The evolutionary paradox of the Roraima pollen of South America is still not solved

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The pollen and spores from the Paleoproterozoic Roraima Formation in South America has often been cited by creationists as evidence against the evolutionary interpretation of the fossil record. It has, however, received little interest from the scientific community, having been ignored altogether since the 1970s. Although the discovery was published in *Nature*, there were no subsequent articles dealing with it. The consensus seems to be that the microfossils represent a case of contamination. In the original article in *Nature* an additional objection was raised: since the sediment containing the microfossils is described as thermally metamorphosed, the pollen and spores should have also been affected by heat, but they are not. Since there has been a lot of discussion in the blogosphere and some creationists have requested our help, we decided to take a closer look at this particular case.

A time of honesty

In the 1940s and 1950s the discovery of fossils outside the accepted evolutionary position in biostratigraphy was usually honestly reported and discussed. In the following years, examples that could not be explained were simply ignored, never being mentioned again.

Although this paper will only deal with the South American fossils and sediments, I would like to also mention that it does not represent the only such case: the discovery of vascular wood and six-legged, composite-eyed insects in the Precambrian salt deposits of the Salt Range in Pakistan.[1–3] After many unsuccessful and well-documented efforts to explain the discoveries away, a veil of silence covered them so that the most recent available reference[4] to the Salt Range does not mention any fossil finds.

The Roraima Formation pollen

Microfossils have been reported from the Roraima Formation (RF) in British Guiana as early as 1964,[5] soon after its Paleoproterozoic age was 'established'. They were described as sponge spicules and possible remnants of foraminifera and radiolaria. The previous year well-preserved pollen and spores were found in rocks from Cero Venamo (composed of the same RF rocks) by botanist Dunsterville. His discovery was treated with suspicion, given the Precambrian age for the formation. Then in 1966, Stainforth[6] announced the discovery of pollen and spores (henceforth called 'microfossils') in the same formation at Paruima. The microfossil assemblage is described as different from the present local floral association and is most likely 'Tertiary' (Stainforth mentions some authors who place it in the Miocene). Although no palynological inventory is presented, angiosperm pollen must be included. I have not been able to identify a single palynological study published on this topic, and this strongly suggests a reluctance on the part of the scientific establishment to get involved in topics challenging evolutionary dogma.

The host rock was described as 'hornfels' linked to an extensive underlying dolerite sill.[6] Based on more recent references,[7] this sill seems to be the Cotingo Sill, which can reach 420 m in thickness.

Stainforth mentions in his article that the *in situ* character of the microfossils was rejected by some (but makes no name reference) in favour of contamination by meteoric water. This position was further supported by the assertion that the heat that caused the original pelite (shale) to turn into hornfels would have 'baked' the microfossils (a process known as *graphitization*). That was countered by others who pointed to the lack of credible mechanisms that can cause pollen-containing meteoric water to infiltrate compact, impervious hornfels rock. It was also suggested that if contamination did occur, since it would have happened over a very long time, the microfossils should have been much more mixed, making assignment to a well-defined geological age virtually impossible. Stainforth's conclusion to his *Nature* article has become a staple to many creationists:

> "As stated, we offer no solution to the paradox. It is clear, however, that the botanist Dunsterville in his hunt for rare orchids stumbled on a highly intriguing geological problem."[8]

It is fair to say that nothing much was heard of or done about this discovery until creationists started referencing it in the 1990s. One would have expected *Nature* to encourage and publish new research aiming to eliminate the paradox, but nothing seems to have happened. Only the advent of the blogosphere has brought all sorts of debates, refutations, counter-refutations, etc. to the surface. However, nothing new has ever been produced for either of the original two opposing positions. Contamination is simply the default explanation and the only argument brought in its favour is the fact that if there were microfossils in the original sediment before it was thermally metamorphosed, they should have been 'baked'. Since that is not the case, the microfossils must have entered the rock after metamorphosis; so contamination is the unavoidable conclusion. We shall further analyze this claim based on the available published material.

The hornfels

When an igneous body is intruded into a host rock, it will melt ('digest') a part of it and will also create a *contact aureole* around in which *contact metamorphism* occurs. Immediately next to the igneous body (centimetres to hectometres) *thermal metamorphism* is caused by sheer heat transfer which results in certain minerals of the host rock (*protolith*) changing (adapting in fact to new conditions), essentially by losing whatever type of water they include in their lattice. Pressure is low and plays essentially no role in the chemical changes minerals undergo. What results is a more compact rock known as *hornfels*. However, in the vast majority of such contacts the hot fluids escaping from the igneous body will cause a subsequent, more extensive metamorphism, known as *metasomatism* (which often erases thermal metamorphism signatures). Many valuable ores originated this way, particularly where the igneous bodies came in contact with limestones (initially producing a *skarn*).

When investigating any kind of metamorphic formations, geologists have relied on the mineral association present in the rock, which has led to the concept of *metamorphic facies*—essentially quantifying the amount of metamorphic changes as *metamorphic grades*. Laboratory experiments have established the temperature and pressure ranges of various minerals,[9] and when they are found in metamorphic rocks, estimates of the genetic conditions can be inferred, assuming no secondary processes occurred.

In the case of hornfels, four increasingly higher-grade facies have been separated[10] (figure 1):

- *albite and epidote facies* (also contains chlorite, muscovite, and tremolite)
- *hornblende facies* (also contains cordierite, andalusite, garnets, and biotite)
- *pyroxene facies* (the pyroxenes are diopside and hypersthene; also contains cordierite and anorthite)
- *sanidine facies* (also contains andalusite, cordierite, garnets, and diopside).

Some minerals are common to several facies, so that it is only by index minerals or/and associated minerals that a facies can be identified.

There is little information about the mineralogy of the RF hornfels in which the microfossils have been found. Stainforth simply states that both the Cerro Venamo and Paruima samples have been described (based on microscopy) as 'true hornfels' within the cordierite–andalusite range. X-ray diffraction investigation described the rocks as 'fairly typical hornfels'.

It is most unfortunate that one cannot accurately locate the microfossil-bearing layers in the recent stratigraphic synthesis (which elevates the RF to 'Roraima Supergroup') because there are no references at all to any microfossils.[7] As in the case of Pakistan's Salt Range fossils, silence is used to avoid uncomfortable facts.

Figure 2 presents a simplified stratigraphy of the Roraima Supergroup (RS) with the location of the doleritic sills. Based on Stainforth's description and cross-section, it seems the microfossils were recovered from the Cuquenan Formation (CF), which is described as "distal turbidities (lacustrine or marine?)", i.e. fine, rhythmically interlaminated sandstones, shale and siltstone with parallel lamination.[7]

The sill

A sill is an igneous intrusion 'sandwiched' between preexisting layers or, in the case of metamorphic rocks, foliation/schistosity. If one is looking for an abundance of sills that are very visible in the landscape, South America is the place. From Patagonia (where Darwin mistook them for submarine lava flows) to Venezuela, they have given the continent's relief a characteristic signature.

There are at least four major sills[7] within the RF (figure 2) marking the base, middle and top of the formation and allowing a supposedly reliable radiometric dating of this otherwise unfossiliferous supergroup. They are interpreted as being emplaced essentially simultaneously during the *Avanavero Magmatism*,[7] consisting of both plutonic and subvolcanic mafic rocks (gabbro, dolerite and differentiated rocks).

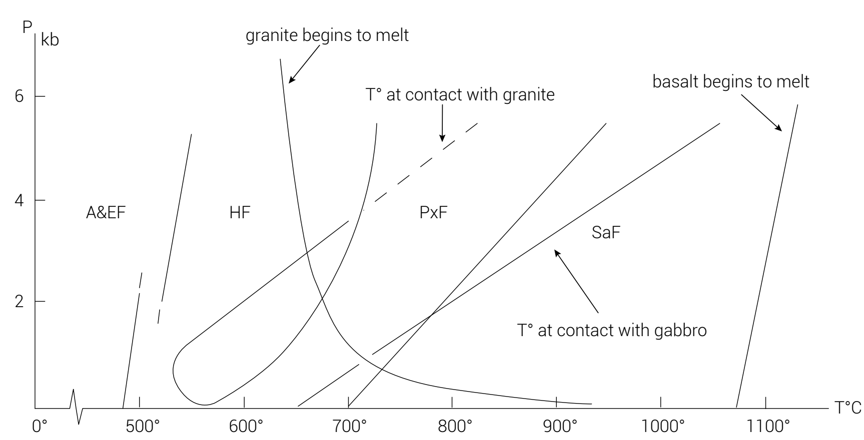

Figure 1. PT conditions for the 4 hornfels facies: A&EF = albite and epidote facies; HF = hornblende facies; PxF = pyroxene facies; SaF = sanidine facies (from data in Rădulescu, ref. 10).

The radiometric dating

Given the lack of fossils (with the exception of 'out of place' microfossils), the age of the RF/RS has always been controversial and illustrates the history of geological dating prior to radioisotope dating as well as the tribulations of K-Ar radiometric dating.

In the 1930s the RF was considered of Mesozoic age, probably based on the tabular structure. Correlation with the Minas Series in Brazil led, in 1939, to a different (tentative) age, namely Neoproterozoic. In the 1950s, the discovery of an unconformity (the upper one in figure 2) led some geologists to the conclusion that the sediments above the unconformity were of Triassic age, the ones below, Cambrian.

The 1960s brought the first radiometric dating (K-Ar and Rb-Sr on plagioclases from Roraima dolerite sills)[11] as well as paleomagnetic studies.[12] Many of the calculated ages were at odds with undeniable stratigraphic relationships as well as the paleomagnetic data, which led some researchers to consider multiple dolerite emplacement episodes, rather than a single one.[11] Excess of argon was also frequently invoked. All ages pointed to the Paleoproterozoic but most were considered too old, and it has been suggested that the sills were contaminated during their long travel through sediments they were also ingesting.[7] The discovery of detritic diamonds in the RS in the 1960s has raised the interest in the sedimentology and age of these remote and difficult-to-access rock formations. The first U-Pb dating (considered by many as 'bullet-proof') was performed in 2000 on baddeleyite (a kind of zircon) from *Avanavero* gabbro,[13] followed in 2003 by a more detailed radiometric dating of the *Avanavero Magmatism* and its sills[7] (see ages and details in figure 2). It should be noted that every dating was performed on zircons (baddeleyite included) which were not considered native to the igneous rocks but rather 'inherited' (detrital zircons reworked by the igneous activity) and therefore they ultimately represent rocks older than the igneous ones.

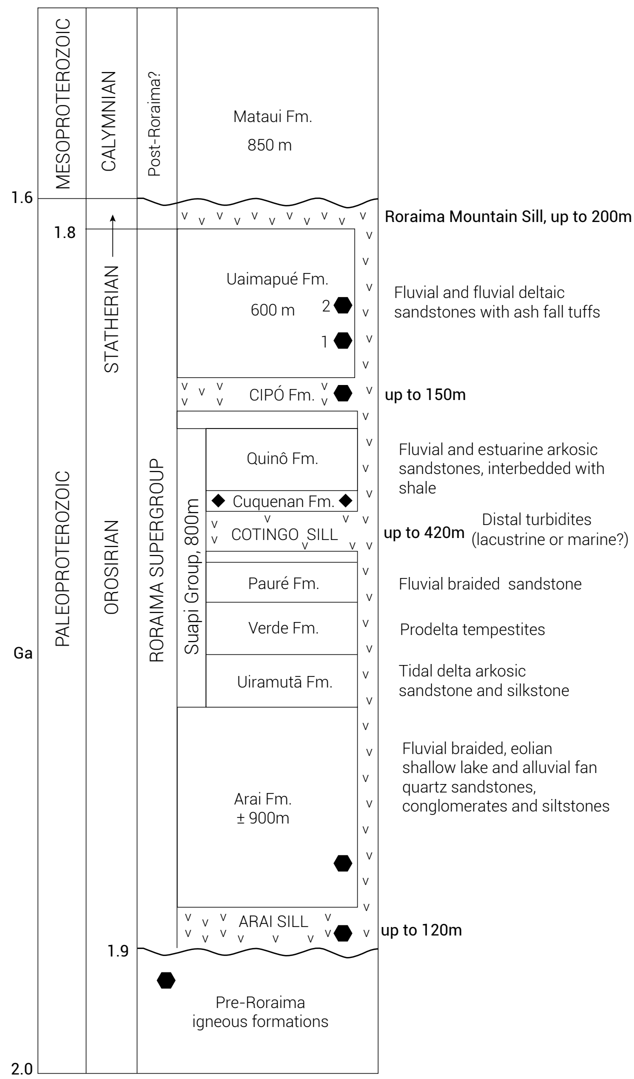

Figure 2. General stratigraphy of the Roraima Supergroup (redrawn after Schneider Santos *et al.*, ref. 7). The hexagons represent U-Pb dating samples, the diamonds best estimated location of microfossil samples.

Discussion

The Roraima Supergroup—a closer look

The RS is described as fluvial sandstones deposited in a large foreland basin.[7] The largest continuous outcropping area is in the Pacaraima Plateau (73,000 km^2) where Brazil, Venezuela and Guyana meet. There are also many Roraima-like outliers, confirming that the original basin was much larger. The supergroup is bound by two unconformities (figure 2). The lower one is placed at 1.9 Ga, the upper one at 1.6 Ga, which would mean this basin was active and extremely stable for at least 300 Ma (the interval comprised between the two unconformities). Both unconformities have a quasi-global extent,[14] and so do the original sediments found between them. On the other side of the Atlantic, the RS equivalent is the Birimian Supergroup with its diamondiferous metasediments[15] in Ghana (West African craton), very similar in fact to the RS unmetamorphosed sediments. Similar Paleoproterozoic quartzites are found in Colorado, northern New Mexico (Ortega Formation) and central Arizona.[16] In Asia, on the Siberian craton, same age pelites (now metamorphosed) have been deposited in similar conditions.[17] In Australia's Northern Territory, before the Pine Creek orogen formed, Paleoproterozoic sediments similar to the RS have been deposited and then intruded by dolerite sills.[18]

The hornfels

It is quite surprising that an unusual circumstance like this has received such shallow mineralogical and petrographic attention. There seems to be only one available microscope picture of a thin section from Paruima (in Stainforth's original article) and neither the resolution nor the description allow a significant assessment, so that one is left with trusting what the author was told (there is no mineralogical study accompanying this article) by others. Prof. H.H. Hess from Princeton is mentioned, having confirmed (by way of X-ray diffraction) a "fairly typical hornfels, largely muscovite plus little quartz, no clay minerals and no chlorites." No poikiloblasts (new crystal growth containing relicts of the original crystal from which it grew) of index minerals (also known as *mineral qualifiers*) are mentioned although they are expected when an original mineral undergoes metamorphosis.[19] Hess's diffractograms must have been single-mineral ones, i.e. he must have had individual index minerals like cordierite extracted from the samples and analyzed (although such a mention is not made in the original text).

The mineralogical descriptions are at odds with known hornfels mineral assemblages. For example, cordierite should not be found in 'micaceous ground' as the explanation to the thin section photo in Stainforth's paper claims, unless chlorite is also present (it is generally believed that cordierite in hornfels comes from the complex thermally induced combinations between chlorite, muscovite, and quartz).[20]

Based on this and the fairly visible roundness of the cordierite crystals (at least in the photo provided by Stainforth), one cannot exclude a detrital origin of the cordierite in these samples, rendering the hornfels less 'typical'.

Diagenetic changes of microfossils

It is most reasonable to assume that heating organic matter incorporated in a mineral matrix can cause whatever organic carbon is preserved to change into the more stable form of graphite (graphitization). In organic matter carbon assumes a variety of forms but in the mineral realm, it exists in an elementary state only as graphite or diamonds. However, the history of science abounds in reasonable assumptions that have been proven wrong. Professor Michaels Duff (Abdus Salam Chair of Theoretical Physics at the Imperial College in London) is quite straightforward about that:

> "It is dangerous to pin your beliefs on any theory of physics because it may turn out to be wrong."[21]

The only way to confirm the graphitization assumption is to test it directly. To this author's knowledge, there is only one such experiment performed according to modern standards, which reproduced the assumed conditions of thermal metamorphism. It consisted in heating microfossil-containing sediments (non-metamorphic shales of the Proterozoic Ruyang Group in China, rich in acritarchs like *Dictyosphaera delicata* and *Shiuyousphaeridium macroreticulatum*) to over 500°C for durations compatible with real cases of thermal metamorphism. The samples were than treated the same way pollen-containing sediments are (palynological maceration). The separated 'baked' acritarchs were studied via Raman spectroscopy and scanning electron microscopy. The experiment concluded that *no graphitization occurred* and that the acritarchs have preserved their original morphology.[22]

Microfossils have been found to have survived extreme metamorphic conditions (up to 710°C in high-grade gneisses) in Schwarzwald, Germany.[23] The alleged world's oldest fossils—acritarchs from the Harris Greenstone Domain of the Gawler Craton in South Australia—have survived not only regional metamorphism but also several consecutive volcanic events.[24]

In conclusion, the suggestion that 'unbaked' microfossils have been preserved in the metasediments in the proximity of igneous sills in the RS cannot be ruled out.

The sills

Although a well-established geostructural feature, sills, especially when thick and extending for kilometres (like the ones in the RS) are not easy to explain. How does a 400-m dolerite intrusion ingest and digest a hard sedimentary rock over many horizontal kilometres, while remaining perfectly parallel with the host rock and chemically 'pure'? Sills are believed to advance in a melted state along bedding planes (or some kind of lamination in obviously pre-existing rocks) by breaking, ingesting, melting, and assimilating the host rock. There are no records of intraformational sill emplacement associated with any historic volcanic eruption ever studied (we would not consider more or less horizontal bodies of igneous rock inserted in pre-existing pyroclastics as a valid example).

There are thermodynamic calculations pertaining to the time needed for such bodies to cool, but not to the total amount of energy required for emplacement. Neither are there clear chemical models that would allow igneous rocks to incorporate a virtually equal volume of sediments to their own volume, and yet remain mineralogically unaffected.

Such problems would be significantly diminished if sill emplacement occurred in unbound, water-rich sediments, which would mostly be displaced, not ingested.

The contamination

There are only two conceivable ways in which surface waters can reach inside the rocks of a table mountain: *per descensum* (down seeping) through the entire sedimentary sequence (exploiting primary and secondary porosity) and, when the rock is exposed in escarpments, by pellicular flow along the rock walls. Since some of the samples were collected from inside notches (3–3.5 m (10–12 ft) undercuts), the latter is definitely not the case, as pellicular flow could not reach such locations. We shall therefore concentrate on the former case.

Tabular structures, particularly the ones that contain insoluble lithology (which is definitely the case with RS) can only allow water to penetrate deep inside along fractures and bedding planes. The RS is composed of quartz-rich detrital sediments with a few shale intercalations and thick igneous sills. While humic acid may enhance the ability of meteoric water to penetrate along joints and fault lines, it is a known fact that in such conditions acidity is lost within the first 10–15 m below surface.[25] Although the discovery of huge caves in the RS[26] came as a major surprise to karstologists (after all, such massive karst should not form in sediments so rich in quartz—for all practical purposes they are 'quartzites' to karstologists), it soon became obvious that all caves were located right under the surface of the table mountains (tepuys). On Mount Roraima—where the largest caves are located (figure 3)—all parakarst[27] is found in the Mataui Formation[28] (figure 2). Most of these massive caves are underground passages for substantial sinking streams which, in limestone karst, generate extensive aquifers, with all interconnected voids below them filled with water. That is not the case with the Roraima parakarst, where such aquifers would be cut by the continuously retreating vertical walls, so that water should be continuously pouring out below the cave stream outlets (resurgences), which are all high up in the walls. So this provides clear evidence that there are no aquifers below the caves. This means that the chance that meteoric water could infiltrate deeper into the RS is extremely slim.

Given the above, if the stratigraphic column in figure 2 is correct, advocates of meteoric water contamination of the CF will have to infer miracles. If the microspores are of Tertiary age, the meteoric water that transported them would have had to cross the 850 m of the Mataui Formation, the Roraima Mountain Sill, the 600 m of the Uiamapué Formation, the Cipó Sill, and the Quinô Formation. Even this assumes that there were no other sediments overlaying the Mataui Formation.

Even if pollen- and spore-carrying meteoric water could have reached the hornfelsic rocks, they would have had to infiltrate them as well. Stainforth describes the sampled rock as follows:

> "… cleaves along finely laminated bedding planes which are coated with limonite. Every effort was made to avoid these planes and some pieces processed were the central nubs left after chipping away the external parts of large blocks of the rock, which was dense enough to sound when struck with hammer. Nevertheless, microfossils of the same type as before were recovered."[6]

Under normal circumstances the presence of limonite ($FeO(OH) \cdot nH_2O$) is evidence for secondary (epigenetic) chemical alteration of the rock. If that has been going on since (at least) the Tertiary, the limonitized bedding planes should also have extensive and very visible deposits of clay minerals—the most stable form of silicates in the present surficial environment. None are mentioned in any of the literature I managed to consult. Neither are clay minerals present in the thin sections and X-ray diffractograms. This suggests the limonite is not epigenetic but rather syngenetic, i.e. as almost always with thermal metamorphism, before the igneous body cools, thermal metamorphism makes way to metasomatism, even if for a period too short to generate the whole range of index minerals. Limonite would be an obvious by-product of hydrothermal solutions removing iron from the olivine in the dolerites. The bedding planes would have been the only available paths for the hydrothermal solutions. The metasomatic phase would have been very short-lived, though, and at temperatures high-enough to prevent clay minerals from forming.

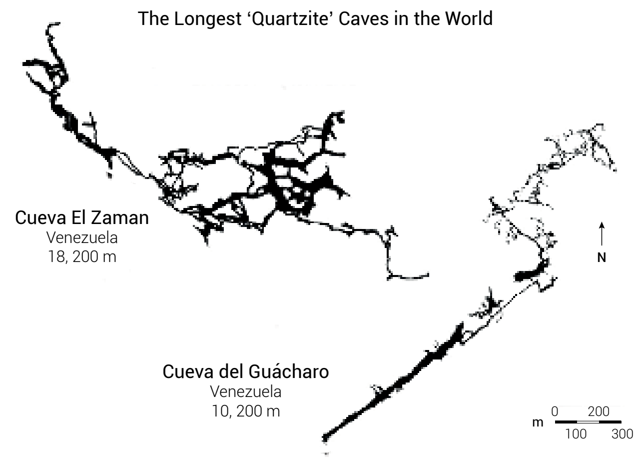

Figure 3. Plans of the world's longest caves in 'quartzite' (actually quartz sandstones) of the Mataui Formation (after Šmida *et al.*, ref. 26).

The thin section clearly shows that the hydrothermal solutions could not penetrate the massive hornfels; so then how could cold, meteoric water do it? The 'corporate' answer is "somehow, since we know there were no plants in the Paleoproterozoic!"

There is yet another unusual thing about this classic case of 'out of place fossils': if contamination (unfolding for at least 65 Ma) affected hornfels rocks so deep into the RS, it should be widespread in the area, especially in the formations overlaying the CF. In other words, there should also be plenty of pollen in the superjacent rocks if contamination really occurred, and yet nothing of the sort has been reported. A few well-selected samples could therefore settle the issue in the most scientific and straightforward fashion. One should always remember the famous Holmesian adage: "when you have eliminated the impossible, whatever remains, however improbable, must be the truth."[29]

Wrong biostratigraphy or wrong radiometric dating?

With all the above in mind, since according to observational science contamination is the least probable of all possibilities (a Holmesian 'impossible'), there seem to be only two solutions:

a. The whole evolutionary biostratigraphy which places the first angiosperm pollen in the Early Cretaceous[30] is wrong, angiosperms being in fact present throughout the entire geologic column (does that sound like something you have already read about?). This would of course be the equivalent of Haldane's rabbit and mortally wound the 'evolutionary elephant'.
b. The CF is Tertiary in age and not Paleoproterozoic, completely rejecting radiometric dating. If so, the very concept of radiometric dating and particularly its reliability needs to be questioned.

Either possibility is simply unacceptable to the evolutionary establishment, hence the escape into the improbable: contamination. A concept that has already served to settle similar problems before: when radiometric dating is clearly at odds with the established biostratigraphy, contamination ('radioisotope contamination') is invoked. Or, when accepting contamination would challenge the very concept of radiometric dating, 'out of place fossils' ('fossil contamination') are invoked.

Conclusion

Based on what has been published thus far and the established geological and mineralogical facts, the presence of pollen in Paleoproterozoic metasediments in the Roraima Supergroup remains a paradox. It can only be explained away through contamination if a whole range of improbable and contrary to sedimentological and hydrogeological tested facts are invoked.

The scientific establishment's reluctance to address the paradox is difficult to explain, especially since creationists have been systematically using this argument against the Darwinian dogma. It may well be that any serious investigation would unavoidably harm one or more areas of established geology and hydrogeology, and that is something that should be avoided at any cost. Which may be good news for creation scientists, since such an attitude is usually reflective of a besieged mentality. It is clear then that accepting that any one (or more) elements of the fortress are structurally weak while under siege is dangerous.

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