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# A Hydrothermal Model of Rapid Post-Flood Karsting

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## A HYDROTHERMAL MODEL OF RAPID POST- FLOOD KARSTING

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**ABSTRACT**

Existing karstogenetic models have not explained the inception and development of global karst, especially the origin and occurrence of extensive secondary porosity and flowpaths. Karstogenesis appears to be explainable by proposing a hypogene model of origin, previous to the exogene one. Known to ore geologists for a long time, hydrothermal karsting could very well be responsible for global karsting, provided a global hydrothermal activity. The geological conditions towards the end of the Flood and immediately after may well have included such widespread hydrothermalism and if so, rapid karsting would have resulted. Post-Flood karstogenesis was also boosted by acids produced by decay of huge quantities of organic matter. Present day ocean bottom hydrothermal vents have been found to extract actively calcium from igneous rocks and to redeposit it as carbonate chimneys. This confirms the acidic character of hydrothermal solutions and supports a rapid hydrothermal karsting model. Hydrothermal karsting after the Flood may have unfolded in consecutive stages, marking the shift from *per ascensum* (upward) exclusively hypogene karsting in the initial phase, towards a *per descensum* (downward) exogene karsting. This led to multi-stage cave systems and subsequently to the fusion of surface and subsurface karst. Subsequently, exogene karsting has re-shaped hypogene karst into the karstlands of today.

### INTRODUCTION

#### What is karst?

"Karst" is a term introduced by Austrian geographers and geologists in the 19$^{th}$ century while they were studying the limestone terrains east of Trieste, in what is now Slovenia. They actually germanicized the Slovenian name "Kras" used to define that particular area. The most specific features of this type of relief are: caves, potholes, swallow holes, karstic springs, sinkholes, karren (also called "grikes", "pavements" "runnels" and many more). There are many definitions of karst but few true karstological ones i.e. approaching the issue from a systems perspective and a solid field and lab experience I selected two from world authorities:

"*Karst is a terrain with distinctive hydrology and landforms arising from a combination of high rock solubility and well developed secondary porosity. … Karst can be viewed as an open system composed of two clearly integrated hydrological and geochemical subsystems operating upon karstic rocks. Karst landforms are the products of the interplay of processes in these linked subsystems"* [23].

After pointing out that since karst is totally connected to subterranean drainage, Bakalowicz (a world authority in the area of karst hydrology) simplifies the definition [11]:

"*Karst is an aquifer presenting a set of surface and subsurface forms organized in order to evacuate subterranean waters through one outlet."*

Karst terrains are essentially defined by the extensive, sometimes predominant, role played by the dissolution of a group of rocks generically called “karstic” (limestone, dolomite, rock salt, rock gypsum) in the formation of their relief.

**How, when and for how long did it form?**

*Karstology* (the interdisciplinary approach of karstlands) claims that karsting (formation of karst relief) unfolds in episodes [57]. According to most karstogenetic models, a karsting episode begins with the onset of subterranean drainages and continues with the gradual fusion of the surface and subsurface features. As for the onset of any karst drain, the same models require at least 10 to 20 Kyrs [6, 14, 26, 27, 44, 57]. Therefore, even if self-contained, a complete karsting episode should require periods of time at least one order of magnitude longer [16, 28].

As seen, investigated and understood today, karst’s peculiarity is given by the complicated interrelationship between various factors: the way water penetrates the lithostructure depends on the sedimentological and structural characteristics as well as the water’s chemical properties (controlled by climate and associated biota). The main driving process is the solution of substrate by infiltration of acidic water. The initial source of acidity is hydration of atmospheric $CO_2$ [23, p. 53], significantly increased by soil $CO_2$ (due to green plant root activity and soil microfauna and microflora) [23, p. 64] and crustal exhalative $CO_2$ in active volcanic and tectonic areas [23, p. 63]. Bögli [13] suggested another source of increased acidity i.e. the mixing of solutions (“mischungskorrosion”).  All of the above are valid for *exogene* karsting in which *meteoric* water moves gravitationally downwards. Such a water movement implies a hydraulic gradient, defined by an input and an output of the flow. Consequently, any karst relief is ultimately controlled by a *base level*, i.e., the surface fluvial network or the sea, collecting all subterranean drainages.

**Problems with uniformitarian karstogenesis**

There exists a tremendous amount of field and lab data that puts theoretical karstology into a delicate position**:** *karstogenetic theories cannot explain how the extensive cave systems of today grew from simple infiltration of acidic runoff through a discontinuous fissural network, given the fact that experimental data shows that aggressiveness (unsaturation) is lost within the first 4 to 10 meters from the surface?* [1, 18, 19, 29, 33, 42, 46, 47, 54, 56, 59, 61, 62]. *Even more so because experiments show that real drains through karstic rocks only appear if the input and output points exist from the beginning, i.e., infiltration at one end does not create a karstic outlet at the other. It is the pre-existence of the outlet that favors infiltration* [22,60].

Many authors [22, 23, 27, 60] admit that this and vadose subterranean flows in caves could have only come into existence if *conduits were present at the very beginning of karsting processes*. Field data and experiments in China showed that the absolute majority of drains are fluvial, karst drains being a clear exception (due to very special prerequisites, like pre-existing outlets) [8, 39]. Because tectonics couldn’t have created such prerequisites (conduits) in the assembly of presently karstified rocks worldwide, there must have been another type of karsting, that preceded the classical, gravitationally driven karsting. In my opinion, that other type of karsting was *the hydrothermal one*.

Relatively new to karstological literature, hydrothermal karst/karsting (HTK) was long known to ore deposit geologists. To them it represents merely an acidic phase of the generally alkaline, ore-depositing hydrothermal solutions. In general terms this is a case of *hypogene* karsting, driven by acidic solutions ascending from the crust (*per ascensum*) not infiltrating from the surface. The solution cavities generated are normally filled with the very solutions that created them. In most cases, the solutions’ temperature (between 50 and 200°C) and chemical composition falls within the post-magmatic hydrothermal domain. Hence the generic term. Whereas geological literature abounds with radiometric ages for ores deposited in HTK, nobody appears to have paid attention to the rate of HTK processes, the general position being “hydrothermal karsting must have been quicker that exogene karsting.”

Recent discoveries have added yet another type of hypogene karsting generically termed *sulfuric-acid speleogenesis* (SAS) [48] (because it only creates subterranean relief, i.e., caves) in the Guadalupe Mountains (US). The Guadalupean karst is now explained as having formed *per ascensum*, by sulfuric acid resulting from the oxidation of $H_2S$ rising from the subjacent oil deposits [32]. Sulfuric acid speleogenesis is believed to be very rapid, possibly only taking centuries [23, p. 113; 29]. Furthermore, the investigations in this peculiar karst have revealed a significant bacterial component of speleogenesis, i.e., bacterial dissolution of the limestone. [30]. Very similar speleogenesis has been reported in the small karst area of Tabasco, Mexico [30] (uncertain origin of $H_2S$, highly active bacteria) and in Argentina ($H_2S$ generated by hydrocarbons) [25].

## A CHALLENGE FOR YOUNG EARTH CREATIONISTS

### Karst denudation as a measure of the rate of karsting processes

To provide a rough estimate of the pace at which karsting processes unfold, karstologists measure *karst denudation rate* (KDR), i.e., the sum of both chemical and mechanical erosion processes, quoted as an equivalent thickness of rock removed per unit of time across a horizontal surface [23, p.97]. Selected and specially fitted areas are measured every year and the thickness of removed rock is averaged for the entire region (*overall rate*). This is usually expressed in millimeters per thousand years (mm $ka^{-1}$). One mm $ka^{-1}$ is the equivalent of 1 cubic meter per square kilometer per year ($m^3$ $km^{-2}$ $a^{-1}$). Though many different factors influence it, climate is believed to be the most important on a regional scale. Table 1 presents a summary of measured KDR in various areas of the world.

Extrapolating the highest recorded rate of 100 mm $ka^{-1}$ over the post-Flood period, the total karst denudation of a given limestone terrain should have not exceeded 5 meters. This is far too little compared to tower karst areas, for example, that display hundreds of meters of denudation [39, 12].

Austin [2] suggested that KDR was much higher immediately after the Flood and consequently exogene processes could have generated rapid karsting. We will discuss this hypothesis later. In the meantime, let us point out that if we are to incorporate karsting into a Young Earth scenario, KDRs orders of magnitude higher need to be invoked, and, because such magnitudes are not present in exogene karsting today but have been calculated for the SAS, we should further concentrate on this. However, SAS cannot possibly account for the global karstlands because it appears to be confined to the vicinity of oil deposits or other local sources of $H_2S$.

**TABLE 1**
**Measured rates of solutional denudation ($m^3km^2a^{-1}$)**

| Area | Overall rate | Source |
|---|---|---|
| Fergus R., Ireland | 55 | Williams [59, 61] |
| Derbyshire, UK | 83 | Pitty [46, 47] |
| Northwest Yorkshire, UK | 83 | Sweeting [56] |
| Jura Mountains (France & Switzerland) | 98 | Aubert [1] |
| Coleman Plains, NSW Australia | 24 | Jennings [33] |
| Somerset Island, NWT, Canada | 2 | Smith [54] |
| Riwaka South Branch, New Zealand | 100 | Williams & Dowling [62] |
| Waitomo, New Zealand | 69 | Gunn [29] |
| Caves Branch, Belize | 90 | Miller [42] |
| Kentucky River, Kentucky, USA | 25 | Douglas [18, 19] |
| Green River, Kentucky, USA | 29 | Douglas [18, 19] |

### Attempts to meet the challenge

Austin [2] suggested that "After the flood waters had completely receded, the regional groundwater level would be in disequilibrium and horizontal flow would be significant. Acids from organic decomposition at the surface and at depth would tend to move to just below the water table where the highest horizontal velocities of flow would exist." The author makes no mention of the duration of these processes, but obviously implies that cave formation and the subsequent speleothem formation could have occurred in the time elapsed after the Flood.

This model assumes that the effective karsting processes recorded and even quantified today (assumed to take place in the immediate vicinity of the water table), boosted by the post-Flood special conditions mentioned above, could have generated large karst drainages immediately after the Flood. Austin also provides a calculation according to which, given the existing field data in the Kentucky karst, 59 meters of cave conduit - 1 square meter in section - could be dissolved every year by the water infiltrating on one square kilometer, if it were all concentrated in one conduit. That is the equivalent of 59 cubic meters of removed limestone per year per every square kilometer. Let me emphasize that Austin's calculation is based on the existing, essentially uniformitarian measurements and paradigm, intending to point out the problems the existing data leads to: there is way too little karsting if the measured KDR was on for the duration of time uniformitarian models claim it was! Still, Austin's calculated KDR is twice the values for the same area presented in Table 1. The reason is that whereas the data in the table is based on direct measuring, Austin's estimate is indirect and based on a theoretical rather than applied karstology approach i.e. the input-output function is assumed to be linear. In Austin's calculation, the average amount of rainwater infiltrating every year into central Kentucky karst is 1 cubic meter for each square kilometer. The amount of dissolved limestone is estimated by the calcium ion content in the karst springs discharging the infiltrated and calcium-enriched rainwater. The author makes no mention however what the total average annual discharge of karst springs in the area is. Extensive experimental data - [7, 9, 66 to quote a few] - shows that the water budget (amount of infiltrated water against amount expelled through outlets) for karst aquifers is seldom even, some of the infiltrating water being stored. Consequently, on the average less water exits karst aquifers then enters them every year. This is how many karst springs manage to maintain a relatively constant discharge even during long periods of drought when karst aquifers receive less water than they discharge. It has been shown [4, 5] that floods actually push out 'old' water, stored in what Mangin [38] calls "annexes". It is thus evident that the input-output function is not linear and corrections need to be considered.

The long-term recorded chemical composition of a karst spring (the "chemograph") varies, sometimes significantly, especially during floods, when very high calcium ion concentrations are measured [5]. These high concentrations are typical to water from the annexes, essentially stagnant reservoirs adjacent to the main drain [38], and they represent the result of much more than a years' worth of soluted limestone. Nevertheless, theoretical models average their input against the main drain's chemical composition and that mean obviously does not represent the annual dissolution.

Austin's model considers all the calcium ions in karst spring waters to come from the dissolution of massive limestone. In reality, there is a considerable amount of calcium coming from the dissolution of breakdown blocks and finer carbonaceous cave sediments, as well as from reprecipitation of previously dissolved materials (like speleothems) [23, p.100], thus, making estimation of karst denudation by spring chemograph even more difficult. All of these are not meant to discard Austin's model, on the contrary, by pointing to its less applied aspects they emphasize its correct, applicable ideas.

One such idea the important role played by organic acids resulting from the enormous amounts of decomposing organic matter produced by the Flood played. Austin places these acids in an exogenous context i.e. "acids from organic decomposition at the surface and at depth would tend to move just below the water table" [p.vii]. This appears to be motivated by the karstological concept according to which most of the speleogenesis takes places in the vicinity of the water table "epiphreatic theory" [17, 51, 55, 58]. Far from being accepted by all karstologists, this theory is poorly supported by field data. Bakalowicz [10] who works with the world's only laboratory solely dedicated to theoretical and applied karst hydrology research at Moulis, in the French Pyrenees, (where I spent a couple of months in joint research with him) has found that karsting occurs throughout the whole of the karstic rock unit, rather than being limited to the vicinity of the water table. Back to Austin's model, if large amounts of organic acids existed inside the sediments (very likely given the rapid burial during the Flood) they must have been incorporated in the global, hot solution circulation associated with diagenesis and hydrothermalism, being less sensitive to gravitational, base level-controlled circulation. As for the organic acids forming at the earth's surface, I would suggest they would play a significant role later, as the hypogene karst (and consequently significant flowpaths) came closer to the surface.

## RAPID HYDROTHERMAL KARSTING AS A CONSEQUENCE OF THE FLOOD

### HTK – a closer look

Hypogene hydrothermal karsting was first revealed through mining of ore deposits, long before the concept of karst was introduced. I have noticed for example, that the Bronze Age miners who extracted copper from the Great Orme Mine (Llundudno, North Wales, UK) had often mined through hydrothermal karst passages in order to reach the copper-rich dykes [63]. Karstological references today mention the presence of HTK even in the pneumatolitic stage [40], but it is in the hydrothermal-proper stage [20, 24, 36, 43, 52] that most references abound because significant amounts of ores are exploited from proper hydrothermal cave systems.

Highly active today both on continents as “geysers” (most famous being Geysir in Iceland, from which the name comes, Old Faithful in Yellowstone and Rotorua in New Zealand) and on ocean bottoms as “hot vents”, hydrothermal springs left clear signatures in the geological archive. Strata-bound “polymetallic sulfide ore deposits” (or “volcanogenic massive sulfide” – VMS) like the ones in Precambrian formations which I investigated for 7 years in northern Romania [40, 53] are such signatures. The Archaean granite-greenstone belts of the Isua (Greenland), Barberton (south Africa) and Pilbara (Australia) formations [15] are interpreted as the result of hydrothermal activity. Recurrent, strata-bound marker-horizon cherts in limestones of different age are now interpreted as of hydrothermal origin (precipitation of silica) [41, 67]. There is one important common characteristic of all these modern and ancient hydrothermal features, namely *acidity*. Modern hot vents are often found to expel solutions with a pH of 3 or below [65]; for all the above-mentioned particular mineralogical settings associated with ancient hydrothermal solutions (HTS) to be possible, a pH below 7 is required.

Besides acidity, hydrothermal activity requires a number of elements: (a) a source of water; (b) a source of heat; (c) a transport mechanism; (d) flow paths. I believe that during and immediately after the Flood hydrothermal activity unfolded at a paroxysmal pace.

(a) Diagenesis is a major source of water as *dewatering* is a necessary step towards the complete lithification of waterlain sediments [50]. Given the global and catastrophic characters of the Flood, one would expect enormous amounts of *seawater* to have been trapped in the rapidly accumulating sediments. There is little doubt that large volumes of juvenile water associated with the extreme volcanicity was added to the oceans during and immediately after the Flood. Consequently, there appears that tremendous amounts of fluids were on the move inside the Flood-lain sediments, and there is little doubt that the organic acids were “taken by the flow”.

(b) The main source of heat is the inner structure of the earth. It reaches sediments and the water in them either through magmatic activity (volcanicity and plutonism) or by the global geothermal flux. Geothermal convection has also been mentioned associated with uranium ore deposits [49]. Some authors suggested that accelerated radioactive decay could had been associated with the Flood [31], and, thus, significant amounts of heat released. Heat may also come from a number of exothermic chemical reactions associated with diagenesis, like hydration of clay minerals for example [55]. Let us note that because water was literally impregnating all unlithified sediments and it’s thermal inertia is lower than that of solids, one would expect that most of the regional geothermal energy (significantly higher than today, due to the upset internal thermodynamics of the planet, [3]) was conveyed to it, and, thus, intraformational fluids were much hotter than today. The abundance of hot solutions may well have accelerated lithification and consequently early strongly cemented rocks, like limestones, dolostones, cherts could have been present interbedded with terrigenous unbound sediments in the late stages of the Flood.

(c) HTS were driven by a number of complementary processes. Global gravitational compaction during diagenesis is such a post-Flood process. Before and especially after lithification, tectonics (both plicative and disjunctive) represented a major source of displacement of fluids. Finally, geothermal convection must also be considered as a possible driving force of fluid circulation, especially under continuously changing intraformational conditions (diminishing primary porosity, increasing secondary – tectonic – porosity, density contrasts due to variable geothermal gradients [34]).

(d) In present-day lithostratigraphic units, flow paths are provided by the sum of sediment porosity, from pores through bedding planes to the fissural network. In unbound granular sediments flow is in fact mass flow while in cemented rocks it is mainly channelized. Limestones and other soluble rocks represent a special case in which porosity (both primary and secondary) is not constant, increasing with time because of rock removal by solution. Secondary tectonic porosity is the most important to karsting. Consequently, in the initial post diagenetic conditions, syngenetic (mainly compaction) joints provided extensive intraformational porosity. As tectonic movements gained momentum, these joints became faults and they often interconnected, creating abundant flowpaths.

Under the unique, catastrophic conditions during the Flood and immediately after, one would expect a global circulation of HTS throughout the entire crust, both mass flow and channelized, that could have subsequently exponentially decreased, as suggested by Austin [2]. In a seminal paper, Wilson *et al.* [64] have provided an excellent frame of reference for mass flow of hot solutions in carbonate platforms. Though their main topic is dolomitization by geothermal convection of seawater, one may easily translate their simulation within the above-mentioned Flood conditions. The paper suggests that dolomitization took place by reaction fronts, i.e., mass flow of fluids not in equilibrium with the host rocks [64, p. 729]. It also points out that in carbonate platforms, at depth of only 2 to 3 km, temperatures could rise above

70°C [64, p. 729]. With the significant addition of heat coming from the sources mentioned above, the conditions could be more than ripe for hydrothermal activity.

**Hydrothermal karsting after the Flood**

In order to have HTS actively dissolving limestones and other karstic rocks, they must have a significantly acidic character. Seawater by itself cannot be acidic; various diagenetic processes however supply acids. One significant source of acidity is the decomposition of organic material [36]. Various gasses like juvenile $CO_2$, for example, also contribute to this acidity. Cooler (100-170°F) acidic hydrothermal vents discovered at Lost City Field, located 15 km away from the spreading axis of mid-ocean North Atlantic ridges, were found to have built almost exclusively carbonate chimneys up to 60 m high [35]. The source of calcium (and heat) is attributed to hydration of peridotites [35]. In other words. HTS can produce heat and extract calcium from an igneous rock not at all rich in the ion and build submarine carbonate structures. So one wonders, how much calcium would HTS extract and redeposit in the extreme conditions of the Flood? Let us also point out that similar vents within the ultraslow-spreading rift areas bear witness that “faulting is the mechanism that allows for prolonged focused venting where magmatic heat supply is low” [21].

Under all the above circumstances, I believe that very rapid karsting by hydrothermal solutions at the end of the Flood and immediately after constitutes a perfectly acceptable scenario that may have unfolded in the following consecutive stages:

**Stage 1**: As karstic rocks rapidly formed and their diagenesis contributed to increased local acidity, their primary and especially secondary, tectonic porosity was intensely circulated by HTS, regardless of their position relative to the surface. Typical HTK results, with very large chambers connected through narrow conduits; the larger the chambers, the slower the karsting, as fresh solution supply is somewhat limited by conduit flow. Consequently the very large chambers would act as reservoirs for HTS, circulation upwards from them being more strictly controlled by petrographic and structural factors. I would compare these chambers and the way they supplied karsting above and around them to batholiths and their associated dykes and sills. I would like to re-emphasize one important thing: karsting is a process that self-increases porosity; hence the flow paths become more efficient and, as long as the HTS supply is abundant, the rate of HTK increases. The replacement of large volumes of rock with water could have resulted in some positive isostatic movements. This corroborates with the fact that the most developed type of karst – the tower karst – has been proven not to be the result of tropical climate conditions (as previously believed, [12, 37]) but rather of very rapid regional uplift [39].

**Stage 2**: As deep hydrothermal activity decreased and the karstic rocks were approaching the surface, the *per ascensum*, convectional movement of solutions was gradually replaced by gravitational *per descensum* movement of solutions from the reservoirs. By this time, due to isostatic movements and sometimes the incipient orogenic movements, new tectonic pathways were accessible and the HTK’s main (soluting) thrust shifted from chambers to conduits. Incipient cave systems began to develop and subaqueous speleothems could have also formed during this stage. Let us note that most of present-day cave systems include large chambers alternating with rather narrow conduits.

**Stage 3**: Hydrothermal activity left deep below, the reservoirs began emptying by supplying hypogene karsting below them. This would create a significant hydraulic head for any liquids present above them. The drawdown would drain all voids above and consequently conduit karsting would intensify. In a very short time (due to high relief energy and accelerated uplift) surface solutions of the type Austin suggested would reach hydrothermal karst and consequently a mixing of solutions and processes will occur. This also caused a vertical staging of chambers and conduits, a setting known today as “multi-phase cave systems” [23, p. 274].

**Stage 4**: According to local/regional conditions, some of the chambers/reservoirs would raise above local base levels and their drain would be directed towards them. While they may have played a role in stage 3, the flow-induced primary porosity pathways were probably decisive during this stage, controlling the onset of drain conduits. By this time the hypogene karsting has completely given way to exogene karsting followed by an ample and rapid reshaping of the old HTKs (breakdown and collapse being the major agencies). Surface karsting – incipient from the moment karstic rocks were subjected to subaerial conditions – has dramatically increased as the result of surface and hypogene karst becoming connected.

## CONCLUSIONS

Karstogenesis is still active as a predominantly exogenic process, but it cannot explain its inception and development to the scale of magnitude we see today, unless some other karsting process, much ampler and independent from exogenic conditions, had provided proper conditions.

(1) HTK appears to be not just a possible alternative, but also a prerequisite and the source of the major karst systems of today.

(2) Known (quantifiable and quantified) rates of hydrothermal karsting can easily explain the formation of all presently known karst within the very restricted post-Flood timetable, while exogene karsting cannot yet provide an alternative explanation.

(3) HTK also explains the presence of karst in virtually every corner of the planet, regardless climate (much more difficult to explain within exclusive exogene conditions).

(4) HTK may well have developed in stages, gradually shifting from an exclusively upward movement of karsting solutions to a downward (gravitational) one. Therefore, I believe that a closer look at cave and karst systems, keeping in mind the markedly different genetic conditions during the various stages and their mineral associations, could provide a promising area of future investigation and a better karstogenetic model that the ones presently in use.

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