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# CAVERN DEVELOPMENT IN THE MALMANI DOLOMITE, TRANSVAAL: THE WOLKBERG CAVE

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A dissertation submitted to the Faculty of Science, University of the Witwatersrand, Johannesburg, for the degree of Master of Science.

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This dissertation has not previously been submitted as a dissertation or thesis for any other degree at any other University.

Johannesburg, 1975

## ABSTRACT

The Wolkberg Cave has been examined in order to derive its sequence of development and to assess the validity of general theories of speleogenesis. These aims have been achieved by means of a detailed examination of features preserved within the cave, and the assessment of the implications of various models in the light of this information. It has been concluded that the Wolkberg Cave, a cave of great antiquity, has had a structurally controlled, phreatic origin. Its modification since exposure in the vadose zone has been complex, and a sequence has been derived to describe this development.

A study of available speleogenetic theories has indicated that no one theory adequately describes the development of the Wolkberg Cave. Therefore, a model has been derived to account for its genesis, and it has been suggested that this model be further applied to other Transvaal caves, although caution is necessary.

## PREFACE

The proliferation of speleogenetic studies in karst literature has resulted in little agreement regarding the mode of development of caves. A number of general theories have been proposed (Davis, 1930; Bretz, 1942; Ford, 1971), but the controversy continues. Speleogenetic studies in South Africa have done little to resolve the problem since the general theories only partially explain the development of caves, particularly in the Transvaal (Wilkinson, 1973). Wilkinson (1973) has further shown that a model proposed to account for cavernous development in the Transvaal (Brink and Partridge, 1965) is inadequate. The conflict may be resolved by further comparison of theory and the evidence preserved within caves.

In the present study, the Wolkberg Cave, one of the largest in the Transvaal, is examined in order to assess the validity of available speleogenetic theories. Specifically, this study aims to establish a model of speleogenesis which will account for the development of caves in the Malmani Dolomite. This aim is achieved by means of a detailed study of the Wolkberg Cave, the establishment of its sequence of development and the examination of applicable models in relation to the evidence preserved within the cave.

The dissertation presents the results of the study in four parts, the first being a statement of aims, a review of the

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relevant literature and a brief discussion of the physical setting of the cave. The second part presents the evidence preserved within the cave, and this information is synthesized in Part Three to develop a sequential history for the cave. The third part further contains a discussion of the validity of available models, the derivation of a more suitable model and a discussion of its limitations. Finally, the conclusions reached in this study are presented in Part Four.

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# PART ONE: INTRODUCTION

# CHAPTER ONE

## INTRODUCTION

Karst landforms develop by the action of solution processes, and are commonly associated with limestones and dolomites. Dolomites are generally considered to be less susceptible to karst development than limestones due to the mechanisms of solution of the dolomite molecule (Douglas, 1965; Rauch and White, 1970), and are recorded as exhibiting fewer karst forms than are typically associated with limestone areas (Gams, 1969; Pluhar and Ford, 1970; Sweeting and Sweeting, 1972).

Exposures of dolomite in South Africa occur mainly in the Transvaal and the Northern Cape and assemblages of karst features may be expected from these regions. Published research has primarily considered the development of caves and the origin of fossil bearing breccias in the caves (King, 1951; Brink and Partridge, 1965; Partridge, 1968). Surface forms in the North-Eastern Transvaal have been examined by Marker (1971), who concluded that the landscape is largely relict, and that the surface karst assemblage is anomalous since the density of forms is low in comparison to limestone karsts.

Some attempts have been made to examine the genesis of caves in the Transvaal. Brink and Partridge (1965) and Partridge (1968) have proposed a model for the development of caves at different

levels controlled by the relation of the water table to the land surface. It was suggested that caves will develop slightly below the water table during prolonged periods of planation, and that caves may be related to erosion surfaces. This model was examined by Marker and Moon (1969), who discussed a large sample of the caves in the Transvaal, and found that they were all horizontal rectilinear networks of passages, implying that they have developed slightly below the water table. It was further shown that these caves have formed in distinct bands below specific planation surfaces. However, Moon (1972) showed that caves developed in the Sterkfontein area displayed no relation to particular periods of stillstand of the water table. The Sterkfontein cave system was examined by Wilkinson (1973), who found that the general models of cave development could be adapted to that system, and that it preserves evidence of climatic oscillations.

Since the results of previous workers are conflicting, confusion exists on the mode of development of caves in the Transvaal. The aim of the present study is to examine the Wolkberg Cave, one of the largest in the Transvaal, to attempt to establish its origin, and thereby further test the relevant theories of development in this context. This aim will be achieved by a detailed study of the cave, the establishment of its history and the examination of the applicable models in relation to the evidence preserved within that cave.

A review of the relevant literature will now be presented to provide the theoretical background for this study.

# CHAPTER TWO

## SPELEOGENETIC THEORIES

Studies of speleogenesis in carbonate rocks have concentrated on the mechanisms which cause the development of cavities, and on the causes of localisation of these mechanisms at specific sites within the rock. The primary mechanism of development has been recognised as the corrosive action of ground water, but no generalisation may be made regarding the localisation of this action. Studies concerned with site selection have concentrated first on the general zone of development in relation to the piezometric surface, and secondly on the concentration of corrosive processes at specific sites within that zone. Following the work of Davis (1930) and Bretz (1942), it has been recognised that many caves have developed within the phreatic zone, and that caves having a vadose origin are rare.

The major theories of cavern genesis will now be evaluated to determine those most appropriate for application to the Wolkberg Cave. This will be facilitated by a consideration of the factors affecting the selection of corrosion sites, and consideration of the evidence from South African case studies.

### LOCUS OF DEVELOPMENT

Three major groups of theory may be recognised, dealing with

phreatic, water table[1] and vadose modes respectively.

Phreatic Modes

The occurrence of cavern development at random depth below the water table has been proposed by Davis (1930), who assumed that a deep circulation of ground water along curved flow paths which are related to the hydrostatic head and the location of resurgences will occur during most of a surface erosion cycle. As limestones are dominantly impervious, the flow will be concentrated along joint and bedding planes approximating curved paths, and random solution along these paths will result in a complex three dimensional network of joint and bedding plane controlled passages. Davis indicated that the size of galleries will increase away from the divides due to increasing water volumes, and that the process of development should occur throughout the complete erosion cycle, although the effects of solution might be enhanced during the later stages. Rejuvenation of the land surface will cause a lowering of the water table and thus drainage of the caverns, and permit a subsequent deposition of speleothems to occur in the vadose zone.

These proposals were strongly supported by Bretz (1942), who modified the theory to include an intermediate clay fill stage

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1. Water table development is here used to denote development at or slightly below the piezometric surface.

during the period of almost completely static water towards the close of an erosion cycle. Furthermore, Bretz enumerated the distinctive features of both phreatic and vadose conditions, and he concluded that most of the caverns he observed were of phreatic origin, although later vadose modification may have occurred. More recent studies have indicated that much of the known cave development has occurred in the phreatic zone, although a large proportion has been close to the piezometric surface (Halliday, 1957; Bretz, 1960; Thrailkill, 1960; White, 1960; Ford, 1971; Marker, 1974).

Water table modes

It has been suggested that as limestones do not constitute a porous medium, little deep circulation of ground water will occur, the bulk of the circulation being concentrated close to the piezometric surface (Swinnerton, 1932). Thus, major cavern development will be concentrated in this zone, being instigated when a hydrostatic head sufficient to promote ground water movement is developed by the incision of surface streams. Furthermore, development will propagate down the gradient of the piezometric surface from the input end of the system, as it is at this point that the water would be most aggressive. The latter contention has been opposed by Rhoades and Sinacori (1941) who agreed, however, that the locus of development should be near to the piezometric surface. They indicated that in the early stages

of the development of ground water circulation in limestone, the flow will approximate Davis' deep circulation, but with the ·ment of openings by solution, the gradient of the piezometric · will flatten, concentrating most of the flow, and therefore solution, in the higher levels of the phreatic zone. The major flow concentration will be at the resurgence, and cavern development will therefore be initiated at this point, propagating headwards.

The occurrence of speleogenesis close to the surface of the piezometric zone has further been predicted from a consideration of both hydrological and chemical influences (Davies, 1960; Thrailkill, 1968). Similarly, a large number of recent studies of individual caves have indicated that many caves have formed close to the surface of the phreatic zone.

Vadose modes

A vadose mode of speleogenesis, attributing the process to the influence of both solution and the corrasional effects of a free air surface stream, has been proposed by Piper (1932), Gardner (1935) and Malott (1937). Bretz (1942), supported by many recent studies, has indicated that a vadose origin is rare, but that such a cave will be characterized by the features of a normal sub-aerial stream, with emphasis on the form of the channel in both long and cross section.

The features affecting the concentration of solution within

the rock will now be examined to enable the evaluation of the development of cavities at specific sites.

## FACTORS AFFECTING THE SITE OF SOLUTION

The primary factors affecting the sites of solution in carbonate rocks are considered to be the rock structure, lithology, climate and hydrological conditions (Sweeting, 1972). Other controlling factors are recognised, but their effects are considered to be minor. The influence of any specific factor is often difficult to assess since the factors may act indirectly or be inter-related, and, furthermore, more than one factor is generally involved in the selection of sites.

### Structure

The influence of structure is related to the provision of partings or planes of weakness in the rock which will allow the ready ingress and passage of water. Thus, joints are frequently cited as influencing the orientation of cave passages (Deike, 1969; Weaver, 1973), or as controlling the form of passages in detail. Faults are also recorded as controlling site and development of caves since, although rare in relation to joints, they provide major partings for the transmission of water, and a number of cave systems have significant sections ascribed to the influence of faults (Sweeting, 1960; Ford, 1964; Glover, 1974). The influence of faults may be enhanced by the occurrence of mineralisation

during or post faulting, particularly if the mineral developed is more soluble than the surrounding rock, as has been noted by Waltham (1971).

Folded rocks are thought to influence development to a lesser extent although the locating effects of tension joints in the crests of anticlines have been noted by Waltham (1971). In more general terms, Ford (1971), as will be described below, has indicated that the rock dip and hydrological conditions may exert a critical control on the form of the cave developed.

Lithology

Lithological control of the sites of solution may be effected in three ways, due to the influence of impermeable strata, bedding planes or variations in the chemical composition of beds. Impermeable strata restrict and direct the passage of water through the rock, frequently defining the location of cave passages in detail (Sweeting, 1972; Waltham, 1972). The primary influence is the restriction of downwards motion of water, initiating cavern development along the bed, and controlling the passage form in cross-section as erosion breaches the impermeable bed (Waltham, 1974). Bedding planes, being marked discontinuities in the rock, readily direct water, resulting in the localisation of solution.

Chemical variation between beds results in variations in the solubility of different beds, frequently causing the preferential

solution of beds. Glennie (1950) has shown that Ogof Ffynnon Ddu has developed predominantly in one bed, whilst Waltham (1970) has ascribed the development of groups of caves at different altitudes in the Ingleborough district to the influence of hydrology and lithological variation. Furthermore, Jennings and Sweeting (1963) have shown that the form of caves developed in reef limestones is different from that developed in other limestones.

Climate

The effects of climatic variation are closely linked to variations in temperature and both the amount and distribution of precipitation, since these factors will, either directly or indirectly, influence the amount of the $CO_3^=$ ion which may be dissolved by percolating water. The major influence is indirect, since the amount of $CO_3^=$ which may potentially be dissolved is dependent upon the amount of $CO_2$ present in the soil, and this, in turn, is controlled by the amount and type of vegetation present. The percentage of $CO_2$ present in the soil is therefore dependent on seasonal and annual variations in the vegetation cover, which are strongly influenced by temperature and precipitation variations.

Hydrology

The hydrological control of sites of solution is indirectly related to a number of other factors, in particular, structure, since the rock structure provides paths within which water flow

is constrained. Both Rhoades and Sinacori (1941) and Thrailkill (1968) have indicated the theoretical influence of hydrological conditions, and Ford (1971) has indicated briefly the effects of hydrology on cave development in the Mendip Hills, but little direct evidence of these effects is available.

It is now necessary to consider those theories of cavern genesis which are directly applicable to the Wolkberg Cave, namely, theories describing speleogenesis in tilted strata, and the theories proposed to account for cavern development in the Malmani Dolomite. Theories relating cavern genesis to erosion cycles will also be considered briefly since it has been proposed that the development of the Wolkberg Cave is related to the development of erosional bevels on the surface (Marker, 1974; Talma, Vogel and Partridge, 1974).

## SPELEOGENESIS IN FOLDED LIMESTONE

An examination of caverns in tilted strata by Davies (1960) has indicated that development had taken place in a zone of maximum solvent flow, slightly below a sub-horizontal water table, and that the slope of the passage floors reflected the gentle gradient of that surface towards the major valleys. Davies proposed that the development of caves is a progressive, non-cyclic process having four distinct stages involving initiation by solution at a random depth below the water table, integration of passages close to the

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