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Travertine cascades around the world

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Abstract: A pictorial overview of some of the world's finest travertine barrages and cascades. Carbonate travertine is polygenetic, both chemical and organic, and both karstic and geothermal, with a full range of sites between those extremes

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Travertine is widespread in karst terrains, and less so elsewhere, and some of its varieties constitute spectacular landforms, many of which become popular visitor sites for geologists and non-geologists alike. As a rock it is a terrestrial variety of limestone, in that it is deposited on land by freshwater (Fig.1). It is created by precipitation of calcite from supersaturated water, in a chemical process induced at most sites by algae and other plants extracting, for their photosynthesis, the carbon dioxide upon which carbonate dissolution depends. The terms *travertine* and *tufa* are interchangeable, though travertine commonly refers to the harder, denser, laminated material, whereas porous material accreted around living plants is more often known as tufa. What is more, it was originally confused with volcanic tuff, when both tufa and tuff were known as *tufo*, where used as building stones in ancient Rome. The main source of that tufa was, and still is, around Tivoli, 25km east of the city.

***Figure 1**: Travertine at its finest: terraces and pools at Pamukkale, in eastern Turkey.*

***Figure 2**: Travertine dams along a stream course amid lush plant growth, at Tat Kuang Si, close to Luang Prabang in the Mekong Valley of central Laos.*

Travertine deposition can produce a wide variety of morphologies (Ford 1989; Pentecost, 1995, 2005; Ford and Pedley, 1996). Spring mounds (and towers), fissure ridges, paludal sheets (in marshes), fluvial and lacustrine crusts, and cemented terraces are all common (Pentecost and Viles, 1994). However, the travertine known at the great tourist sites is that which forms barrages (or dams) by active deposition beneath its own cascades and then impounds rather beautiful pools and lakes (Fig.2). Travertine cascades, and their dams, range in height from a few millimetres to more than a hundred metres. Their key feature is the precipitation of calcite where the water flows over the dams, and this can be due to simple evaporation, degassing of turbulent water, decline of its carbon dioxide towards atmospheric levels, or loss of carbon dioxide by plant photosynthesis, and is commonly the result of a combination of all of the basic processes (Fig.3).

Pure travertine is white, but many of its cascades and lakes are very colourful. The turquoise colour of many lakes is due to reflection of light from suspended calcite, but most other colours are due to algae on the surface of the travertine, with yellows added by iron minerals.

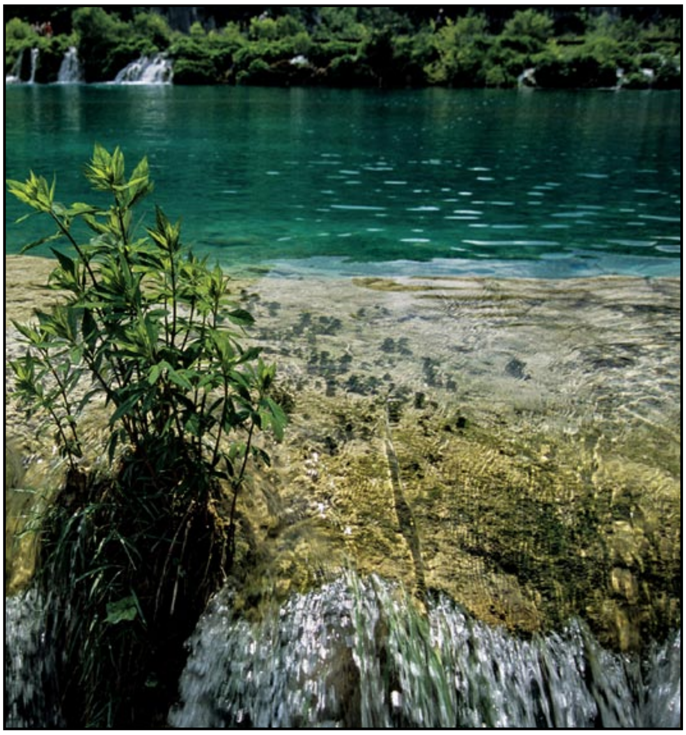

Figure 3*: Calcite being precipitated as water flows over a travertine cascade at Plitvice, in the Croatian karst.*

Travertine is polygenetic; in simple and convenient terms its occurrences can be divided into three broad groups. Karstic, or meteogene, travertines are formed in cool waters under the influence of plant photosynthesis. Geothermal, or thermogene, travertines are formed in hot waters by essentially chemical precipitation. The large third group occupies the intermediate situation, where travertine is formed in warm waters that have circulated to great depth within limestone terrains. Boundaries between the groups are not clearly defined.

Occurrences of travertine cascades and deposits are scattered all over the world, but only some of the finer barrages and cascades are included in this pictorial overview of some of the more spectacular travertine landforms. Further information on the geomorphology and evolution of many of the sites is readily available in publications such as those by Pentecost (1995 and 2005) and Ford and Pedley (1996).

Karstic travertine

This is formed of calcite that was taken into solution by rainfall-derived groundwater enriched with biogenic carbon dioxide from the soil profile and then precipitated due to subsequent loss of the CO_2. It is comparable to stalagmite deposits and gour barriers formed in caves, except that precipitation is enhanced in daylight where the CO_2 is extracted by bryophytes (mosses, etc.) and cyanobacteria (notably blue-green algae). Chemical processes are also involved, and there is on-going debate about the amounts of chemical versus organic calcite in travertine; the ratio is probably different at every site. Precipitation is not always at the source springs but can occur at downstream sites where the conditions are favourable with respect to temperature, turbulence, tributary mixing, and plant activity.

Among the finest travertine cascades anywhere are those at Plitvice, inland in the Dalmatian karst of Croatia (Emeis *et al*., 1987). The River Korana emerges from distant springs with temperatures around 7°C, before algal growth during the warm summers becomes a major factor in downstream calcite precipitation. There are 16 beautiful lakes lying between cascades over tree-covered travertine dams along seven kilometres of limestone canyon (Fig.4).

Figure 4*:*
Cascades over one of the travertine barrages along the part of the Korana River that flows through the Plitvice canyon in the Plitvice Lakes National Park (Plitvička jezera), Croatia.

Figure 5:
A small part of the staircase of travertine dams, pools and cascades at the Krka National Park, inland from Sibenik in southern coastal Croatia.

Figure 6:
The tufa cascades of Kravica, on the Trebižat River, in the karst of southern Bosnia and Herzegovina.

Also of note within the Dalmatian karst of Croatia are the chain of beautiful travertine cascades at Krka (Fig.5), behind the coastal city of Sibenik, and the splendid Kravica cascade (Fig.6), just over the border, in Bosnia and Herzegovina.

Cooler climatic conditions across northern Europe restrict algal growth, and thereby greatly reduce the scale of any travertine barriers that form. Gordale, in northern England, is typical of travertine developments in the region, though its cascade below the Hole in the Wall (Fig.7) is the only one in this area that is actively forming travertine at the moment, whereas deposits at most other sites are currently being eroded (Pentecost, 2013).

Figure 7:
Travertine being deposited by the cascade from the Hole in the Wall, at Gordale Scar, near Malham, in the Yorkshire Dales, with an old travertine bank on the left, formed where the stream flowed prior to 1730.

***Figure 8**:*
The waterfall of Duden cascading off the edge of the extensive travertine terrace at Antalya in southern Turkey. This is the greatest expanse of travertine anywhere in the world. Though it is largely being eroded in the waterfalls along the coastal cliffs, active deposition is continuing at sites farther upstream and inland.

Plant activity in the warmer waters of Mediterranean regions is better suited to the formation of karstic travertine. Extending over 650km^2, with thicknesses reaching 270m, the travertine accumulation at Antalya, in southern Turkey is the largest in the world (Burger, 1990). Rivers pour across its terraces, forming chains of cascades, with the Duden waterfall dropping 40m directly into the sea (Fig.8).

Within the great desert belt south and east of the Mediterranean, the splendid travertine cascades of Ouzoud (Fig.9) and Imouzzer both lie within the limestone mountains of Morocco's High Atlas.

***Figure 9**:*
The multiple travertine cascades at Ozoud in Morocco. This is now a major tourist site, and even offers very short boat rides across the pools to the foot of the main waterfall.

In the mountainous Dhofar of southern Oman, 40km east of Salalah, Wadi Darbat contains the world's largest single travertine barrage. It is nearly a kilometre long and around 100m high (Fig.10). Any lake that once existed behind it is now full of sediment, forming a flat plain that extends back more than 5km. For most of the year, the near-vertical travertine wall is dry except for one small stream, but during each khareef (the local annual monsoon), almost its entire length can come alive with massive waterfalls. Dating has shown that much of the travertine was laid down during pluvial stages at around 30–20 and 9–6 ka BP, and nowadays there is little or no deposition related to the annual floods.

At only a slightly smaller scale, there are also huge deposits of travertine on the limestone mountain of Jabal Akhdar in northern Oman.

A classic site, which is now rather inaccessible, in Afghanistan, is the spectacular chain of lakes that lies along the desert valley of Band-e-Amir (Fig.11). Some of the ten travertine dams are remarkable for their narrow crests and steep outer walls (Fig.12). Water emerges from limestone springs, drains through the lakes, and then sinks into alluvial deposits (Lindner, 1982).

Figure 10*: A small part of the massive travertine barrage in Wadi Darbat, in southern Oman; the white streak in the right distance is the travertine kept clean by permanent stream flow; the person in the middle foreground indicates the scale.*

Figure 11*:*
The chain of lakes impounded by travertine dams along the desert valley of Band-e Amir in Afghanistan.
[Photo: Jerry Eldridge.]

Figure 12*:*
Impounding one of the lakes at Band-e Amir, not the largest, but the finest, of the travertine dams has a wall of calcite standing ten metres above the desert floor.
[Photo: Bill Renshaw.]

***Figure 13**: The great travertine cascade of Huangguoshu in southern China.*

China's largest waterfall is Huangguoshu, on the limestone plateau of Guizhou. Formerly known as the Dabong River, the Baishui River (meaning *White Water*) drops 74m over a screen of travertine (Fig.13) between many smaller travertine cascades both up- and downstream, including the Doupotang cascade a kilometre upstream. The warm and wet lands of Southeast Asia contain many travertine sites within their karst terrains; the pools and cascades of Tat Kuang Si (Fig.14), near Luang Prabang in Laos, are particularly beautiful.

Limestone areas in Central America also include spectacular travertine sites. In Chiapas State, southern Mexico, a river pours off the faulted edge of a limestone plateau to create the Cascadas de Chiflon, which descend 120m over great screens of travertine, including a 70m single-drop waterfall, the Velo de Novia (Fig.15).

***Figure 14**: Part of the series of travertine cascades at Tat Kuang Si, in central Laos.*

***Figure 15**: The powerful Velo de Novia (Bridal Veil Fall) is the tallest of the Chiflon cascades on travertine in southern Mexico.*

Figure 16*: Multiple cascades over low travertine dams at Agua Azul, in northern Chiapas, Mexico.*

Figure 17*:*
One of the larger barrages at Agua Azul in Mexico.

Figure 18*:*
A small part of the long series of calcite dams and pools that form the Dunn's River Falls, the classic travertine site on Jamaica's northern coast.

Figure 19: *Havasu Falls, with low travertine dams and pools below, in the Havasupai canyon, deep inside Arizona's Grand Canyon.*

Farther north in Mexico, but still in Chiapas State, Agua Azul is a popular tourist site with a chain of beautiful blue lakes retained by, and cascading over, low dams (Fig.16), and also more-massive banks (Fig.17) of white travertine.

Just south of San Agustín Lanquín, inside the border with Mexico, the Guatemalan Natural Monument of Semuc Champey ("*Where the river hides under the stones*") comprises a long run of low travertine cascades and turquoise pools along the Rio Cahabón.

Best known among the many travertine sites within the islands of the Caribbean, Dunn's River Falls lie near the town of Ocho Rios on the northern coast of Jamaica. Dunn's River, which is fed by carbonate-rich water from springs in the higher limestone areas to the south, has only a short course, over which it drops less than 60m to sea level. At its lower end the river has built a staircase of travertine cascades totalling some 55m in height and 180m in length (Fig.18). The cascades terminate where the short river enters the Caribbean at the western end of a sandy beach.

Northwards into the cooler or drier lands of the USA, there are few travertine deposits that are not associated with geothermal waters. Those within the Grand Canyon are perhaps the finest (Ford and Pedley, 1996). Powerful springs that emerge from the Mississippian Redwall Limestone sustain the thriving Havasupai community in their large village, 600m below the rim of the canyon, far to the west of the main Grand Canyon visitor sites. Below the village, Havasu Creek cascades over a series of travertine dams, among which the two largest are marked by Havasu Falls (Fig.19) and Mooney Falls (Fig.20), each dropping about 30m into rather lovely pools.

Figure 20: *Mooney Falls, the second cascade on Havasu Creek, with a wall of old and heavily weathered travertine preserved on the left.*

Figure 21: *Steam rising from pools on the travertine terraces at Mammoth, in the great Yellowstone National Park, Wyoming, USA.*

Geothermal travertine

Travertines within a separate group have been formed by warm or hot waters unrelated to karst. These waters have high concentrations of carbon dioxide derived from various sources, including decomposition of marine limestone, or emanating directly from the upper mantle in areas of volcanic activity. Those two main sources are recognizable by the signature ratios of their stable carbon isotopes at contrasting sites, and the high concentrations of carbon dioxide, from either source, account for their high loads of carbonate in solution.

The Mammoth Terraces, in America's Yellowstone National Park, form the world's largest area of geothermal travertine. Throughout most of the Park hot waters rising along faults in and around the old calderas deposit siliceous geyserite at vents. Mammoth is an exception, where the waters rise through the Palaeozoic Madison Limestone, emerging saturated with carbonate and at a temperature of 73°C (Bargar, 1978). They release CO_2 on emerging, and thermophile bacteria catalyse the process of calcite deposition (Fig.21). Isotope ratios confirm that 95% of the emergent water is of meteoric origin and, after entering the ground, the rainwater was heated at depths of around a kilometre. The net effect is magnificent (Fig.22).

On the North Island of New Zealand, the huge, now-lost, geothermal Pink and White Terraces at Waimangu were silicious. They were justly famous until they were covered by the waters of Lake Rotomahana as its size increased twentyfold during the 1886 eruption of the Tarawera volcano. Their modern equivalents at nearby Orakei Korako are more modest but are also siliceous.

Figure 22: *Part of the extensive Mammoth Terraces at Yellowstone.*

Figure 23:
Tallest of the travertine cascades in Wadi Zarqa Ma'in, Jordan's side of the Dead Sea rift.

Figure 24:
The Cotton Castle of Pamukkale, in western Turkey, seen from afar.

Figure 25:
Finest of the travertine terraces at Pamukkale in Turkey, now pure white with new layers of calcite deposited when the spring water is directed over them at intervals.

Figure 26:
Travertine terraces at Pamukkale. The barrage in the foreground is a concrete dam coated with travertine, intended for visitors to walk on or bathe in its pool; the terraces beyond are in their natural form, where visitors are no longer allowed to roam.

There are other notable geothermal travertines elsewhere in the world. At Zarqa Ma'in, on the Jordanian side of the Dead Sea rift valley, travertine cascades are fed by radon-rich water emerging at 63°C (Fig.23). Their source is in sandstone aquifers at depth, but there is some mixing with meteoric groundwater that is derived from the adjacent limestone plateau. Downstream of the Meskhoitine springs in Algeria, travertine terraces are forming in groundwater (derived from volcanic sources) that emerges from the springs at nearly 90°C.

Pamukkale, in western Turkey, is one of the world's great travertine sites (Fig.24). Translating as *Cotton Castle*, its dazzling white terraces are truly spectacular, with cascades that extend over 120m in total height and reach a length of two kilometres (Fig.25). Four main springs yield water at 36°C from faults in Neogene limestones along one wall of the Denizli graben (Ozkul *et al*., 2013). Much of the spring water is of geothermal origin, also emerging at higher temperatures nearby, but it is mixed with cooler drainage from the local karst.

Though most commonly described as a thermogene site, its close association with the karst makes Pamukkale a contender for the high end of the large intermediate group of polygenetic travertines that are formed by a mixture of geothermal and meteoric waters. The biogenic contribution to the depositional processes at Pamukkale is minimal, and it is the lack of algae that accounts for the pure white appearance of much of the site's travertine (Fig.26). Deposition has been continuous for 14,000 years, and some of the material has been dated back to more than 100 ka.

A variant of geothermal travertine is formed where hot, lime-saturated waters emerge from springs in the floors of lakes. Mixing with the cooler lake water causes rapid precipitation of calcite, which forms underwater towers that are exposed only if and when lake levels fall. There is some uncertainty about the role of bacteria in the formation of these towers. Perhaps best known are those in Mono Lake, in California, fortuitously exposed since much of the lake's inflow has been diverted into the water supply for Los Angeles (Fig.27).

Of similar origin, but far larger, are the fault-guided lines of travertine towers at Lake Abhe, on the Djibouti–Ethiopia border (Fig.28). These have been exposed since the level of the lake (which has no surface outlet) declined by many tens of metres because of reduced rainfalls in the Ethiopian Highlands catchment and continuing evaporation within the desert.

Figure 27*: Towers of travertine exposed by the falling level of Mono Lake in California.*

Figure 28 (above)*: Some of the travertine towers along the Djibouti shore of the shrunken Lake Abhe, at the end of Africa's Rift Valley.*

Travertines of deep limestone waters

The third and largest group of travertines encompass those formed by meteoric waters that have circulated to depths great enough to undergo significant geothermal warming. They are essentially karstic, though not all lie on limestone outcrops. Their carbon dioxide is derived largely or entirely from soils, with only limited geothermal input, so the travertines are distinguished by low proportions of the carbon-13 isotope (which occurs at higher levels in most thermogene sources). The modest warmth of their waters can enhance algal growth and consequent biogenic deposition of calcite, but this is not the case at every site.

An extensive cluster of travertines lies around Tivoli, east of Rome, but these are largely flat-lying, lacustrine deposits that lack any dramatic cascades (Pentecost and Tortora, 1989). Multiple springs along faults yield, or have yielded, water at temperatures around 24°C, with meteoric waters from the Mesozoic limestones of the Apennines constituting the main sources. Most of the travertine is finely banded, reflecting seasonal variations during its deposition in shallow lakes, and many of the deposits have long been quarried to provide easily worked stone that has been used for construction work in Rome (Fig.29). A separate Italian travertine is quarried at Rapolano, near Florence, and has become the signature stone for McDonald's burger outlets in Europe.

Figure 29*: Columns of banded travertine around St Peter's Square in Rome, fashioned from rock that was sourced from quarries east of the city.*

***Figure 30**: Just one tiny section of the great chain of travertine dams, pools and small cascades at Huanglong in China.*

***Figure 31**: The "Yellow Snake" or "Yellow Dragon" of travertine that floors the valley at Huanglong in the mountains of Sichuan, China.*

***Figure 32**: One of the chain of cascades over travertine dams in the forested Jiuzhaigou valley in China.*

Among numerous travertine localities in the karstlands of China there are many that were created by waters warmed by deep circulation in limestone, which therefore fall readily into this intermediate category. Within the mountain ranges of Sichuan, Huanglong (meaning the *Yellow Snake* or *Yellow Dragon*) has an exceptionally beautiful chain that comprises more than 3000 lakes (Fig.30), each one impounded behind its own low travertine dams. These extend for some three kilometres along a single wooded valley, with a descent of about 300m (Fig.31). Their feeder water emerges from a small group of powerful, fault-guided, springs carrying meteoric groundwater from limestone beds that are locally buried beneath outcrops of sandstone and slate. The average water temperature of 6°C indicates a deep circulation (mean air temperature is only 1°C), and calcite precipitation is then due to CO_2 degassing, with little or no algal impact in the cold mountain environment at an altitude of 3500m.

Nearly 100km north from Huanglong, and at a much lower altitude, Jiuzhaigou has 12km of valleys floored by 14 large lakes, each impounded by travertine dams with their own curtains of cascades that are up to 20m tall (Fig.32). Amid lush forest, the biogenic influence on calcite deposition is conspicuous, with travertine forming on and around abundant plant debris in the lakes and also over the many cascades (Pentecost and Zhang, 2001).

Now accessible via a new road, Baishuitai, near Lijiang in the mountains of northern Yunnan consists of another extensive suite of beautiful white travertine terraces, though it is smaller than its neighbours in Sichuan Province. Farther west, in the Himalayas, travertine cascades draped over limestone slopes from Dhaulagiri down to the Kali Gandaki valley are localized close to major faults that have probably facilitated deep circulation of the supply waters. Still farther west, on the southern slopes of Iran's Elburz Mountains, the clean travertine terraces and impounded pools at Badab-e Surt are fed by water at a temperature high enough to suggest deep circulation.

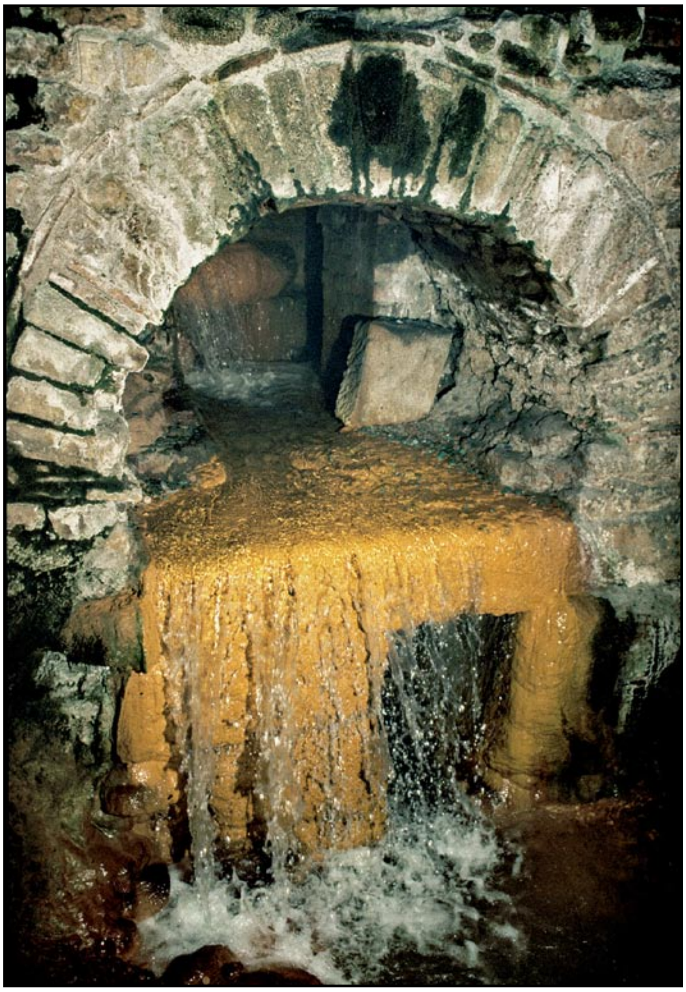

***Figure 33**: Travertine formed by emergent spring-water at the Roman Baths in the city of Bath in Somerset.*

Britain has a number of spa towns, each based on a source of water heated by its deep underground circulation. Many of the spring sites include examples of travertine deposition on limited scales. The water at Bath (*Aquae Sulis*) emerges at 46°C, apparently having descended to depths of 2500m along its flow-path from the Mendip Hills karst (Gallois, 2007). Travertine is now being deposited over the stonework where the thermal water emerges into the Roman Baths (Fig.33).

In England's Derbyshire Peak District, thermal spa waters at Buxton and Matlock have temperatures of only around 20–27°C, related to circulation to lesser depths than those at Bath. Extensive travertine deposits occur associated with the thermal springs at Matlock. Elsewhere in the Peak District, actively growing travertine forms small barrages at karstic sites along parts of the River Lathkill.

A spectacular variant of travertine is provided by its natural bridges. These are formed where sheets of travertine have developed in river valleys on top of unconsolidated sediments. At any site where part of those sediments is then removed, commonly by the piping action of seepage water, the river may then be able to switch its course and flow beneath the surviving travertine. The so-called Inca Bridge (*Puenta del Inca*), about 100km west of Mendoza in Argentina, is a particularly fine example (Fig.34).

Greater implications are presented in situations where piping failure has not yet occurred and the overlying travertine has become inactive and less recognizable. Built in 1885, the Les Cheurfas dam in Algeria was founded partially on gravel deposits with a travertine-cemented crust that was mistaken for bedrock limestone; subsequently, leakage of the impounded water washed out the unconsolidated gravel beneath the crust and eventually led to catastrophic collapse of the dam wall.

Travertine for tourists

Sparkling cascades tumbling over white rock do tend to make successful tourist attractions, and many of the world's great travertine sites have been made more easily accessible by the construction of footpaths and viewing platforms. But tourism has had other impacts. At the Dunn's River Falls in Jamaica, for example, algal coatings are scraped off the travertine barrages regularly so that the surfaces are not too slippery for tourists to clamber over (Fig.35).

In Turkey the site at Pamukkale suffered from horrendous mismanagement when a road was built right up the middle of the travertine terraces in the 1950s (Fig.36). The offending road was subsequently closed, and is now buried beneath a chain of low concrete dams, which have since been covered with fresh travertine deposited by the natural waters diverted to flow over them. Whereas it is banned in the numerous natural pools, swimming is permitted in the dammed ponds along the old road, which many visitors assume to be natural anyway (Fig.37).

Figure 34. Puenta del Inca (the Inca Bridge), formed of travertine that has been undermined by the Rio Mendoza in the Argentine Andes.

Figure 35*: Tourists on a 'guided walk' up the travertine cascades along Dunn's River in Jamaica.*

Figure 36*: An old photograph from Pamukkale, showing the travertine terraces and pools that were cut into in order to build the dreadful and intrusive road up the centre of the site.*

Figure 37*: A recent photograph of Pamukkale, at the same location as Figure 36, with hordes of tourists in and around the chain of pools retained behind low concrete dams that were built along the line of the old road.*

Fortunately, the travertine-dammed pools at Yellowstone's Mammoth site are too hot for swimming, and those at China's Huanglong are too cold. The thin air at high altitude adds another dimension at Huanglong, where visitors up from the lowlands take breaths from rubber bags full of oxygen to help them along the footpaths beside their beautiful Yellow Dragon.

Many of the more remote travertine sites do not suffer from the pressures of visitor numbers, so their pools can be enjoyed by non-geological pleasure-seekers. At Jordan's Zarqa Ma'in, show-off lads vie to endure the hottest water in the upper cascades nearer to the source. Such is the nature of mass tourism.

Different folk will have their own favourites, but nevertheless Huanglong probably rates as the most magnificent of the world's many splendid sites and sights created by travertine (Fig.38). The best of the world's travertine cascades and lakes can still be appreciated for their beautiful landscapes.

Figure 38*: Arguably the finest in the world: just some of the many travertine dams at Huanglong in China.*

References

Bargar, K E, 1978. Geology and thermal history of Mammoth Hot Springs, Yellowstone National Park, Wyoming. *U. S. Geological Survey Bulletin*, 1444, 55pp.

Burger, D, 1990. The travertine complex of Antalya, southwest Turkey. *Zeitschrift für Geomorphologie, Supplement Band*, Vol.77, 25–46.

Emeis, K-C, Richnow, H-H and Kempe, S, 1987. Travertine formation in Plitvice National Park, Yugoslavia: chemical versus biological control. *Sedimentology*, Vol.34, 595–609.

Ford, T D, 1989. Tufa: the whole dam story. *Cave Science*, Vol.16, 39–49.

Ford, T D and Pedley, H M, 1996. A review of tufa and travertine deposits of the world. *Earth Science Reviews*, Vol.41, 117–175.

Gallois, R W, 2007. The formation of the hot springs at Bath Spa, U.K. *Geological Magazine*, Vol.144, 741–747.

Lindner, L, 1982. The age of the Bande Amir travertines in Afghanistan. *Acta Geologica Polonica*, V.32, 289–296.

Ozkul, M and 9 others, 2013. Comparison of the Quaternary travertine sites in the Denizli extensional basin. *Sedimentary Geology*, Vol.294, 179–204.

Pentecost, A, 1995. The Quaternary travertine deposits of Europe and Asia Minor. *Quaternary Science Reviews*, Vol.14, 1005–1028.

Pentecost, A, 2005. *Travertine*. [Heidelberg: Springer.] 446pp.

Pentecost, A, 2013. Travertine and tufa. 111–116 *in* Waltham, T and Lowe, D (eds), *Caves and Karst of the Yorkshire Dales*. [Buxton: British Cave Research Association.]

Pentecost, A and Tortora, P, 1989. Bagni di Tivoli, Lazio: a modern travertine deposition site and its associated micro-organisms. *Bolletin Societa Geologica Italia*, Vol.108, 315–324.

Pentecost, A and Viles, H, 1994. A review and reassessment of travertine classification. *Géographie physique et Quaternaire*, Vol.48, 305–314.

Pentecost, A and Zhang Z, 2001. A review of Chinese travertines. *Cave and Karst Science*, Vol.28, 15–28.