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Pseudokarst in the Western Cape, South Africa: Its palaeoenvironmental significance

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Abstract: Pseudokarst is well developed in many areas of the Western Cape on quartzitic sandstones of the Table Mountain Group. Two areas on the Cape Peninsula are described. Both have large surface dolines and pinnacle karst as well as cave systems. Area 1 refers to Table Mountain itself and the Back Table. Area 2 is the Silvermine Kalk Bay Mountain region further south. There the density of pseudokarst forms, including over 70 known caves, are concentrated in a relatively small area. Most caves are shallow phreatic in origin and appear to have developed as conduits feeding water movement towards the Noordhoek - Fish Hoek trough to the south. The pseudokarst is relict. This pseudokarst has formed beneath plateaux developed on horizontally bedded Peninsula Formations sandstone of the Table Mountain Group, at varying heights, 1000m on Table Mountain, 750m on the Back Table and 500m on the Silvermine Reserve. The discussion focusses on the age of the weathering that created the pseudokarst landforms and thus the age of the karst itself. It is concluded that the pseudokarst developed beneath the Late Cretaceous-mid Miocene African Surface and that Miocene and later Pliocene uplift caused differential uplift of the fault blocks along the Cape Peninsula mountain chain.

INTRODUCTION

The term **karst** is applied to landforms and landform assemblages where chemical solution overrides regional geomorphic processes. The term is conventionally restricted to landforms developed on carbonate rocks, although karst features also occur on halite and on gypsum. Karst landscapes are characterised by disrupted surface drainage since water disappears underground through enlarged fissures to flow through caves and emerge elsewhere as springs. Dolines, enclosed hollows of variable dimensions, are a common surface characteristic. Joint enlargement may result in negative troughs and aligned upstanding pinnacles. Underground, network caves can be characteristic.

Pseudokarst is a term applied to landscapes that have many karstic features but which have developed on rock types normally considered as insoluble. Pseudokarst in southern Africa occurs in the Western Cape, along the Eastern Transvaal Great Escarpment (Marker, 1975), in Swaziland (Watson, 1985;1986) and on Chimanimani mountain in Zimbabwe (Craven and Penney, 1994). It has also been reported from many other parts of the world such as Venezuela (White et al., 1966), Central Australia (Jennings, 1979) and from Mainland China (Anon, 1988). The existence of pseudokarst, karst characteristics developed on normally insoluble rocks, implies strong chemical weathering over a long period of time. This paper focuses attention on the importance of pseudokarst in the Western Cape of South Africa.

In the Western Cape, pseudokarst areas are recognisable from surface widening of joints, the development of cavernous weathering on upstanding pinnacles and the opening of keyhole slots in cliffs by seepage water. These surface forms constitute the spectacular landscape of the Cederberg, with joint widening particularly conspicuous in the Wolfberg Cracks. Their effects can be seen on the summit plateau of Sir Lowry's Pass and on the Cape Peninsula mountain chain. We will focus on two areas of the Cape Peninsula: Table Mountain itself, particularly the Back Table which is designated Area 1, and the Silvermine/Kalk Bay mountains designated as Area 2 (Fig.1).

GEOLOGY

The host rock, in both areas, is Palaeozoic Peninsula Formation sandstone of the Table Mountain Group (Table 1). The Table Mountain Group are the basal members of a suite of quartzites and shales that constitute the rocks of the Cape Fold Belt. In the Cape Peninsula only the uppermost Table Mountain Group are present (Table 1). The Peninsula

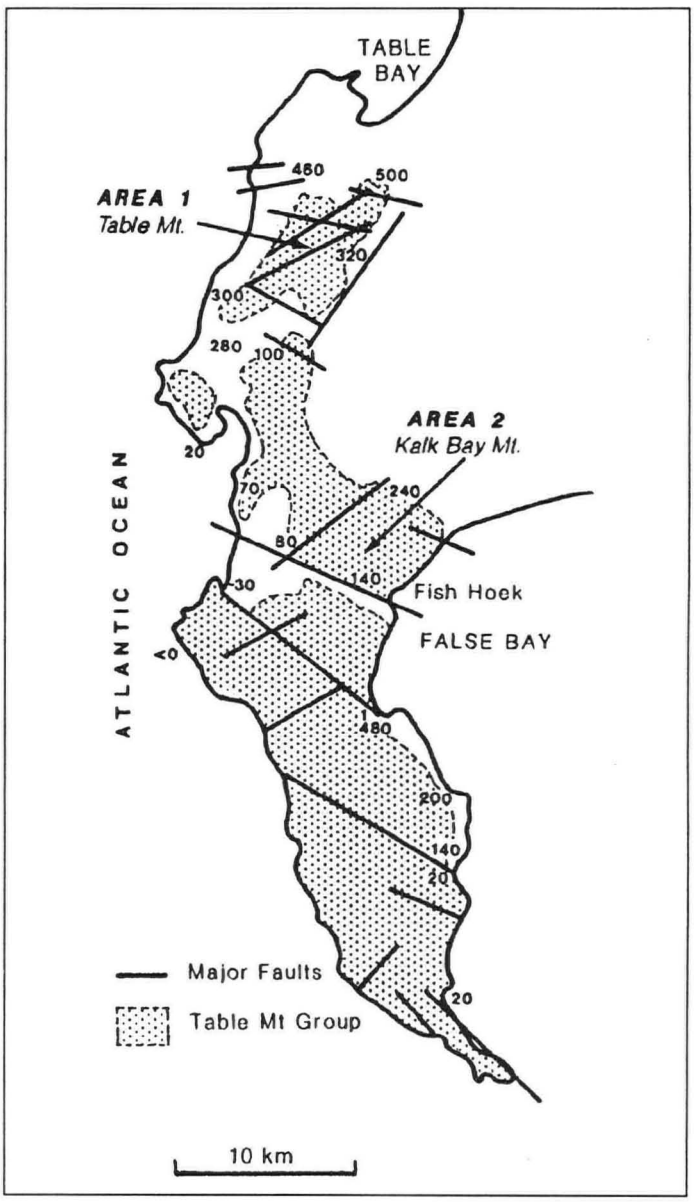


Figure 1. The Cape Peninsula showing the location of the Table Mountain (Area 1) and the Silvermine/ Kalk Bay Mountain (Area 2) pseudokarst areas. Major faults shown. Figures denote basal altitudes of the Peninsula Sandstone Formation.

GROUP	FORMATION	LITHOLOGY	AGE
Table Mountain Group	Pakhuis Formation	Glacial sediments and shales	Silurian
	Peninsula Formation	Quartzitic sandstone with minor shale bands	Silurian
	Graafwater Formation	Red shales	Ordovician
UNCONFORMITY			
Cape Granite Suite			Precambrian
Malmesbury Group		Shales	

Table 1. An Outline Geological Sequence for the Cape Peninsula.

more closely bedded. It is well jointed and overlies a bed of reddish hued sandstone and mudstone which constitutes the basal Graafwater Formation shales (Theron, 1984). Commonly, massive and thinner bedded units alternate. The most spectacular pseudokarst is developed in the massive well-jointed beds. The lithology is silicious throughout. The matrix of both quartzite and sandstone beds is crystalline silica.

TOPOGRAPHY

The Cape Peninsula mountains are essentially tabular, in contrast to the steeply folded Table Mountain Group sandstones that make up the majority of the Western Cape mountains. Late Palaeozoic to early Mesozoic orogenesis was accommodated by block faulting in the Cape Peninsula and not by folding. The Cape Peninsula mountain chain is therefore divided into separate blocks at different elevations (Fig.1). Strong structural lineaments exist, in addition to faults that cause considerable displacement.

TABLE MOUNTAIN (AREA 1)

On Table Mountain small water absorbing dolines occur along the edge of the Central Table, and in Echo valley (Fig.2). Between Echo and Ark valley there is surface joint-widened karst with strongly developed small-scale etching associated with flared slopes. The Valley of Isolation is a large karst depression, about 1000m in length and about 500m in width (Plate 1). This depression has a minimum depth of 16 m. The northern side is cliffed and reaches an altitude of 900m On this cliff there are two caves. Both are characteristic of water emergence (spring) sites. The upper cave is now perched and dry whereas the lower cave is still an active spring emergence. Numerous keyhole slots, a form of phreatic tube, are visible in the same cliff face. The emergent water disappears into one of the floor depressions leading into a cave (Plate 1). The depression floor contains a number of small dolines developed in sand overlying massive collapse blocks. The entire doline complex is clearly old as shown by the large block collapse that underlies the more modern floor infill. It is the underlying collapse material which facilitates formation of the small dolines.

Another huge enclosed hollow is located on the northern slopes above Orange Kloof, in length 2750m and width 500 m. The northern side of this depression reaches an altitude of approximately 750m whereas the southern slope is lower, reaching only 720m. Pinnacle karst forms are associated with the plateau surface at 750m. Several caves including Wynberg Cave, Bats, Giants, the Metro system, Climbers, Smugglers and Vivarium caves, are associated with the higher ridge and the hollow. Most of these caves are considered to be caused by solutional widening of rifts, associated with unloading towards Orange Kloof (Fig.2).

THE SILVERMINE/KALK BAY MOUNTAIN AREA (AREA 2)

One of the most spectacular pseudokarst areas on the Cape Peninsula is located in the Silvermine Reserve (Figs.1 and 3). The mountains there reach a maximum altitude of 537m in the north on Upper Steenberg Ridge. A plateau terminating in three ridges aligned northwest-southeast, is the main pseudokarst area (Fig.3; Plate 2). The main drainage is into

Plate 1. Valley of Isolation doline on Table Mountain looking north-east.
(1 = Upper dry emergence cave, 2= position of active lower emergence cave, arrow shows approximate location of cave absorbing flow, actual position hidden by vegetation).

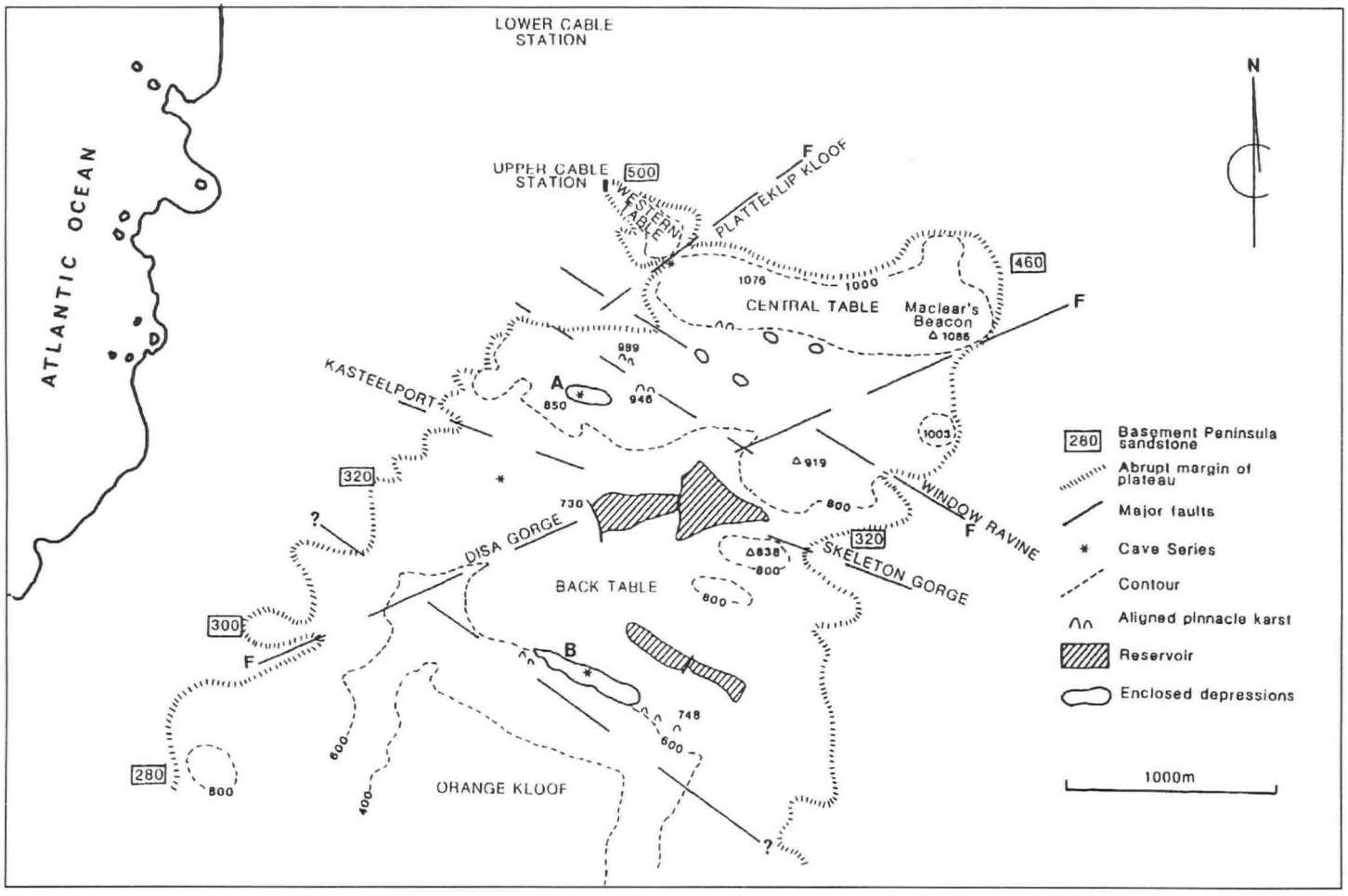


Figure 2. Pseudokarst areas on Table Mountain : Area A is on the Back Table; Area B is Wynberg Peak.
(No altitudes are shown below the plateau level. On the plateau both contours and spot heights give altitudes in metres)

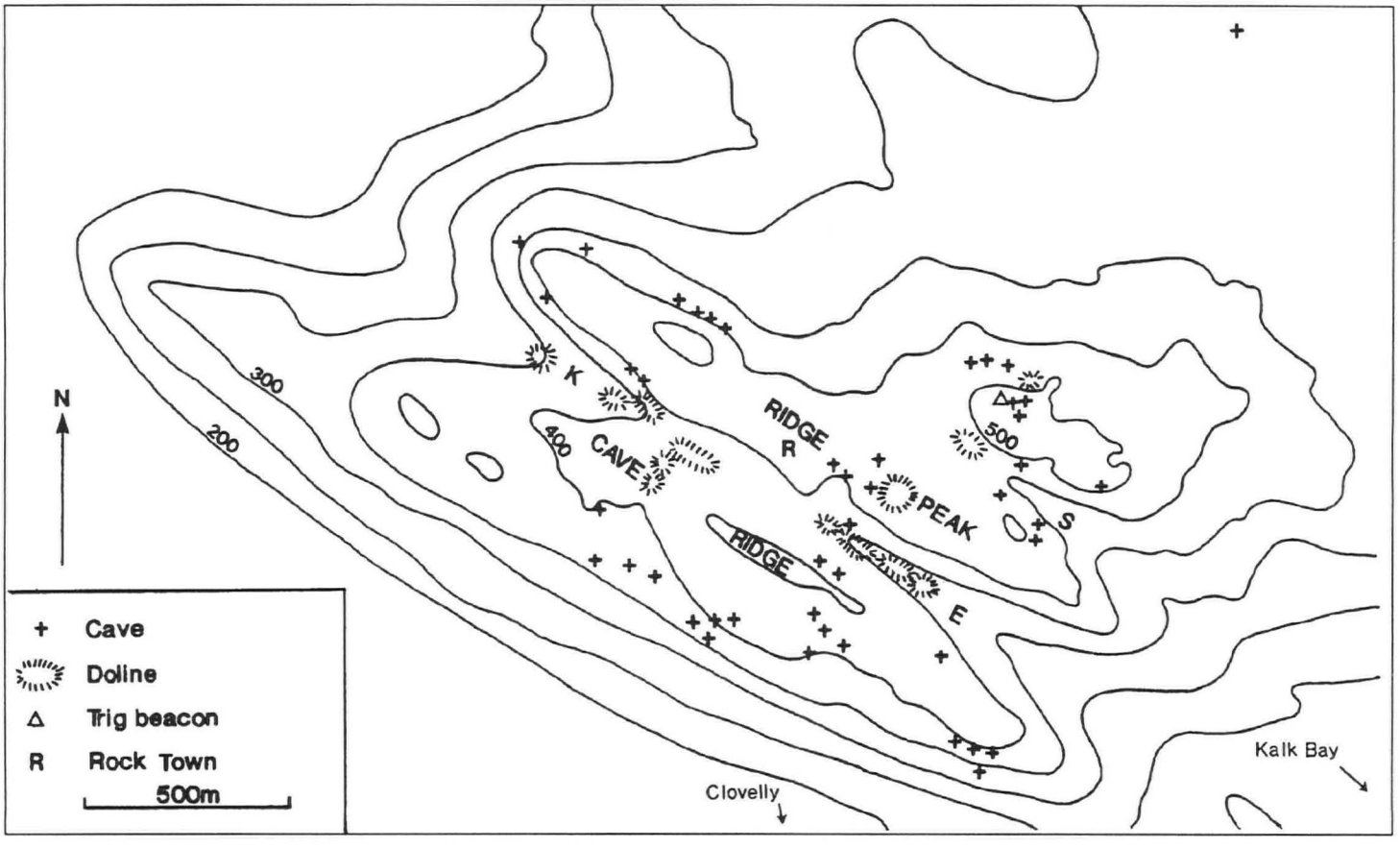


Figure 3. Silvermine/Kalk Bay Mountain pseudokarst area (contours at 50m interval, 100m interval contours labelled on uphill side. S= Spes Bona valley; E=Echo valley; K= Kleintuin kloof).

Plate 2. Pseudokarst surface on the Silvermine Reserve showing Cave Peak (1), Ridge Peak (2) separated by Echo Valley (4) and the Amphitheatre (3) view southeast. The Robin Hood entrance to Ronan's Well is indicated by an arrow).

the Silvermine River. All the major valleys carry small streams, many of which dry out at the height of summer. Aligned dolines occur within these valleys. The Silvermine area also has well-developed surface aligned pinnacle forms associated with joint widening. This type is restricted to areas above 400m altitude. The most spectacular location is close to The Amphitheatre and several large caves, and is known locally as the Rock Town (Fig.3; Plate 3). These pseudokarst landforms will be described in detail.

Surface landforms

Large **karren** or pinnacle forms, occur above 400m altitude on or close to the summit of all the ridges. The best examples can be seen on Upper Steenberg Peak and Kleintuinkop (Fig.3; Plate 3). In these areas the terrain consists of large clint-like blocks separated by troughs (grikes). The troughs range from 0.8m to 2.5m in width and may reach 4m in depth. The floors are on bedrock with a shallow veneer of sand. In places these grikes are deeper and may lead into caves. Sunbeam Cavern is one example. This cave is 18m deep and the entrance is covered by rock collapse (Swart, pers. comm). The entrance to Robin Hood's Cave is another example. The trough there is 25m in length and has a maximum depth of 22m. This is one of the entrances to Ronan's Well, some 200m in length.

Small **arches** also occur. The best known can be found at the northern end of Echo valley and on top of Kalk Bay Mountain. Solution rill karren groove many blocks. The entrance to Climax Cave has good examples. Many horizontal rock surfaces show basins, or kamenitza, development. Floors and sides show evidence of case hardening. Even in vertical rock faces, small tubes, 5 to 10cm in diameter and between 5cm and 15cm deep, penetrate the rock. During wet weather water and silt pour from some of these holes, suggesting that they extend further than is at first apparent. Rib-like structures occur in some of these holes. These are all examples of phreatic or epiphreatic weathering. Tentatively it is suggested that ancient phreatic tubes now truncated by slope recession, are utilised by current winter drainage.

Dolines occur in three of the larger valleys (Fig.3). A number of these are small, up to 2m in diameter and 1m in depth. The larger depressions are more than 20m in diameter and up to 10m in depth. Many are choked by fallen boulders, derived from collapse and cliff recession. Some dolines occur in series as in Kleintuin Kloof, which are associated with the movement of underground water down the kloof. Massive collapse has also occurred in Echo valley, again related to water movement. Some dolines at lower elevation are hidden within forest remnants both in Echo and Spes Bona valleys.

Most of these depressions are stable but one, at the head of Echo valley, is active. This collapse first appeared in about 1976 and has grown wider and deeper each winter. It is currently 14m by 11m in dimension and 3m maximum depth. It has formed in sandy valley infill which feeds through the bottom of the sinkhole. Another large doline is located above the Amphitheatre at an altitude of about 455m. This depression is 15m in length and 8m wide. The entrance to Drip Water Pot is located among the boulders at the southern end of this depression (Fig.4; Plate 2). Other caves entered from depressions are Six Moles Cave and Mossies Den.

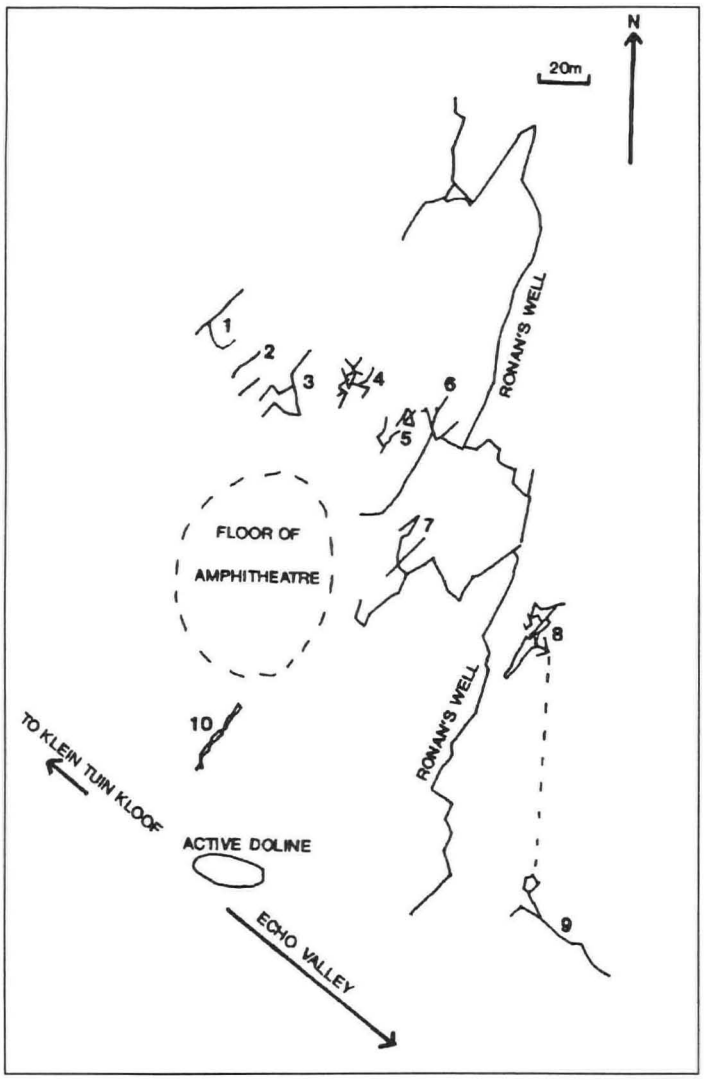
Water sinks and springs

Surface water tends to be seasonal, drying out at the height of the summer dry season. The streams either drain to the northwest into Silvermine River or to the southeast directly to False Bay. There are two types of springs: cliff resurgences and valley floor resurgences. The majority of cliff resurgences occur on southwest facing cliffs and are small in volume. There is no consistency in altitudes. In caves such as Bettie's cave on Kleintuinkop, water actually runs into the cave and soaks away into the sand in the terminal chamber. Valley floor springs are the source for bigger streams (Table 2). None provide the entrance to caves.

VALLEY	ALTITUDE (m)
Spes Bona	410
Pecks	400
Kleintuinkloof	320
Bailie's	320
Echo	310

Table 2. Valley Floor Springs.

Figure 4. The concentration and alignment of caves associated with The Amphitheatre lying to the northeast of Kleintuin Kloof and Echo valley.



Although isolated caves occur in the northern part of this area, cave density is exceptionally high in association with the three ridges overlooking Kalk Bay-Fishhoek, known as Cave Ridge, Ridge Peak and Kalk Bay Mountain (Fig.3). The ridges are separated by the Spes Bona and Echo valleys. Within this high cave density area, a particularly high density of caves occurs in association with the Amphitheatre, possibly a large breached doline surrounded by well-developed pinnacle pseudokarst (Fig.4; Plate 2). Most caves are shallow phreatic and are either linear or network in plan (Figs. 5 and 6). Caves are most frequent on the northeast of the valleys: only small, apparently truncated cave remnants occur along the southwest walls. There are approximately 70 known caves ranging from 10m over 750m in length (Table 3).

Cave surveys demonstrate that most are network caves developed along well defined joints (Figs.5 and 6). Most are shallow and suggest shallow phreatic dissolution (Kavalieris, 1977). Passages show a number of characteristic cross sections: low, wide passages correspond to bedding planes, whereas vertical narrow slots exist along defined vertical joints. A circular cross section is sometimes seen, notably in Oread Halls. This form is characteristic of conduit flow within the upper phreatic zone. These passages appear to meander slightly. This is characteristic of master conduits. A number of cave passages have domed terminal chambers. Rock pillars occur within the passages. Some are free standing, others are attached to both floor and ceiling. Partially formed pillars, not separated from the cave walls form ribs (Plate 4).

Table 3. Cave Dimensions.

CAVE NAME	A	B	C	D
Avernus	176	85	35	
Boomslang	507	130	70	
Clovelly	191	67	53	
Devil's Pit	78	40	34	22
Drip Water Pot	122	38	15	
Echo Halt	124	71	16	
Harbour View	260	57	23	35
Labyrinth	210	71	32	
Muizenberg	196	58	30	
Oread Halls	333	110	82	
Ronan's Well	615	291	59	20
Tartarus	162	57	26	
Tjoklet's Grotto	77	51	13	
Vier Grotte	107	45	18	
Ystervark	125	49	42	

All dimensions in metres
A= total passage length
B= length along major axis
C= overall width along minor axis
D= depth from surface unless horizontal

Although no large speleothems occur in these pseudokarst caves, they are not entirely devoid of formations. Small 5mm to 10mm stalactite nodules occur on the ceilings and walls of many caves. These consist of an amorphous silica. No calcite is present.

DISCUSSION

The existence of pseudokarst implies strong chemical weathering to dissolve the silica matrix before fine sand washes or blows out (Martini, 1984). The Cape Peninsula pseudokarst is relict, as shown by its altitudinal position and by the breakdown that affects many karstified valleys and many cave entrances. The Harbour View - Lower Aladdin cave complex is truncated by cliff retreat above Clovelly. The present multiple entrances formed part of the network plan.

Cave Peak, Ridge Peak and Kalk Bay Mountain, separated one from the other by the Spes Bona and Echo valleys, carry the highest density of caves (Figs. 3). These caves are essentially phreatic tubes narrowing and becoming impassable northwards, but coalescing to form larger conduits towards the south. Some caves still carry drainage in winter and flow is southwards. Because they are now truncated by Echo and Spes Bona valleys and by cliff recession, they indicate an ancient water movement towards the Fish Hoek - Nordhoek valley. The concentration of cave development on the three ridges overlooking Kalk Bay and the clear

Figure 5. Ronan's Well, the longest sandstone cave showing network development.
(E= horizontal usual entrance. Surveyed by S.A.S.A. (Cape) 1982 by A.Hitchcock and S. Hine).

evidence of conduit flow towards the Fish Hoek - Noordhoek fault trough suggests that the fault trough must have been in existence as a negative landscape feature when the pseudokarst developed.

The development of a joint-guided surface pseudokarst with flared slopes and pinnacles indicates sub-soil solution followed by stripping of the overburden. The cave characteristics are indicative of a shallow water table with water movement through phreatic tubes joining to form conduits (the caves entered by people). The association of cave levels indicates a falling water table with periodic still-stand. Cavernous weathering and surface micro features form subsequent to exposure. Clearly much of the superficial cavernous weathering still occurs today, enhanced by salt weathering (Young, 1987). However the disintegration of associated case-hardening would seem to suggest reduced process at present.

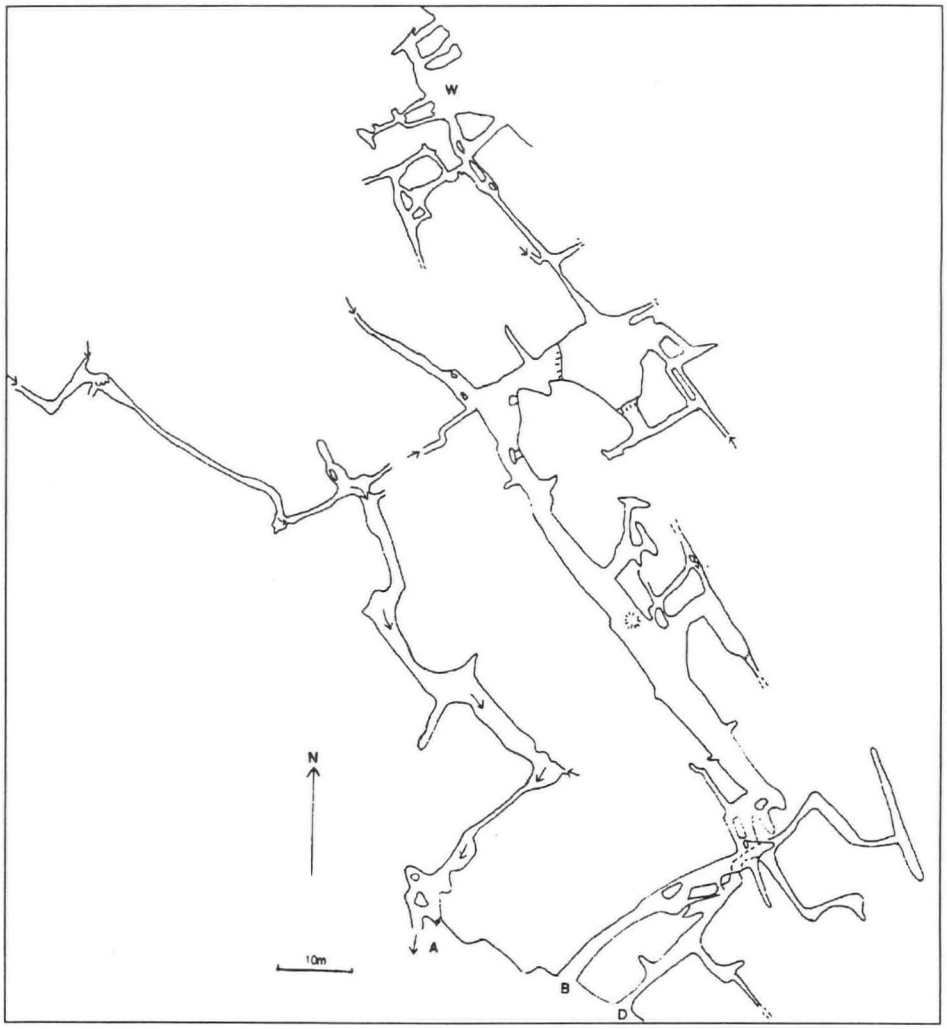
High temperatures, regular rainfall and a forest cover are the likely conditions for such concentrated solution in a non-carbonate rock. Throughout the Cape Province, remnants of a coastal platform considered to be part of the extensive Late Mesozoic African surface are capped by silcrete and laterite overlying deeply altered saprolite. African Surface planation took place over at least 40 million years, following the separation of the southern continents (break-up of Gondwanaland). The African surface below the Great Escarpment developed in relation to the current sea level. Uplift in the Miocene and Pliocene periods brought this period of planation and deep weathering to an end. The African surface was then uplifted and warped. Could the pseudokarst have been formed contemporaneously? This weathering period is certainly the most pronounced in the Cenozoic geomorphic record and the most likely to account for strong weathering of silicious rocks and the development of pseudokarst.

The very different surface elevations of the various pseudokarst localities even on the Cape Peninsula itself must be addressed. (Table 4). Could late Tertiary faulting with displacement have occurred? The different blocks are undoubtedly separated by major faults but conventional wisdom decrees that South Africa forms part of a stable plate. Only now are the effects of Cenozoic tectonics being appreciated (Maud and

LOCATION	SURFACE ALTITUDE	CONTACT ALTITUDE	ALTITUDE DIFFERENCE
Table Mountain:			
Central Table	c. 1050	500	550
Blinkwater/Echo	c. 950	480	470
Back Table	c. 750	320	430
Silvermine:			
Steenberg Peak	c. 500	240	260
Cave Peak	450	140	370
Ridge Peak	500	c. 100	400
Kalk Bay Mountain	510	80	430

Table 4. Height of Pseudokarst Surfaces.

Figure 6. An example of a shallow phreatic network pseudokarst cave. (Arrows show direction of water flow. A= Avernus Cave, B= Boomslang Cave, D= White Dome cave, W= Wesssel's Grotto. Surveyed by S.A.S.A. (Cape) 1982 by C.J.Larkin and A.N. Hitchcock).



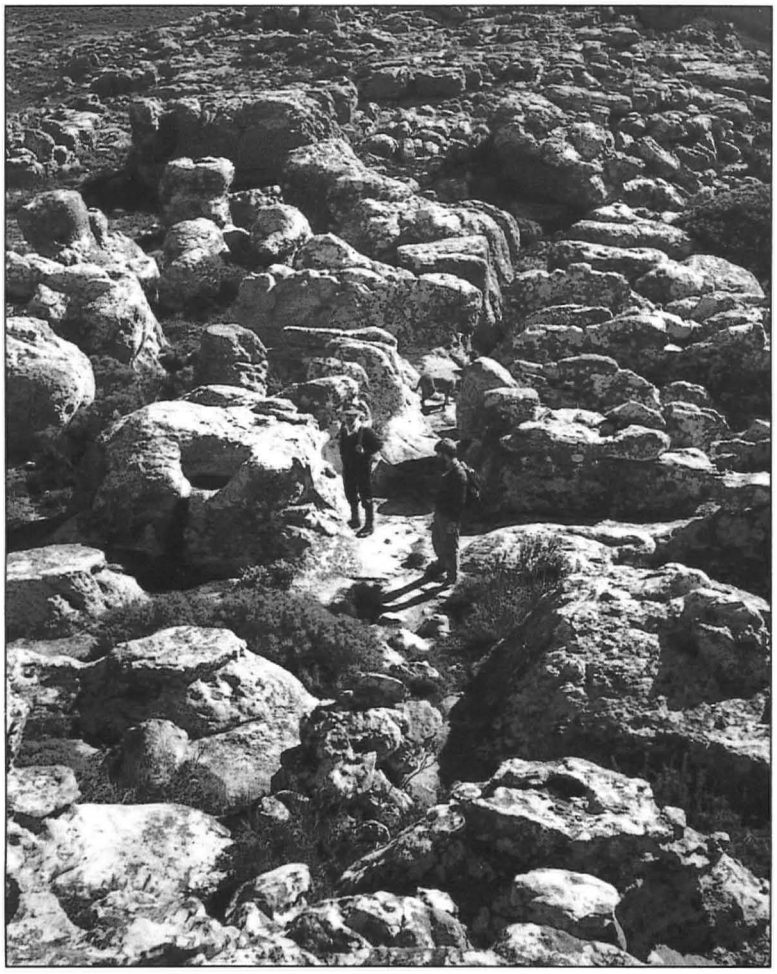


Plate 3. Rock Town, aligned pseudokarst pillars and grikes. People for scale. The high ground in the middle ground is Upper Steenberg Peak.

Partridge, 1987). When the elevations of the pseudokarst areas are related to the basal altitude of the Peninsula Sandstone at the contact with the underlying Graafwater Shales, it is clear that the blocks must have undergone differential uplift (Table 4). On Table Mountain, the Central Table has a surface altitude of 1050m, whereas the Back Table has an altitude of 750m and the three ridges in the Silvermine Reserve reach altitudes of only about 500m (Table 4; Fig.2). With one exception the relative constancy of altitude above the Peninsula Sandstone base suggests that differential uplift is a reasonable assumption. Furthermore Tertiary flora reported from the Noordhoek basin at the western end of the Fish Hoek trough, rests on weathered granite with ?silcrete at a depth of -80m (Coetzee, 1986).

A long period of time was necessary for the planation of the African Surface and the development of deep weathering mantles on it. Uplift is known to have occurred in both the Miocene and the Pliocene Period (Maud and Partridge, 1987). The dismemberment of the African Surface during the Pliocene uplift is hypothesised as having caused differential uplift of the Cape Peninsula mountains so that they now stand at differing altitudes above sea level. The presence of deeply weathered granite in the Noordhoek Basin and at -80m on the west coast is corroborative evidence that the African surface weathering previously affected the Cape Peninsula and that differential uplift occurred. As a consequence, surface pseudokarst also occurs at different altitudes in different areas on different fault blocks.

Most surface pseudokarst sites show large block weathered collapse, which, in kloofs such as Echo Valley and Kleintuin Kloof, is overlain by more recent cliff spall forming scree. The latter may well be a product of the Last Glacial event when the Cape Peninsula lay almost 200km inland and annual temperatures dropped between 5° and 8°C. The massive block collapse is very much older as the blocks are themselves weathered. Pseudokarst development pre-dates even that event. Perhaps the disintegration of the karst by massive block collapse accompanied the uplift and disruption of the African surface?

CONCLUSION

Attention has been focused on the existence of well-developed pseudokarst on the mountains of the Cape Peninsula. Two areas have been discussed in detail. The formation of the pseudokarst is considered to have been due to strong chemical weathering associated with the formation of the Cenozoic African Surface. The present differences in elevation of these pseudokarst areas are attributed to Pliocene differential uplift.

ACKNOWLEDGMENTS

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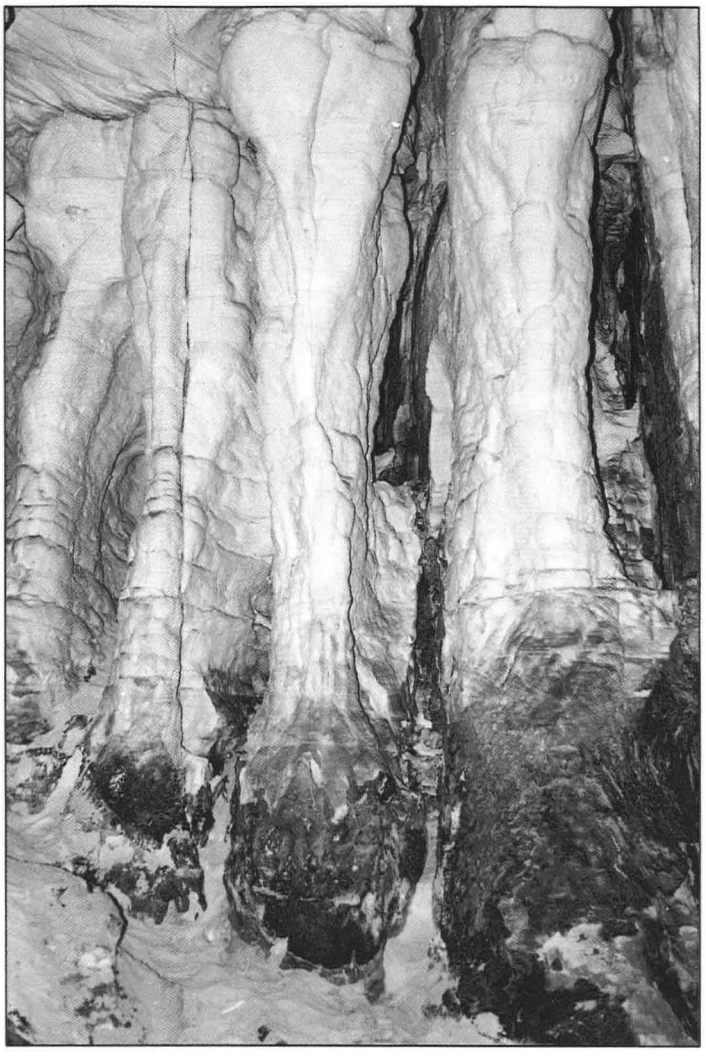
Plate 4. Rock ribs (columns) developed by solution in the shaft entrance to Ronan's Well. Each rib is approximately 4 m in height.



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