# TUFA DEPOSITS AND BIOLOGICAL ACTIVITY, RIVERSLEIGH, NORTHWESTERN QUEENSLAND

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## INTRODUCTION

Tufa is a consolidated to unlithified freshwater secondary limestone deposit that contains biological remains and forms in ambient- to near-ambient-temperature waters in karstic terrains. It owes its origin to solution weathering, where solutes produced by carbonation are reworked through the karst system and deposited in streams and lakes (Figure 1). Tufas form unique constructional landscapes, and are an important source of palaeoenvironmental information (Martín-Algarra *et al.*, in press). At Riversleigh, northwestern Queensland (Figure 2), tufas range in age from the Late Oligocene to actively developing landforms. Its tropical location makes it one of the few sites in northern Australia capable of preserving a record of Quaternary monsoon variability.

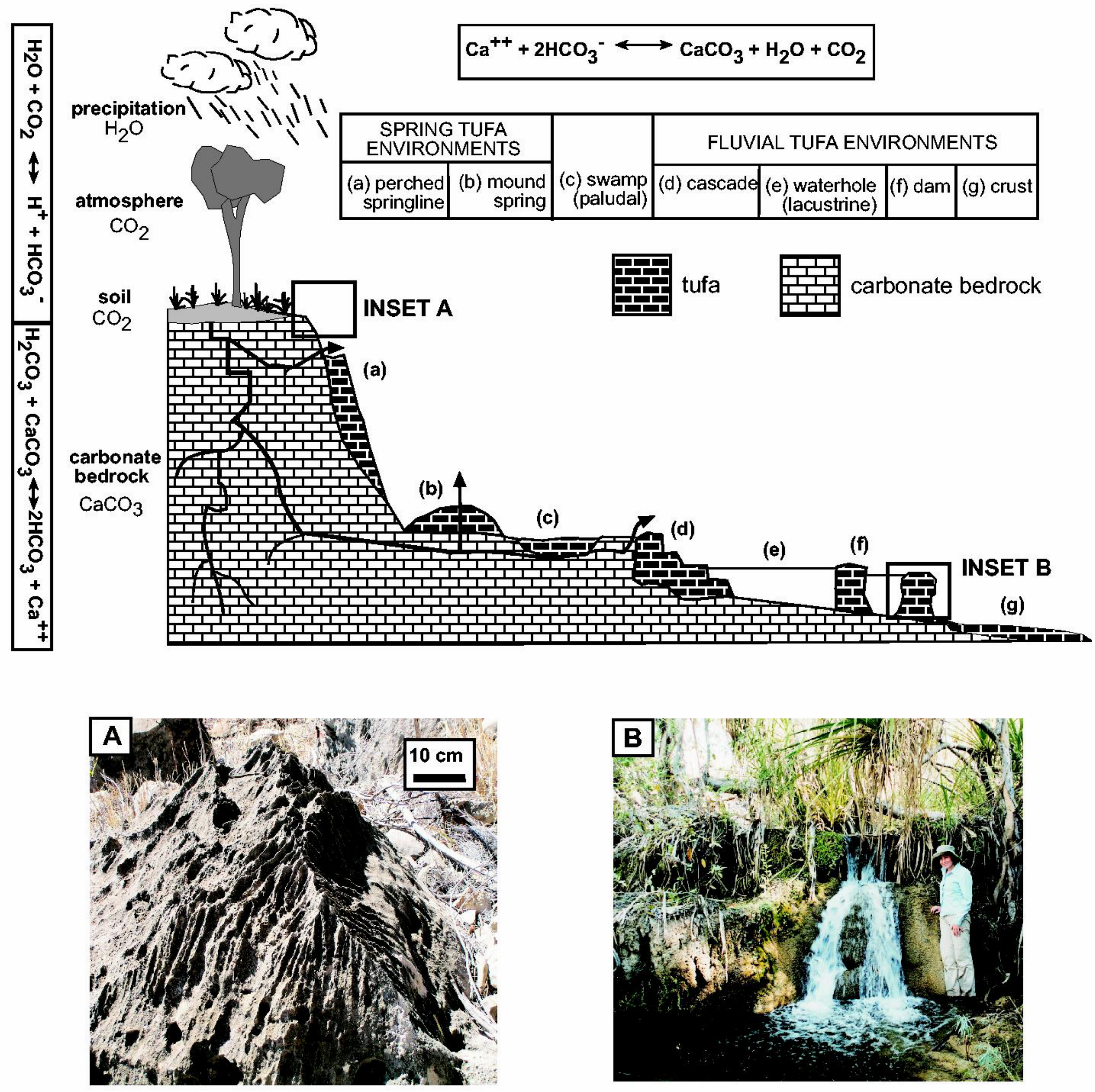


**Figure 1:** Tufa formation. Dissolved limestone bedrock (Inset A) is reprecipitated as tufa (Inset B), which may form in spring, swamp or fluvial environments. Tufa dams are the most common deposit type at Riversleigh (Inset B).

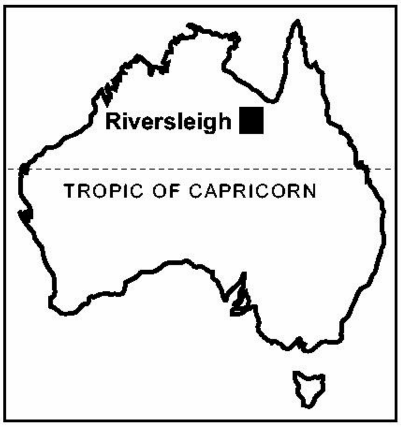


**Figure 2:** Location of Riversleigh, northwestern Queensland, Australia.

Evidence of a biological role in tufa formation is widespread at Riversleigh where the perennial rivers and a mean annual temperature around 25°C provide ideal conditions for aquatic insect larvae activity and vegetation growth. This evidence can be used to reconstruct palaeo-depositional conditions and regional palaeoenvironments. Biomediators such as aquatic insect larvae (Humphreys *et al*., 1995; Drysdale, 1999; Carthew *et al*., 2002) and plants (Pentecost & Whitton, 2000; Pedley, 2000) are important in tufa formation and geomorphic evolution. Their significance at Riversleigh is the focus of this study.

## AQUATIC INSECT LARVAE AND TUFAS

Larval midges (Diptera: Chironomidae), moths (Lepidoptera: Pyralidae), and caddis-flies (Trichoptera: Philopotomidae & Trichoptera: Hydropsychidae) are present in the Riversleigh tufas and accelerate its formation. The larvae of each of these insect families are associated with distinctive dwelling and feeding constructions that provide substrata for calcite deposition and subsequently become calcified and incorporated into the tufa deposits on which they were built (Figure 3A, B, C & D). This significantly increases the primary porosity and accumulation rate of the deposit. The constructions trap small phytoclasts (e.g. leaves and twigs) that are then incorporated into the tufa, which also enhances its porosity. Furthermore, larval constructions physically disrupt water flow and enhance the local turbulence, increasing carbon dioxide loss. This accelerates calcite precipitation and tufa formation. As the tufa deposit enlarges it further interrupts water flow, increasing turbulence, loss of carbon dioxide, and, subsequently, tufa accumulation.

The larval constructions are also invaluable for interpretation of palaeotufas (Drysdale *et al*., in press). Each type of larval tufa reliably represents a particular type of hydraulic environment within the stream because each larval family requires specific hydraulic conditions. Larval chironomids are common in shallow flowing water on dam fronts and crests where they build a small cylindrical dwelling tube composed mainly of salivary silk secretions. Pyralid larvae shelter in silken structures that may have the form of a marquee or they may be more tube-like. These larvae also burrow into soft tufas. The marquees are common in microphytic brain tufa (Figure 3E) that forms near dam waterfalls whereas tube-like shelters and burrows are typically present where water is gently flowing over tufa dams. Larval philopotomids construct a fixed silken retreat that is elongate and irregularly rounded. The philopotomid larval constructions are commonly found in association with larval chironomid tubes. Larval hydropsychids also construct a fixed tube-like retreat, which is made from sediments and organic particles harvested from their surroundings and bound together with silk. The hydropsychid larvae build elaborate silken nets at the retreat entrance to trap food particles; the nets also trap suspended calcite particles and act as nuclei for in situ precipitation of calcite. Larval hydropsychids dominate swiftly flowing areas of the stream at depths of up to 1.5 m.

## MICROPHYTES AND TUFAS

Microphytes, such as cyanobacteria, bacteria and algae (including diatoms), are present on all tufa surfaces at Riversleigh and are important to tufa development. Measurement of tufa deposition rates at Louie Creek, 50 km north of Riversleigh, showed that the highest rates are associated with microphytes (Drysdale and Gillieson, 1997). Microphytes provide an excellent framework for calcite deposition and they provide structure for the tufa deposit. The upright growth habit of many of the microphytes present at Riversleigh encourages the formation of tufa normal to the original substrate, which enhances its accumulation rate. Primary porosity provided by microphytes that eventually decay and leave voids within the rock increases the tufa volume. Microphytes may even actively cause calcite nucleation (Merz-Preiβ, 2000).

The formation of one particular Riversleigh tufa type, calcite rafts, is intimately associated with microphytes, especially diatoms. The rafts consist of thin (< 50 μm) aggregates of calcite crystals that form at the air-water interface. Diatoms typically inhabit the rafts, attaching themselves with a mucilaginous stalk. These stalks, and even the diatom frustules, are sites of calcite precipitation and eventually the diatoms become entombed by calcite. Voids are left within the rafts following decay of the biological material. Calcite rafts are restricted to pools of standing water, primarily upstream of tufa dams, and their presence in sedimentary sequences is a reliable indicator of these conditions.

In addition to calcite rafts, microphytic tufas formed throughout the full spectrum of depositional environments at Riversleigh provide reliable evidence of hydraulic conditions. For example, the microphytic brain tufa (Figure 3E) is restricted to locations where water is lapping or spraying the tufa surface, which occurs around channel banks and tufa dam fronts near waterfalls.

## MACROPHYTES AND TUFAS

Macrophytes play an important role in the development of tufas at Riversleigh by providing framework material for new deposit formation and growth of existing tufas, and through bioprotection. The macrophytes may be incorporated into tufa deposits while in life position or they may provide woody debris that is later integrated into a tufa deposit. New tufa deposits are commonly initiated following floods on piles of woody debris sourced from riparian and in-stream vegetation. The material in these deposits ranges in size from small leaves and twigs to large tree trunks and forms phytoclastic tufa when calcified (Figure 3F). This tufa type has a very high porosity and can result in deposits of considerable volume. Phytoclastic tufa containing large voids formed from the decay of tree trunks and branches is a reliable indicator of flood deposition. Smaller phytoclasts may also be regularly contributed to the stream, and subsequently to the tufas, by leaf and branch drop.

Calcified root mats formed around melaleuca trees (Figure 3G), and calcified clumps of pandanus tree trunks and prop roots (Figure 3H) dominate insitu macrophytic evidence in Riversleigh tufas. Both structures are usually inhabited by microphytes and provide a suitable substrate for tufa formation. In particular, melaleuca root mats assist in the formation of tufas by creating a stable substrate for calcite deposition and subsequent deposit growth. Larger tree roots extending into the stream also play a role in initiating tufa dam formation. Both root mats and larger in-stream roots are typically sites of intensive larval activity, which play an important role in tufa accumulation. This further adds to the value of macrophytes in tufa formation. The tree roots are also a common component of vegetation on tufa surfaces and appear to provide some protection from physical abrasion during floods.

## CONCLUSIONS

Biological material is an important component of the Riversleigh tufa system. Aquatic insect larval constructions, microphytes, and macrophytes all contribute to formation of the tufa. These different biota do not influence the tufas in isolation; instead there are close relationships between each of them. Biological material has a significant involvement in the initiation of new tufa deposits and also enhances their ongoing accumulation by providing a framework for deposit development, increasing local stream turbulence and carbon dioxide loss, increasing the primary porosity of the rock and acting as a bioprotection agent. The distinctive tufa structures associated with calcified biological matter provide reliable evidence of the full range of depositional conditions occurring at Riversleigh. This enables the palaeoenvironmental context of fossil tufa deposits to be interpreted and implications for regional palaeoclimates to be determined.

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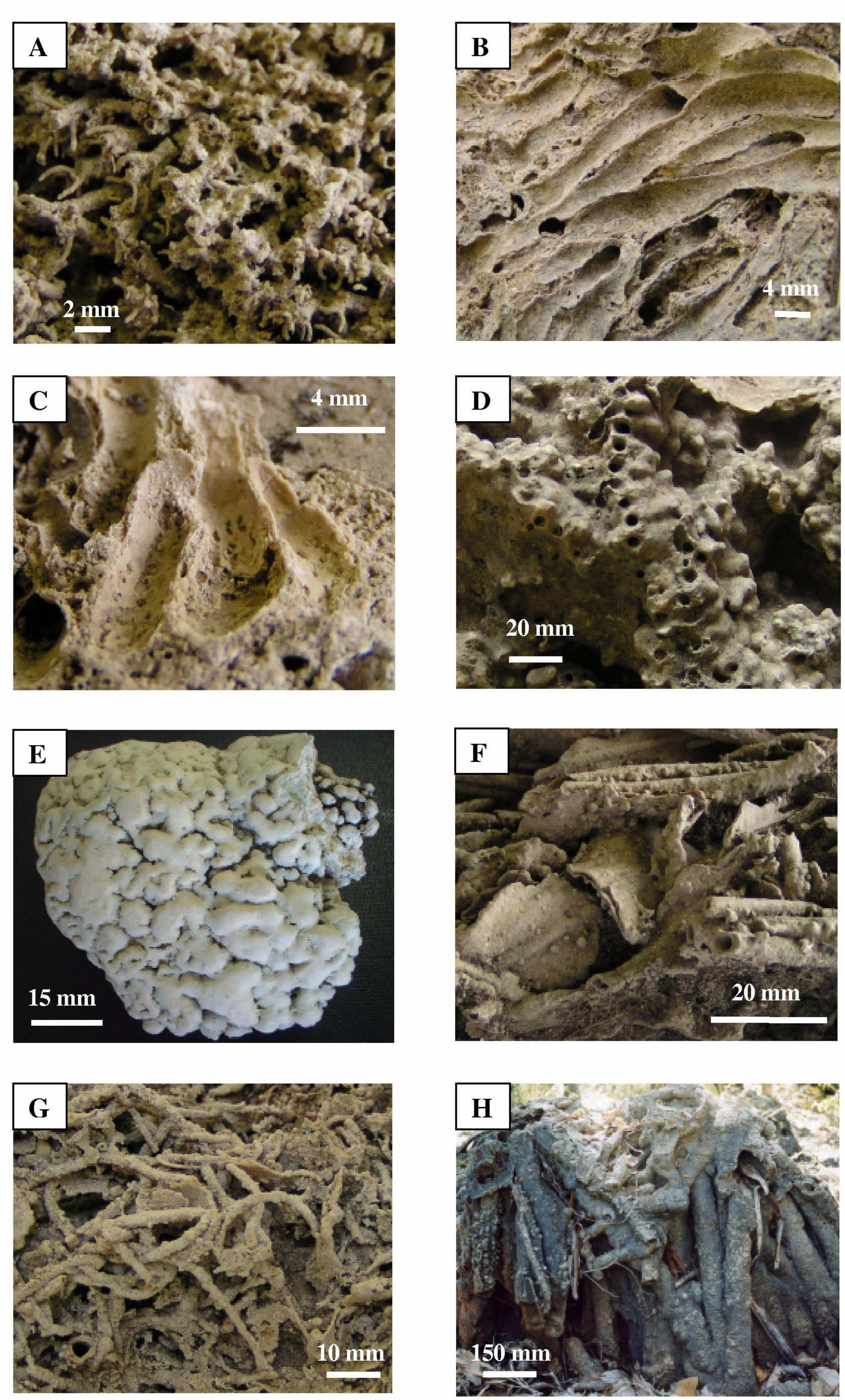
**Figure 3 (overleaf):** Biological components in tufas result in a great variety of deposit types. A: larval chironomid tufa consisting of calcified dwelling tubes built by chironomid larvae. B: larval pyralid tufa formed from silken retreats that have been incorporated into the tufa. C: larval philopotomids also construct silken retreats that become part of tufa deposits. Underside of a philopotomid tufa sample. D: larval hydropsychid tufa containing an array of retreats (seen as round holes). Silken nets once present at the end of each retreat have been lost through weathering. E: microphytic brain tufa formed from calcification of rounded microphyte colonies. F: phytoclastic tufa containing small twigs and leaves. G: macrophytic melaleuca root mat tufa. H: macrophytic pandanus root tufa formed from calcification of a clump of pandanus palms. Pandanus tree trunks are supported by prop roots, which dominate the two calcified pandanus clumps seen here.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