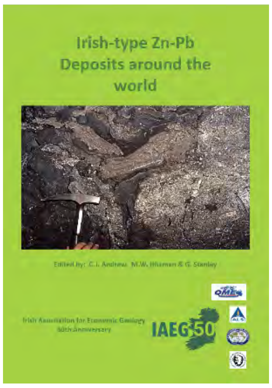

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On Irish bacteriometallogenesis and its wider connotations

Michael J. Russell

Dipartimento di Chimica, Università degli Studi di Torino, Italy

Corresponding Author: Mike Russell michaeljrussell80@gmail.com

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On Irish bacteriometallogenesis and its wider connotations

Michael J. Russell

Dipartimento di Chimica, Università degli Studi di Torino, Italy

All models are wrong, but some are useful.
George Box 1976

Abstract: Rapid and widespread access of surface waters to jostling segments of the upper crust marks the first step to metallogenesis in the Irish early Carboniferous. Overall, siting of these ore-forming systems involves two types of fluid-charged autocatalytic cracking engines. The more obvious is a province-wide diffuse type, excavating downward from the generally submarine surface to where waters are heated, dissolve metals and become buoyant enough to exploit channel ways back to the surface. Another, rather more obscure engine, starts near the mantle-crust boundary and either produces a through-going crustal structure to vectorially guide pressurized mantle volatiles and perhaps accompanying magma toward the surface, or it autonomously drills its way through the entire crust by penetrative convection, as in a diatreme. Either way ore-forming solutions are perhaps best incubated where both engines interact within the crust. But precipitation of minable metal requires structural down warp basins and associated saline, sulphate-reducing microbiome traps. So, whilst there is no unique explanation for the distribution of the orebodies, the Navan orebody, its southwest extension (SWEX) and its neighbour to the south, Tara Deep, do fall on a putative N-S Geofracture (Gf 3) first proposed in 1968/1969. But the N-S geofracture hypothesis runs strongly against the "academic" grain! Moreover, no further discoveries can be unequivocally assigned to the hypothesis. So why persist with the notion at all? Well, there have been some other indications of such structures in adjacent countries and, most notably and farthest afield, on Mars which acts as a time machine for our planet! There the seismically active Cerberus Fossae structures have similar crustal joint aspect ratios of 40 to 55km, as with the putative Irish (and Scottish) examples. And five cold springs, sequentially younger to the east, happen to lie well-spaced along a 250km stretch of the northernmost Fossa. Yet there are no signs of mineral sulphide accumulations on Mars. Perhaps lacking there were sulphate-reducing bacteria required for the deposition of economic ores as in Ireland. Indeed, it was the discovery of light sulphate sulphur in the Irish ores, along with lithochemical and geological evidence for an exhalative aspect to them, that inspired the submarine alkaline vent theory (AVT) for the emergence of life. In this theory exothermic serpentinization drives hydrothermal convection cells to produce the exhalations into the Hadean Ocean. Here the free-energy converting iron minerals (oxyhydroxides and sulphides) act as nano-engines in spontaneously precipitated membranes to generate the appropriate organic molecules required for life's onset from volatile and hydrothermal delivery of CO_2, H_2, CH_4 *and* the trace elements. These prebiotic nanoengines are powered by the electrical and pH disequilibria focused across the mineral membranes amounting to ~1 volt.

Keywords Irish Zn+Pb+/-Barite ore deposit theory: downward excavating hydrothermal cells, NS geofractures, evidence of exhalation, life's emergence and microbiomes.

Introduction - Mineral exploration from the late 1950s

Mineral exploration was initiated and energized by Pat Hughes and Mike McCarthy, the enterprising leaders of Northgate Exploration Limited established in Canada, on their return to Ireland in the late 1950s. The terrain in the Superior Province mining camps where they worked had reminded them of Ireland's Central Plain so maybe – they reasoned – ore was hiding there too? With this comparison in mind, they came back to a country well prepared for a modern approach to mineral exploration. A geological survey of the entire country had been undertaken in the latter nineteenth and early in the twentieth centuries at six inches to the mile, and Grenville Cole's (1922) exhaustive memoir and map of localities of minerals had also just been reprinted (1956). Geological and mineralogical information along with geological field maps at six inches to the mile were lodged in the Geological Survey in Dublin where they were available to these explorers along with pertinent advice from the then Director, Murrogh O Brien, and field geologist, Mark Cunningham (see O Brien 1959, p.12). Indeed, Murrogh O Brien suggested Tynagh to them as a prospective area. Dublin also housed the Dublin Institute for Advanced Studies, established in 1940. Conceived of by the mathematician and Prime Minister of Ireland, Eamon de Valera, and initially built around the physicist Erwin Schrödinger (Moore

1987), geophysical surveying was an early endeavour. Tom Murphy began a gravitational Survey of Ireland and published a series of maps between 1952 and 1962. One of these revealed a line of small low bouguer anomalies with a Caledonoid trend destined to achieve fame as the "Navan – Silvermines line", and later as the Iapetus Suture (Murphy 1962; Phillips *et al*. 1976)!

Northgate's consultant at the time was Duncan Derry, an exploration geologist particularly well-versed in modern tectonic and ore genesis theory and who fully subscribed to the recently resurrected syngenetic theory of ore genesis (e.g., see Derry, 1979, 1980). The syngenetic theory was not new to Ireland. Weaver (1838) had championed 'Neptunist' ideas, suggesting that the Ballyvergin copper, and other mineral showings in the Irish Carboniferous Limestone, were deposited on the early sea floor (but see Russell, 1972 for evidence of an epigenetic origin). Nevertheless, the contemporary research in Ireland had favoured an epigenetic origin for the vein and fault related Silvermines deposit largely based on H. N. Rhoden's careful descriptions (Rhoden, 1958). Yet the discovery of Tynagh in 1961 by Irish Base Metals pushed the pendulum the other way and was the subject of a classic "preliminary account" by Derry, Clark & Gillatt (1965). Derry and his colleagues gave a subtle and prescient interpretation of ore genesis in which they argued that the primary ore "*resulted from solfataric solutions issuing during a period of local vulcanicity from fissures that may have followed the same zone as the present North Tynagh Fault. These solutions, carrying relatively high proportions of barium, lead, zinc, iron, copper and silver, precipitated the sulphide assemblage near the surface by seeping into a reef or mud-bank complex in an area of active or recent organic growth. The iron and silica remaining in solution was deposited in a protected basin off the edge of the reef under conditions of little or no organic growth*" (Derry *et al*. 1965 p. 1231).

Derry *et al.* (1965, p. 1230) qualified their description with the remark that a later redistribution of sulphides, not necessarily involving more than local mobilization, provided the more massive *"replacement" type of ore and cross-cutting veinlets*." Their work implied that mineralization began in the early Carboniferous. Schultz (1965), the first chief mine geologist at Tynagh, was not convinced. In developing the underground orebody, he had been given cause to expect layers of stratiform ore between drill hole intersections spaced at 50 metres (Derry *et al*. 1965, fig. 3), interpolations that failed to materialize! Thus disappointed, Schultz would concede no synsedimentary contribution, and believed the Tynagh ore to have been introduced in the Jurassic. In his opinion the accompanying iron formation bore no relation to the sulphide deposit and was "thought to have been derived by intensive chemical weathering of uplifted Lower Carboniferous sediments and possibly also exposed Old Red Sandstone" (Schultz, 1966).

Notwithstanding this dispute, the development of Tynagh started a minerals rush and several 'majors' joined the search. Many of the incoming and well-travelled company exploration geologists also had the 'syngeneticists' mind set", given voice in Ireland by Rio Tinto Zinc Corporation's geologist, Jocelyn Pereira (1963a). Of course, much of the thinking was developed behind closed doors but important influences of the time were Haddon King from Australia, a country boasting giant stratabound and stratiform base-metal ores. These had been interpreted in the nineteen thirties by consultants such as Schneiderhöhn in 'Neptunian' terms (Schneiderhöhn 1944; King 1958; King & Thompson 1953; Stanton 1955a, 1955b; Wade & Solomon 1958). Another influence was Garlick (1953) who considered the Zambian Copper Belt ores to have been deposited near shore in an enclosed basin. Pereira (1963a) also championed the importance of shorelines as sedimentary traps and this approach was a factor in ConZinc-RioTinto's discovery of zinc and barite at Keel.

Following Tynagh, Mogul of Ireland thought to re-examine the failing lead veins at Silvermines. Pattern drilling of 164 holes along the Silvermines Fault based on Rhoden (1958) was disappointing. Consultant 'Peck' Weber, climbing Silvermines Mountain and looking north to the immediate downfaulted plain, declared that drilling should step out to search for a sedimentary-exhalative Meggen-type pyritic-zinc-barite deposit (Schmidt 1918; Ehrenberg *et al*. 1954; Weber, 1964). The discovery of the base-metals in Lower Carboniferous rocks in 1962 comprising the "Upper G" orebody followed his epiphany, though not all associates went along with his boast! Nevertheless, in parallel to the development of the Upper G orebody at Silvermines, Magcobar Corporation developed an open pit into what proved to be a high tonnage stratabound barite deposit (similar to their founding Magnet Cove deposit in Arkansas (Zimmermann & Amstutz, 1964) and at Walton, Nova Scotia (Boyle, 1963; Russell, 1968) just to the east of the Mogul's discovery; another echo of Meggen. The syngenetic paradigm was the apparently well set in Ireland!

The SedEx v. MVT wars, 1980 to ~2010

Yet, in spite of these early discoveries, the syngenetic approach received strong pushback, motivated first when the expected layers of lead-zinc ore at Tynagh interpolated from drilling failed to meet expectations during underground mining. Further disillusion ensued as stratiform ore at Rio Tinto's deposit at Keel failed to materialize during underground development (Patterson, 1970). The discovery of the Gortdrum copper-mercury deposit, clearly of epigenetic replacement origin, sounded the death knell for a simple syngenetic model for Irish orebodies. Far from clarifying the situation, the discovery of the stratiform ore at Navan in 1970 only deepened the dispute (O'Brien & Romer, 1971; Andrew & Ashton, 1985; Libby *et al*., 1985; Andrew & Poustie, 1986; Peace & Wallace, 2000).

Lost in the debate was the fact that the so-called syngenetic school *did* recognize not only the occurrence, but also the genetic importance of epigenetic footwall and fault-related developments at the largest base-metal operations in Ireland, prominent at Tynagh, subordinate at Silvermines, though there supported by a sulphur isotope study (e.g. Russell, 1975; Coomer & Robinson, 1976; Taylor & Andrew, 1978). Such a hybrid model was further developed by Boast and collaborators (1981) who straddled the apparent syngenetic-epigenetic divide, and yet espoused the syndiagenetic model in their careful textural and isotopic study of the Tynagh deposit.

By contrast, those championing the epigenetic hypothesis were to make no acknowledgement of exhalative aspects, insisting that all the ores were epigenetic (e.g., Schultz 1966) until just after the turn of the century.

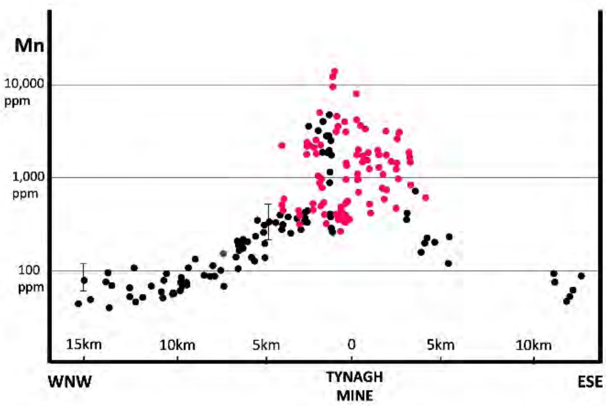

***Figure 1**. The syngenetic manganese enrichments in Waulsortian mudbank limestone around the Tynagh mine (redrawn from Russell, 1974).*

Thus, in spite of the publication of the 7 km radius of manganese aureole at Tynagh (Russell, 1974, soon to be repeated at the Meggen mine by Gwosdz & Krebs (1977; *cf*. Yesares *et al*., 2022)) – the enrichment was passed off as a deep replacement halo, to the author's view impossible to imagine as a post lithification diffusion in the fine carbonates of the Waulsortian (Figure 1). And hydrothermal chimneys (Figure 2a) were considered Holocene stalactites, and their associated worms discovered by Banks (1985) – so similar to the *Paralvinella* found at N 21° on the East Pacific Rise (Desbruyères *et al*., 1983) – were 'reinterpreted' to be an accident of recent petrification of a 'dying' worm having 'fallen in' to chimneys from the vadose zone (Figure 2b)! Also, at this time the mine geologists in the Silvermines B zone had delineated, by careful isopach mapping of the thickness of the unmineralized Waulsortian, how the orebody was confined by these mudbanks and thus must have been truly syngenetic with sedimentation, conclusions consistent with the sedimentary structures found in the ores

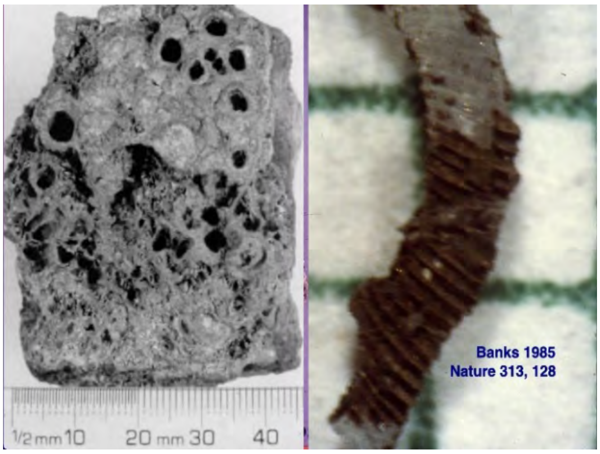

***Figure 2.** a) A nest of hydrothermal chimneys from Magcobar barite open pit, Ballynoe, Silvermines, Ireland (Larter et al., 1981) (b) worm discovered by David Banks (1985) from within a comparable chimney at the Tynagh Mine to be compared with the Paralvinella found at N 21º on the East Pacific Rise (Desbruyères et al., 1983; Russell, 1996, figure 2).*

themselves (Taylor & Andrew, 1978; Taylor, 1984; Andrew, 1986).

Remarkable too was the then general avoidance of comment on the fluid inclusion evidence for temperatures of hydrothermal solutions well in excess of 200°C at Tynagh and Silvermines, which lay in strong contrast to the MVT deposits west of the Mississippi (Samson & Russell 1983, 1987; Banks & Russell, 1992). Thus, this imposition of the epigenetic, late replacement scheme also led to the abandonment of hydrothermal convection as a means of delivery of metal to the Carboniferous host. And by the late 1980's an epigenetic MVT model began to take over as the dominant view in Ireland, as witnessed during the Irish Association for Economic Geology (IAEG) Decade conference in Dublin 1990, with the push for epigenesis again influenced by geologists with experience from North America (1992, IAEG Volume).

The epigenetic model reached its zenith during the important SEG Field Conference in 1995 and in the Irish deposits review paper in the SEG Carbonate Hosted Base-Metal Deposits volume. The adoption of a fluorite-absent Mississippi Valley Type genetic model came with its seemingly implicit (though ironically not unambiguously tested) topographically driven fluid flow mechanism for moving cooler mineralizing solutions. This also resulted in a leaning towards the larger scale convergent tectonic setting which the model requires, contrasting with the extensional regime favoured by the syngenetic school. What made this turn of events particularly remarkable is that already in the early 1970s the Degens & Ross book "Hot brines and recent heavy metal deposits in the Red Sea" was being avidly devoured by mineral explorationists the world over (see especially Bischoff, 1969). And the 1980s saw the final vindication of the exhalative-sedimentary ore theory so persuasively championed and developed by Stanton (1972), this with the discovery of black smokers and their accompanying dynamic environment comprising sulphide feeders, chimneys, mounds and various types of breccia on the East Pacific Rise (Edmund 1979; Koski *et al*. 1984).

But the die was cast and the subsequent discoveries of Galmoy and Lisheen were automatically assigned to, and described in terms of, epigenetic theory (Hitzman 1992, 1995). Still the battle raged between those who would brook no exhalative, or even near seafloor aspect, principally on the basis of textural and palaeomagnetic grounds, and those who would interpret texture, fabric, geometry and geochemistry of the ores as a continuum between exhalative features, sub-seafloor fill of open space and replacement of partially to wholly lithified sediments variously developed in most of the Zn+Pb orebodies. To deny the possibility of a syngenetic aspect was to close the door on syngenetic phenomena, so sending morphological treasures revealed in fleeting underground outcrops to oblivion, much to the detriment of deeper understanding.

Yet it wasn't the morphological structure and geochemical evidence – the essence of intuition of mine and field geologists alike – but isotopic studies, particular of sulphur, that finally forced some accord.

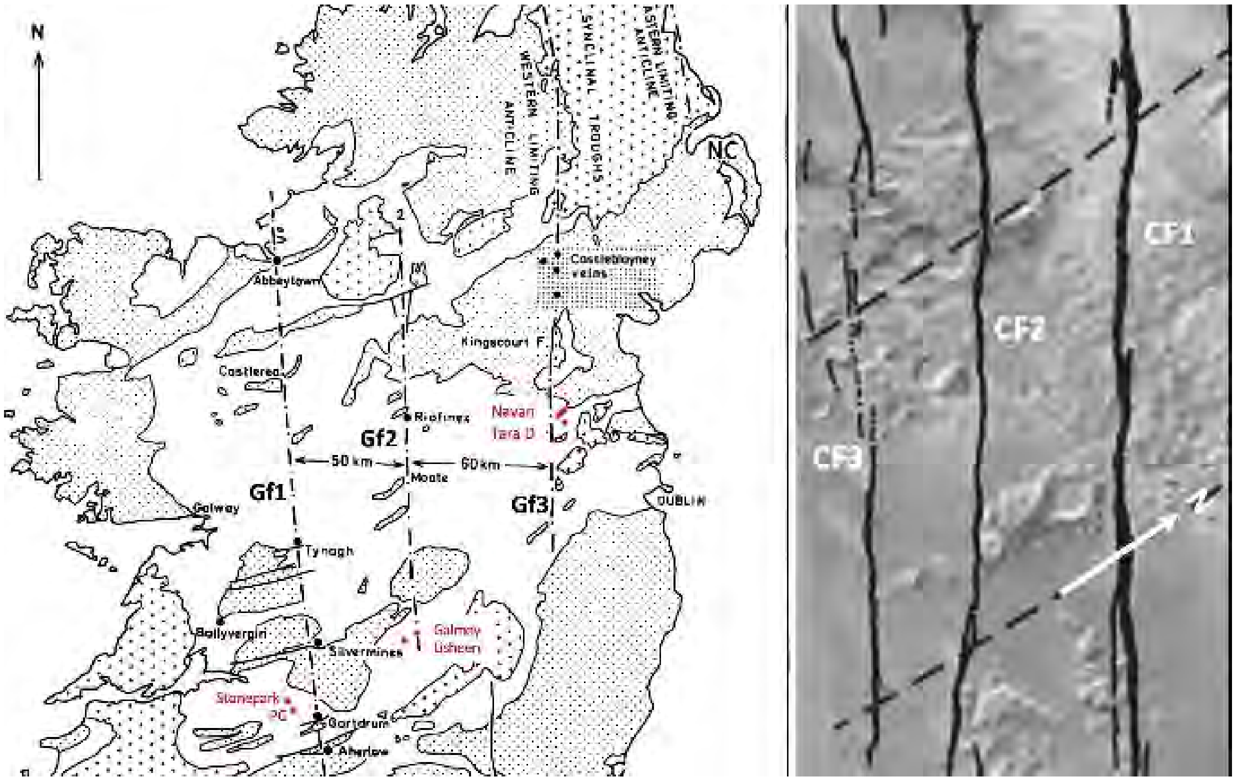

Figure 3. *A composite of figures 1 from Russell (1968, 1969) and Russell & Burgess (1969) where it was suggested that the putative geofracture (Gf1) might explain the distribution of known mines as well as the Aherlow prospect. Gf2 was speculatively extrapolated north and south from Riofinex' Keel trial on the basis of the lie of the land. Gf3 was drawn through the Kingscourt Fault active in the early Carboniferous (Jackson, 1955), the Castleblayney veins and Wright's (1919) "Western Limiting Anticline". Gf4 (not shown) was recognized as weak (Russell, 1972b). However, The discovery of a N6°W trending Tertiary Dike along exactly the same line as extrapolated 10 km northward from the N6°W Pb-Zn vein at Conlig-Newtownards (NC) also occupied by a tertiary dike is offered as its replacement (Yeates, in Russell 1969; Smith, 1991; Caston et al. 2015; Moles et al. 1996, 2016) And see Andrew figure 1, this volume, for the distribution of all mines and showings.*

b) Comparison with Cerberus Fossae on Mars at the same measure but different orientation (Perrin et al., 2022; Stähler et al., 2022). The fracture sets are spaced ~40–45km apart, occur en echelon and are highly segmented (Rivas-Dorado et al., 2022). There has been discussion that the Cerberus Fossae may suffer volcanic tremors (Grindod et al., 2018; Kedar et al., 2020), and recent studies on marsquakes support tectonic activity in warm crust near the solidus temperature at around 30km depth (Stähler et al., 2022; and personal communications with Bruce Banerdt and Simon Stähler).

A 'bacteriometallogenic' solution

Navan dwarfed the Silvermines and Tynagh deposits, and most (though not quite all!) geologists considered the ores discovered there to be epigenetic replacements. A shock was delivered by Fallick and collaborators (2001) who surmised from isotopic studies that around 95% of the Navan ores were precipitated as a product of bacteriogenic sulphate reduction, presumed to occur just beneath the sea floor. The other ~ 5% was considered a result of direct precipitation from sulphide-bearing ore fluids (Fallick *et al*., 2001). Sulphur isotopic studies *favouring bacteriogenic precipitation at Silvermines and Tynagh deposits had previously been published by Coomer & Robinson (1976), Boast et al. (1981) and Boyce et al. (1983). Data from the later discoveries at Lisheen and Galmoy also both revealed substantial quantities of bacteriogenic sulphide (Hitzman et al., 2002; Barrie et al., 2009; Doran et al., 2022). But it was the enormity of Navan that forced the "war's" end (apart from a few skirmishes!). Perhaps naming all these as "bacteriometallogenic" can cement an accord over the origin of Irish type deposits?*

Ore fluid sources and controls: the dispute still lingers!

The SedEx-MVT dispute still lingered on in discord over the sources of the mineralizing fluids and structural controls to the orebodies: 'basin brine and near surface tectonics' versus 'deeply circulating saline-seawater', though Murphy *et al*. (2008) attempted another hybrid explanation. Pereira (1963b, fig. 6) had stressed the importance of NW-SW trending steep to vertical deep fissures originating at the crust-mantle boundary in the guiding of deeply sourced hydrothermal fluids at fault intersections and thereby to mineral exploration. Ralph Horne (1975a, 1975b) continued with this theme, an exploration view currently being reprised through the discoveries at Stonepark and Pallas Green and prospects further to the northwest (see Andrew, this volume).

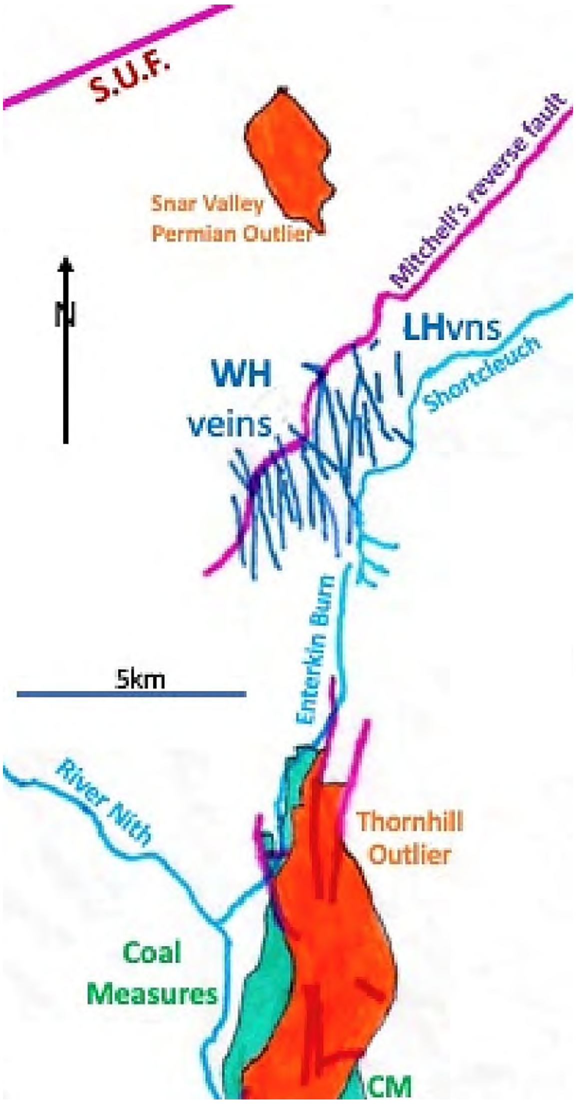

Figure 4. *Portion of putative Gf5 comprising Leadhills-Wanlockhead vein system and Thornhill Basin (Vaughan 1974).*

At around that time, and in contrast, Russell (1968 fig. 1, 1969 fig. 2) (Figure 3a) proposed four north-south geofractures spaced 50 to 60 km apart as the main control, remarking that Ireland and its surrounds suffered east-west extensional stress which resulted in fracturing, refracturing and "geofracturing" of the crust in the late Tournaisian – producing structures that will be compared to those presently developing in Cerberus Fossae on Mars (Figure 3b). In this theory vertical north-south zones of brittle fracture produced at the crust-mantle boundary made their way toward the surface aided by high pore-pressure conditions and deep intrusion of volatile magma. Hot pore fluids bearing the ore-metals dissolved from the Lower Palaeozoic basement were argued to have escaped along intersections of the geofractures with Caledonoid faults. In regard to structural control of ore genesis, Russell (1968, p. B126) had remarked that "the occurrence of sulphide ore deposits in Ireland, either as epigenetic or syngenetic bodies, is not significant in respect to the origin of the mineralizing solutions" – an anticipation of the accord mentioned above. What mattered to Russell were the supposed N-S geofractures as guides to upwelling ore fluids (Russell, 1968, 1969).

We learned from Thompson (pers. comm. 1985) that the indisputably epigenetic copper (-mercury) deposit at Gortdrum (Thompson 1966) was discovered on the basis of a line drawn southwards from the old mines at Abbeytown, through Tynagh and Silvermines to intersect the faulted margin of the Glenbane ORS inlier in County Tipperary. And Navan was found in late 1970 (O'Brien & Romer, 1971; Derry, 1979) close to the intersection of the southern extrapolation of the north-south trending Kingscourt Fault and major NE trending faults related to Murphy's Caledonoid line (Russell 1968 fig. 1, 1969 fig. 2).

An exploration strategy prevalent at that time was the "proximity" argument of "*outside* exploration teams". This approach searched for "fairways" more comparable to MVT type deposits and supported exploration strategy in taking licenses around perimeters of promising claims and active mines much closer than the 20km spacings suggested by Russell (1978) – an empirical "honey pot" approach successful in the Superior Province and the Mississippi Valley ore clusters and runs (Hitzman, 1992). Indeed, many among the new exploration geologists to arrive from North America assumed the Irish lead-zinc deposits to be just another example of Mississippi-Valley-Type carbonate-hosted deposits – a prejudice according to Russell that undervalued the uniqueness of the Irish ores with their indications of exhalative aspects (Russell & Skauli, 1991). The MVT-take also ignored the genetic clues in the Caledonian basement so well revealed to the NE of Ireland and beyond (Pattrick & Russell, 1989; Moles & Nawaz, 1996). However, notwithstanding Russell's antagonistism to MVT-minded explorationists, there is the fact that Lisheen was a success chalked up in the first decades of exploration in Ireland discovered only 10km (not the 20km advocated by Russell, 1978) from the Galmoy mine, using an MVT model (Hitzman, 1992, 1995; Lowther *et al*., 1999). Other such deposits so claimed are the SWEX and Tara Deep but in the view of the present author these are "*inside* exploration" discoveries of contiguous or near contiguous deposits (Ashton *et al*., 2003, 2015, 2018; Drummond, 2021).

N-S geofractures revisited

Imitating the kingfisher has long been a strategy of prospectors in their search for ore – but they don't publish (company geologists keep their own council (Derry, 1979))! And academic geologists are wary of "linear controls". I am reminded of Bob Shackleton's admonition – his distinction between "crypto structures" and what he termed "halucino structures". "The first are there though you can't see them, the second aren't there though you think you can see them." With prior experience prospecting for Falconbridge Nickel in Canada (Russell, 2019) I had absorbed "the string of pearls" mantra and, in an August 'academic' vacation time, managed to get published "Structural controls of base metal mineralization in Ireland in relation to continental drift" (Russell, 1968, 1969) (Figure 3a)! That putative direct relation to continental drift was clearly overreach (and wrong), but let's look at the first few lines of the 1968 abstract:

A hypothesis is presented that suggests that both the genesis and the siting of the newly discovered base metal deposits in the Carboniferous rocks of Ireland are controlled by the intersection of north-south upper mantle fissures with east-west to *northeast-southwest faults of Caledonian trend. It is proposed that the intrusion of magma at these intersections gave rise to a convective or a partial convective system within the pore waters which leached metals from the Lower Palaeozoic geosynclinal sediments and precipitated them in the overlying Carboniferous rocks or on the Carboniferous sea floor.*

One of the more polite (and here partially redacted) responses to the paper elicited the following: "As the ••••••••, a department given to the study of the Irish ore field, we feel best placed to expurgate this speculation before it enters the realms of Irish mythology".

So why persist? Lisheen and Stonepark/Pallas Green mineral bodies don't seem to fit (Hitzman *et al*. 2002; McCusker and Reed, 2013; Andrew, this volume, figure 3). But Navan, SWEX and Tara Deep do (Ashton *et al*., 2003, 2015, 2018) (Figure 3a)! This structure, N-S Geofracture 3 of Russell, (1968, 1969), as projected northwards beyond the Kingscourt Basin, is a 25km long "half-graben" active in the early Carboniferous which happens to intersect directly, some of the north-south Pb-Zn-Ba veins near Castleblayney in County Monaghan (Cole, 1922; Jackson, 1955; Russell, 1968; Strogen, 1974; Derry, 1979**,** Strogen *et al*., 1995) (Figure 3a). However, the southerly extensions of the N-S trending faults defining the Basin deviate away to the south-west before meeting the Navan body. But against this are bouguer anomalies indicating that deep structure still retains a north-south orientation when projected southwards (Young, 1976), and that it does underlie all the Navan orebodies, a fact overlooked by Brown & Williams (1985) and Johnston *et al*. (1996).

This leaves geofracture 3 with a minimum length of 70km (Figure 3a). As an aside, this length is similar to that of the uniquely straight geofracture running N6°W from the Conlig-Newtownards lead-zinc veins into the North Channel recorded in 1975 (Fowler, 1959; Russell, 1969, Caston, 1975, Moles & Nawaz, 1996) as described in Russell & Haszeldine (1992).

Also paralleling the "Kingscourt-Navan" (Geofracture 3) are the affine N-S trending Thornhill Basin and Leadhills-Wanlockhead veins occupying comparable terrain 225km along strike to the NE in Southern Scotland projected as Geofracture 5 in Russell (1972, 1973, 1979) (Figure 4). Over time 400 thousand tons of lead-zinc ore have been won from these NNW to NS trending veins – comparable with the non-bacteriogenic ore tonnage at Silvermines and Tynagh (Mackay, 1958; Floyd, 2003). In spite of blunt refusal to see a pattern here the veins can be unequivocally traced structurally southwards, without break, through the upper reaches of the N-S trending Shortcleuch water and the N-S trending Enterkin Burn directly into the N-S Thornhill Basin of Carboniferous and Permian age to the south (Figure 4). However, in this case the 'geofracture' as seen prescribes a length of only 20km (Vaughan, 1974, fig. 25). 1974).

Although the NS control of these veins is there for all who would see, a secondary control is also all-important but less appreciated – Mitchell's reverse fault dipping north (Vaughan 1974). During early Carboniferous hydrothermal fluids feeding the Leadhills-Wanlockhead veins would have been guided up this low-angle NE-trending reverse fault which also acts as the present hanging wall (Temple 1956; Mackay 1959; Vaughan 1974; Samson and Banks, 1984; Pattrick & Russell, 1989). Had the sea extended over the Southern Uplands at this time one might imagine a notional development of a ≥4km long NE-SW trending orebody being produced in early Carboniferous sediments?

I leave it to the reader to consider, as did the much-lamented Derek Romer, possible extrapolations to the south of Thornhill and north of Leadhills (and see Russell, 1992). Pattern recognition has been a requirement for survival since the beginning of time, and perhaps these discrete structures are rebuffed for reasons of form in the academic press, and for proprietal reasons from company geologists?

While there is not enough new data to retrieve the other putative geofractures from academic limbo, further study of Pb-Zn veins in Ireland, Scotland, Northern England and North Wales, where ores are of a similar age, temperature (≤280°C) and salinities (≤30% NaCl) (Samson & Banks, 1988; Moles, 1996; Haggerty & Bottrell, 1997; Baron & Parnell, 2005; Wilkinson, 2010) may be instructive in improving ore genesis modelling (Haggerty & Bottrell, 1997; Banks *et al*., 2002). And, more outlandishly, otherworldly comparisons with Cerebus Fossae on Mars may be enlightening where the refractions of crustal grain are much less of a complicating issue as discussed next (Figure 3b).

Actualistic geofracturing of Cerberus Fossae, Mars

Mathieu Lapôtre and collaborators (2022) consider Mars a time machine for Precambrian Earth. Here we consider present day seismicity on Mars as a reprise for similar structural activity in early Carboniferous times in Ireland. Cerberus Fossae, in Elysium Planitia, are young and seismically active west-northwest-trending tectonic fissures a thousand kilometres long separated by unbroken crust at 40 to 45km intervals (Head & Marchant, 2003; Plescia, 2003; Jaeger *et al*., 2010; Perrin, 2022; Jacob *et al*., 2022.) (Figure 3b). NASA's InSight mission to Mars has recorded multiple ∼3.5 magnitude "mars-quakes" in the vicinity of Cerberus Fossae (Giardini *et al*., 2020; Andrews-Hanna, 2022; Sun & Tkalčić, 2022) as anticipated by Böse *et al*. (2017) and Panning *et al*. (2017). Moreover, Roberts and collaborators (2012) identified a dense distribution of boulders along a 90 to 150km stretch in fossa G2 that they interpreted as results of large palaeo-quakes causing surface rupturing over the last 2.5 Ma.

The comparison with Ireland is made the more noteworthy as both terrains are suffering, or have suffered, volcanism, pyroclastic activity and widespread tuffaceous sedimentation (McCusker & Reed, 2013; Elliott *et al*. 2019; Horvath *et al*., 2021; Slezak *et al.*, 2022). Crustal thicknesses too, as measured, are comparable, perhaps approaching 40km in Elysium Planitia (Knapmeyer-Endrun *et al.,* 2021), and a little more than 30km in Ireland (Landes *et al*., 2005; Mather & Fullea, 2019).

According to Stähler *et al*. (2022) the depth of low frequency mars-quakes in Cerberus Fossae indicate faulting in the lower part of the crust. Higher up the marked drop in stress suggests that 'hypocenters' are located around an active dike at depth (Nahm *et al.,* 2016). Rivas-Dorado and collaborators (2023)

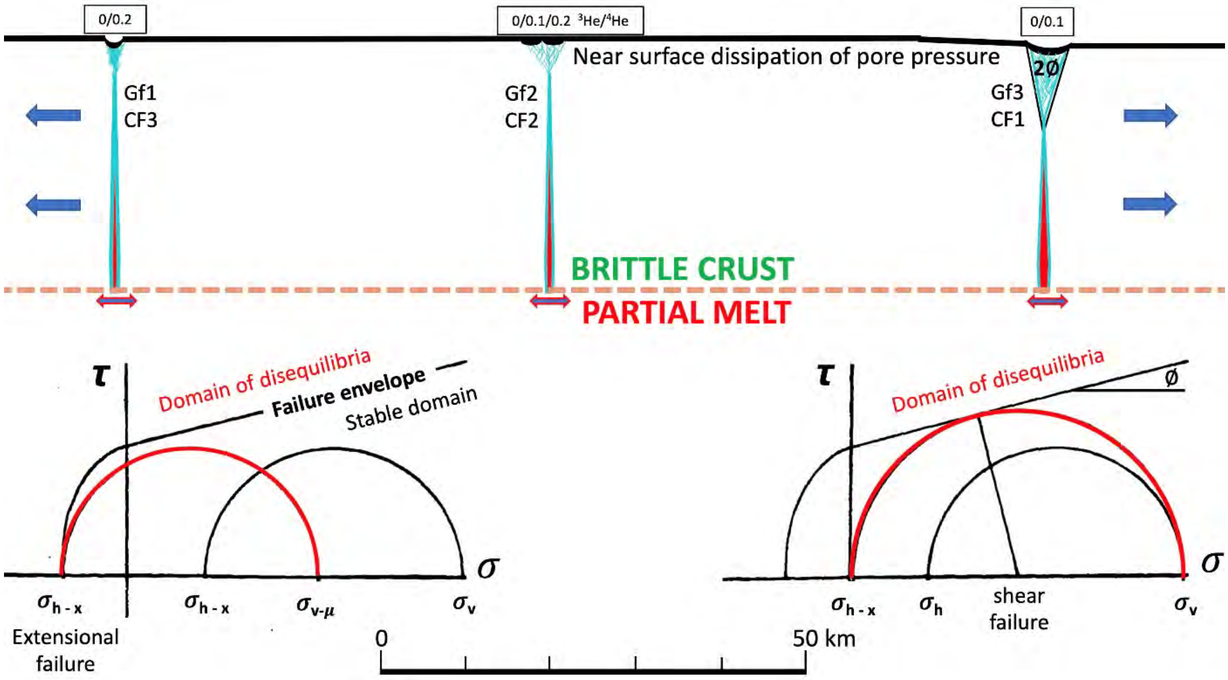

Figure 5. *Proposed model for geofracture formation in Ireland and Cerberus Fossae, Mars, showing section through both uppermost lithospheres subjected to horizontal tensile stress (large arrows). In the left hand and central regions extensional stress increases in the brittle-to-ductile zone by an amount μ, which effectively lowers the hydrostatic stress by the same value, thus driving a Mohr stress circle of small diameter (σ_v - σ_h where σ_v is the earlier vertical effective stress and major principal stress and σ_h is the earlier horizontal effective and minor principal stress) against the failure envelope at a point where it crosses the normal stress (σ) axis so that tensile fractures form with the plane of rupture perpendicular to the minor principal stress (Russell, 1972, 1973; Rivas-Dorado et al., 2023). Similar models are presented in Nahm et al. (2016) and by Stähler et al. (2022) who model dyke injection to mid-crustal level as interpreted from the first focal mechanisms of marsquakes (Brinkman et al. 2021; Kedar et al., 2021). It is speculated here that the same is likely true for geofractures in Ireland in the early Carboniferous. Nearer the surface, as pore fluids gain access and escape up and along permeable cross structures, pore pressures drop and the stress circle retreats to the right despite a drop in tensile strength, so that Gf1(CF3) and Gf2(CF2) do not reach the surface (Russell, 1969; Rivas-Dorado et al., 2023). No increase in pore pressures occurs in the region to the east so a similar type of failure cannot take place. Instead, at a correspondingly greater distance from Gf2(CF2) the horizontal compressive stress σ_h is reduced by an amount x so that the Mohr stress circle of relatively large diameter touches the fracture envelope to the right of the shearing stress (τ) axis and normal fault failure results (Russell, 1969; Rivas-Dorado et al., 2023). The double headed arrows signify the tensile stress concentrations associated with the bottom of the geofractures which attract fluids from a degassing mantle, thus providing engine-like feedback and so concentrating the heat required to drive the hydrothermal systems (Russell, 1972; Bailey, 2012; Davidheiser-Kroll et al., 2014).*

model graben initiation as dike-induced with stress-strain models analogous to the Irish Geofracture models of Russell (1972, 1973, and see Rubin & Pollard, 1988; Rubin, 1993; Broquet & Andrews-Hanna, 2022) (Figure 5).

While there are no signs of hot springs associated with Cerberus Fossae, five outflow channel systems emanating within, and spaced along, a 250km stretch have been identified in the northern-most fossa (Burr *et al.*, 2002; Berman & Hartmann, 2002; Plescia, 2003; Tanaka *et al*., 2014; Cassanelli & Head, 2018). The sequential sources of fluid young to the east, perhaps engendered by a dike migrating in the same direction (Brown & Roberts, 2023). There are certainly no signs of mineral precipitation at the springs themselves and Brown & Roberts (2023) suggest these aqueous emanations to be a result of ice melting. However, Cerberus Fossae are offered as a model for the geofracture concept, if from another world, and are counted here as actualistic examples of the geofracturing process – a seismic process we liken to cracking engines expanded upon below?

Autocatalytic cracking engines

Any self-ordering structure, whether it be convection, plate tectonics, ore genesis or life itself, functions as an engine (Cottrell, 1979). Although we are looking at self-ordering of structures responsible for hydrothermal convection cells through the imposition of tectonic disequilibria as played out most notably in surface geology, is it possible to also sort out the primary stress vectors operating deep in the crust in those early

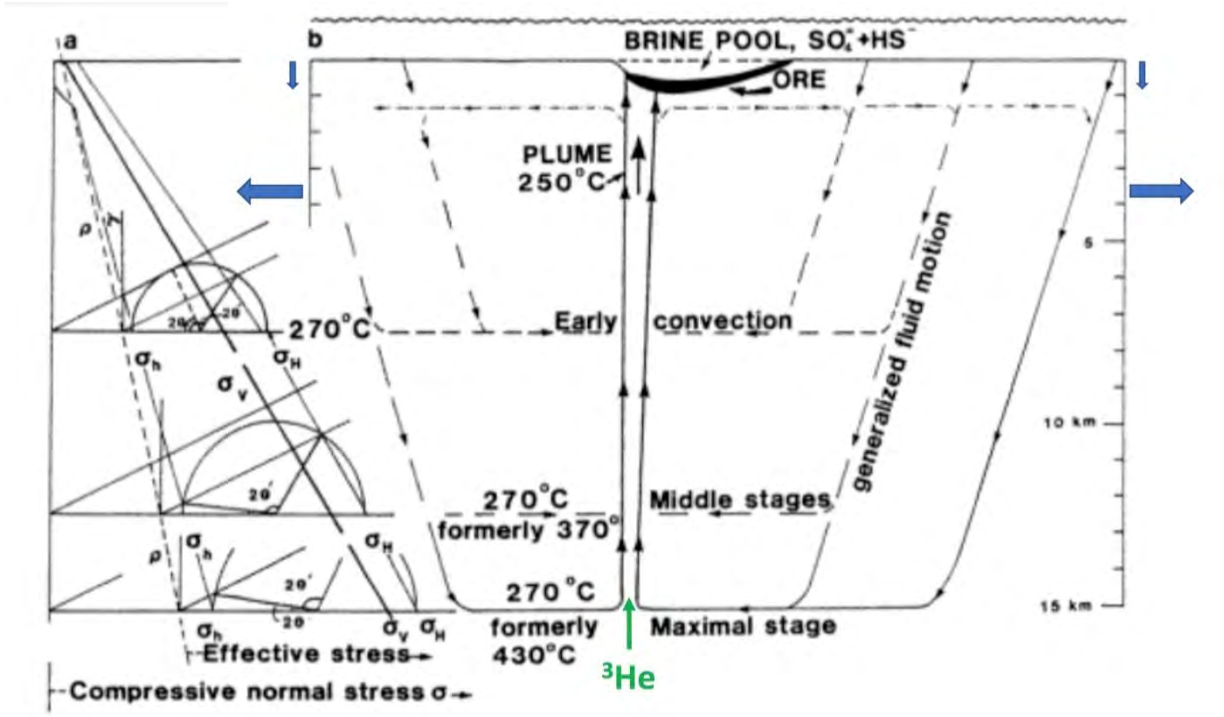

Figure 6. *The downward excavating hydrothermal model for the generation of the Irish $Zn+Pb\pm BaSO_4$ deposits from expanding hydrothermal cells involving saline seawater (after Russell & Skauli 1991). The system acts as a self-organizing heat exchanger. (a) Stress conditions conducive to open system convection in the developing brittle crust. The large diameter Mohr circle represents high differential stress. Dry vertical joints just fail in these hypothetical conditions down to the 270°C isotherm in the upper 8 km of the crust. Below 8 km the curve through the origin is not intersected by the Mohr circle so vertical joints are stable. But as the upper crust is cooled by hydrothermal convection to ~270°C, seawater can gravitate into the joints and increase the pore pressure to hydrostatic values. The reduction of effective pressure removes resistance of cross-joints to shear between θ and θ'. The influx of seawater leads to positive feedback, increasing the effective stress. Downward "excavation" of the hydrothermal system is the consequence as the base of the cell tracks the brittle to-ductile transition zone at ~270°C. (b) Hypothetical conditions forcing closed-system convection and preventing exhalation thus explaining barren inter-ore layers. In this case normal faults rather than vertical faults develop as σ_v takes over as the minimum principal stress. Abbreviations: ρ = hydrostatic pressure, σ = normal compressive stress, σ_h = least horizontal stress, σ_H = maximum horizontal stress, θ = minimum angle between active vertical joint planes and θ' = maximum angle between active vertical joint planes and σ_H.*

Carboniferous times, as it is now with Mars? To attempt this, we look to Cottrell's cracking engine hypothesis which sees such dissipative structures as examples of autocatalytic free-energy-converting machines (Cottrell, 1979; Russell *et al*., 2013). We are interested in large systems charged with trace metals that were brought to a halt – trapped – before complete dissipation of their solutes. What is needed as we have discussed, is another dissipative structure to take over as a trap, in Ireland's case a microbiome that includes sulphate-reducing bacteria (Fallick *et al*., 2000; Blakeman *et al*., 2002; Gagnevin *et al*., 2012).

As an attempt to understand ore genesis and particularly where to further prospect we invoke two types of "cracking engines" involving aqueous fluids: one diffuse and downward-excavating that exploits the much-fractured near surface; the other an upward facing mega-engine controlling failures with a north-south trend at the more isotropic mantle-crust interface. Is it possible to resolve how and where these two putative systems interacted and exerted their overall effect – perhaps at the downwardly mobile upper-to-lower crust boundary where the influence of Caledonoid structure wains – to eventually plumb a depth of 12 to 15km (Russell, 1978; Bonadio *et al*. 2021)?

Upward cracking engines as explanation of "geofracture-guided" and autonomous diatremes

As introduced by Kutina and collaborators (1967) geofractures are a set of through-going crustal joints separated by intervals of 45 to 65km, depending partly on crustal thickness yet unrelated to earlier structural grain. Their relative continuity – up to 200km on Earth and 1000km on Mars – implies initiation at a depth where the lithosphere is mechanically isotropic. The initiating engines are assumed to nucleate at the base of the continental crust and vector upwards (Figure 5).

They are imagined as products of all-round extension of crusts "floating" on degassing and partially molten upper mantle producing. Here, fluids are drawn towards the tensile stress

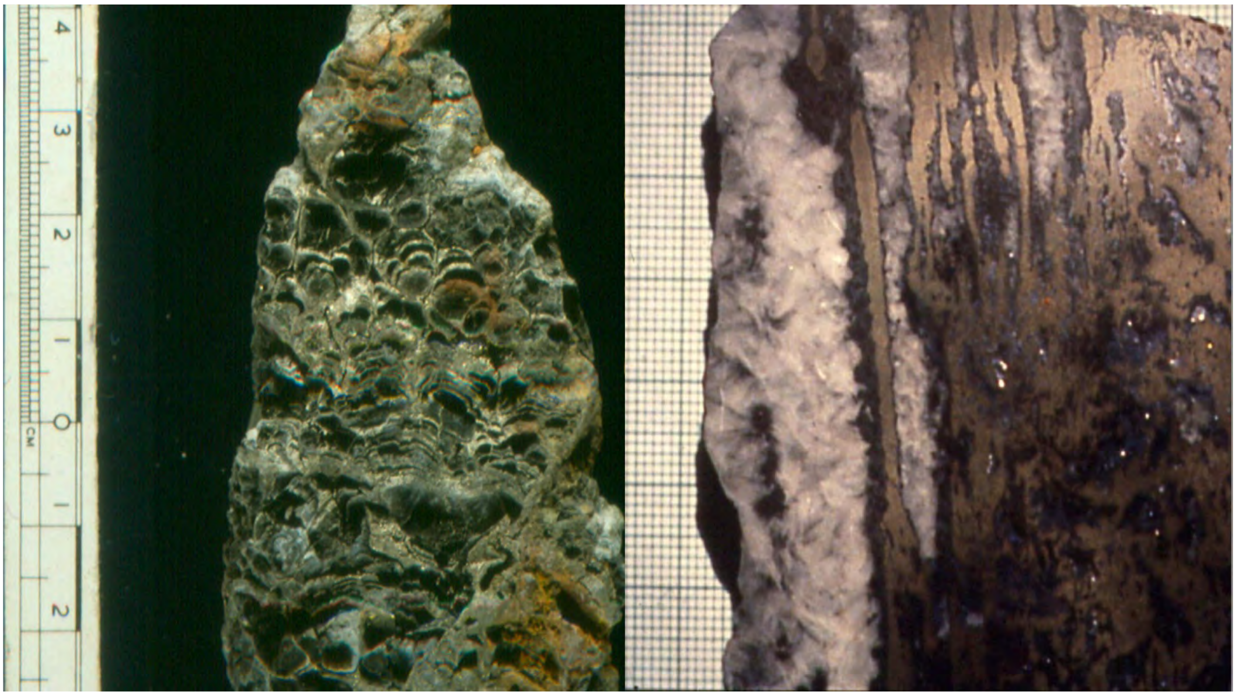

Figure 7. *a) Iron sulphide/organic carbon fossil microbialite from the eastern area of Ballynoe open pit 20 meters NW of chimneys with strong biogenic sulphur isotope signature (Boyce et al., 1983; Russell, 1996, figure 3); b) fossil sulphide natural chemical garden from Tynagh gifted by John Hutching (and see Banks 1985, figure 2c). Both structures were fundamental to the moderate temperature hydrothermal theory for the emergence of life (Russell et al., 1989)*

concentrations producing linear zones of high pore pressure which has the effect of focusing heat in those regions (Bailey, 1970; Russell, 1972, 1973; Davidheiser-Kroll *et al*., 2014; Rivas-Dorado *et al*., 2022, 2023; Stähler *et al.,* 2022).

A portion of the low-viscosity magmas and/or volatiles rise along these fractures reaching a high level in the crust at the fracture intersections and cross-faults in Ireland (Pereira, 1963b; Russell, 1968; Kedar *et al.,* 2021) (Figure 5). Here, some of these intrusions centred on the intersections act as 'hot spots' and drive convective systems within pore waters in the Lower Palaeozoic geosynclinal rocks and in basement below (Walshaw *et al*., 2006; Yesares *et al*., 2019). This heat from the top of the mantle, along with that conducted from the geofracture walls, is then transferred upwards by way of a convective system in crustal fluids at high pressure even relative to ambient stress. The geofractures provide a planar conduit for upcurrents of these fluids where, nearer the surface, rising plumes take advantage of cross-cutting faults or other permeable structures and eventually mushroom out at a variety of scales. Wherever there is adequate reduced sulphur then base-metals would be deposited over the intersections, but where the sulphur was insufficient, then smaller deposits are dispersed around the main node. The Castleblayney veins may be an example of the latter phenomenon. Not known at present is how far these solutions could migrate from the centres along surface fracture before they might meet further conditions likely to precipitate (further) ore as a putative "escapee" deposit?

Elsewhere too, some pockets of highly volatile magmas could make their own way up through the crust to the surface by penetrative convection (Elder, 1966). Here they have the potential to induce upper-crustal convective hydrothermal ore-generating systems independently of, and distant from the supposed geofracture. Any resultant ores occur as sedimentary and/or replacement deposits above the intrusions or can be overtaken and redistributed by diatremes (Elliott *et al*., 2019). In general, some relationship with Tournaisian magamatism has long been suggested (Derry *et al*, 1966; and see (Kushiro, 1965; Francis 1967; Upton *et al*., 2004). That a mantle contribution to some of the orebodies is evidenced by the exciting ^{3}He/^{4}He studies of Davidheiser-Kroll *et al.* (2014). These authors demonstrate a strong link with Galmoy, Silvermines and possibly Tynagh, although not with Navan and Lisheen. As might be expected, the fluid inclusion temperatures follow an approximately similar trend (Davidheiser-Kroll *et al*., 2014). ^{3}He/^{4}He does suggest that mantle heat was a factor in driving the hydrothermal fluids responsible for the Irish Pb-Zn ores (Davidheiser-Kroll *et al.,* 2014). Further research using this technique on the Irish ores, and the British vein deposits is surely warranted (Davidheiser-Kroll *et al.,* 2014).

Downward Excavating Cracking Engines and their approximate locations

Miller & Nur (2000) have pointed out that fluid flow in the crust is either extremely rapid or extremely slow. Furthermore, permeability can change by orders of magnitude instantaneously when pore pressures increase to induce seismicity and hydrofractures or decrease to effectively lock the crust uneasily out of tectonic equilibrium (Lister 1975; Sibson *et al*., 1975; Russell *et al.* 1995). Russell's estimation that ore deposits will occur at spacings of between 20 and 30km has been placed in doubt by the discoveries of Lisheen and Galmoy separated by

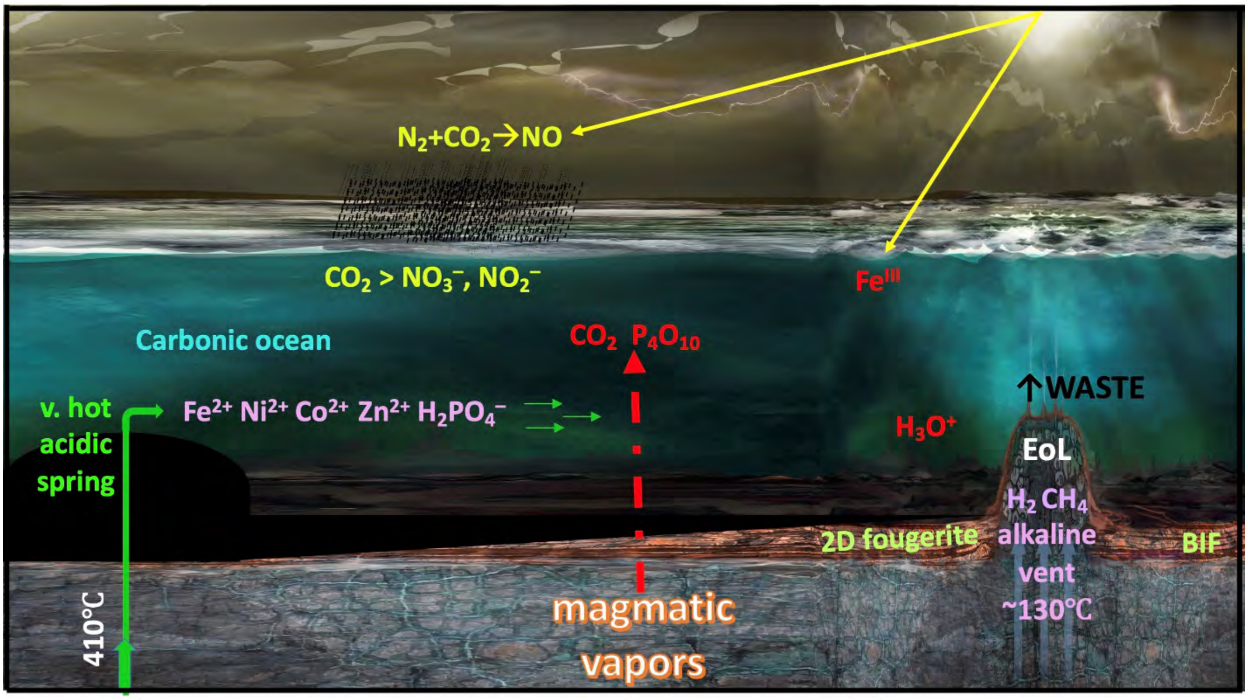

Figure 8: *The submarine alkaline vent theory for the emergence of life~ 4.3 billion years ago (Russell et al. 1989, 1997, 2005). Note that the pH disequilibria leading to the precipitation of iron sulphide and oxyhydroxides is the inverse to that leading to the precipitation of sulphide structures registered in Tynagh, Silvermines and Navan (Banks, 1985, Boyce et al. 2003; Anderson et al., 1998*)

a distance of 10km, and other showings along Rathdowney trend (Hitzman *et al.* 1995; Wilkinson *et al*., 2005). This "mistake" was based on ideal "Combarnous and Borries" convection cells of common aspect ratios operating in an isotropic crust (Nield & Bejan, 2006). Colin Andrew's composite isopach maps, with their demonstration of the upper crustal instabilities of the time, illustrate well the likely complexities imposed on near surface hydrology (Andrew, this volume). Getting surface waters into the crust must have been unusually rapid to feed the hydrothermal convection cells responsible for the orebodies, calling for the intermittent sudden 'takeover' of the vertically imposed minimal near the surface stress to a general horizontally vectored minimum stress (Russell 1972, 1973; Walsh *et al*., 2018) (Figure 6). And density contrasts of early Carboniferous saline bottom waters would also have played into these complexities.

Thus, we might conclude that the upper crust in those times was anomalously unstable and permitted major infusions of waters to the then hot crust. Bear in mind continual operation of the convection cells were assisted by positive feedbacks, many of them non-linear (Miller & Nur 2000). These were consequences of, i) the cooling of the crust through the brittle-to-ductile transition zone and the downward excavation of the cell, so that further heat was tapped, ii) the increased height of the cell, iii) the increase in *effective* stress brought about by hydrostatic pressure in newly pores forced open at the base of the cell, iv) exothermic hydration and oxidation reactions as the convecting water is 'metasomatized' in the crust, v) the decrease in thermal conductivity of the medium as porosity is increased, vi) the decrease of kinematic viscosity of water with temperature (Russell & Skauli 1991; Haack & Zimmermann, 1996; Miller & Nur 2000).

Hydrothermal convection can operate by mass transfer within porous media, in this case the metamorphic sedimentary, volcanic rocks and granites of the Caledonian orogen in a series of downward-excavating hydrothermal cells (Russell, 1978; Russell *et al*., 2000; Wilkinson *et al*. 2010).

The ultimate depth of convection was considered to be 15km where an equilibrium was reached between collapse of siliceous rock resulting from pressure and heat-flow. that surface water can gravitate to depths approaching the 15km and/or the 270°C isotherm suggested by Russell (1978), and yet be maintained at hydrostatic pressure (Guha 1974; Simpson 1976; Russell *et al*. 1995). Townend & Zoback (2000) have demonstrated how faulting keeps the crust strong by puncturing local zones where pore pressure approaches lithostatic. Furthermore, in situ bulk permeability can be ~10^{-15} to ~10^{-17} m^2 three to four orders of magnitude higher than that measured on core samples. At such bulk permeabilities water takes between 10 and 1000 years to traverse 1 to 10km (Townend & Zoback 2000; Ingebritsen & Appold, 2012), faster at high temperatures where viscosity drops by nearly an order of magnitude (Russell 1978). We may consider the threshold required for advective flow to be around~10^{-15} m^2, a value that may obtain to 12 or even 15km (Russell *et al*. 1995; Townend & Zoback 2000; Ingebritsen & Appold, 2012). The strongly exothermic retrograde water/mineral reactions would have augmented both the process of convection and the metal content of the hydrothermal solutions (Bischoff *et al*. 1985; Haack & Zimmermann 1996).

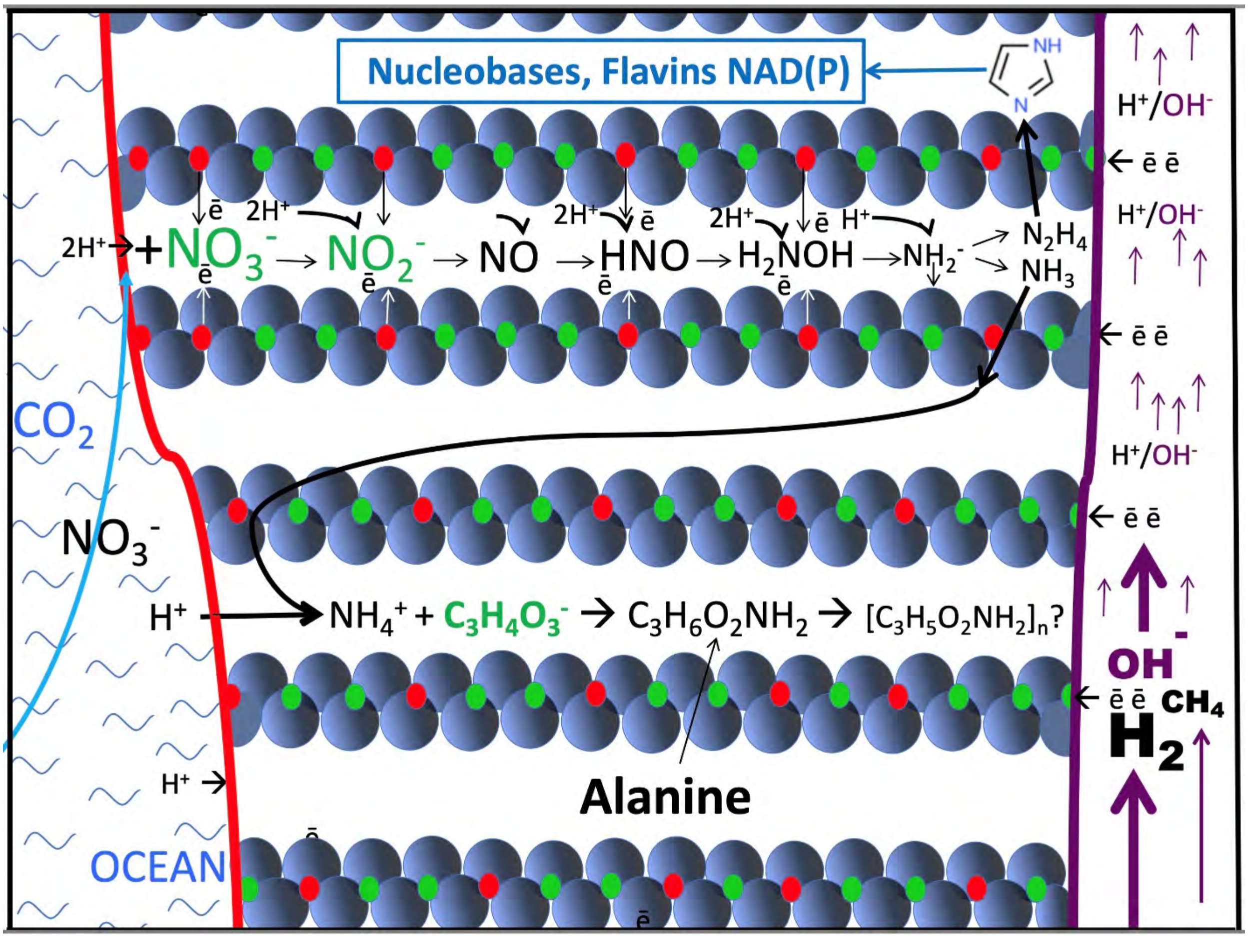

Figure 9. *Sketch of the precursor to iron formations of the mineral green rust; the nanoengine fundamental to bring the electro-mechanochemical disequilibria at a submarine alkaline vent to life (cf. Arrhenius 2003, Arrhenius et al 1997; Russell, 2018; cf. Derry et al., 1965; Russell, 1975).*

'Beyond the basin scale': lead-zinc veins of similar age in the British Isles

True to Barnicoat and colleagues' admonition that the tendency to limit the area of study just to basin scale in Ireland is "mistaken", our present conference goes a long way in rectifying such parochial views (Barnicoat *et al.,* 2000). Even the immediate metallogenic province surely cannot be restricted to Ireland, so where else might we look? We have conceded here that even without the bacteriogenic addition at Navan-SWEX-Tara Deep this would still leave a whopping 3Mt tons of ore grade sulphides. However, using this same assumption Silvermines and Tynagh (Boast *et al*., 1981) would be left with 500,000 tonnes or so of primary sulphide. Of course, the Shallee 'feeder' veins at Silvermines were mined on and off for centuries but even these would likely not attract a modern venture. However, the Silvermines veins may offer clues to a fuller understanding. Perhaps such veins elsewhere are all that is left of "Irish-type" ores either long eroded away or perhaps they were merely feeders to subaerial geysers at the time? So, let's look at similar veins of likely early Carboniferous age beyond the 'basin' towards the east; to Scotland, England and Wales (Pattrick & Russell, 1989). Could studies of these veins cast light on the hydrothermal origin and siting of the Irish ores (Pattrick & Russell, 1989; Banks *et al.,* 2002)?

We have already touched on the north-south trending veins in Northern Ireland and the high-tonnage vein deposits at Leadhills-Wanlockhead in Scotland. Other veins with commensurate tonnage running north-south are found at Great Laxey on the Isle of Man (Ford, 1993, 1998; Quirk & Kimbell, 1997), Greenside in the Lake District of England (Gough, 1965), and Llanrwst in North Wales (Haggerty *et al*., 1995; Haggerty & Bottrell, 1997; Mason 2018). However, these latter veins are associated with others of contrasting trends, e.g., the E-W Foxdale vein 20km from Laxey on the Isle of Man (Ford, 1998), the Keswick veins of various trend ~15km to the WN-W of Greenside (Stanley & Vaughan, 1982) and the Llanfair Veins also of various trends 16km to the NW of Llanrwst (Haggerty & Bottrell, 1997). It is notable that the veins of more variable trend are those developed south of the Iapetus Suture. Indeed, once we are as far south as the extensive Central Wales lead-zinc-silver district and the West Shropshire Orefield in England, most of the richer veins run EN-E, and N-S veins are absent (Jones 1922; Dines, 1958; Hughes, 1959; Fletcher *et al*., 1993; Bevins *et al*., 2010; Wilson *et al*., 2016; cf. the Rathdowney trend in Ireland: Torremans *et al.,* 2018; Turner *et al.,* 2019).

The questions then arise regarding the more widely separated and dispersed veins south of the of the Silvermines fault/Iapetus suture and its continuation:1) are these escapees from the main convective system (Doran *et al*., 2022) possibly as a result of blockage of the main channels, or 2) are they derived from independent convective systems, perhaps unrelated to basement structure?

The hydrothermal iron mineral nanoengines that drove life into being

The discovery of hydrothermal pyrite chimneys and associated pyritic microbialites in the Ballynoe open pit in Ireland (Larter *et al.,* 1981; Boyce *et al*., 1983; Russell *et al*., 1988) (Figures 2a; 7a) inspired the germination of what was to evolve into the submarine alkaline vent theory for the emergence of life (Russell *et al.*, 1989, 2005, 2014). A natural pyrite chemical garden retrieved from the underground workings at Tynagh gifted by John Hutching was particularly inspiring. Chemical gardens are generated on dropping a crystal of, for example, hydrated cobalt chloride into a sodium silicate solution (water glass). The water is released along with fraction of the cobalt chloride as it dissolves to a strong acid/weak base, which is drawn to the sodium silicate (strong base/weak acid) solution, causing precipitation of a cobalt-tinged deposition of a silica barrier or membrane separating the two out-of-equilibrium fluids, so producing the chemical gardens (Barge *et al.,* 2015a). The same structures can be produced by simply injecting a solution of cobalt chloride into sodium silicate (Russell *et al*., 1989; Barge *et al*., 2015b).

In the Tynagh example (Figure 7b) the acidic metal-bearing solution meets the alkaline (bacteriogenic) bisulphide to produce an FeS membranes that eventually sulphidizes to pyrite (Russell, 1988). But given that the Hadean ocean floor was mafic to ultramafic, moderate-temperature hydrothermal solutions then would have been alkaline rather than acidic. In this case the natural chemical garden produced would be the ferrous-ferric oxyhydroxide green rust (the mineral fougerite) – known to be the major precursor to the Banded Iron Formations – the iron in the ocean being derived from 400°C hot acidic springs (Russell *et al*., 1997; Arrhenius *et al.,* 1997; Arrhenius, 2003; Halevy *et al*., 2017). Minor iron sulphide (mackinawite) would also accompany the green rust constituting the membrane defining the chemical gardens, in my view comprising the first compartments of life.

Warm to hot springs worldwide are known to carry hydrogen and often methane in solution. These are the fuels of life, and the methane carries reduced carbon to the system as well. In the Hadean such a green rust membrane keeping the two fluids: – the hydrothermal solution alkaline and the carboxylic ocean – apart, produces an electrical disequilibrium summing to around 4pH units and ~800 millivolts, just the disequilibria driving life to this day (Russell, 2018; Fracchia *et al.,* 2018; Duval *et al*., 2020; Nitschke *et al*., 2022). In those conditions at a submarine mound at that time, oceanic CO_2 was 'hydrogenated' at the FeS sites to the carboxylic acids with protons and hydrothermal hydrogen (Hudson *et al*., 2019); nitrate and nitrite ions were reduced to ammonium and the nitric oxides within the aqueous interlayers of green rust (Hansen *et al*., 2001); the carboxylates were aminated to the amino acids (Barge *et al*., 2019) and then condensed to short peptides, all through the operations of what might be called traps, flexible pumps or nanoengines (Branscomb *et al.,* 2017) (Figures 8, 9).

The generation of peptides mark the organic takeover from the metals, and pyrophosphate through their spontaneous sequestration (Nitschke *et al*., 2013). We now look toward experiments to test the further potential of fougerite/green rust, in conjunction with Fe(Ni)S additives, to execute a number of proposed 'reactions' in well-ordered sequence; the mineral acting as a "minimal agent" with an ability and unpredictability to exploit the steepest gradients at a submarine mound and put them to work for emergent metabolism (Figure 9).

Conclusions

1. Free and sudden access of surface waters to the upper crust resulting from anomalous tensional (seismic) events in the near surface marks the onset of metallogenesis in Ireland (Figure 6).

2. North-south tensional structures named 'geofractures' appear to control some of the major ore-forming systems, notable Navan in Ireland and Leadhills-Wanlockhead in Scotland (Russell, 1973).

3. Temperatures of updrafts as gleaned from fluid inclusions in the main orebodies averaged ~190°C as would be expected from downward-excavating hydrothermal cells sourced from saline seawater driven by crustal heat, cf., quartz solubility measurements and geothermal drill hole solutions at temperatures, also 190°C (Russell, 1978; Robinson, 1982). However, high temperatures up to ~270°C are also possible given near instantaneous quartz dissolution in pressurized systems such as those interacting with mantle volatiles (Robinson, 1982). And top temperatures of 240°C are recorded at Tynagh and Silvermines, the same ores that boast the highest $^3He/^4He$ ratios (Banks *et al.,* 2002; Davidheiser-Kroll *et al*., 2014).

4. Helium isotope studies combined with fluid inclusion research look to be a promising approach to assessing mantle contributions to the ore-forming solutions both in Ireland and in the British vein deposits of similar age (Davidheiser-Kroll *et al*., 2014).

5. Naming the Irish ore deposits *sensu stricto* as predominantly "bacterio-metallogenetic" on the basis of multiple sulphur isotopic investigations offers a way of overcoming the SEDEX v MVT controversy.

6. Understanding far-from-equilibrium structures as engines is a way of assessing their effectiveness for use. And it reminds us that, at bottom, we are all slaves of the Universe to do its bidding as entropy-generators.

7. The transdisciplinary nature of mineral exploration prepares proficient exponents of the art/science/philosophy of the 'calling' for dealing with the issues facing us all and everywhere in the next decades as best as we are able.

The aphorism heading this contribution, *viz*., "Since all models are wrong" requires the scientist to "be alert to what is importantly wrong" (Box, 1976). Thence, knowing that models can never be "truth" and that the models presented, or re-presented, here are decidedly radical, the reader is invited to rank them from very useful, to useful, to somewhat useful to, finally, essentially useless (Burnham & Anderson, 2002)! Or the other way round? I start the ball rolling by admitting that the model directly attributing N-S tensional faults to Continental Drift (Russell, 1968) was dead wrong.

Acknowledgements

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