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Introduction

People have been interested in caves for a very long time. Our distant ancestors used them for shelter, as sources of water, and as places in which to conduct essential rituals. They adorned their walls with quite sophisticated artwork, at whose meaning we can only guess. Caves are featured in our mythology. They are used as places of worship in many cultures, and as places in which to store prized foodstuffs and wine throughout the world. Over the last 200 years, they have attracted scientists, artists, photographers, and recreational cavers. This book aims to provide a real understanding of how caves form, how they can inform our knowledge of past environments and climates, and the values – both environmental and cultural – that they provide to humanity.

1.1 Some Basic Propositions

This book is based around several propositions:

Firstly, that caves are a measure of the intensity and persistence of the karst (rock solution) process, and its interruption by other geomorphic processes. In limestone, as well as the continued efficiency of the solution process through time, cave development is affected by tectonic activity and sea-level change. If the solution process has operated efficiently through time, then extensive caves will be found in a limestone massif. If that process has been severely interrupted by glaciation, aridity, or sea-level change, then these processes will also be reflected in cave morphology. Thus, the extensive caves of the Nullarbor Plain in Australia formed as large phreatic tubes under increased rainfall intensity during the Pliocene. The progressive aridity of the Australian continent since that time changed the process regime, so that collapse aided by salt wedging has replaced solution as the dominant process. Deepening of the caves has been enhanced by sea-level lowering in the Pleistocene, and today there are extensive flooded tunnels under the arid plain that have been explored by divers for up to 6 km. All these processes are reflected in cave morphology, and we now have the prospect of dating these events by analysing the calcite, gypsum, and halite formations found in the caves. In regions where climatic change has been minimal, such as the ever-wet tropics, variation in cave development may reflect regional uplift patterns alone. In the karst towers of China, caves are found at various levels – right up to the summits – having been abandoned by their streams as the valleys have incised into rapidly rising

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terrain on the margins of the Tibetan plateau. A more extreme example is provided by the alpine caves of the Canadian Rockies, which hang hundreds of metres above the valley floors and have been abandoned as the cordillera has risen over geologic time. Finally, the fluctuations in sea level during the Quaternary have produced cave development well below present mean sea level, such as the Blue Holes of the Bahamas.

Secondly, that caves are a product of both surface and underground geomorphic processes. Solutes and sediments from the non-karst catchment of a cave combine with karstic solutes and sediments; these may be homogenised and lose their identity, or may be deposited in discrete units, such as flood deposits. This is somewhat akin to the way in which the products of catchment processes are integrated within a lake basin and combine with processes in the water column and on the lake bottom to produce distinctive physical, chemical, and biological properties. Quaternary science can be applied to caves as well as lakes, and the caves provide us with an array of information about landscape processes on timescales, ranging from yesterday to millions of years.

Thirdly, that once these products of surface and underground processes enter the cave system, they are likely to be preserved with minimal alteration for thousands, perhaps even millions of years. In the near-constant temperature and humidity of the cave, weathering processes are reduced in intensity compared with the surface environment. The normal deepening of valleys leads to incision within the cave, leaving deposits in abandoned higher-level passages. These passages are out of the reach of all but the largest floods. The unctuous clays common in caves have a great deal of resistance to erosion: so, once deposited, it is very difficult to erode cave sediments. Caves can be regarded as natural museums in which evidence of past climate, past geomorphic processes, past vegetation, past animals, and past people will be found by those who are persistent and know how to read the pages of earth history displayed before them. Caves have become increasingly important as sources of proxy records of the changes in atmospheric conditions over long time periods – tens to hundreds of thousands of years – and today rival ice cores in the quality of the information that can be gained. Isotopic analyses coupled with radiometric dating techniques can provide records of annual variation in temperature and other environmental parameters, while cryptotephra and pollen that reflect unique environmental conditions can be extracted from individual growth layers in a stalagmite.

Fourthly, the unusual ecosystems in caves have attracted the interest of biologists and ecologists for over a hundred years. Deprivation of light and other stimuli produce physiological adaptations to cave living, often producing somewhat bizarre-looking animals that have thus attracted attention despite their cryptic habits. Cave biota are totally dependent on periodic inputs of nutrients, usually swept in by floods. These organisms are also severely disadvantaged by quite minor disturbances. Thus, they have low resilience in the face of a change to the cave ecosystem. The spectrum of impacts on caves has serious consequences for their biology and ecology, and adequately conserving cave biota is a major challenge for protected area management.

Finally, caves are contested spaces. They are subject to the demands of various forms of recreation, both commercial and non-commercial; the exploitation of cave waters and the very rocks in which they have formed; extraction of gas and oil in karstic terrains; the alteration of the surface soils and vegetation for agriculture and other extensive land uses; and

the creation of transport networks to facilitate regional economic development. Cave and karst management is dependent on the implementation of sensible public policy and legislation, with community involvement essential to maintain the values of the caves and karst.

1.2 Now the Details…

This book is organised into four sections. In the first section, contemporary processes of cave formation are examined. In Chapter 2, some definitions of caves and their host karst terrains are outlined, and consideration is given to caves as geomorphic and biological systems. Caves can be regarded as three-dimensional networks in which individual links may become abandoned or may develop through time. The nature of a cave at any time is a function of inheritance of previous states and the contemporary climatic and tectonic setting. The state of the hydrological network (Chapter 3) may be fully phreatic, fully vadose, or a combination, depending on the position of the water table in a cave. The nature of individual linkages (passages) may change, depending on the frequency of floods and their exploitation of existing or potential conduits in the rock. In caves with a temporary or permanent air space, the nature of the cave climate will determine the kind of speleothem deposits that form (calcite, ice, gypsum, and halite). There is also a feedback between climate and the karst solution process.

The roles of the kinetics of bedrock solution, and of rock architecture and cave collapse in the evolution of the position of the subterranean water table and in cavern enlargement, are outlined in Chapter 4. The effects of brine and gypsum on cave formation are regionally important. The formation of weathering caves and pseudokarst caves is another aspect of the subject. The final form of a cave owes much to both the purity of the limestone and the network of fissures that dissect the rock (Chapter 5). Following a brief treatment of limestone lithology and structural variation, examples of cave passage shapes in different limestone settings are given. Geological history plays a key role and may override other factors. Some of the largest and deepest caves are formed by combinations of these factors. The deep circulation of water in limestone leads to the development of flow networks, which are the precursors of the caves we can enter and map now. The legacy of this mode of origin is a suite of erosional forms in cave passages – bellholes, cupolas, and spongework – which can provide useful diagnostics as to the long-term history of the cave system.

The second section of the book deals with past processes and their products. The diversity of cave formations has long fascinated people. Chapter 6 considers the interior deposits of caves, principally the calcite stalactites and stalagmites familiar to most visitors and known to karst scientists as speleothems. Thus, the basic mechanisms of calcite deposition are described, including the roles of trace elements and cave biota in providing shape and color variation. Effects of tectonics and of hydrologic change on cave formations are outlined. Gypsum and halite speleothems are also briefly reviewed. In the tropics, biogenic deposits, such as guano, are dominant and have economic significance.

Caves can be seen as underground gorges and floodplains in which sedimentation proceeds in modes analogous to those of surface fluvial systems (Chapter 7). Cave sediments may be of external or internal origin; various types and their properties will

be described (glacial, fluvial, aeolian, and biogenic). The deposition and alteration of entrance sediments in caves have relevance for our understanding of cave palaeontology and archaeology. Relationships exist between cave sediment structures and depositional energy, and interactions between cave sedimentation and hydrology are thus relevant to understanding past and present processes.

In the last two decades, a bewildering array of dating techniques have become available to the cave scientist, and these are briefly reviewed in Chapter 8. The most important of these is uranium series dating, with several variant forms. This technique will be outlined in detail, with examples from Europe, North America, and Australasia. Other techniques, such as palaeomagnetism and radiocarbon, will also be considered. These dating techniques have radically altered scientific thought about caves and wider landscape evolution. Calcite speleothems can be used as paleothermometers through the technique of oxygen isotope analysis. Carbon isotope analysis on speleothems has great potential for determining changes in the surface vegetation above the cave. This extraction of proxy records from cave interior deposits is the fastest developing field in karst research and is reviewed in Chapter 9.

In the third section of this book, the use of caves by various organisms, present and past, is considered. Physiological and evolutionary adaptations to cave living occur in many phyla of the animal kingdom, and also in both flowering plants and fungi. The basic characteristics of the cave ecosystem and its constituent trophic levels are described in Chapter 10. This relates back to the basic concepts of mass and energy flow in the karst system. The role of external energy sources is critical for cave life. Cave biota are dependent on periodic inputs of nutrients, usually swept in by floods. They are also severely disadvantaged by quite minor disturbances. Thus, they have low resilience in the face of a change to the cave ecosystem.

Caves have long been of importance to people – for shelter, water supply, and food, and as places of worship. Chapter 11 reviews our knowledge of cave archaeology. This exciting field has regained importance in recent years with major discoveries of hominid sites in Southern Africa and Central Asia. Much has been learnt about the processes of alteration of cave sediments and the effects on archaeological and palaeontological material. As well, re-interpretation and re-excavation of cave sites in Europe have led to new insights into the lifeways and rituals of our ancestors and our near-relatives, such as the Neanderthal people. Recent discoveries of cave art, improved dating, and new interpretations have changed our perceptions of prehistoric people and their rituals.

Recent uses of caves (Chapter 12) include the mining of cave formations and guano, for hydroelectricity, for storing gourmet foods, as refuges in times of war, and as sanatoria. Around the world, increasing cave tourism presents problems owing to the irreversible degradation of cave ecosystems and alteration of cave microclimates. The addition of energy sources (heat, lint, and dead skin cells) alters the trophic status of caverns. For appropriate use and to avoid degradation, caves should be classified in terms of their limits to acceptable change for the proposed use (recreation, resource extraction). This classification must be dynamic to allow for seasonal changes in cave function and use. Cave lighting and pathways must be designed to minimise the effects on cave microclimates and biota. Subtlety and effective interpretation are the key tools of cave managers. Only through public education can the aims of ecologically based cave management be achieved. There is now a global network of cave scientists considering these problems.

The final section of the book reviews our changing approaches to cave management (Chapter 13) and catchment management on karst terrains (Chapter 14). The rapid development of cave mapping and photography techniques have greatly enhanced our view of the world of caves. The use of 3D scanning has produced stunning visual material that has aesthetic appeal, aids cave exploration, and enhances our understanding of the development of the cave. These techniques are reviewed in Chapter 15.