STERKFONTEIN CAVE SYSTEM : EVOLUTION OF A KARST FORM

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DECLARATION

I, Murray Justin Wilkinson, hereby declare that this thesis is my own work and has not been submitted for a Master's Degree at any other University.

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ABSTRACT

The Sterkfontein Cave System is a karst cave developed on the Dolomites of the Transvaal System, fifty kilometres north-west of Johannesburg in South Africa. It lies beneath a small hill and was first exploited as a source of lime. Later it became a tourist and scientific attraction of world renown when some of the first australopithecine remains were recovered from a deposit within it. This deposit has been exposed on the surface near the hill summit, by the process of surface lowering and consequent deroofing of the chamber containing the deposit. Excavations are under way to recover fossils and artefacts, to determine the extent and to clarify the stratigraphy of the deposit.

The Cave System is comprised of four separate caves: the deroofed Fossil Cave (containing the bone-bearing deposit mentioned above) lies immediately south of Lincoln's Cave. Tourist Cave, the largest in the system underlies both of these. Fault Cave is situated a short distance north-east of this complex. The system measures three hundred and fifty metres (east-west) and two hundred and fifty metres (north-south); its vertical extent is almost sixty metres. Static water bodies occupy all the lowest points in the caves.

It is hypothesised in this work that the cave system fits models of cave development established overseas, and that evidence of climatic oscillation, in the form of changes in travertine deposition and fluctuations in water body level, is preserved in the system.

The evidence for erosion throughout the system is overwhelmingly phreatic, with some features which owe their existence to aggressive percolating meteoric water. The system thus fits Davis' (1930) hypothesis that caves form phreatically and then undergo a phase of replenishment

when the water table drops. Little definite evidence for vadose erosion exists, however.

Consideration of cave plans and sections, and of surface and underground fractures and fracture zones indicates that the system may be divided into two morphological categories, namely, bedding plane passages in the northern half of the system and fracture zone caverns of great vertical extent in the southern half. The bedding plane passages adhere to Ford's theory (1971) that steeply dipping beds (i.e. where dip exceeds five degrees) are conducive to deep phreatic weathering along bedding planes (the dolomite in the vicinity of Sterkfontein dips thirty degrees north). The fracture zone caverns are determined purely by the particular structural lineaments of the area.

The water bodies appear to be poorly connected since the piezometric surface descends towards the local drainage line.

The deposits of the system consist of various kinds of speleothems in relatively small quantities, and large volumes of externally derived hillslope soil and debris. No deposits of the kind Bretz (1942) encountered in many American caves have accumulated in the Sterkfontein Cave System. The non-calcareous deposits of the System occur as large colluvial debris cones or slot fillings, the older deposits usually cemented by percolating carbonate-charged water. Many of the cemented deposits have been partially destroyed by re-solution due to rising phreatic water and/or percolating meteoric water. Generally, newer debris cones accumulate beneath the undestroyed remnants of the cemented cones, having entered apparently by the same route as the older debris material. A model to explain this sequence is presented.

The large debris deposits only occur in the large fracture controlled caverns, and many appear to be connected with deposits in higher caverns, and even with the surface Fossil Cave accumulation.

Changes in travertine deposition and fluctuations of ground water level - as shown by re-solution levels preserved against the various deposits - are best explained as responses to changes in climate. The dating of such changes is extremely approximate: they may have occurred at any time between fifty thousand and two million years ago.

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PART I

INTRODUCTION AND SETTING OF THE STERKFONTEIN CAVE SYSTEM

CHAPTER 1 - INTRODUCTION

1.1 The Sterkfontein Cave System has developed in the Proterozoic Dolomite Series. It is therefore a karst cave. It lies in the Blaauwbank River valley, 50km north-west of Johannesburg.

It attracted attention originally as a source of lime for industrial purposes. However, it is now part of a protected nature reserve because its fossils have become world renowned, and also because the cave system has become a tourist attraction.

The prolific speleothems in the cave system have been mined extensively for industrial purposes and many of them have been destroyed. Mining ceased in 1939 however, when the price of lime dropped to an uneconomic level. Directly above the tourist caverns lie a mass of fossil-bearing breccias which are exposed on the surface of the hillside. The breccias have attracted the interest of archaeologists since the 1930's when Dr. Broom discovered austrolopithecine remains embedded in them. Later fossil finds aroused world wide interest.

1.2 This study aims to investigate the development of the cave system, the surface, breccia-bearing cave and the three interconnected, underground caves as a whole. In specific terms the aims of this study are twofold:- It is hypothesised that:

1. the Sterkfontein Cave System fits the models of cave development established overseas;

2. the Sterkfontein Cave System, like other cave systems in the Transvaal, preserves evidence of climatic oscillations in the variation

of calcium carbonate deposited, and fluctuations in water table levels.

1.3 The Cave System was chosen for detailed study for a number of reasons.

1.3.1 No detailed study had yet been made of the system, although the archaeological site was well documented.

1.3.2 A detailed study such as this provides an ideal opportunity for testing various models of cave development.

1.3.3 Sterkfontein, being one of the largest cave systems in the Transvaal, can be expected to yield new information on the development of caves in the Transvaal.

1.3.4 The accessibility of Sterkfontein from Johannesburg favoured it for study.

1.3.5 Work on other areas in the Transvaal dolomite outcrop has shown that caves preserve evidence of past climatic conditions. It was likely, therefore, that Sterkfontein would also contain similar evidence, which might be compared profitably with climatic sequences derived from other areas.

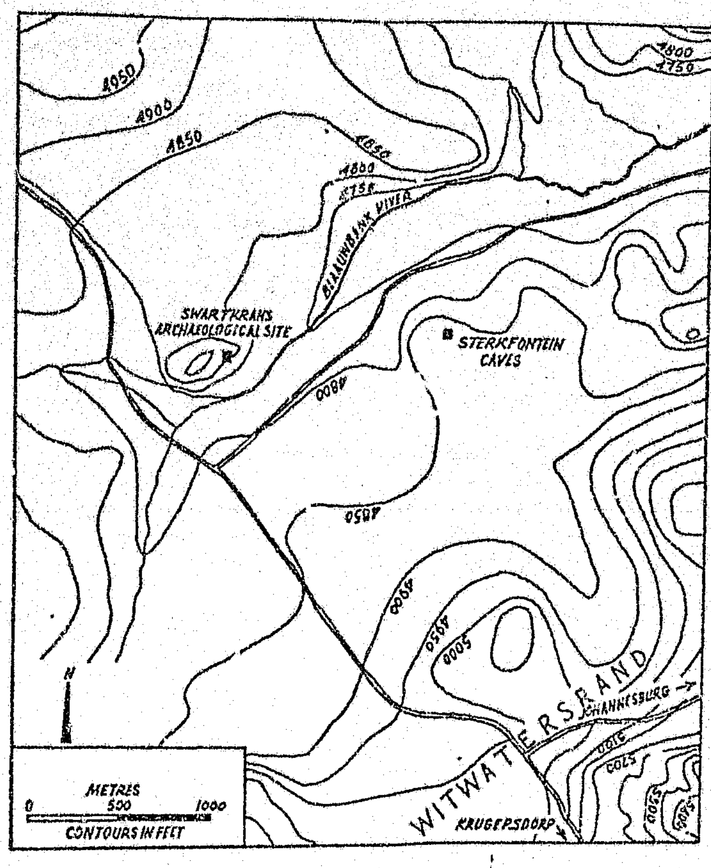

Fig. 2.1 Blaauwbank river valley in the vicinity of Sterkfontein

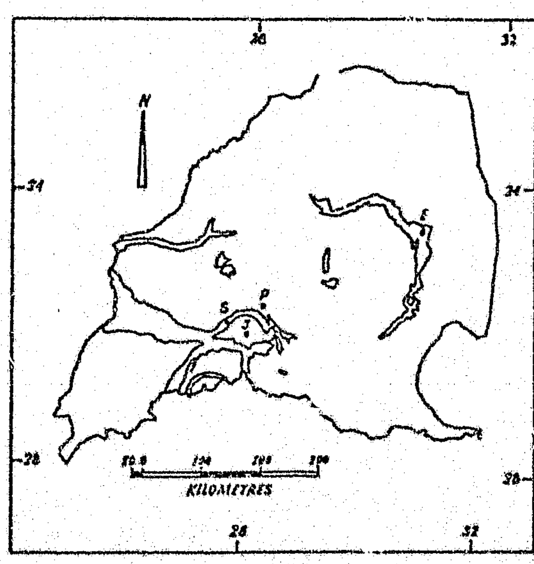

Fig. 2.2 Distribution of dolomite in the Transvaal
S : Sterkfontein Caves; E : Echo Caves; P : Pretoria
J : Johannesburg

CHAPTER 2 - THE SETTING OF THE CAVE SYSTEM

2.1 Topographic Setting

Sterkfontein is one of the many caves in the vicinity of the north-east flowing Blaauwbank River. It is situated beneath a small hillock one kilometre south of the river (Fig. 2.1.). The altitude of the top of the hill is 1485m. and that of the river bed 1450m. The Witwatersrand quartzite ridge forms high ground to the south (average elevation 1740m.), and the Timeball Hill quartzites form a belt of high ground to the north (average elevation 1600m.). The intervening Dolomite Series descends to 1450m. since the main drainage line occupies the outcrop (Fig. 2.1.). The average degree of relief of the area is 300m.

Whereas the bevelled summits of the dolomite outcrop have been attributed to a somewhat depressed 'African' erosion surface, the quartzite ridges are believed to represent a pre-Karroo bevel (Partridge, 1968). The valley incision, represented by the Blaauwbank River and its associated valley system is here assigned to the 'Post-African' cycle.

The infilled valley system is dry upstream of Sterkfontein but downstream of the spring the alluvium has been incised to a depth of 8m. The surrounding valley slopes are covered with a varying depth of soil, many metres thick in pockets, but with bedrock outcropping on more exposed sites, such as the Sterkfontein hillock.

2.2 Geological Setting

The Dolomite Series in which the Sterkfontein Cave System has developed, outcrop extensively in the Transvaal around the granite domes as well as around the Bushveld Igneous Complex (Fig. 2.2.). The width of the outcrop varies; in the Sterkfontein area the dolomite is exposed in

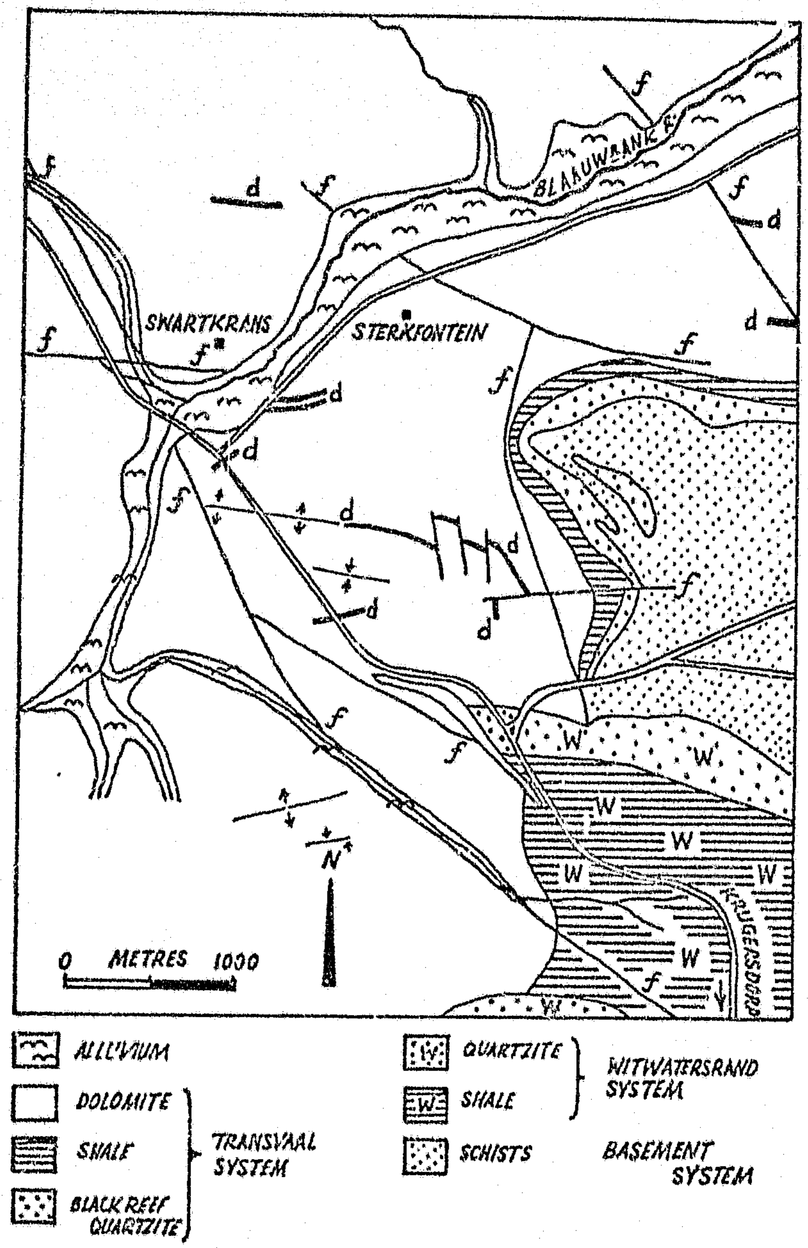

Fig. 2.3 Geology of the Sterkfontein area

a tract 16km. wide, dipping to the north.

The Proterozoic Dolomite Series, part of the Transvaal System, lies conformably on the Black Reef Quartzite, the thin basal member (20m) of the system. The Dolomite Series are overlain unconformably by the Pretoria Series, the upper member of the Transvaal System, immediately to the north of Sterkfontein. The Series is 1500m thick in this region.

The Transvaal System itself rests unconformably on the Witwatersrand System and on the Basement Schists, the oldest rocks in the area. These rocks outcrop to the South of Sterkfontein forming a prominent ridge.

The Dolomite Series is generally formed of massive dolomitic limestone, blue-grey in colour. Towards the base of the series, however, there are numerous interbedded narrow chert bands and occasional shaley layers. There is also a concentration of chert, towards the top culminating in the massive 'Giant Chert', a siliceous conglomerate marking a major erosional unconformity. Diabase sills and dykes have been intruded into the Dolomite Series. The dip of these rocks averages 30^{o}N, although the occurrence of an east-west trending syncline and anticline to the south-west of Sterkfontein affects the general dip (Fig. 2.3.). In places faulting has affected the dolomite strata and the interbedded sills. Fault breccias of dolomite blocks occur in the shatter zones, and can be seen on the surface at Swartkrans, 1km upstream from Sterkfontein.

The dolomite is 'blue-grey, compact, and minutely crystalline' (du Toit, 1962) with large proportions of magnesium carbonate added to the basic calcium carbonate constituent.

The lithology of the dolomite suggests that it was formed in a shallow sea environment; the presence of oolitic beds indicate direct precipitation. The numerous siliceous chert bands (95% silica - Brink and Partridge, 1965), indicate changing environmental depositional conditions.

Brink and Partridge (1965) elucidate the chemical reaction which occurs when dolomite dissolves: solution produces bicarbonates, in reality Ca^{++} and Mg^{++} ions in solution. Ca^{++} is precipitated as $CaCo_3$ in the form of speleothems underground. Magnesium being more soluble than Calcium is rarely precipitated as a carbonate.

$$3CaCO_3.2MgCO_3+5H_2O+5CO_2 \rightleftharpoons 3Ca(HCO_3)_2 + 2Mg(HCO_3)_2$$

Insoluble materials within the dolomite include chert, quartz, limonite, haematite, manganese dioxide (wad) and carbon (Brink and Partridge, 1965), which weather to form red dolomitic soils.

The dolomites are traversed by a network of north-south and east-west fractures and lineaments induced by the emplacement of the nearb y 'Halfway House' Granite. Furthermore, it has been shown that the north-south fractures are tensional and the east-west fractures are compressional (Eriksson, 1972).

2.3 Previous Geological and Geomorphological Writing on Sterkfontein and the Surrounding Area

The fossil remains of the Sterkfontein breccias were first reported in palaentological papers (Jones, 1937; Broom, 1937), which did not deal with the geological aspects of the deposits, nor with the cave system as a whole. Broom at that time predicted that the deposits would prove to be Upper Pleistocene in age.

The following year Cooke (1938) published the first report on geological aspects of the upper cave deposits. He showed that they were the filling of a cave formed by solution of the dolomite bedrock. He showed too that erosion had since removed the roof of the cave, except in two small localities, exposing the cave fillings on the surface of the hill. He did not consider the underground cave system beyond mentioning that it had developed along two sets of joints.

Cooke (1938) interpreted the cave fillings as evidence of three climatic phases. He recognised two distinct breccias underlain by a travertine deposit.[1] Both breccias were cemented in a matrix of red sand, the lower, older breccia containing numerous unweathered dolomite blocks and very few fossils, and the upper breccias containing few dolomite blocks, but a rich content of fossils. The absence of dolomite blocks in the upper breccia led Cooke to believe that the climate had become wetter as the upper breccia was deposited, the blocks dissolving as the rainfall increased.

Interpreting the underlying travertine deposit as an indication of a wet climate, Cooke proposed a wet-dry-wet climatic sequence for the upper cave deposits. He correlated the second wet phase with the 'Third Wet Phase' of the Vaal Basin (Sohnge, Visser and van Riet Lowe, 1937). He dated the deposits correspondingly as upper Pleistocene.

On the basis of new palaeontological evidence, the dating of the deposit was revised from upper Pleistocene to upper Pliocene (Broom, 1945).

Haughton (1947) described the deposits at Sterkfontein, including in his work a description of the deposits in one underground chamber. He claimed, on the basis of variable stratification, that the underground deposits were not related to those on the surface. He did not attempt to date the deposits, beyond saying that they were of Pleistocene age.

The formation of the Sterkfontein Cave System was attributed to control by 'solution along two main fissure directions and secondary joint planes' (King, 1951). King found that Sterkfontein, in common with other caves in the Transvaal, exhibited a phase of older red sand deposits overlain by a travertine, which was in turn overlain by younger red sand deposits.

In contrast to Haughton, King claimed that the underground de-

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[1] 'Travertine' is used in the sense of sheet flowstone deposited underground

posits contained older red sand, and on this basis he connected the surface and the underground deposits. He claimed that the newer red sand extended into the underground cave system as an unconsolidated deposit.

King suggested a Pliocene age for the older red sand deposits.

Robinson (1952) dated the Sterkfontein sequence as Upper Pliocene, from faunal evidence, thus corroborating Broom's conclusion (Broom, 1945).

Oakley (1954), on the other hand, placed the sequence in the Pleistocene, and Sterkfontein in the Kageran-Kamasian interpluvial.

Brain (1958) made a detailed analysis of the breccias at Sterkfontein and other Transvaal caves. His aim was to clarify the sequence of climatic changes during the period of breccia accumulation. Consideration of the angularity of grains in the breccia matrix, of the chert-quartz ratios, and of the particle size gradings led Brain to propose the following climatic sequence: originally, conditions comparable to those of today were followed by a 'fairly intense dry phase', which gave way once again to the original conditions.

Brain (1958) suggested that the Sterkfontein deposits belong to the first Interpluvial and span one of the dry peaks of that Interpluvial.

Brain (1958) envisaged the present-day underground caverns forming immediately beneath a water table. He postulated that a large dolomite block collapsed into the underground cavities thereby opening a cavern above the Fossil Cave[2] - very near the surface of the hill. Many solution pockets, eroded into the exposed breccia mass, were recognised. Most were filled with modern soil (Brain, 1958).

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[2]This name is ascribed throughout to the breccia-filled, de-roofed cavern exposed at the hill surface, from which fossils have been recovered.

Robinson (1962) argued that it was unlikely that the Fossil Cave originated due to the collapse of one very large dolomite block; he proposed that the cave had originated by means of a series of small collapses and regarded the Fossil Cave as an independent high-level cavity separated from the lower caverns by a bedrock floor in situ. He suggested that the floor subsequently collapsed thereby establishing the routeway by which surface-derived debris has entered the low-lying caverns.

Having exposed and excavated a large new area of the Fossil Cave breccias, Robinson (1962) concluded that three unconformable deposits existed rather than a single continuous deposit as envisaged by Brain (1958). Robinson's arguments, discussed later, involved repeated slumping of the Fossil Cave deposit into the underground caverns.

Basing their ideas on those of Davis (1930) and Swinnerton (1932), Brink and Partridge (1965) attributed the lower level chambers of the cave system (i.e. Tourist Cave) to water table levels related to the present cycle of erosion, and correspondingly attributed the upper level cavities (e.g. Fossil Cave) to the previous erosion cycle. Marker and Moon (1969)however, argued that both upper and lower level chambers are best assigned to the earlier (Afr[illegible]) cycle, the lower level cavities forming 'during a later phase of [illegible]'. These workers invoked deep-lying water tables which are often encountered in the Transvaal dolomites.

Moon (1972) showed that cave passages in the Sterkfontein vicinity of the Blaauwbank valley are aligned preferentially along the east-west fractures of the area - i.e. the compressional fractures (Eriksson, 1971), which Moon argues are more likely to produce shatter zones in the dolomite with the consequent proliferation of microjoints.

Brink and Patridge (1970) reinterpreted the breccia stratigraphy of the Fossil Cave, claiming that the lowest of the three breccias was a collapse deposit rather than a gradual accumulation as Brain (1958) and Robinson (1962) had regarded it. Furthermore, Brink and Partridge (1970) identified a fourth breccia body along the north wall of the Fossil Cave; and also suggested that the fillings of the solution pockets in the breccias are predominantly decalcified breccia.

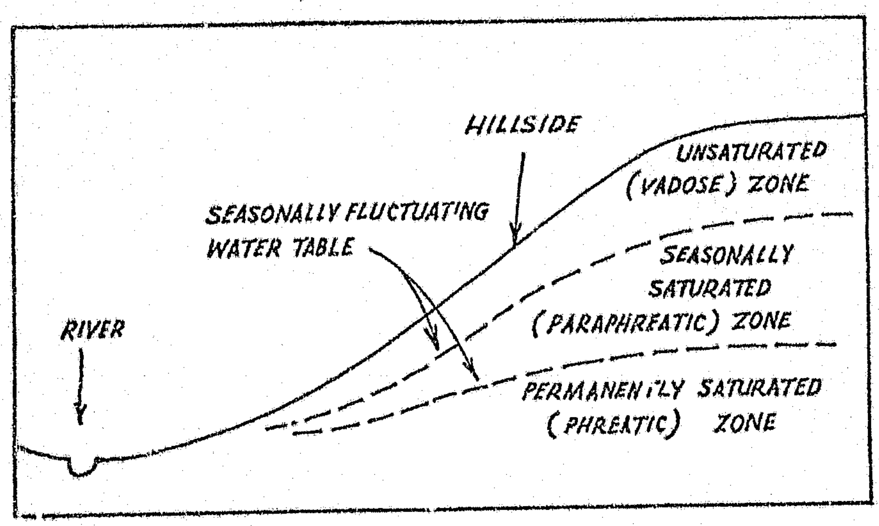

Fig. 3.1 Saturation zones beneath a hillside

CHAPTER 3 - GENERAL THEORIES OF CAVERN DEVELOPMENT

3.0 The salient features of the main theories of cave development are reviewed in this chapter in order to assess their validity for the Sterkfontein Cave System.

3.1 Bretz (1942) has noted that 'conditions of subterranean (water) flow are notably different below and above the water-table', and it is because of this fact that theories of cavern development debate the merits of cave-forming processes above and below the water table. Early American theorists debated the question of cavern development above the water-table in the vadose zone (Fig. 3.1.), or at the water-table itself. Early European theorists however, (e.g. Katzer, 1909 and Bock, 1913) considered that a continuous water-table did not exist, and that cave formation was carried out by flowing water under hydrostatic pressure, thus implying formation in the saturated zone.

In 1930 Davis published an important contribution to cave development theory in which he argued that caves develop in two cycles as opposed to the earlier one-cycle theories (Davis, 1930). Caves were said to be formed by solutional excavation of calcareous rocks beneath the water-table during the first cycle, and then filled with travertine deposits during the second cycle when tectonic uplift and stream rejuvenation have emptied the cave of water. Davis reasoned that caves may form at any depth beneath the water-table, an idea discredited by later writers, but being held once again by the most recent theorists, in modified form.

Swinnerton (1932) also produced a theory of cavern development in the phreatic zone, but qualified Davis' theory to a large degree. Swinnerton argued that caves develop along paths of maximum ground-water flow, which he showed would theoretically exist along the shortest distance between sink and spring - i.e. along the water-table. Ford (1971) points out that most local cave studies in the last 25 years have agreed with the hypothesis of water-table controlled cave formation.

Rhoades and Sinacori (1941) combined aspects of both Davis' and Swinnerton's theories. They postulated deep phreatic weathering early in the karstification process giving way later to shallow phreatic solution at the water-table. Rhoades and Sinacori argued that a master conduit develops headwards from the point of discharge, and in so doing modifies the flowlines of the ground-water circulation and reduces the depth of circulation with time.

This theory introduced the concept of a cave changing the pre-cave water-table, in contrast to a water table determining the position of cave development. The concept has been employed in recent theories of speleogenesis.

Bretz (1942) provided an impressive amount of evidence in support of Davis' deep phreatic zone theory. By careful examination of many cave features he distinguished the vadose-formed from the phreatic formed; moreover he showed that most caves have vadose features superimposed on phreatic features, thus supporting Davis' two-cycle concept of cave development. Bretz further claimed that a stage of clay infilling normally intervenes between the solutional stage and the travertine deposition stage. Bretz's techniques are some of the mainstays of modern speleological investigation.

Other vadose theories appeared after Davis' publication, and that of Gardner (1935) has a bearing on present day thought. Gardner argued that caves form when stream incision drains beds within the limestone mass which are particularly prone to solutional attack. The caves are deemed to develop solely above the water-table as the caves become integrated into the hydrological regimen of the area. Gardner's idea of preferential solution in certain beds is borne out by recent studies on individual caves (Glennie, 1956; Ford, 1964).

3.2 In South Africa Brain (1958) proposed a model of cave development for the Transvaal based substantially on the ideas of Swinnerton (1932). Brain proposed that caverns develop 'immediately below the water-table', and regarded the action of vadose streams in the Transvaal dolomites as 'insignificant', He stressed the importance of percolating meteoric waters in enlarging vertical joints and fissures.

Since Brain was particularly concerned with the fossiliferous cave fillings, the evolution of cave deposits forms an important part of his overall model: externally derived deposits enter the cave voids as soon as surface lowering and even development allow entry of hillslope material. The cavities are partly or entirely filled with travertines and externally derived material (which become cemented by calcium-rich percolating water). Surface lowering continues and ultimately deroofs the upper cavities exposing the solidified deposits at the surface. With time all evidence of the cave and its fillings may be removed. Brain mentions roof collapse as an important feature of some Transvaal caves.

Brink and Partridge (1965) followed Brain substantially in his model for the development and infilling of cave voids in the Transvaal. However, they elaborated on Brain's model by ascribing successive cave-forming water-tables to four cyclic landsurfaces which appear to have bevelled the high lying areas of the Transvaal (King, 1962).

Brink and Partridge (1965) also present a model for the evolution of the notorious sinkholes and the compaction subsidences of the West Rand dolomites, which however, they class as pseudokarst features developed directly above and in concert with voids (not necessarily open to the surface) in the dolomite bedrock.

Some years earlier Sweeting (1950) drew attention to the fact that cave levels in the Ingleborough District of north-west England are related to erosion surfaces in the area. Waltham (1970) however, has since shown that at least some of the caves are controlled by shale bands in the limestones, and cannot, therefore, be attributed solely to water-table control. Marker and Moon (1969) have demonstrated statistically, the coincidence of cave levels and erosion surfaces in the Transvaal, as well as noting that almost all the caves studied (35 caves, some multi-levelled, form the basis of this study) are phreatic in origin with little vadose modification. This study supports that of Brink and Partridge (1965) with evidence from a number of caves in other parts of the Transvaal.

Moon (1972) has since shown that the abovementioned statistical study is not strictly applicable to the Blaauwbank River Valley - in which Sterkfontein is situated - since the amplitude of relief in the valley is the same as the amplitude of the variation in cave levels from one erosion surface. The development of Sterkfontein has in the past been related to both the African and Post-African surfaces (Brink and Partridge, 1965). Although this may be true in fact, the important conclusion of the statistical study does not apply directly to the Sterkfontein cave system.

3.3 Breaking away from the traditional approach to cave development theory, Ford (1971) has argued that:

> there is no one general case of limestone cavern development which can be so precisely defined as older theories would have it. Rather, there are three common cases: the predominantly vadose cave, the deep phreatic cave and the water-table type cave.

In Ford's formulation the controlling factors are the steepness of rock dip, topography, the frequency of permeable bedding planes, joints and faults, and the frequency and geometry of their interconnection.

The type of cave which will develop depends firstly on the number of fissures with 'significant penetration' of ground water - i.e. the ratio of joint length to bedding plane length - and the hydraulic conductivity (Ford, 1971). High conductivity produces a water-table type cave (when rock is highly jointed or when the dip of the rock is shallow (less than 5%), since bedding planes prevent water from descending into the deeper layers of the rock. Low conductivity produces the deep phreatic type cave and is common in steeply dipping limestones, since bedding planes 'guide water to great depths'.

Recently many studies have stressed the importance of lithological and structural factors, recognising with Ford (1971) that various other controls are often dominant in determining the development and morphology of caves.

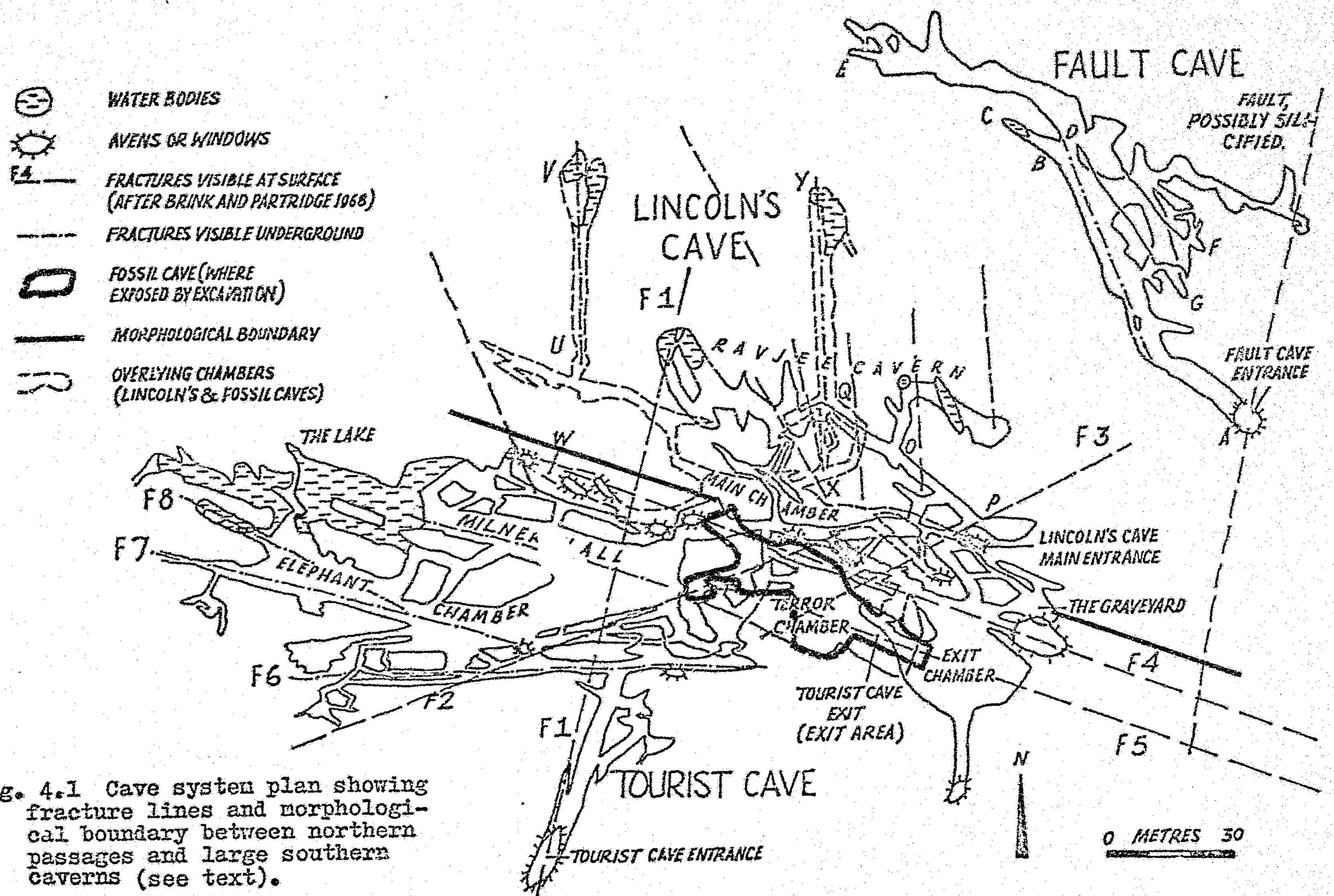

Fig. 4.1 Cave system plan showing fracture lines and morphological boundary between northern passages and large southern caverns (see text).

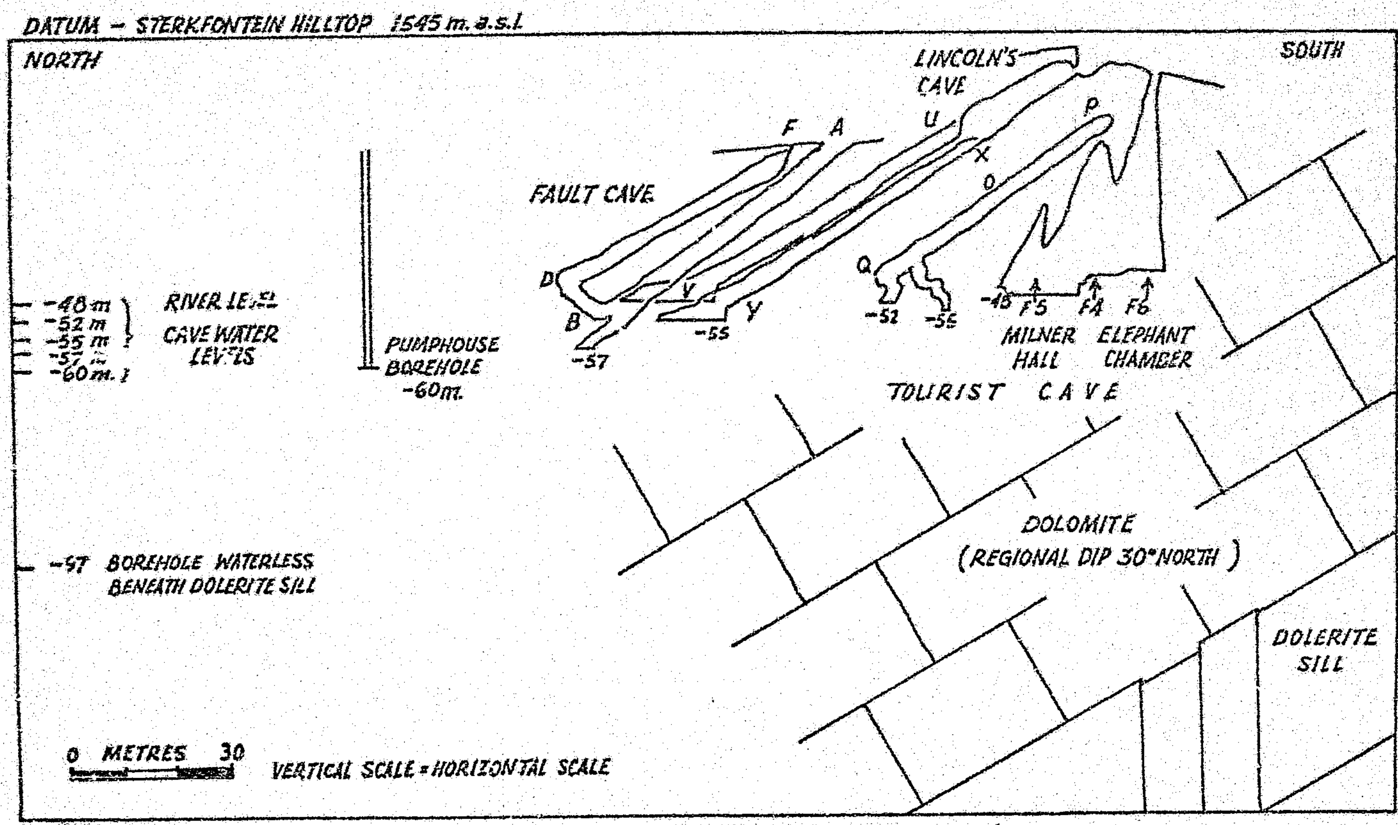

Fig. 4.2 Supe…posed cave sections parallel with regional rockdip
(see text for explanation)

PART II

THE CAVE SYSTEM

CHAPTER 4 - OVERALL VIEW - PLAN AND SECTION

4.0 This chapter presents a general description of the form and dimensions of the Sterkfontein Cave System. By means of cave plans and sections the system is also related to the surface geology.

The cave system itself was mapped with the degree of accuracy termed 'D5' on the Butcher and Railton Scale (Butcher and Railton, 1966) No attempt was made to map the underwater passages of the system. No large underwater cavities were discovered.

4.1 The Cave Plan and Section - General Description

The Sterkfontein Cave System consists of three large caves - Tourist Cave, Lincoln's Cave and Fault Cave (Fig. 4.1) - in addition to many small cavities in the hillside. Several voids within this system contain breccias some of which are fossiliferous. The Fossil Cave exposed on the hillside contains one of the largest breccia deposits in the System.

The caves lie at a number of different levels: Lincoln's Cave lies a few metres beneath the Sterkfontein hill-summit and descends with the rock dip through more than 50m to the local water level (Fig. 4.2). The main chamber of Lincoln's Cave and the Fossil Cave lie directly above the Tourist Cave, which itself is connected to the surface by means of various shafts and apertures The Fault Cave is situated north-ea' ' of the Tourist/Lincoln cave complex.

Although no passages connecting these three caves are known some evidence for connections above and below the piezometric surface exists (Chapter 8).

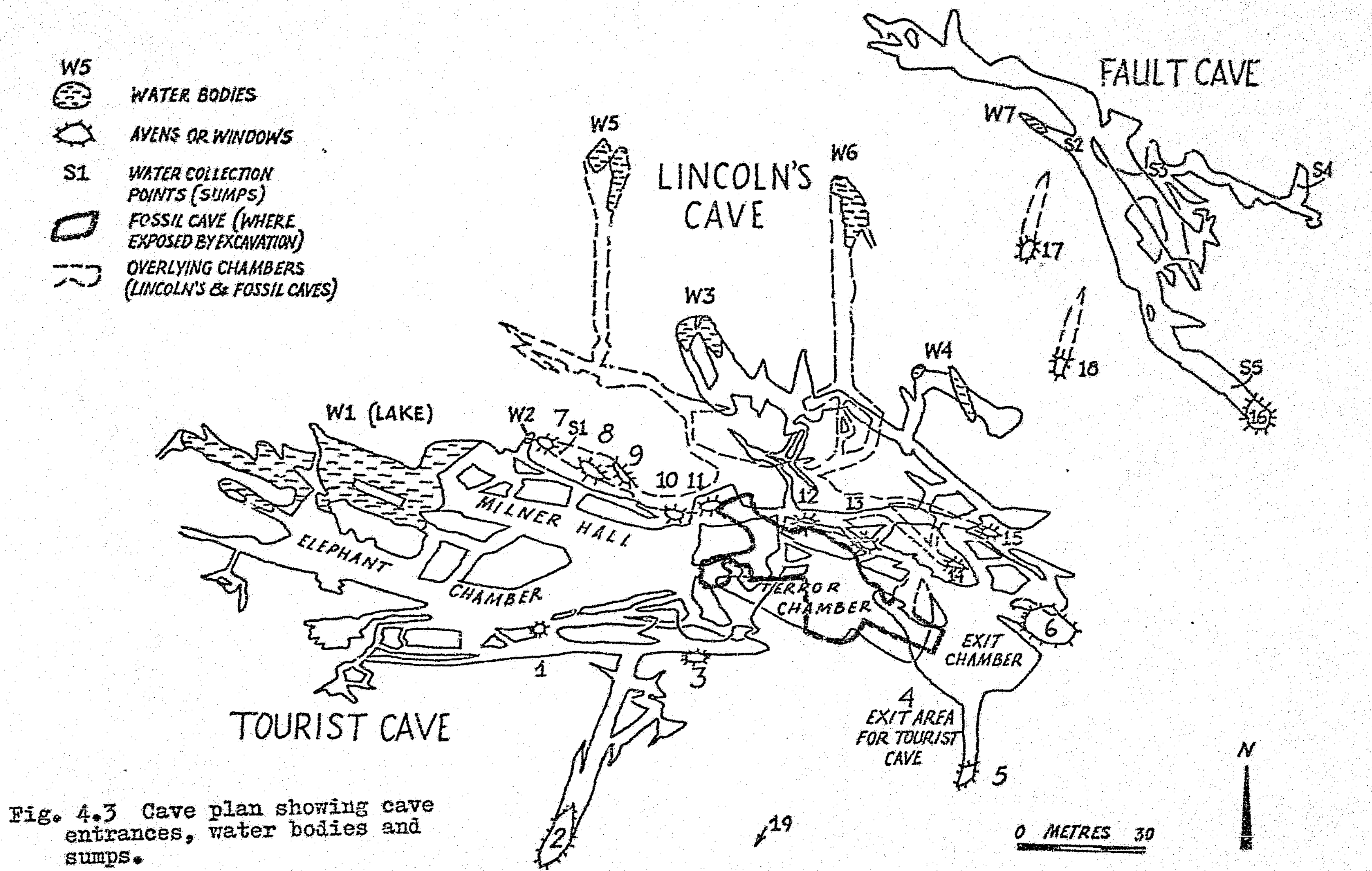

Fig. 4.3 Cave plan showing cave entrances, water bodies and sumps.