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Guano

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GUANO

Guano consists of the accumulated droppings of animals, usually bats, but occasionally of cave-dwelling birds, such as the swiftlets (*Collocallia*) of Southeast Asia, or the oilbirds (*Steatornis caripensis*) of South America. The term originates from the Quechua word *huana* for "dung", and originally applied to enormous accumulations of seabird excreta that sustained a 19th-century nitrate-mining industry on the islands of the Humboldt Current, off the coast of Peru. Bat guano accumulations can be equally extensive. At Carlsbad Caverns, New Mexico, some 92 million kg of guano were reportedly mined between 1903 and 1923 (Geluso, Altenbach & Kerbo, 1987). Niah Great Cave, Sarawak, contained at least 29 million kg of guano and related decomposition products (Wilford, 1951), while some 50 000 m^3 of guano remain in the caves of Mona Island, West Indies, despite extensive mining of the thickest deposits (Peck & Kukalova-Peck, 1981). The original size of the deposits was estimated at 462 000 tonnes.

The size of guano accumulations is a function of the size of the bat colony, the length of time over which accumulation has taken place, and physical characteristics of the cave which determine rates of decomposition and removal. At Bracken Cave, Texas, a summer population of some 20 million Mexican Free-Tailed bats (*Tadaraida brasiliensis*) deposit an estimated 50 000 kg of guano annually (Barbour & Davis, 1969). At Eagle Creek Cave, Arizona, the same species of bat adds as much as 16 cm a year to the existing deposit (Altenbach & Petit, 1972), which shows no appreciable decomposition over timescales of at least 50 years.

Large guano deposits are not homogeneous, but undergo physical compaction, biological degradation, and chemical alteration with time and burial. At Niah Great Cave, Sarawak, Wilford (1951) identified an indistinct stratigraphy consisting of 0.7 m of "fresh" guano, supporting a thriving arthropod community, which merged into 3 m of finely textured "fossil guano", and finally 0.8 m of "rock phosphate". This sequence of deposition is typically accompanied by a progressive loss of organic content and a proportional increase in insoluble phosphatic residue. In very dry caves, such as Tramway Cave, Arizona, bat guano deposits may be preserved for more than 12 000 years without appreciable decomposition. This is possible because insectivorous bat guanos consist primarily of small fragments of insect chitin, which is highly resistant to chemical attack. Moist conditions are necessary to support decomposing micro-organisms capable of producing the enzyme chitinase.

Low rates of chitin decomposition make guano accumulations valuable repositories of paleoclimatic information. Guano chitin preserves a carbon stable isotope signature of the surface community from which it was derived, and this has been used to track climate change over thousands of years (Mizutani, McFarlane & Kabaya, 1992). The carbon content of guano chitin also makes it a convenient material for ^{14}C dating, and the dating of distinctive guano layers in cave sediments profiles has found use in studies of paleontological remains from caves.

Decomposition of bat guano and the bat urine associated with it produces free ammonia, which in Cueva del Tigre, Mexico, can reach 1200 ppm—far above the level of human tolerance (McFarlane, Keeler & Mizutani, 1995). In moist caves, some of this ammonia may be converted to nitric acid by bacterial action, which in turn reacts with the underlying bedrock to produce a suite of nitrate minerals (see Sediments: Biogenic).

Guano deposits associated with fruit-eating bats are common in tropical regions of the world. They are quite different to insectivorous guanos, consisting of dropped and excreted seeds, leaves, and twigs. Many of these seeds germinate in the deposit, producing spindly, pale seedlings, which die after a few weeks from lack of light for photosynthesis. Fruit bat guanos rarely accumulate to great depths or volumes, because decomposition of plant debris is much more rapid than the decomposition of insect chitin.

Unique to the neotropics, vampire bats (*Desmodus, Diaemus,* and *Diphylla*) are cave- and hollow tree-dwellers that feed exclusively on the blood of vertebrates, taking as much as 40% their own bodyweight at a feeding. Blood is a bulky food to carry in flight, so the bats excrete much of the water content within 20–30 minutes of feeding. The guano of these animals that subsequently accumulates in caves is a sticky, tar-like material of concentrated and partially digested blood solids, with a distinctive, ammonia-rich odour.

The South American Oil-Bird, *Steatornis*, is a fruit eater whose guano is very similar to that of fruit-eating bats. A large colony in Cueva del Guácharo, Venezuela, has been famous since it was first visited by Alexander von Humboldt in 1799 (De Bellard Pietri, 1957). In contrast, many caves in Southeast Asia support very large populations of cave swiflets. Bird guano accumulations can be extensive in these caves, but differ little from insectivorous bat guano deposits that often occur in the same caves.

Actively decomposing bat guano accumulations support thriving communities of invertebrates. Detritus-feeding mites are typically present in enormous numbers, preyed upon by predatory mites and pseudoscorpions. These micro-arthropods support rich populations of macro-invertebrates, of which cockroaches, crickets, and predatory tailless whip scorpions predominate. Temperate zone bat guano ecosystems tend to support a lower diversity of macro-invertebrates. In tropical guano ecosystems, productivity may be high enough to support small vertebrates, usually frogs.

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See also **Aves (Birds); Organic Resources in Caves; Sediments: Biogenic**

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GUNPOWDER

For hundreds of years, gunpowder was a mixture of which the main ingredient, saltpetre (KNO_3), was sometimes extracted from caves. Although the Chinese were probably familiar with it, the black powder was unknown in Europe until Roger Bacon (1214–94) of England, discovered the formula about 1248. The other components, sulfur and charcoal, together comprised a fourth of the compound (Pierce, 1952; Lewis, 1956).

There have been other uses, such as a preservative, but the primary importance of saltpetre has been its utilization in gunpowder. The dirt in dry caves is one source of saltpetre, which can be obtained by leaching the sediments with water. The source of nitrates in the saltpetre earth is groundwater seeping into a cave from the surface: dry caves act as receptacles where the soluble nitrate can accumulate rather than be leached away. Other sources for saltpetre have been soils of certain warm countries, especially India's Bahar Province, long controlled by England; cellar walls, stables, the dirt underneath old buildings; and artificial composting beds of decaying animal and vegetable matter (Faust, 1949). In most cases, the soil or product had to be leached in hoppers and the resulting solution treated with an alkali to cause calcium to be precipitated and potassium to be substituted.

It was learned very early on that saltpetre could be found in caves. In 1490, a German cave was explored in search of it, and the Italian Niccolo Machiavelli (1469–1527) noted that one place saltpetre could be obtained was in "desolate caves where raine can not come in" (Hill & Forti, 1997; Faust, 1949). Although mining of saltpetre from caves is best documented in North America, caves in many other parts of the world have also been mined or described as containing saltpetre. These caves or localities include Pulo di Molfetta, Italy; Grotte des Eyzies and Grotte des Espelunges, Departments of Dordogne and Hautes-Pyrenees, France, mined in 1793; Germany, near Hamburg; Minas Gerais and other areas of Brazil; Jamaica; Sri Lanka (formerly Ceylon) "where 22 nitriferous caverns are mentioned" (from Antisell, 1852, p.392); the island of Mindanao, Philippines; St John's in the Cape Verde Islands; and Guizhou Province of China.

The most widespread use of caves for saltpetre occurred in the United States, for about 125 years, beginning in the mid–1700s. Within this time the activity intensified during the wars of 1775–83, 1812–15, and 1861–65. Even though cave saltpetre was noted by a 1700 French Mississippi River expedition (Shaw, 1992), its presence in the American colonies was generally unknown until the limestone regions of western Virginia were settled. A few caves were probably mined there by 1740 (Faust, 1964).

The munition needs of the Continental forces, during the American Revolution, led to increased mining of frontier caves, although their overall contribution remained small. Most of the powder and its elements were imported, and possibly only 3 to 5% of the saltpetre used was derived from caves. Even so, beginning in 1775, Charles Lynch and others made 11 000 pounds (about 5000 kg) from a single southwestern Virginia cave (Jefferson, 1982 [1787]). After the war, Thomas Jefferson estimated that 50 caves were worked in the Greenbrier region of what is now West Virginia (Jefferson, 1982 [1787]). Although that, and other Virginia locales, remained productive, by the early 1800s