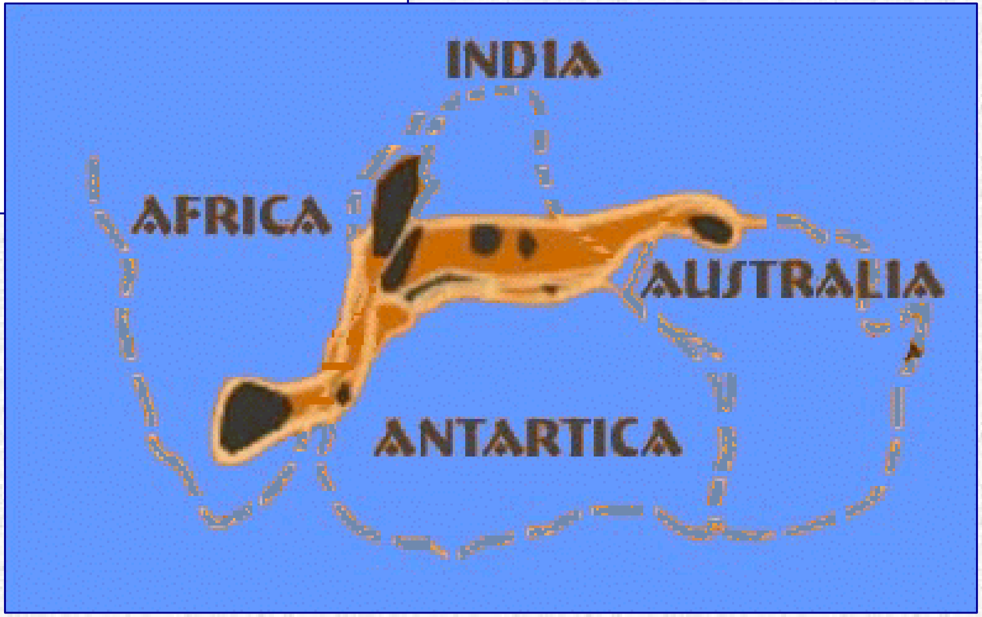
- **Ur is postulated to have been the first continent on Earth**

- **It was comprised of some of Earth's earliest cratons including Kaapvaal (southern Africa), Dharwar, Singhbhum and Bastar (Indian subcontinent), and Pilbara (Australia)**



[After Rogers, 1996]



- **Interestingly, Ur remained largely intact through much of Earth's history till the opening of the Indian Ocean**

- **The southern African, Australian and Indian remnants of Ur have contributed approximately 1.85, 0.35 and 0.1 billion oz gold production, respectively. This amounts to <u>39%</u> of historic global gold production estimated at about 5.9 billion oz [World Gold Council, 2014]. <u>About 3/4 of this gold has come from the Witwatersrand Basin.</u>**

- **Considering <u>less than 3%</u> of Earth's presently exposed continental crust once belonged to Ur, such a large gold endowment is quite profound.**

- **The next youngest supercontinent, Arctica, comprised of cratons of the Canada Shield, Greenland and Siberia that assembled by around 2.50 Ga [Rogers, 1996], has only contributed around 10% of global gold production, a quarter that of Ur.**

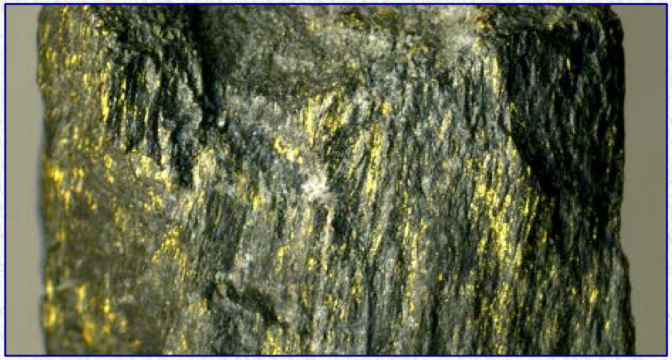
- **When considering the entirety of Earth's continental crust, rocks of Ur have produced about <u>20 times the amount of gold per unit area</u> as their younger counterparts.**

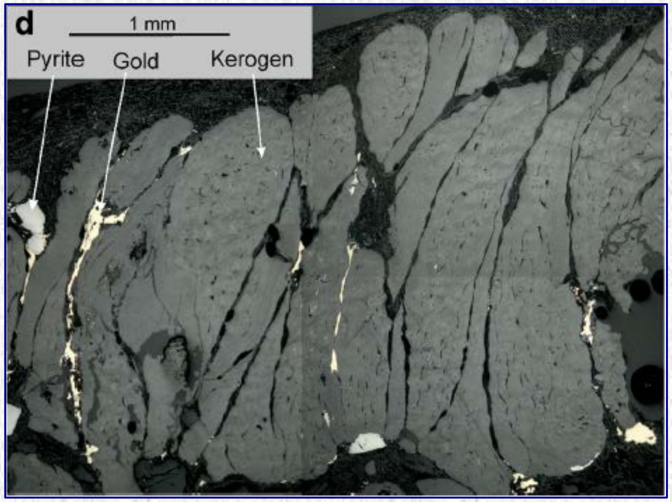
- **The crustal gold cycle started on Ur! How and why?**

- **Over half the gold mined from the Witwatersrand Basin has come from thin carbon seams, or "leaders," especially near the base of the Central Rand Group (~2.9 Ga). Carbon leaders can be extensive covering many square kms.**

- **Carbon seams are dominantly composed of kerogen [Mossman et al, 2007] indicating an *in situ* source derived from living organisms in microbial mat cover that grew contemporaneous with sediment deposition. Seams commonly display filamentous form.**

- **Such seams drape "quiet" sedimentary surfaces, particularly atop transgressive surfaces of erosion, suggesting bacterial mats developed in shallow water (sunlight penetrates to about 200 m) and below storm base thus having been protected from high energy waves.**

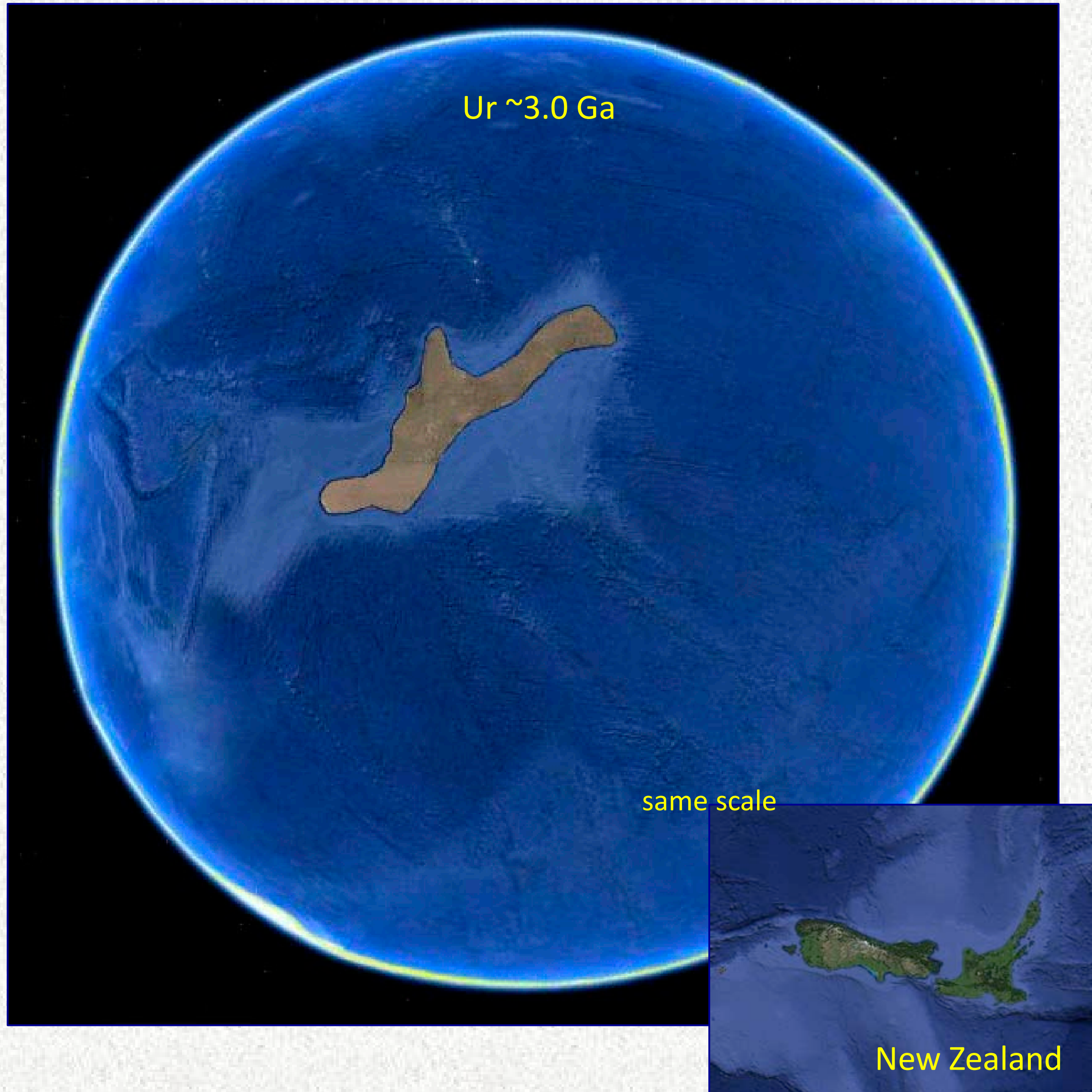




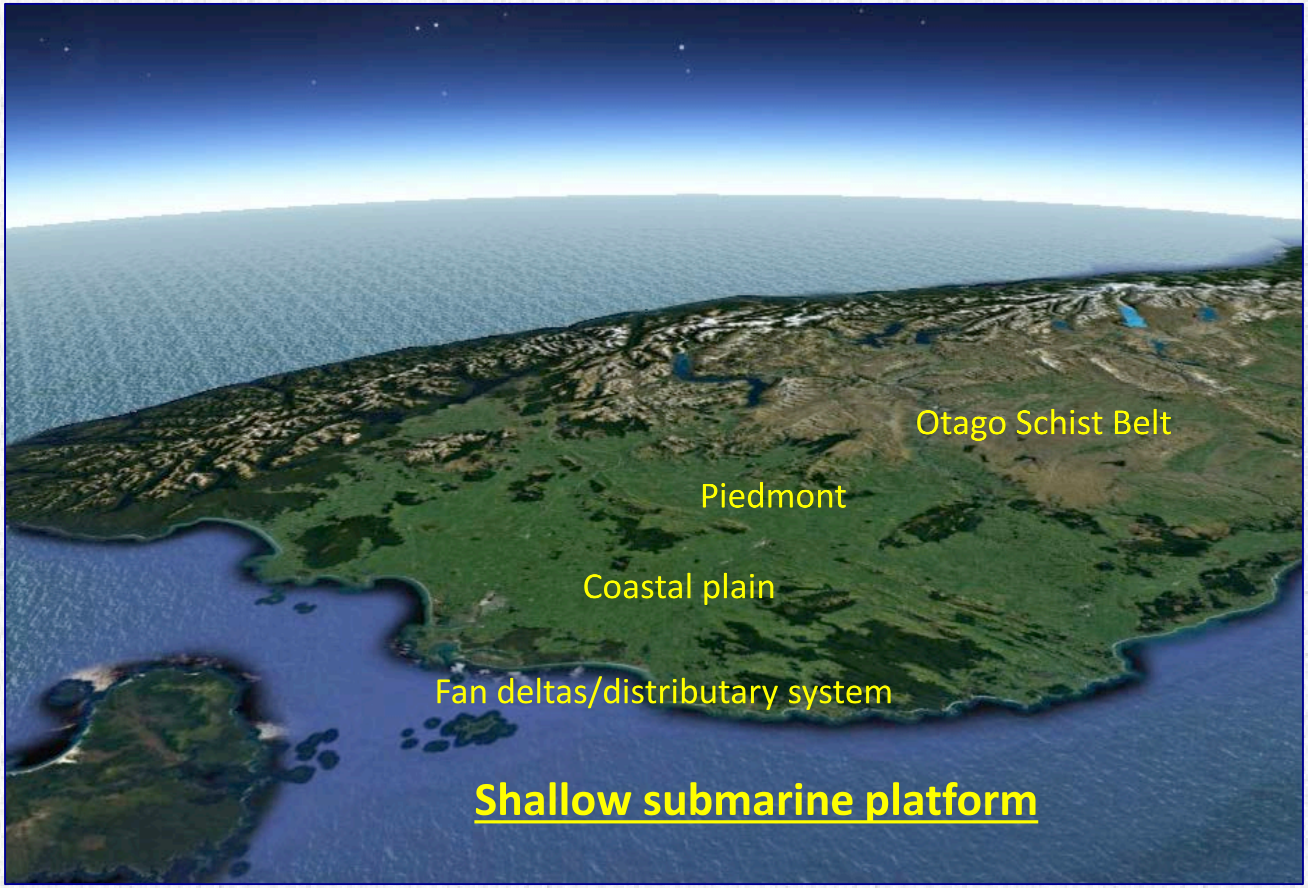
[Frimmel and Hennigh, 2015]

Back to Ur…

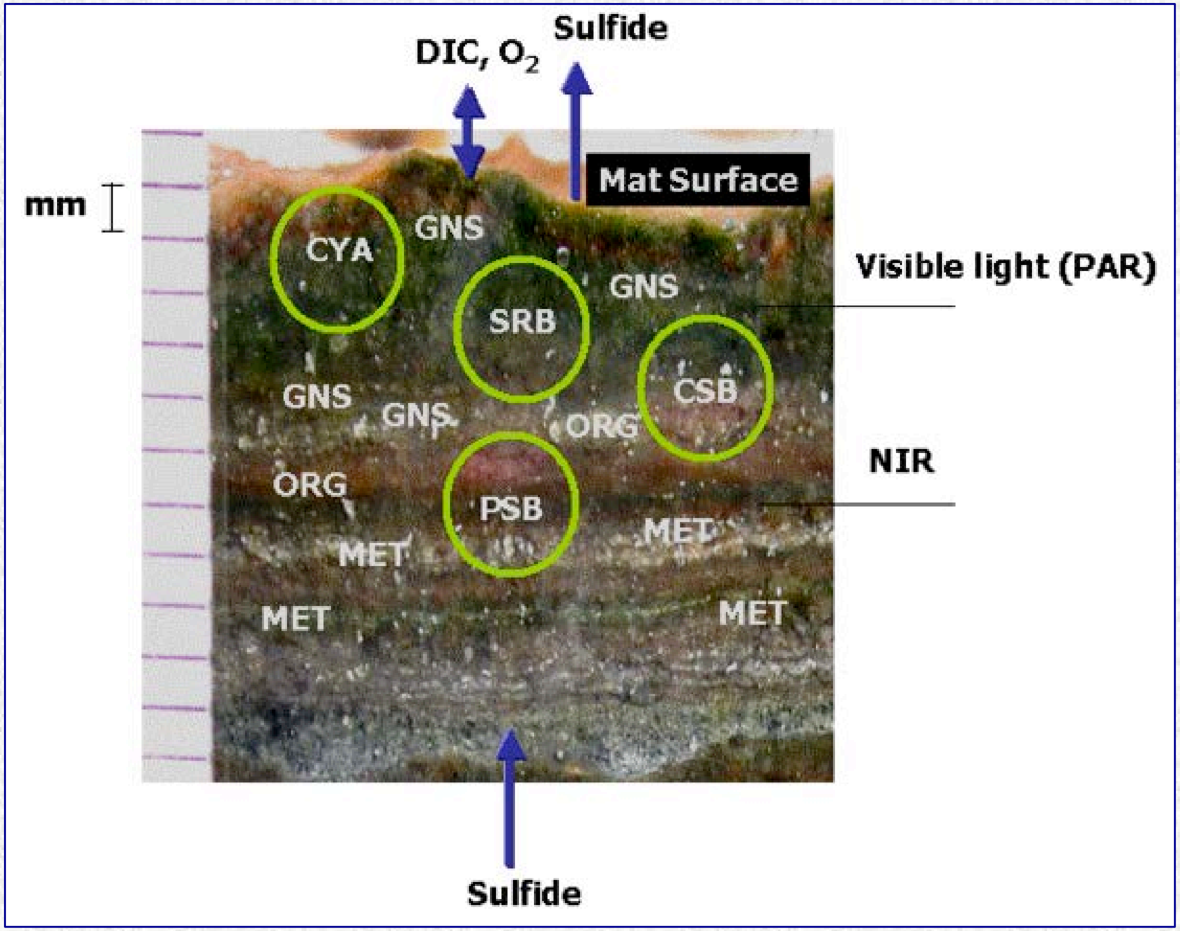
- **Google Earth view of Ur circa 3.0 Ga**
- **Ur was the only significant terrestrial landmass at this time**
- **Ur was somewhat larger than New Zealand and had similar variable topography, a complex coastline with numerous bays and inlets, and a broad, shallow shelf**
- **It was in the shallow waters around Ur that photosynthetic life first evolved. This is where the gold cycle begins.**



- **An analogue to the Witwatersrand Basin, most of Southland and parts of southern Otago, New Zealand, are covered by an extensive piedmont and coastal plain. Offshore, this surface becomes a broad, shallow shelf. Over tens of millions of years, this surface has seen repeated transgressions and regressions of the sea. This is the sort of environment in which the first and greatest gold depositional event on Earth took place.**



- **Evolution of hierarchical microbial mats took place in the shallow submarine environment around Ur**
- **Cyanobacteria, the first photosynthetic life, evolved around 2.9-3.0 Ga**



Microbial mat (NASA)

- *MET = methanogens*
- *PSB = purple sulfur bacteria*
- *ORG = organotrophs*
- *GNS = green non-sulfur bacteria*
- *CSB = colorless sulfur bacteria*
- *SRB = sulfate-reducing bacteria*
- *CYA = cyanobacteria*
- *PAR = photosynthetically active radiation*
- *NIR = near infrared radiation*
- *DIC = dissolved inorganic carbon*

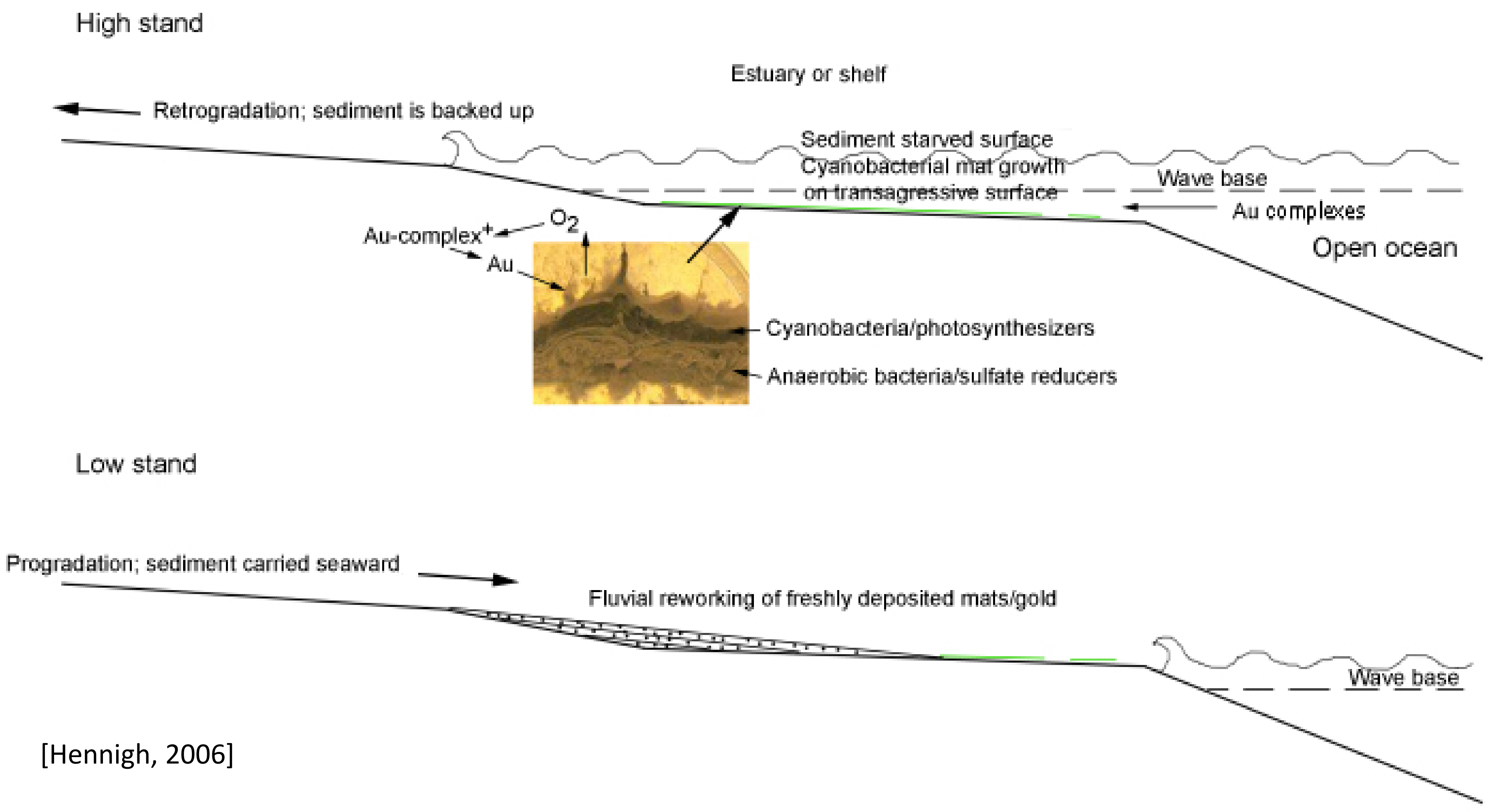
Sippewisset Salt Marsh, Cape Cod

- **Bacterial mats from modern salt water marshes.**
- **Pyrite and marcasite form just a few mm below oxygen-rich waters illustrating how effective bacteria are at moderating their environment**

- **When cyanobacteria joined the hierarchy, the <u>first oxygen was introduced into Earth's hydrosphere and atmosphere</u>**

- **Microbial mat mediated ("3M") model for gold deposition**

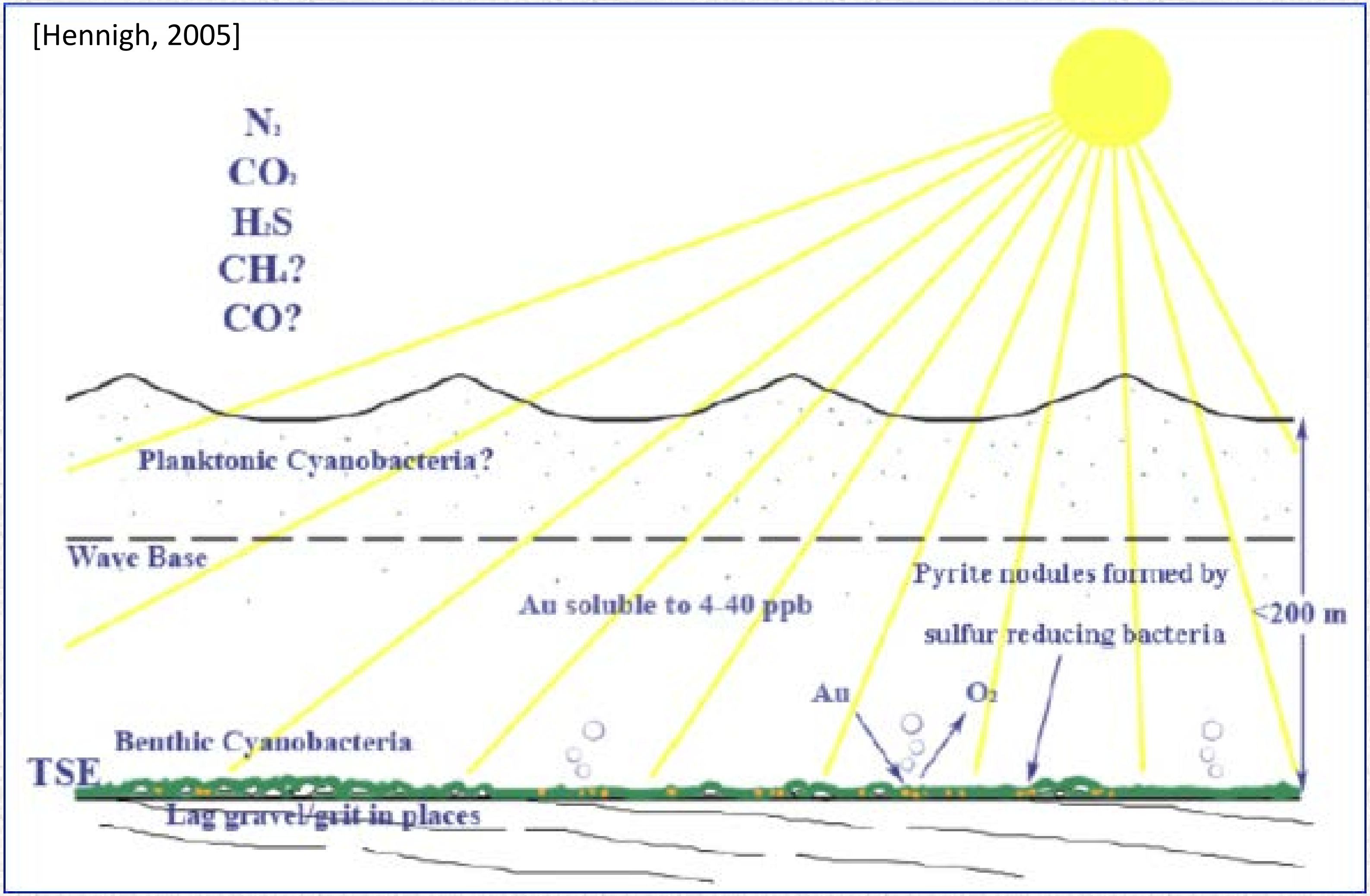
- **Microbial mats flourish during high stands. As cyanobacteria generate oxygen, gold complexes break down causing gold to precipitate within the mat**



[Hennigh, 2006]

- **Early rendition of the 3M model.**

- **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.**



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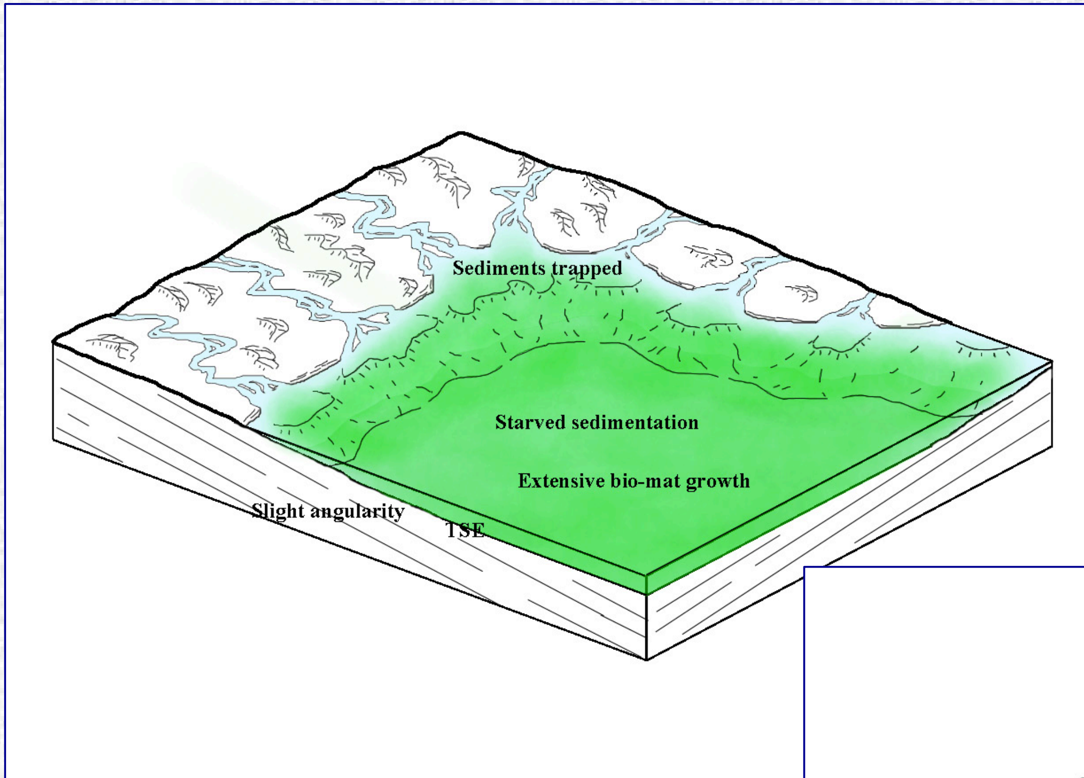
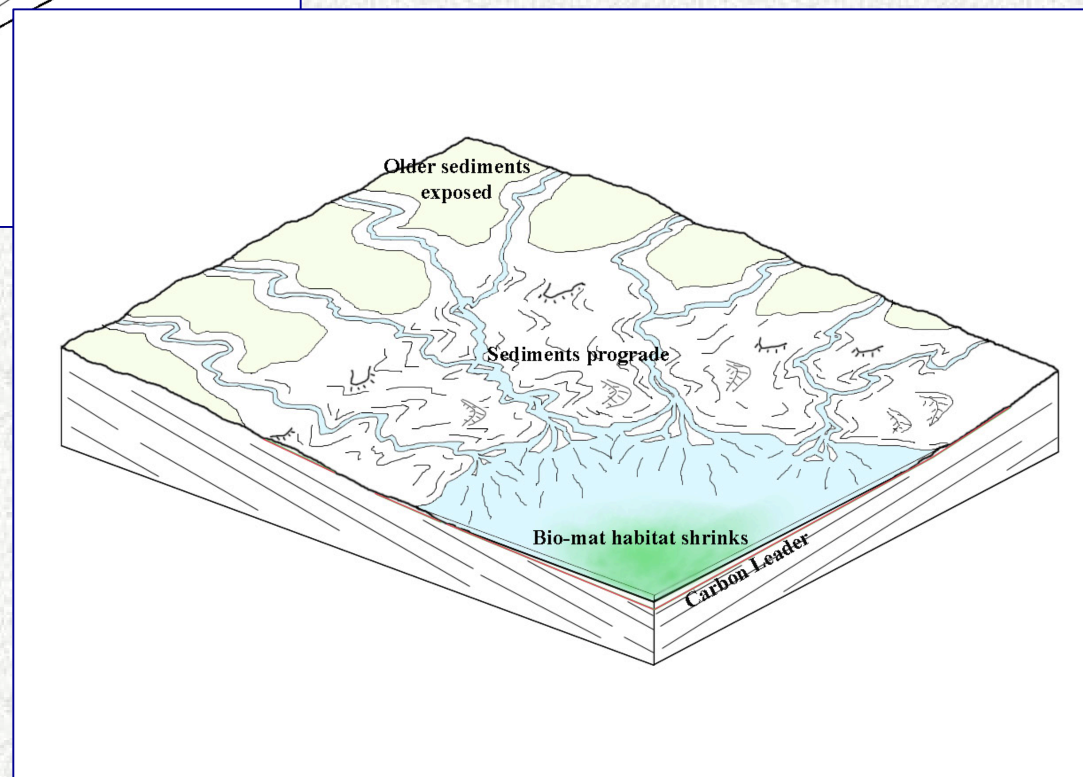


- **Only the 3M model can account for the vast quantity of gold in the Witwatersrand Basin. Other models that rely on "hinterland" gold sources, either physical or chemical, fall short.**
- **The Witwatersrand gold source is <u>indigenous.</u>**



[Hennigh, 2005]

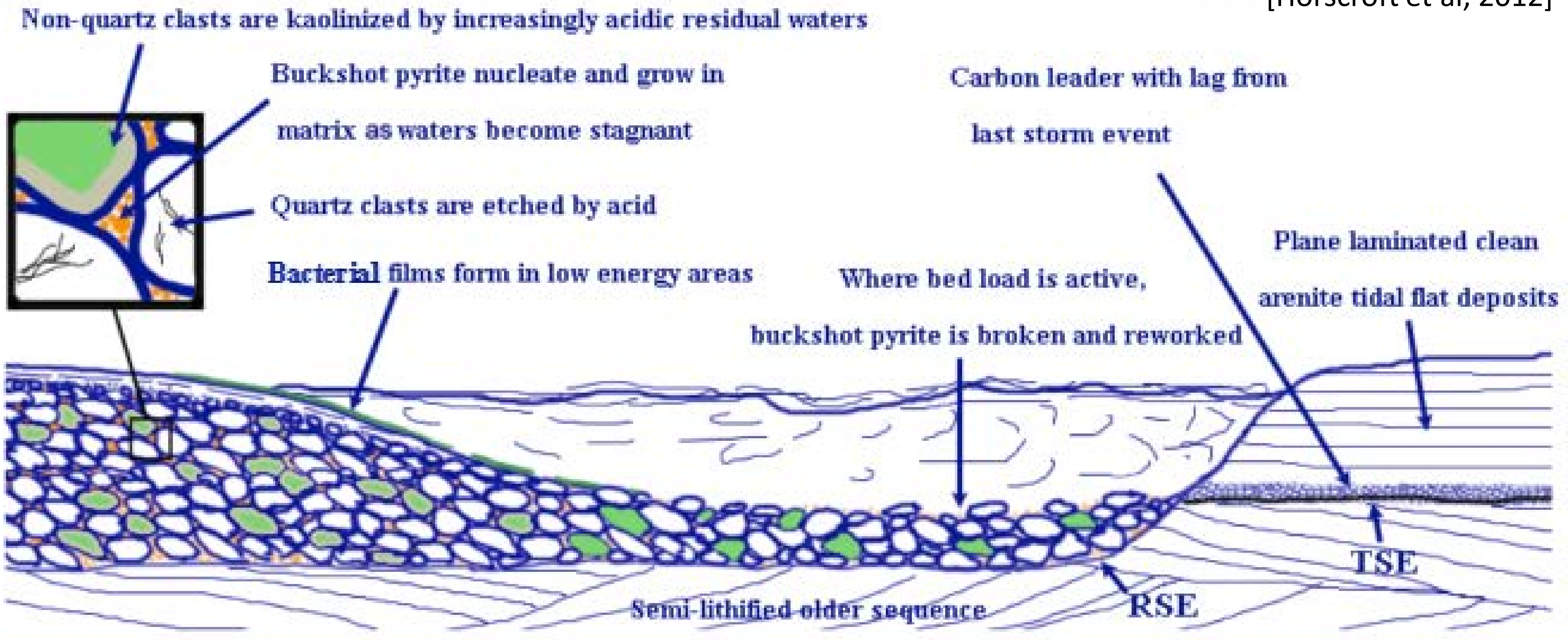
- **The 3M model synthesizes carbon leader mineralization with conglomeratic style mineralization.**
- **One must think in terms of sequence stratigraphy and system tracts to better understand sedimentation patterns.**

- **Gold from carbon leaders was subsequently incorporated into fluvial conglomerates through reworking during periods of regression. Gold particles were also subject to aeolian processes when subaerially exposed.**

- **During subsequent highstands, gold was re-concentrated within younger transgressive lag conglomerates forming sheet-like horizons, or leader reefs (not shown below), covering many square kms.**

- **Generation of huge volumes of clean quartz pebbles and the origin of much of the detrital pyrite found in Witwatersrand ores are largely a result of biological activity.**

[Horscroft et al, 2012]



- **Southland, New Zealand is a giant quart pebble factory that can help elucidate the formation of vast quantities of quartz pebble conglomerates on Ur.**

- **Deposits of polylithic river gravels washed down from the Otago Schist Belt stew in highly acidic shallow groundwater resulting from biogenic activity.**

- **Virtually all clast types, with the exception of quartz, are thoroughly kaolinized.**

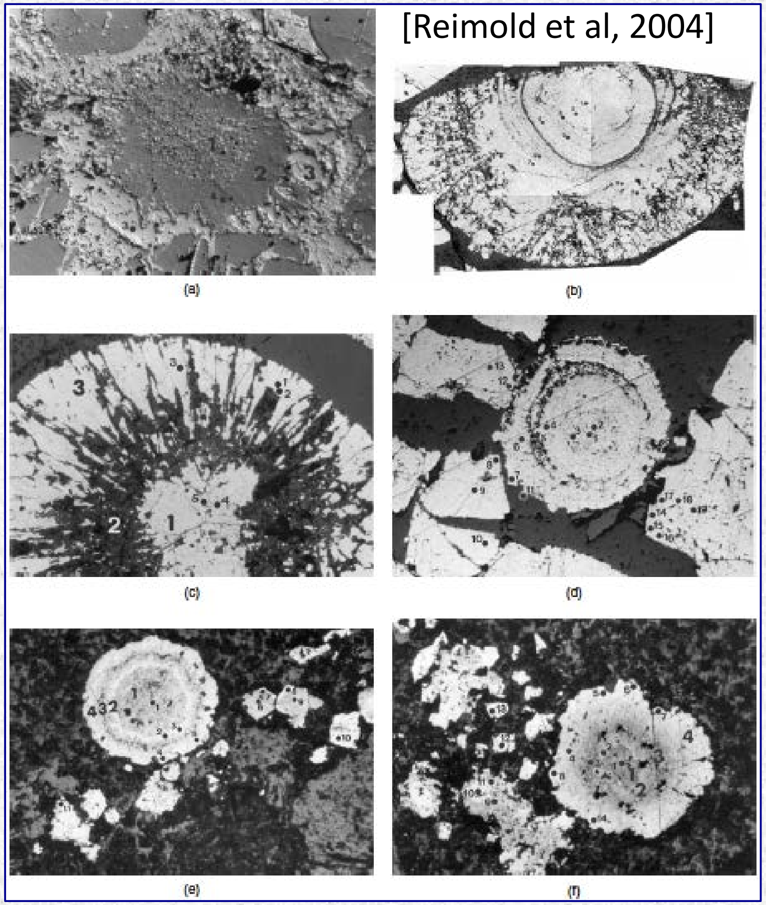
[Falconer et al, 2004]

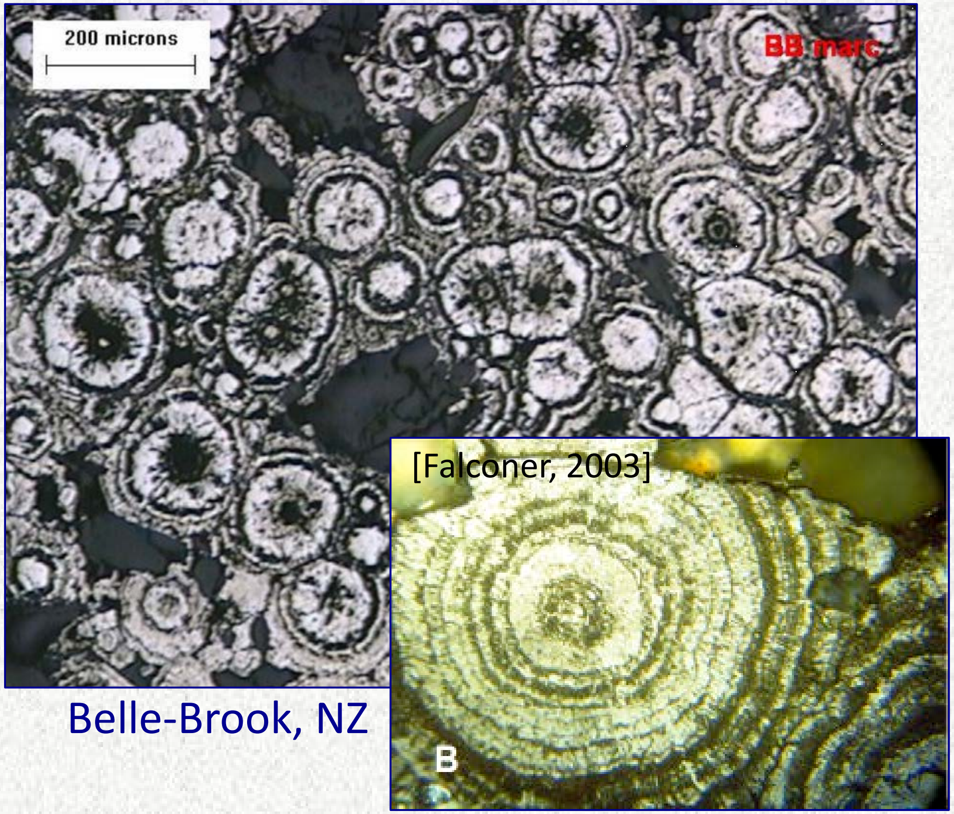
- **Rivers and streams rework these deposits washing away clay and upgrading quartz pebbles.**

- **After a few generations, nearly pure quartz pebble conglomerates are the result.**

- **Concentrically banded "buckshot" pyrite from the Witwatersrand is a product of microbial activity. As these form, variable amounts of Ni, As, Co, Hg and Au are concentrated in narrow growth zones. By fixing toxic elements, bacteria clean their environment.**

Witwatersrand



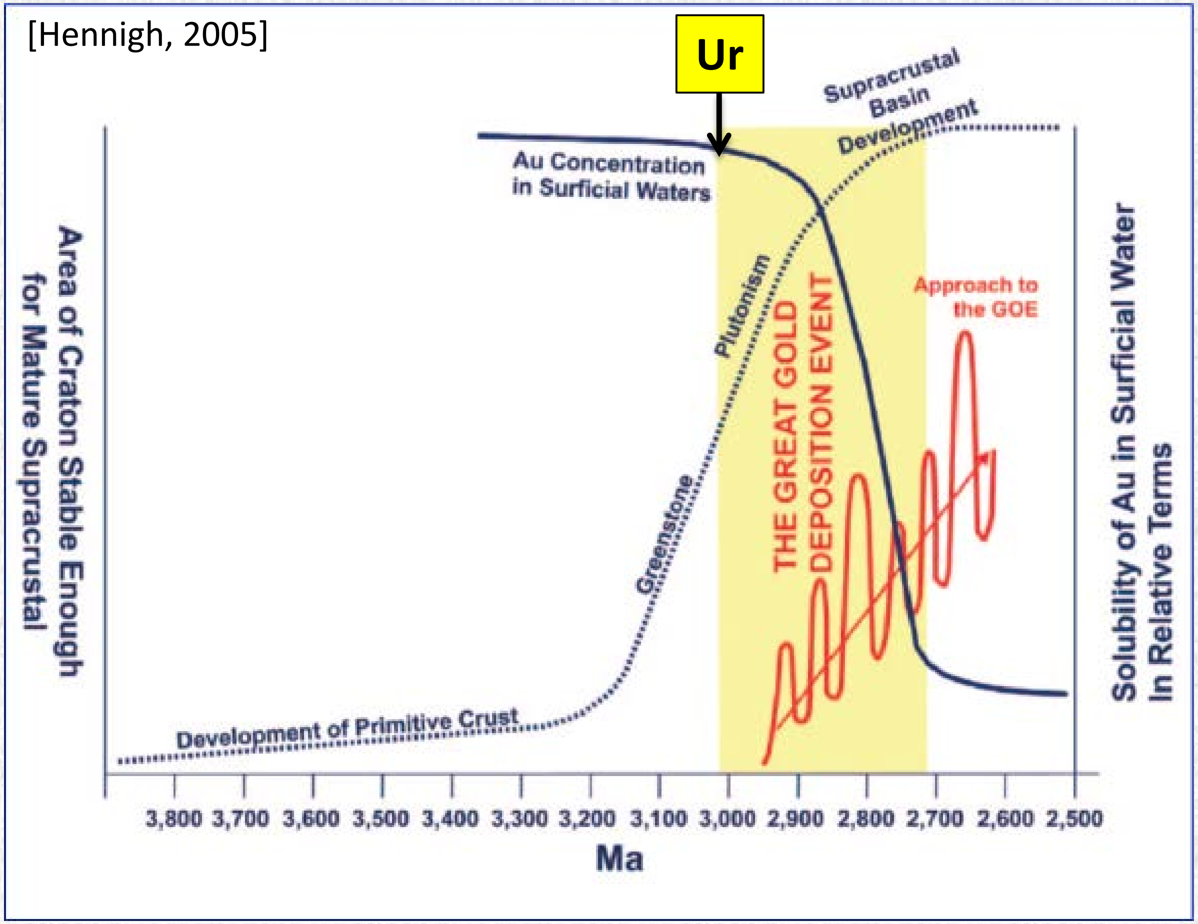


Belle-Brook, NZ

- **Similar concentric pyrite and marcasite particles actively form through biogenic processes in Au-bearing gravels in Southland, New Zealand. Elevated Ni, As, Co, Hg and Au are present in multiple growth rings. An assay of material seen in the top photomicrograph returned 192 ppm Au.**

Conclusion:

- **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.**



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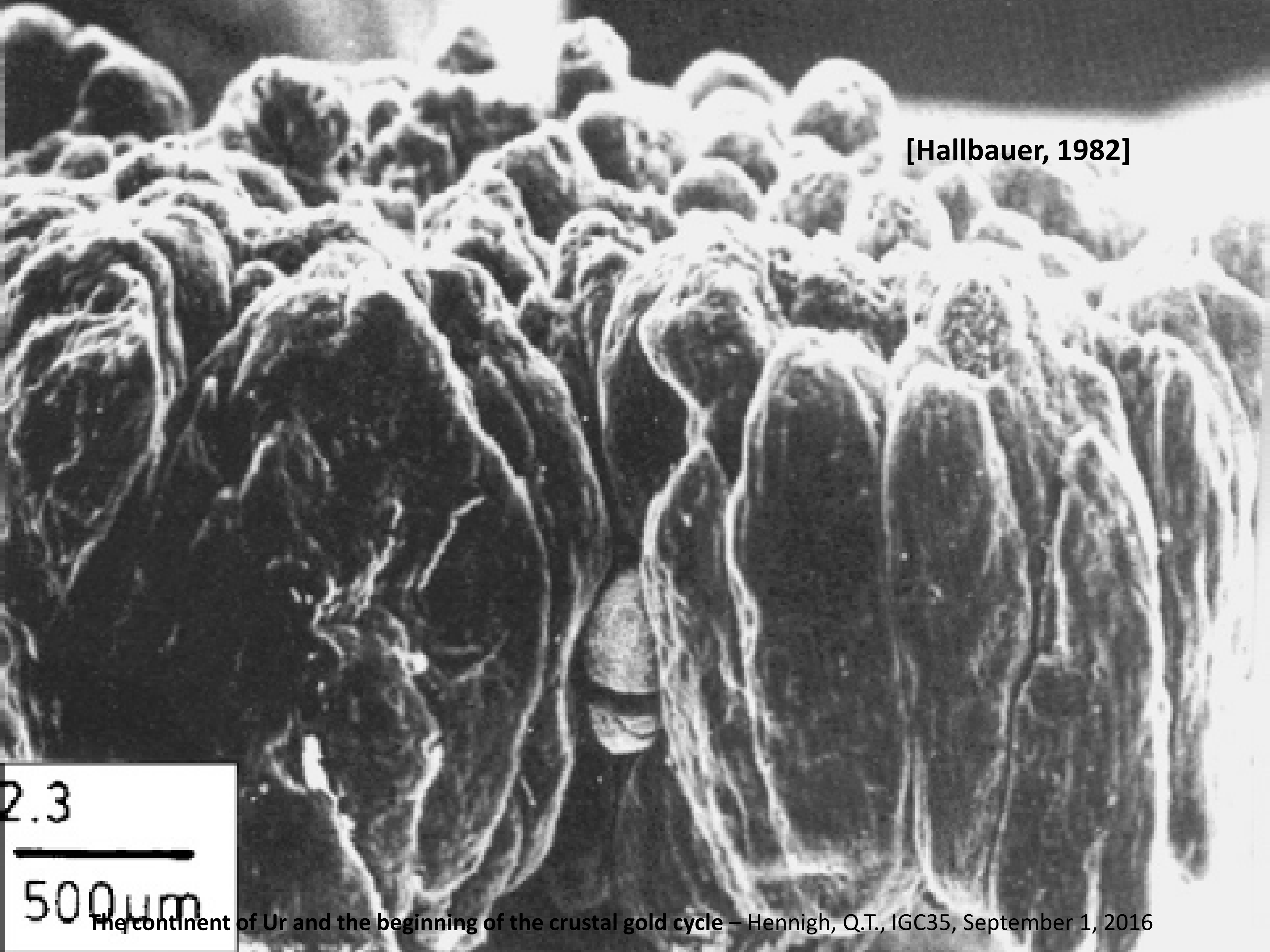
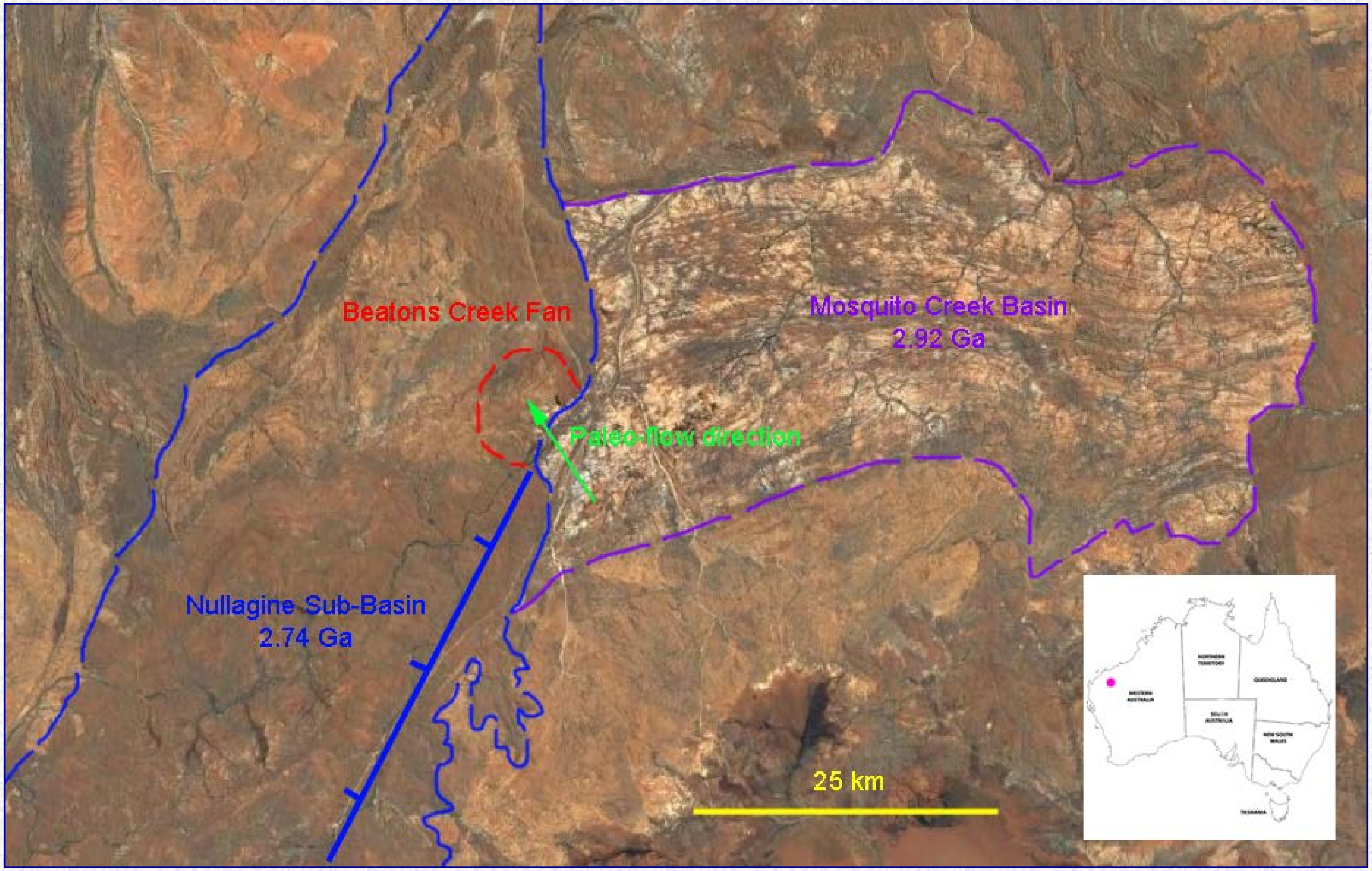


[Hallbauer, 1982]

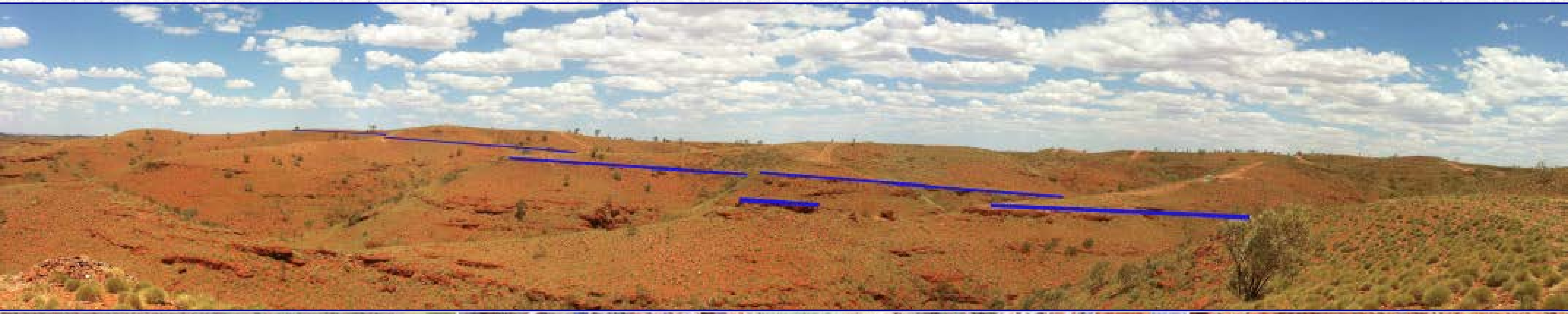
The Pilbara…the other end of Ur:

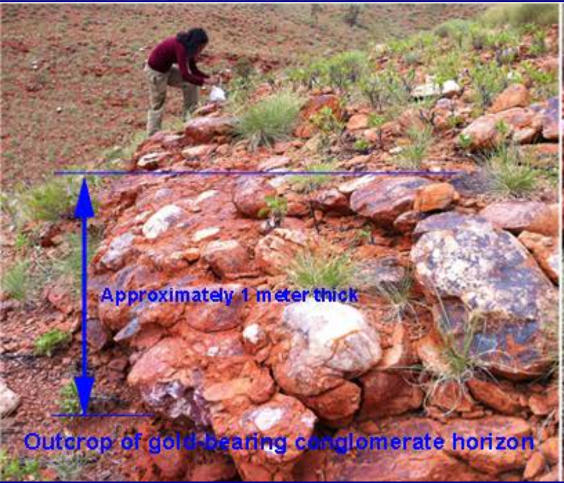
- **Gold-bearing conglomerates occur is at least a dozen places across the Pilbara region, Western Australia**

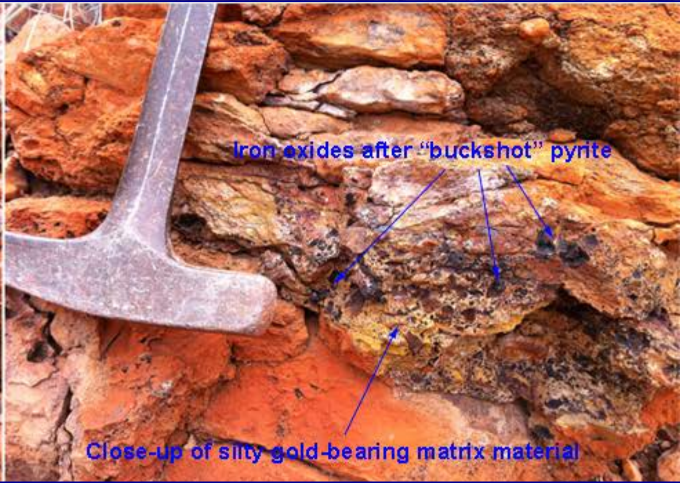
- **Beatons Creek, near the town of Nullagine, is the best developed occurrence**



Gold deposits at Beatons Creek:







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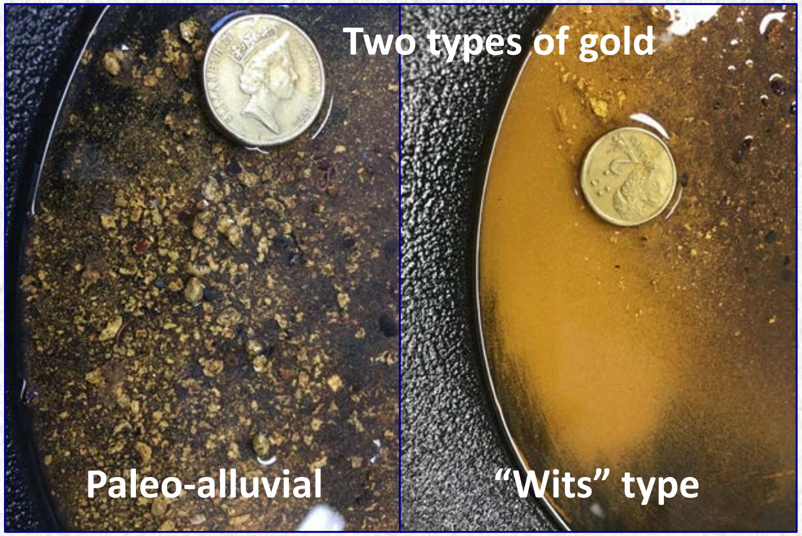

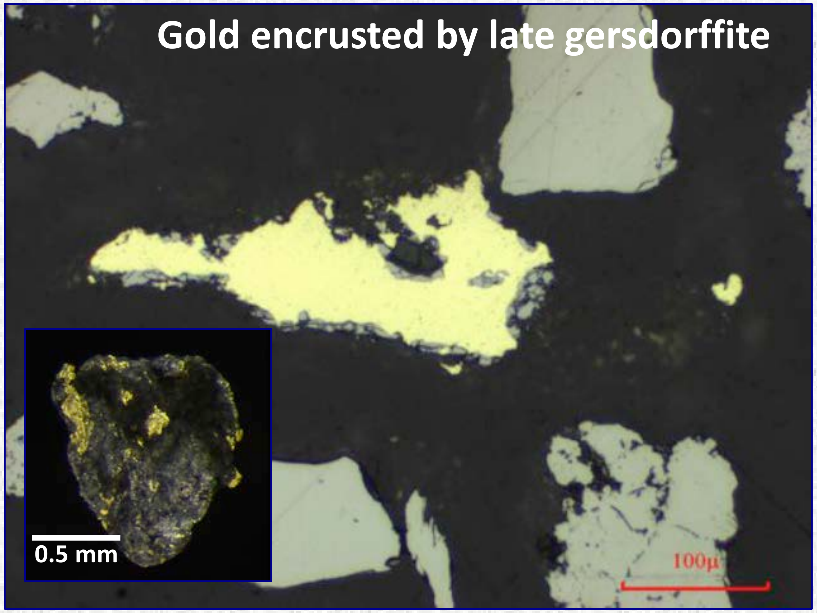

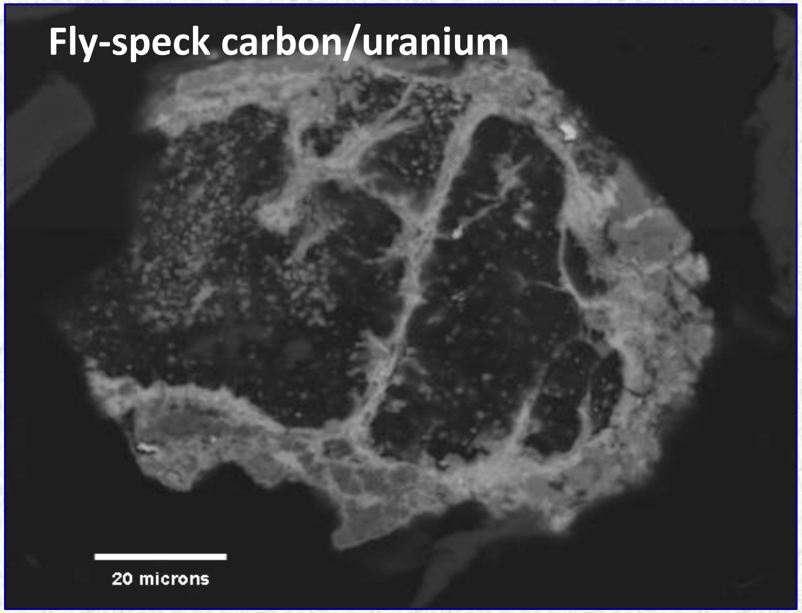

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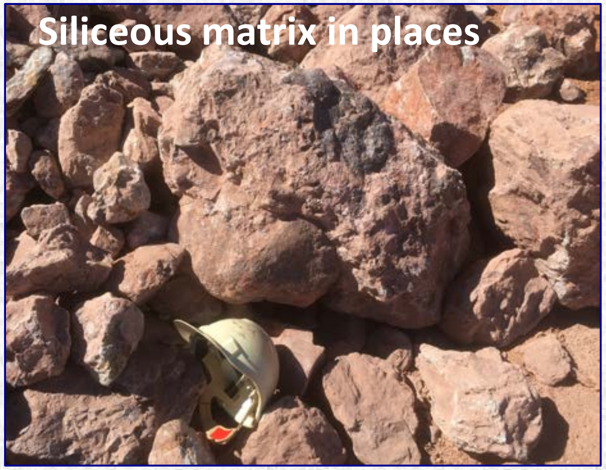
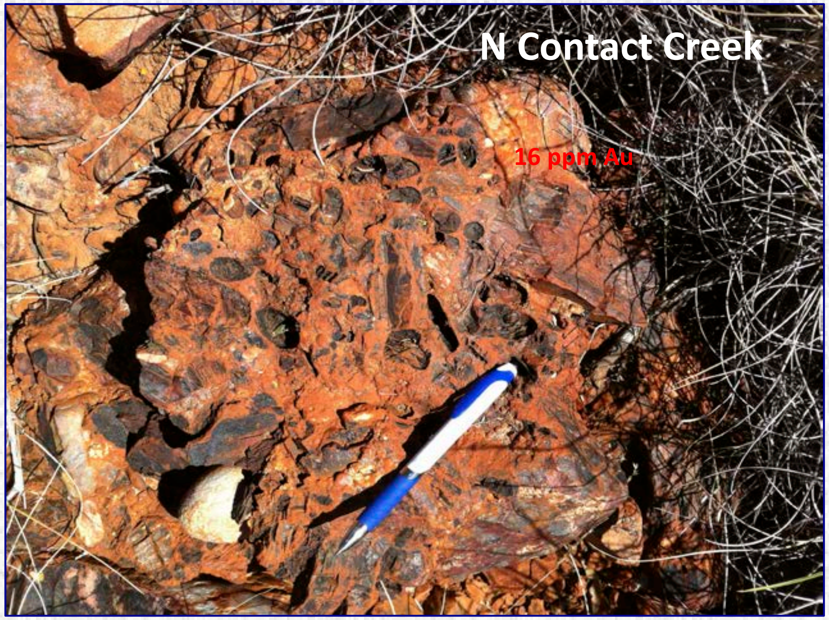


Elsewhere in the Pilbara:



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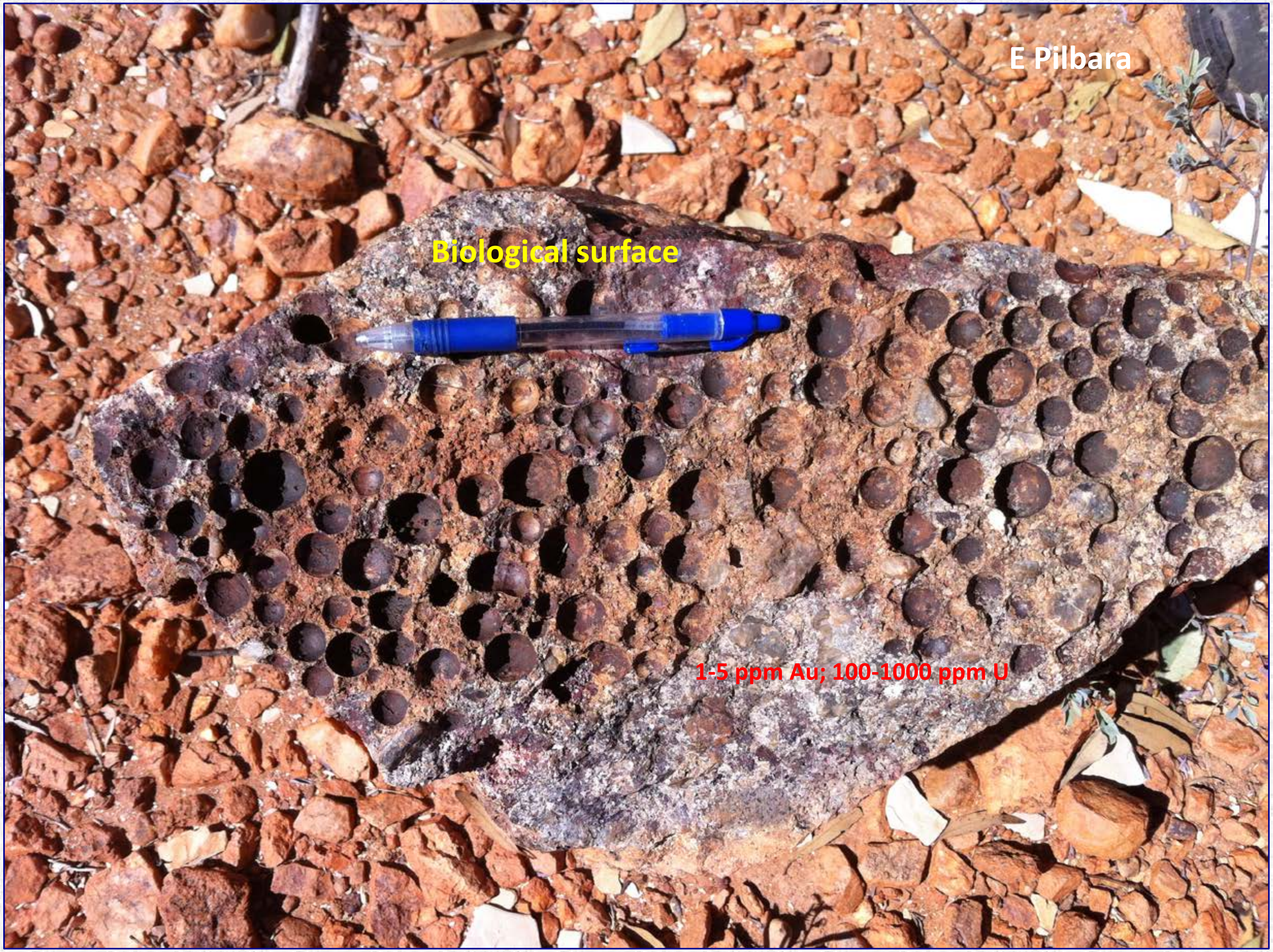

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