25th May 2018

Dachstein Massif Geology Intro

Pangaea began separating into the Eurasian and African tectonic plates, among others, in the Jurassic period about 200+ million years ago (ma), forming a seaway called the Tethys Sea (aka Alpine Tethys, aka Neotethys) that was several hundred kilometers wide. This relatively shallow body of water accumulated a series of relatively pure, very resistant, light gray to whitish and sometimes reddish fossiliferous limestone, dolostone, and marl sediments a kilometer thick during the upper (late) Triassic period from 200-217 ma. Called the Dachstein limestone, it has two facies named “bank limestone” and “reef limestone.” The former were laid down in lagoonal environments whereas the latter were based on eponymous coral reefs. After deposition, the Tethys seabed became tectonically disrupted and the resulting gaps (Neptunian dikes) filled with violet-red limestone (Rotkalke) during the lower (early) Jurassic.

The Dachstein limestone has been identified as a band of mountains extending through Hungary, the Bakony Mountains, Sicily, Calabria, the Balkans, Turkey, and all the way to New Guinea. I think it’s pretty cool that we are exploring the caves of a several-thousand-kilometer long band of ancient limestone in the neighborhood where it was first studied and described.

The most widely used facies of the Dachstein limestone are the bank limestones. Up to 20 m thick, the massive banks are composed of grain sizes considered sandy to muddy (tenths of a millimeter to micrometers) that often contain macrofossils. The limestone beds are separated by 0.5-1.0 m thick layers of dolostone (aka dolomite, magnesitic limestone) in millimeter-thick finer multi-layers and in some places marl (clay and lime, or lime-rich mud). The differing erosional rates of these types of rock in the bank limestone are the reason for the stepped layers we see in the mountains from afar and in the “benches” immediately downhill of the Wot-U-Got (WUG) entrance to the Hirlatzhoehle. The rhythmic changes creating these benches are due to Lofer cyclothems, originally described as sea level fluctuations occurring over several-thousand-year periods. Interestingly, the original horizontal bedding of the Dachstein limestone can be seen in the Dachstein Massif, whereas elsewhere it is tilted, steep and folded, or distorted.

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Dachstein reef limestones were deposited on the seaward sides of lagoon habitats and are not as common as the bank facies. They occur mainly on the south or southeast sides of some mountain ranges like the Hochkönig, High Göll, Tennenbirge, and Hagengebirge and on the western edge of the Dachstein Mountains. I don’t know if there is any reef limestone within our project area, and suspect that it is probably all Dachstein bank limestone.

Judging by its macrofossils, the Dachstein limestones were deposited in relatively shallow waters that were perhaps completely within the euphotic zone; that is, sunlight easily penetrated the water column all the way to the sea floor. In fact, the entirety of the Dachstein limestone exhibits shallow water conditions, so it must have continuously subsided as it built up. This is the same situation as in Florida and the Bahamas, so I feel right at home here!

The project area also contains Hallstatt limestone, a lithostratigraphic unit of middle and upper Triassic age that was laid down in pools and related emerging areas at depths of 50-200 m. This rock type was deposited in partially separated areas and thus its units are of non-uniform ages. Of varying shades of red, gray, and white, this micritic (finely recrystallized mud) limestone has low clay content and its overlying waters supported predominantly pelagic (open ocean) biota such as ammonites and the massive bivalve *Protoconche*. Fossils occur primarily in layered sediments and synsedimentary columns.

The limestones near the WUG entrance contain fossils of ammonites 10-20 cm in diameter and bivalves that may be of the genus *Megalodon*. Thus, there may be Dachstein bank limestone AND Hallstatt limestone on the trail to WUG. Ammonites:

[https://2.bp.blogspot.com/-RH4hwk_MCMA/WwiQOsDdNnI/AAAAAAAAE_Q/xeWqjqGDZIMd5vmkfIcjquTwILkWlz6jgCLcBGAs/s1600/Ammonoids%2Bin%2BTertiary%2BLimestone%2B1.3.jpg]

Compressional tectonics then closed this pre-Mediterranean seaway starting about 100 ma in the Late Cretaceous period but mostly in the Oligocene and Miocene epochs. This resulted in the formation of the Alpine-Himalayan ranges extending from the Pyrenees and Atlas Mountains through the Alps and Carpathians and into the Himalayas and finally Indonesia. Compression also caused the formerly submarine limestones to be pushed into great recumbent folds, called “nappes,” that rose up out of the sea and moved northward, often breaking and sliding over one another in gigantic thrust faults. These overlie crystalline basement rocks, exposed in the higher central Alps and including Mont Blanc and the Matterhorn. The petroleum formations of North Africa and Arabia were created within the Tethys Sea, and the Mediterranean, Black, Caspian, and Aral Seas are remnants of the Tethys.

Deformation continued until about 30 ma in the Early Oligocene epoch when the major phase of strong and rather continuous uplift started in the western Austrian Alps. The uplift was differential, with the central (including Dachstein) and eastern portions meanwhile remaining low-lying and subsiding during the Oligocene and earliest Miocene. At this time, fluvial gravels of the Augenstein Formation were deposited and karst aquifers developed in the latter’s underlying thick, commonly flat lying Triassic platform carbonates. The limestone has been continuously exposed to erosion since uplift began, with the differential rise resulting in a decrease in cave density along an east to west gradient.

Uplift then commenced in the central and eastern parts of the Northern Limestone Alps (NLA) about 10 ma during the Late Miocene, giving rise to three distinct levels of karst aquifers that provide today’s cave systems. The oldest and highest cave level is at about 2100 m – the Ruin Cave level - which is currently being destroyed by erosion. The Giant Cave level forms labyrinths at elevations of 1500-1700 m and includes most of Austria’s largest and well-known caves. The deepest horizon - the Spring Cave level - is today’s hydrologically active phreatic level.

Most of the large, nearly horizontal cave systems above 1500 m are relicts of extensive Tertiary aquifers that drained water to the northern foreland. As uplift and base levels lowered the water table, these phreatic conduits were later modified by vadose processes.

The uranium and thorium isotopes of stalagmites from Giant-level Dachstein-Mammuthöhle and Eisriesenwelt caves indicate an age > 0.5 ma and probably > 1.5 ma. A regional U/Th study confirms the common presence of speleothems older than ca 0.4-0.5 ma, also attesting to the great age of these caves. Some of the speleothems may also be of Tertiary origin, especially in caves at high altitudes that have neotectonic fractures. Intensive weathering of speleothems at cave entrances demonstrate that significant time has elapsed since they were formed.

Paleobotanic evidence indicates that the central and eastern NLA during the Middle Miocene 12-17 ma were close to sea level and had a subtropical climate. It is believed that these regions had widespread peat deposition in near-coastal swamps and densely forested low uplands where well-developed soils, high rainfall, and warm temperatures resulted in high rates of karstification. The paleo-weathered *terra rosa* red loam found in many caves and epigean sites here is attributed to this early phase of subtropical cave development.

Climate has changed profoundly since then. As the Tethys Sea retreated, perialpine foreland basins were filled by erosion products from the rising alpine mountains, and the waxing and waning of mountain glaciers resulted in U-shaped and over-deepened valleys filled with thick, glacially-derived sediments.

Glacial meltwaters utilized and modified pre-existing Tertiary paleoconduits and created or enlarged the vadose shafts that extend down from the karst plateaus to the paleoconduits (and locally deeper). It is considered unlikely that new cave systems formed during glacial periods because the present day base level is at the level of valley floors. This resulted in a thick unsaturated zone and deep entrance shafts in the NLA. Current karst development is widespread in Austria, although at a lesser scale than during the Tertiary, and is the result of dissolution by meteoric water charged with carbon dioxide obtained from the atmosphere and from passing through soil. This classical karst process occurs mostly at low and mid altitudes where vegetation is dense and soils are well developed. Thus, carbon dioxide production and partial pressure in soil decrease with increasing altitude, resulting in little dissolution above 1600-1800 m, coinciding with the 2010 estimate of the timberline in the Eastern Alps.

[https://3.bp.blogspot.com/-1l0Ij77G9kg/WwiQkrZqVKI/AAAAAAAAE_c/G-5xylQs5mwPWKwHVHPRCsxB57wBgD_oACLcBGAs/s1600/Dachstein%2BMountain%2BStream%2B1.3.jpg]

Caves above the timberline are either tectonically uplifted relics of Tertiary karst and/or hydrologically related to glaciation. Glaciers are still widespread in Austria's Central Alps where the equilibrium line in 2002 was at an altitude of 2600-2900 m despite being in retreat since the 1980s. Glacial waters are undersaturated with respect to carbonates and carry high loads of silt- and sand-sized particles (rock flour), so they not only dissolve limestone but also abrade it, especially during high spring/ summer discharges. If initial porosity (fracturing) is present in the limestone, caves near glaciers owe at least part of their existence to those glaciers.

CO_2 concentrations in NLA caves are relatively low at higher altitudes where ventilation is higher and underneath ground surfaces that have thin or no soils. Nevertheless, the partial pressures by volume of carbon dioxide (pCO_2 ppmv) are higher than in the epigean atmosphere (which was 410 ppmv on May 22, 2018), ranging from slightly higher in most areas of most caves to several thousand ppmv in rare locations. In comparison, concentrations up to 1,000 ppmv are considered safe and even normal for occupied indoor spaces, whereas 1,000-2,000 ppmv can result in drowsiness and complaints of poor air. Headaches can start to occur at levels as low as 2,000 ppmv, but workplace limits allow 5,000 ppmv in most jurisdictions. Exposures above 40,000 ppmv can result in permanent brain damage, coma, and death. Cavers can use the cigarette lighter test to ascertain safe levels: any real gap between the lighter nozzle tip and the flame indicates that one should exit the cave.

Radon gas levels roughly follow CO_2 concentrations and are more sensitive to small variations in air flow.

Within NLA cave passages distant from entrances and other places with strong drafts, temperatures range 3-10 °C and relative humidity is near saturation. Despite temperatures above freezing, some NLA caves contain perennial ice, even large quantities of it, although this ice is decreasing over the long term. Most of the ice is a result of unidirectional air flow, although some of it occurs in "cold traps," which are considered "sag-type" caves. Dated wood fragments in the ice indicate that most accumulations were laid down during the Little Ice Age between 1250 CE and 1850 CE. Some ices, however, were emplaced several thousand years ago and others at entrances are seasonal.

NLA karst spring waters typically range 5-8 °C and most are slightly alkaline with pH values of 7.5-8.0. Alkalinity is generally of the calcium-magnesium-bicarbonate ($Ca\text{-}Mg\text{-}HCO_3$) type, and is low to intermediate in alkalinity at 6-18° on the German hardness scale. Hydrographs show maximum spikes in spring discharge volumes during spring and summer due to snowmelt infiltration. Travel times from rainfall events to spring discharges are relatively quick, on the order of a few days, but obviously much quicker in entrance shafts such as WUG.

WUG's entrance is at an approximate elevation of 1975 m, which is 625 m or more below the lower limit of the 2002 Central Alps glacier equilibration line (2600-2900 m), so it is unsurprising that permanent ice is nonexistent here. The absence of trees at the WUG entrance is expected, as it is about 175 m above the upper limit of the Eastern Alps timberline (1600-1800 m) and the ground surface is just plain rock. Here, it suffers the combined stresses of little or no soil, winter coldness and frost wedging, plus year-round desiccation.

How does all this help us find new, undocumented cave entrances? What model(s) can we derive from these historical hydrogeological characteristics? We already have one such model: Stay away from cliff bases because they fill with rocks from frost wedging and snow that melts slowly because it is protected from wind and sunshine. Contrarily, the WUG entrance is at a cliff base and another potential entrance that I found last year is distant from a cliff yet plugged by boulders. Perhaps we need additional prospecting (ridge-walking) models.

One suggestion is to look for dikes in the limestone. Dike material can be softer or harder than its sandwiching limestones, but in both cases surface rainwaters will be captured by and run along the interfaces of the two rock types. The softer rock can then become etched and subsequently enlarged into human-sized cave passages. This model is used in some hard-rock terrains such as North Carolina, where softer basalt dikes intrude into harder granitic gneiss and caves are being carved into the basalt. The Dachstein limestone has occasional dikes and synsedimentary columns made of infilled hard-rock debris. These should be prospected if found in the project area.

Another potential model is to take advantage of the fact that Ruin and Giant Cave levels have entrances that were formed or are being enlarged now that the mountain’s glaciers are essentially gone. These entrances are active even if apparently plugged by boulders. I found such an entrance last year, as evidenced by very cold air in the “hopper” despite it being open to the sun on a warm summer day. I’m not sure of the tack to take here, and we certainly do not want to expend numerous hours removing boulders from holes in the ground. Perhaps we should look for multiple channels in the rock surface pointing to particular holes, like spokes on a wheel? But there are so many channels in the rock up there...

One model used in TAG (from the first letters of Tennessee, Alabama, and Georgia in the USA) is to walk the geologic benches. Most of the rock along the steep hillsides of TAG is limestone, but there are occasional layers of erosion resistant sandstone that form easily walked steps, or benches, that follow a consistent contour. Water percolates down through the rock via joints, enlarging them and forming vadose caves, until reaching the top of a sandstone layer. Subterranean streams form on the top of the sandstone layer and then flow downstrike until popping out along the benches. Flowing over the bench as waterfalls, the water can then sink into the lower limestones and create more cave passages. Occasionally, the water cuts through the sandstone layer and connects both caves into a single cave. Thus, one walks along the benches and looks for holes in the ground. I believe this technique could be modified for Dachstein post-snowfall conditions, but you’re going to have to get up pretty early in the morning to make it work!

Sandstone layers do not exist in the Dachstein Massif, but resistant layers of dolomite and marl do and it might be productive to walk their edges. Now that I think of it, M54 Cave might be downhill of just such a bench. That possibility could be easily ground-truthed in a couple of hours, and if true then it might be productive to follow that bench. Similarly, the edges of the Hallstatt limestone deposit referred to above should be explored.

Another TAG hack is to walk a given contour along one side of a valley in winter when trees have dropped their leaves and it is colder in the epigean air than in the caves. Water-saturated air in multi-entrance caves will be warmer than epigean air and rise from upper cave entrances while simultaneously being sucked into lower entrances. The moisture venting from upper entrances condenses into steam and forms what I call “steamaroles,” which can be voluminous enough to be seen from the other side of the valley. By triangulating each steamarole from several places across the valley, one can chart potential cave entrances and ground-check them later, even much later, like springtime when the weather is more reasonable.

At least three prospecting models are used in Florida. They are not really suitable for Dachstein, but are included here to give exped members additional insight into devising prospecting models. (1) Take a boat along a karst river and look for springs and estavelles (spring-syphons) emptying into the river. All of them have phreatic cave conduits behind them. (2) Wander around karst plains, search for sudden-collapse sinkholes, and examine them for holes in the ground. (3) Some karst lakes drain into caves. These will tend to be underwater phreatic caves and almost all are tannin-stained and spooky, but they are caves nonetheless.

It would be great if an exped member or visitor would take interested cavers on a tour of the geology of the Dachstein project area to point out the various geological features mentioned herein. I would be especially interested in learning how to differentiate in the field the several kinds of rocks, facies, and fossils present.

Posted 25th May 2018 by Buford Nature

3 View comments

Anonymous Mon May 28, 07:39:00 PM EDT

Good combination of facts and ideas there :) WUG's entrance is definitely a lot higher than 1300m though - I think it's a little over 2000m.

Reply

Buford Nature Sun Jul 01, 10:43:00 AM EDT

You are correct about 1300m being wrong. Dunno how I made that mistake. I will change that number. Thanks.

Incidentally, the topographic lines on the map depicting the cave entrances that is available to me are hard to interpret, as its contour lines are only rarely identified. Near WUG, for example, a "2000" identifier confusingly lays over two contour lines, so if I start with the nearby "2218" mountaintop and count down in 100m increments, WUG appears to be at appx 1850m.

I am also confused about the numbers adjacent to other entrances to the Hirlatz Cave system. At first, I thought they were elevations, but no, that doesn't wash. Perhaps they are cave entrance numbers?

Reply

Christopher Holt Sun Aug 19, 05:13:00 PM EDT

Hi Buford - where did you find the carbon dating evidence for the Little Ice Age deposits?

Asking for a friend.

Reply

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