Proc. Univ. Bristol Spelaeol. Soc., 1988, **18** (2), 330–335

REVIEWS

HILL, Carol A. *Geology of the Carlsbad Cavern and other caves in the Guadalupe Mountains, New Mexico and Texas.* Socorro. 1987. 150pp. (Bull. 117 New Mexico Bureau of Mines & Mineral Resources). Price $15, plus $5 postage.
(reviewed by M. M. Sweeting)

The Carlsbad Caverns in the Guadalupe Mountains of New Mexico are among the finest in the world, but are also unlike other great cave systems. In Carlsbad the rooms are huge; the Big Room in Carlsbad is for instance 600 m long, 330 m wide, and 87 m high at its tallest point. But the passages themselves are short and terminate abruptly. The caves are unrelated to the surface relief of the Guadalupe Mountains and are particularly famous for their great variety of carbonate and gypsum deposits. Carol Hill is to be congratulated on this *Bulletin* produced by the New Mexico Bureau of Mines and Mineral Resources. The work brings into focus the new views on the origin of Carlsbad Caverns and their associated deposits and covers in some measure every aspect of the caves. It is divided into two major parts—part I: Speleogenesis—the caves and their deposits; Part II: Mineralogy of the cave deposits. In her introduction Dr Hill says that the memoir is intended for a variety of readers, including not only the geologist but the ordinary caver. However, the scholarliness of the writing and of the diagrams does not make for quick or easy reading and a large amount of scientific background is necessary to get the best out of the text. That said, the *Bulletin* is one of the finest works on a group of related caves that has ever been written. The author shows how the origin of the Guadalupe caves is related to the oil and gas fields of the neighbouring Delaware Basin and gives the evidence for the theory that the exceptionally large caves were dissolved out of the limestones mainly by sulphuric acid and less by carbonic acid. This conclusion is based partly on the nature of the sulphur-isotope values and on the radiometric dating of deposits.

The development of the text is logical, dealing first with the regional setting and the stratigraphy of the Permian limestones in which the caves occur. Not a great deal of discussion is given to the geomorphology and hydrology of the caves, but it is sufficient background for the text which follows. The main emphasis of the whole work is on the nature, arrangement and dating of the many different kinds of deposits in the Guadalupe caves, and their bearing upon the cave origin. There is an interesting section on the meteorology of the caves—air flow, temperature, carbon dioxide content, radon levels—all put into the context, in particular, of the deposits.

Nearly 30 pages are given to the detailed description of the cave deposits and the stratigraphy. This is one of the most valuable sections and discusses the nature of the cave breccias, sands, silts and muds as well as the speleothems. The distribution of gypsum deposits, of clays such as montmorillonite and endellite, and the occurrence of native sulphur are all considered. One of the most interesting speleothem types in Carlsbad is the nodular shaped coralloid (cave popcorn), which decorates much of the Big Room; the so-called popcorn lines are associated with seepage and thin films of flowing water emanating from the porous limestones.

A vast amount of analytical work has been done on all these cave deposits. The sulphur isotopes of the native sulphur, gypsum and pyrite, have been examined. For the carbonate deposits carbon and oxygen isotope methods have been employed and values obtained for the spar infillings in the

limestones, for the speleothems and cave rafts and for the carbonate bed rock. The sulphur-isotope values of the cave gypsum and sulphur form the primary evidence on which the sulphuric acid model of speleogenesis is based; the gypsum and sulphur deposits in the Guadalupe caves are significantly enriched in the light isotope of sulphur (^{32}S). The sulphur-isotope values of the cave gypsum and sulphur compare closely with the values for the H_2S gas liberated from oil and gas reactions in the neighbouring Delaware Basin. Only biologically produced reduction and oxidation reactions could have produced the large isotopic fractionations that characterize the cave deposits.

Laboratories in N. America and Europe have helped to date the carbon speleothems, clays, silts and bone. Uranium-series dating has been the most widely used technique but other methods, including ^{14}C, electron spin resonance, palaeomagnetism and potassium-argon (for the montmorillonite clays) have also been used. Forty-four dated samples are given in table 24, which represents not only a great deal of laboratory work but also of organization.

There are chemical analyses of the rocks and of the cave waters. An experiment to show the effects of sulphuric acid dissolution upon the limestones illustrates the relationships actually seen in the caves between gypsum and silt deposits.

The discussion of the sequence of the events in the development of the Guadalupe caves follows from the data itemized in the first 73 pages. A clear step by step account of the origin of the caves is given, based on the present known facts. I found this one of the most interesting parts of the *Bulletin* to read and the many facts that are given earlier begin to be put into perspective. After reading this Section, one is minded to turn back to look at the primary evidence again. The general conclusion as to the age and date of the caves is that the less than 1,000,000 year dates on the travertines, spar speleothems, cave rafts and the silts confirm that the caves date from the present erosion cycle (a different conclusion from that advanced by Bretz). Indications suggest that the Guadalupe Mountains were uplifted in the Plio-Pleistocene and that the oil and gas migration up dip (which gave rise to the main cave-forming episode) into Guadalupe limestones took place at the same time. The Big Room in Carlsbad is about 800,000 years old; caves at higher levels in the Guadalupes are probably older.

The final part of Section I discusses the regional geological importance of the Guadalupe caves and their implications for the evolution of other intracratonic carbonate basins, particularly those with ore deposits along their margins.

The second part of the *Bulletin* deals with the mineralogy of the speleothem deposits, both carbonate and sulphate. Carlsbad Cavern is especially famous for the beauty and intensity of its speleothems—the term speleothem being used by Hill to denote all secondary mineral deposits, stalactites and stalagmites being two of the most common types. Part II attempts to answer questions such as why are the Guadalupe speleothems so large; why are there so many types; why is there so much popcorn-like decoration in the caves; and why is there such an abundance of carbonate, but relatively few sulphate speleothems. Furthermore, since the present climate of the Carlsbad area is at present semi-arid and with an average annual rainfall of 356 mm per year, most of the present speleothems are dry and inactive.

Both the loss of CO_2 and the evaporation of incoming water is a major influence on carbonate precipitation. Thrailkill has calculated that in one area of Carlsbad as much as 40% of the calcite deposition was caused by

evaporation. There is a long section on the nodular speleothems, particularly the popcorn-shaped coralloids. 95% of all Guadalupe coralloids are subaerial and have been formed either by water seeping through the wall rock or by thin films of condensation water; they can also be formed by splash from overhead dripping or splash from a pool. The last two mechanisms are active today but both the former were active in the past. J. M. Queen believes that the popcorn growth is related to earlier, wetter climate phases in the Pleistocene but Hill points out that the climatic factor is only one of many influencing popcorn evolution.

The stalagmites in the Guadalupe Caves are some of the biggest in the world; many are over 20 m high and some over 30 m. They resemble those found in Mediterranean Europe—Postojna in Yugoslavia and caves in Southern France; we still know very little about the development of these spectacular features.

Compared with the carbonate minerals, sulphate minerals are much more rare in the caves though many types of sulphate speleothems do occur. From the isotope study the most likely source of the sulphate in the sulphate speleothems is pyrite disseminated in the back reef limestones (particularly the Yates Formation). Because the sulphate minerals have high a solubility they are normally found in the dry cave passages. Epsomite and mirabilite are both very soluble and deliquescent and have a rapid growth and decline—appearing and disappearing in only a few weeks according to the seasonal humidity of the cave passages. Gypsum crusts and gypsum flowers are among the other sulphate mineral deposits.

Uranium dates on the oldest speleothems in Carlsbad are consistently older than 350,000 years bp. Dates on the cave popcorn range from 33,000 to more than 350,000 years bp. Cave rafts dated at 50,000 years bp may possibly represent the last fluctuation of base level in Carlsbad and the last significant speleogenetic event.

Hill concludes that the Guadalupe speleothems are large because of the large chambers created by the sulphuric acid mode of dissolution and because there has been sufficient time for the speleothems to grow large; the wet climatic episodes in the Pleistocene period provided the necessary moisture. The profuseness of the speleothems is related to the ease with which groundwater condensed in the underground chambers and the fact that the reef rock is very porous. The variety of speleothems has been caused by many factors—permeability, jointing and the differences in the various limestones, the presence of dolomite, and the importance of evaporation as well as CO_2 loss. Popcorn type speleothems dominate because of the porous and massive nature of the Capitan reef limestones and to the condensation-corrosion process with low humidity and high rates of evaporation in the caves. Most of the travertines were formed in the Pleistocene when the climate was much more moist than today and the great mass of speleothem deposits date from the humid stages earlier in the Pleistocene.

No effort has been spared in the production of this *Bulletin*, yet at the same time there is no waste of words or loose argument. There are over 130 black and white figures and 31 tables. There is also a section of 16 coloured plates illustrating the many different kinds of deposits. There are also 9 sheets of sections and maps in a separate pocket. The reference list is very complete and there is a useful index—something which many memoirs of this type often ignore.

Anyone reading this review might feel that the last word has been said on the Guadalupe caves and Carlsbad in particular. But Carol Hill's work does not leave the reader with this impression; she is only too aware of the further

work yet to be done and how there is much more to do on the geomorphology and hydrology of the caves, in particular.

It is to her credit that she is able to show the way for our further understanding of this fascinating cave area. Both she and the New Mexico Bureau of Mines and Mineral Resources are to be thanked for such a readable and wonderful account of one of the world's greatest cave areas.

BALAAM, N. D., LEVITAN, B., and STRAKER, V. (eds.) *Studies in palaeoeconomy and environment in South West England.* Oxford, B.A.R. British Series 181, 1987. vii, 264pp. ISBN 0 86054 501 6. Price £18, post free.

(reviewed by K. Crabtree)

As the editors record, the original papers were presented at a symposium held in Bristol on 9th February 1985. This in turn was a follow-up of a meeting held four years previously and organized by Martin Bell and Ian Simmons. The brief of the original symposium was to look at the state of environmental archaeology as applied to South-West England and, although that symposium was not published, we have an excellent review of the state of knowledge in the south-west as a result of the HBMC Environmental Archaeology Regional Report edited by H. Keeley (1984) in which Martin Bell gives a report up until 1983. The present volume adds to and updates that review of Bell, and was organized by the incumbents of HBMC contracts in the University (V. Straker) and City Museum (B. Levitan) and a representative of the Central Excavation Unit (N. Balaam).

Some 25 contributors authored the 11 papers, with a prologue by Professor Charles Thomas in which he refers to the U.B.S.S. as 'that splendid body'. The papers have been fully revised since the original meeting and include material (especially radiocarbon dates) not available in February 1985. The volume is produced in the usual B.A.R. format, A4 camera ready copy, but as it was all done on a single word processor, it is all to a common high standard and text font.

As one might expect from such a volume, the papers vary considerably in length and approach. The volume is dominated by a hundred page paper based on the 1983/4 archaeological and palaeoenvironmental survey of the Westward Ho! site. This is a long-needed study as erosion is removing much of the evidence of the Mesolithic midden site on the foreshore and the original work by Churchill (1965) was in need of more detail and updating. This paper is multi-authored with specialist reports by various contributors as well as a synthesis provided by the principal authors led by N. D. Balaam. By careful review of the collections and reports on the site over the years, backed up by the new field evidence, the authors conclude that there are two occupation periods, the well-known Mesolithic one and a Romano-British one, both with peat and debris material. This discovery helps to remove some of the anomalies found in the records of earlier workers. The environmental information points to the Mesolithic midden being within dense fen carr with oaks and not in the inter-tidal zone as suggested by Churchill. The extent of the deposits is now much less than when first recorded in the nineteenth century and, as the site is only exposed for short periods usually in the spring at low tide, thorough excavation is almost impossible. Several questions still remain. The origin of the 'blue clay' is a major enigma. If marine or estuarine and pre 7,000 bp then it is too high