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A REVIEW OF THE REGIONAL STRUCTURAL CONTROLS ON THE OCCURRENCE AND CHARACTER OF THE VENTERSDORP CONTACT REEF

T.S. McCARTHY

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UNIVERSITY OF THE WITWATERSRAND
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by

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ABSTRACT

Economically mineralized Ventersdorp Contact Reef (VCR) appears to be confined to the tectonically active northwestern and western margins of the Witwatersrand Basin and occurs in the West Rand, Carletonville and Klerksdorp goldfields and in the northern extension of the Welkom goldfield. The VCR appears to occur in two distinct forms: (i) the "Western Deep Type" which consists of extensive, residual pediment deposits with pronounced palaeo-relief, which grade distally into extensive gravel sheets with much reduced palaeo-relief. The reef is characterized by small angular unconformities ($<4°$) in the footwall. This type occurs west of the West Rand Fault in the Carletonville goldfield and along the northwestern margin of the Klerksdorp goldfield. (ii) The "South Deep Type" occurs as narrow zones of mineralized conglomerate adjacent to active faults. It is characterized by a more marked angular unconformity in the footwall (10-15°) and rapid facies change into distal gravels and sands. This type occurs at South Deep and to the north of Loraine in the Welkom goldfield. Both types probably become conformable with the underlying strata down dip.

The two types appear to be related to regional tectonic controls: the Western Deep Type reflects a broad erosional pediment produced by uplift and gentle tilting of a basement block underlying the basin margin with the upper reaches of the pediment being more incised; the South Deep Type represents a narrow pediment formed on upwarped strata adjacent to an active, basin-bounding, reverse fault. Mineralization in both types is confined to the zone of active erosion, and it appears that erosion of mineralized strata in the footwall contributed significantly to their gold content.

The two classes of VCR have parallels in the underlying Witwatersrand stratigraphy; the Western Deep type is equivalent to the laterally extensive unconformity based reefs such as the Basal or Vaal Reefs, while the South Deep Type has its equivalent in the Elsburg massives at Cooke Section of Randfontein Estates or the Eldorado Reefs at Loraine Gold Mine. However, the mode of preservation is different in that the VCR was buried beneath lavas while the underlying equivalents were buried as a result of transgressions or alluvial fan progradation. Consequently the VCR has escaped later reworking and primary depositional features of the deposits are preserved although extensive diagenetic remobilization of gold has occurred.

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CONTENTS

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INTRODUCTION

Mining of the Ventersdorp Contact Reef (VCR), which is situated at the base of the Klipriviersberg Group volcanics, first commenced in 1899 on what is now South Roodepoort Main Reef Gold Mine (De Kock, 1941). This horizon was subsequently traced to the north on Luipaardsvlei Estates Gold Mine and to the east to Venterspost and Libanon Gold Mines. The presence of conglomerate at the same stratigraphic position was also reported from the Vredefort area by Nel (1927) and from Heidelberg by Rogers (1922), but neither occurrence proved to be economic. In 1939, exploitation of the VCR commenced in the Klerksdorp Goldfield on Western Reefs Gold Mine (now part of Vaal Reefs) (Thomas, 1979). Exploration of the Carletonville Goldfield during the 1930's proved extensive areas of payable VCR and today the VCR is the major ore-bearing horizon on several gold mines in this gold field. New areas of mineralized VCR have recently been discovered in the West Rand (South Deep Project Area, JCI, 1990) and in the Welkom Goldfield (Sun and Target Project Areas, Anglovaal, 1992). The presently known extent of VCR development is shown in Figure 1.

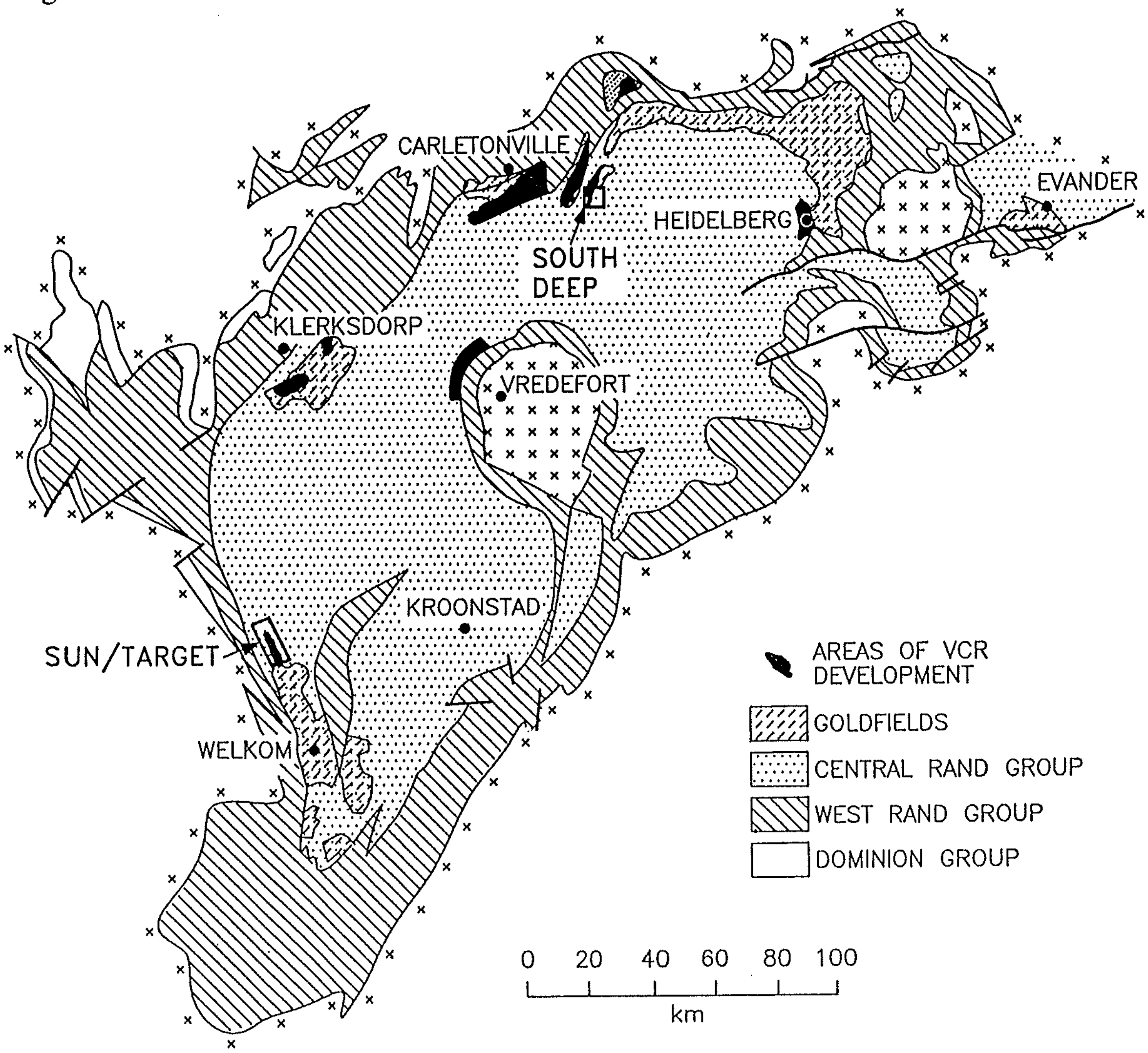


Figure 1: The distribution of known VCR occurrences.

The VCR lies unconformably upon West Rand and Central Rand Group strata and is considered to represent an erosional hiatus which preceded the eruption of the Klipriviersberg Group volcanics (De Kock, 1941, 1964). There is a close spatial association between mineralized VCR and the presence of mineralization in the underlying lithologies. In this review, the occurrence of mineralized VCR is examined in the context of the tectono-sedimentary development of the Witwatersrand Basin.

THE TECTONO-SEDIMENTARY DEVELOPMENT OF THE WITWATERSRAND BASIN

There is now general consensus that the Witwatersrand Basin developed in a compressive, probably foreland, setting, possibly related to the Limpopo orogeny, and the general tectono-sedimentary development of the basin has been interpreted as supporting this concept (eg. Burke et al., 1986; Winter, 1987; Stanistreet and McCarthy, 1991). Myers et al. (1990, 1992) have undertaken a detailed analysis of basin evolution in this context.

Sedimentation in the Witwatersrand Basin commenced with a widespread marine transgression, which gave rise to the Hospital Hill Subgroup, probably in response to thermal subsidence following the Dominion Group rifting event (Bickle and Eriksson, 1982; Clendenin et al., 1988a). The subsequent evolution of the basin was evidently strongly influenced by low angle southwesterly directed subduction beneath the northern margin of the Kaapvaal Craton (Clendenin et al., 1988b) which led to inversion of the Dominion Basin and produced progressively upward-coarsening sedimentary fill. Predominantly marine sequences of the lower portion of the basin gradually gave way to fluvially dominated environments which became progressively more proximal upwards in the succession. The interaction between fluvial and marine depositional systems locally played an important part in the development and preservation of laterally extensive placer deposits. Moreover, the emplacement of intrusives above the subducting plate and the development of associated high-level epithermal systems probably provided the source for the gold mineralization and the abundant siliceous clasts which characterize the placers of the basin (Robb et al., 1991; Hutchinson and Viljoen, 1988).

Detailed analysis of the architecture of the basin led Clendenin et al. (1988b), Myers et al. (1990, 1992) and Stanistreet and McCarthy (1991) to propose a Laramide style, compressive block fault model for basin evolution during Central Rand Group times. Stanistreet and McCarthy (1991) identified at least 19 tectonic blocks which responded to the SW-NE directed regional stress by uplift, by rotation about sub-horizontal axes, with adjacent blocks over-riding each other (Figs. 2, 3) and by strike-slip relative motion (Stanistreet et al., 1986). Sedimentation was predominantly from the uplifted blocks to the north and west, with the basin being open to the southeast, at least in its early stages. These uplifted areas, which were denuded of sedimentary cover, have long been recognized as being fundamental to the development of the basin and have been referred to as "basement domes" (Brock and Pretorius, 1964; Pretorius, 1976). The Vredefort Dome, however, is unrelated to this deformation and has a later, post-Transvaal origin (McCarthy et al., 1990a).

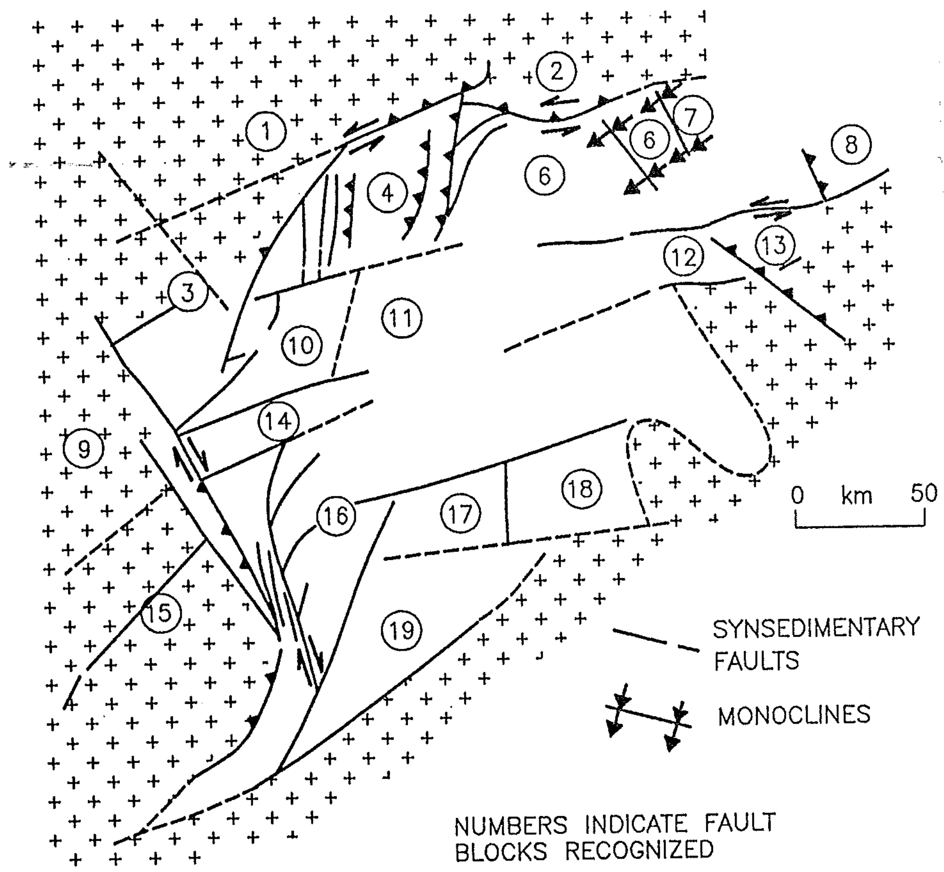


Figure 2: Structural map of the Witwatersrand Basin showing the major syn-sedimentary fault or deformation zones which define the margins of basement blocks. The major blocks are numbered (from Myers et al., 1992).

Sediment accumulation on the intra-basinal blocks was strongly influenced by their movement, but generally the interiors of these blocks are characterized by gradual changes in stratigraphic thickness and general stratigraphic uniformity. In contrast, block margins are characterized by rapid changes in stratigraphic thickness, by folding caused by draping over rising margins and by the merging of unconformity surfaces.

Periodic eustatic falls in sea level or tectonic uplift of blocks caused, for example, by fluctuations in in-plane stress (e.g. Karner, 1986), resulted in widespread erosional degradation, producing extensive gravel covered pediments on which concentration of heavy minerals occurred. These were subsequently reworked and buried during sea-level rise or tectonic subsidence and hence are overlain by upward-fining sequences, culminating in silicious siltstones or shales. Angular unconformities associated with these placers are generally small ($<4°$) but the extent of erosional cutdown may be extreme towards the hinterland because of their lateral extent. Heavy minerals released during erosion of footwall strata would have become incorporated in stratigraphically higher placers with concomitant increase in tenor. The laterally extensive, highly mineralized placers such as the Basal Reef, Vaal Reef, Main Reef, Carbon Leader and Nigel Reef probably formed in this way (Buck and Minter, 1985; Brink, 1986; Verrezen, 1987; Turner, 1979).

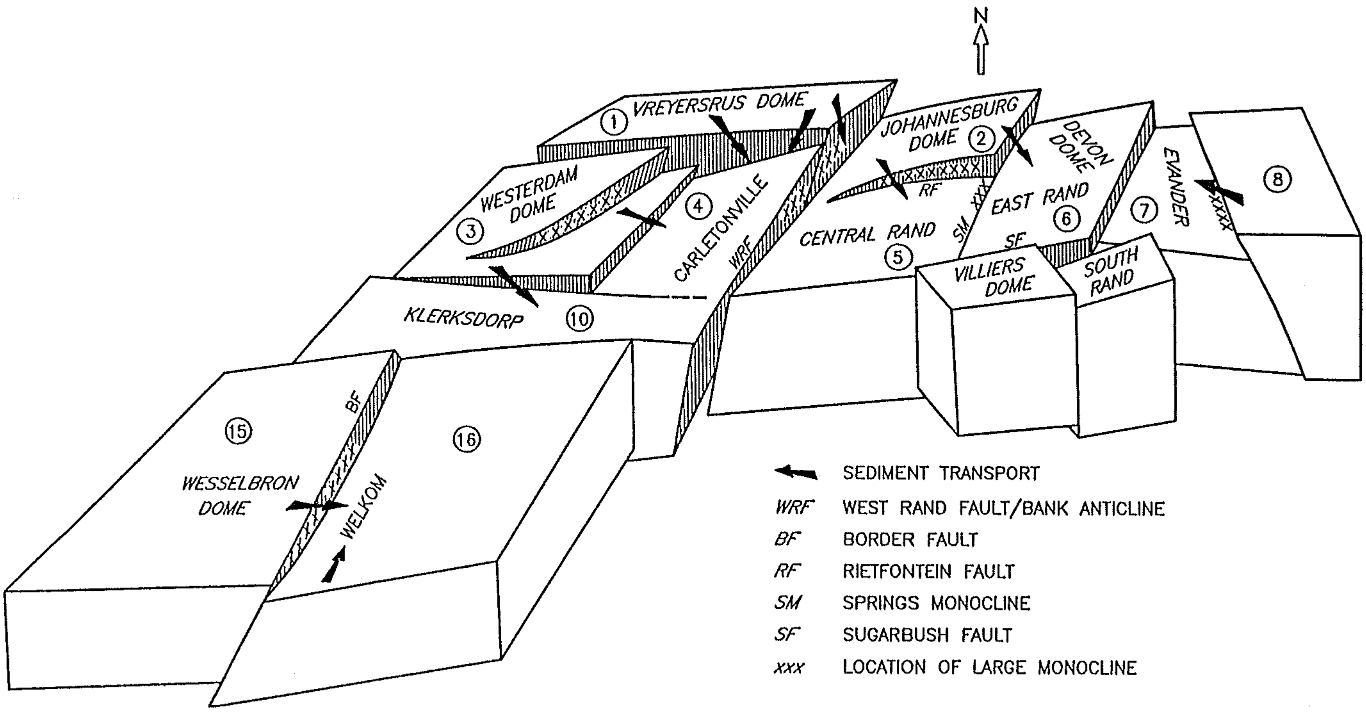
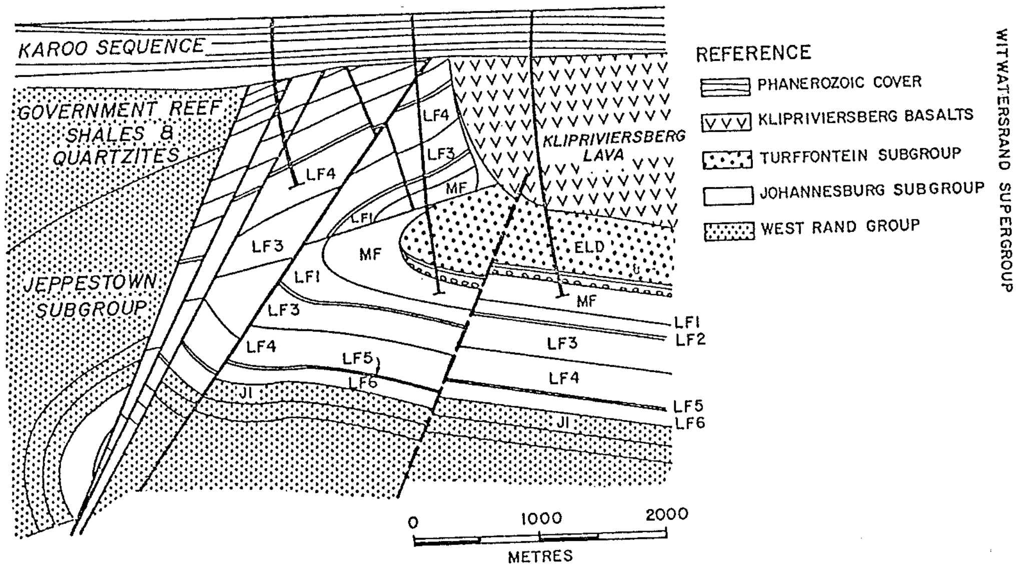


Figure 3: Schematic diagram illustrating the relative movement of some of the major tectonic blocks. Numbers refer to blocks in Figure 2: arrows indicate sediment transport directions reported by Minter and Loen (1991).

Although block movement appears to have commenced during deposition of the Government Subgroup, a generally subdued topography must have prevailed at that time, following as it did directly on an extensive marine transgression. Consequently, placers which are developed in the Government Subgroup have a distal character and gold tenor is low. Moreover, marine transgressions are common in this sequence. However, uplift of the hinterland became progressively more pronounced with time and topographic gradients increased, so that fluvial systems began to dominate and successive placer horizons have a more proximal character (Mellor, 1917; Loen, 1992). Optimal conditions for placerization occurred during deposition of the Johannesburg Subgroup, but towards the end stages of basin development, topographic gradients became extreme as the basin finally closed, and alluvial fans prograded into the basin (e.g. Kingsley, 1986) resulting in the coarse Mondeor Formation conglomerates which are rarely mineralized.

Progressive reverse movement on block margins, which continued throughout Central Rand Group sedimentation, resulted in the development of large, monoclinal to overturned folds adjacent to rising margins (Fig. 4). The significance of these structures was first recognized by Brock and Pretorius (1964) who termed them "Principal Declivities". They have been described from the western margin of the Welkom Goldfield (K.A.M. Tweedie, 1986), from the Klerksdorp area (Brink, 1986; Clendenin et al., 1990), from the northern margin of the basin (McCarthy et al., 1990b) and from the Evander area (E. Tweedie, 1986). As can be seen in Figure 4, pronounced angular unconformities developed in these structures as a result of simultaneous deformation and sedimentation, particularly towards the end stages of Witwatersrand sedimentation. The resulting angular unconformities are markedly steeper than those developed beneath unconformities within blocks, generally exceeding 10°.

A



B

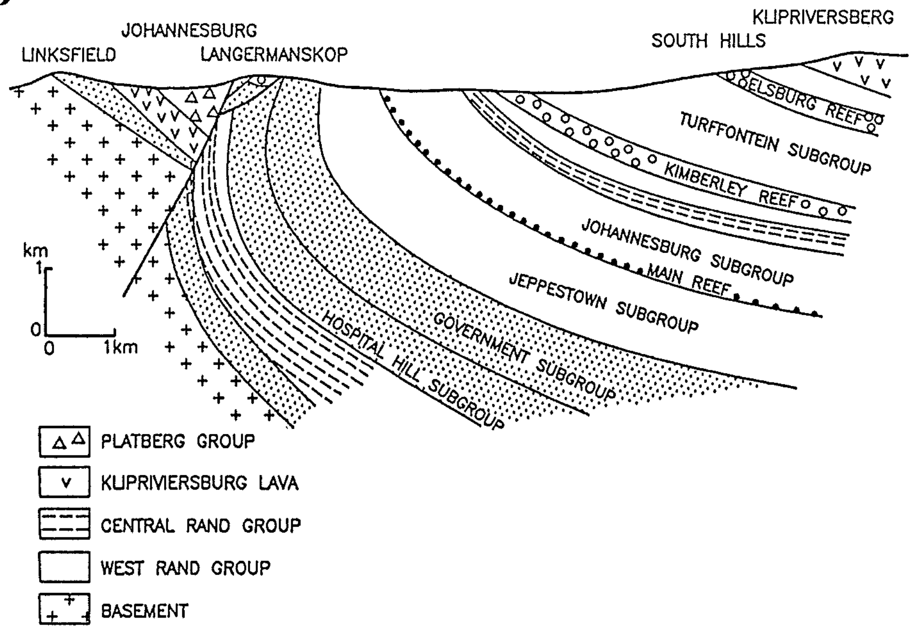


Figure 4: Syndepositional monoclinal structures, which characterize compressive block margins, are exemplified by those from the Welkom (A) and Central Rand Goldfields (B).

Localized placer development was also associated with these structures late in their formation, particularly in the Welkom and West Rand Goldfields (western margins of blocks 16 and 5, Fig. 2, respectively). In these two areas, a narrow (± 1000m) degradational pediment developed, passing rapidly down slope to an aggradational braid plain (Tucker and Viljoen, 1986, and Fig. 5). Placerization occurred on the narrow pediment where merging of unconformity surfaces produced high gold grades in massive conglomerates, such as the Elsburg Massive Reefs on Cooke Section of Randfontein Estates Gold Mine (Fig. 6). Grade falls off rapidly down the palaeoslope onto the braid plain environment, where quartzite partings separate conglomerate horizons.

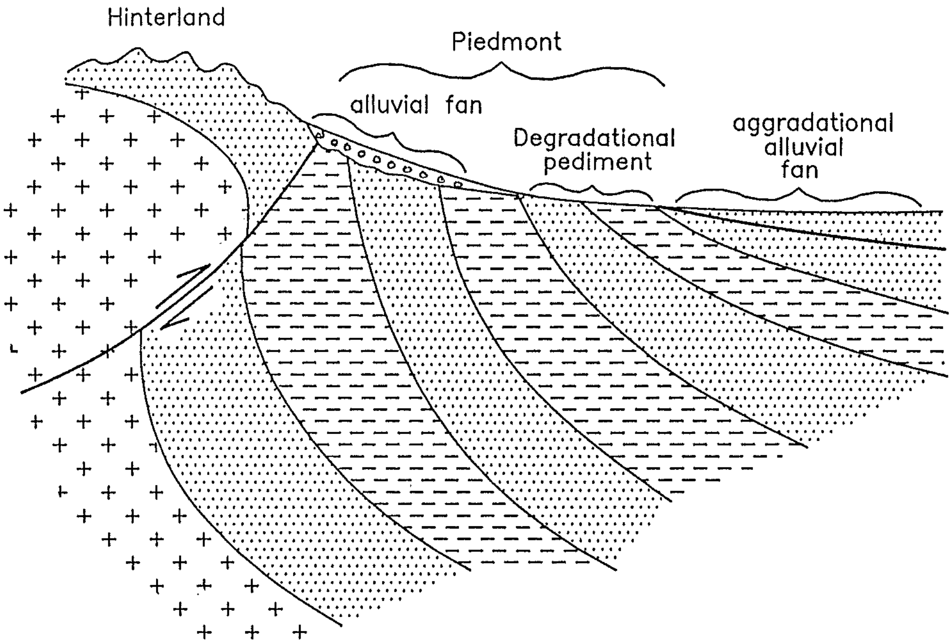
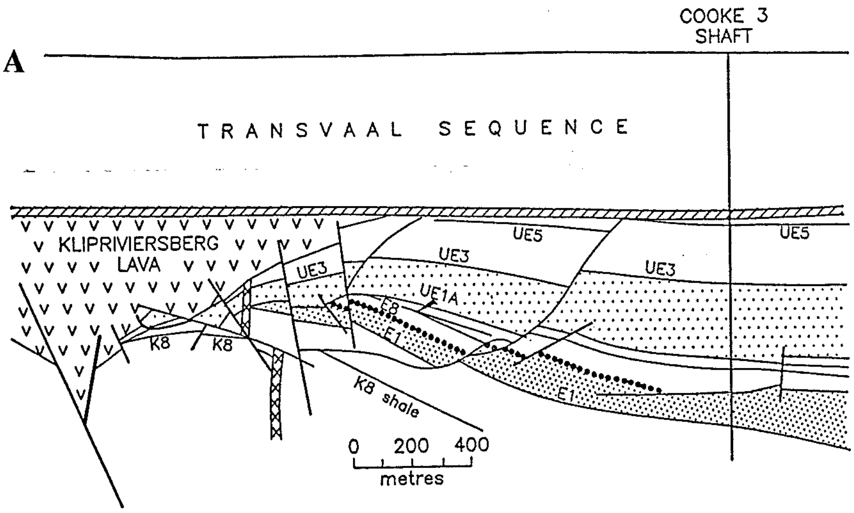


Figure 5: Schematic diagram illustrating geomorphic elements associated with a compressive block margin.

The situation described here is well illustrated by the distribution of mining on Loraine Gold Mine in the Welkom Goldfield. Figure 7a shows a section through the Eldorado Reefs on the northern portion of the mine and Figure 7b the same section restored using the overlying boulder beds of the Uitkyk Formation as datum. The merging of unconformity surfaces and their influence on grade (as indicated by stoping) is clearly evident. The localization of this zone of placerization is illustrated by the plan view of stoped areas on the mine (Fig. 8). It is evident that continual reworking of heavy minerals from the underlying strata was important in the development of this style of mineralization, although contribution of material from the eroding hinterland would also have been important. The erosional pediment must have remained localized for a protracted period - in the nature of a "hinge zone" - separating the degradational hinterland with its alluvial fans from the aggradational alluvial plain (Fig. 5). In this case, the degradational pediment was buried by progradation of a more proximal alluvial fan sequence (the Uitkyk Formation) (see Fig. 5).



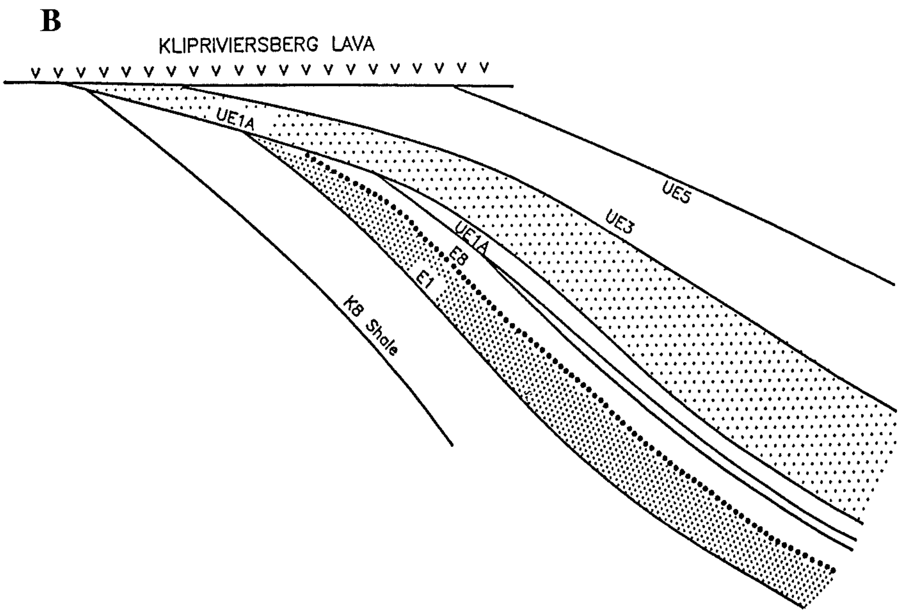


Figure 6A: East-west geological section through Cooke 2 Shaft, Randfontein Estates Gold Mine (from Viljoen, 1989).

6B. Palinspastic reconstruction of the Cooke 2 geological section using the base of the Klipriviersberg Group as datum.

Witwatersrand sedimentation was terminated by the eruption of the Klipriviersberg Group lavas. This event was diachronous, commencing in the north (Linton et al., 1993) (Fig. 9). Sedimentation continued during the early phases of eruption of the Westonaria Formation (Unit 1), producing the so-called "inter-reef lavas" (Hall, 1993), but with time, volcanicity became widespread and the entire basin and probably much of the hinterland became inundated (Linton et al., 1993).

Towards the end stage of the Klipriviersberg Group eruption, extensional conditions developed in the crust, resulting in the collapse of earlier compressive block margins. Widespread normal faulting occurred, producing a "Basin and Range" topography, and

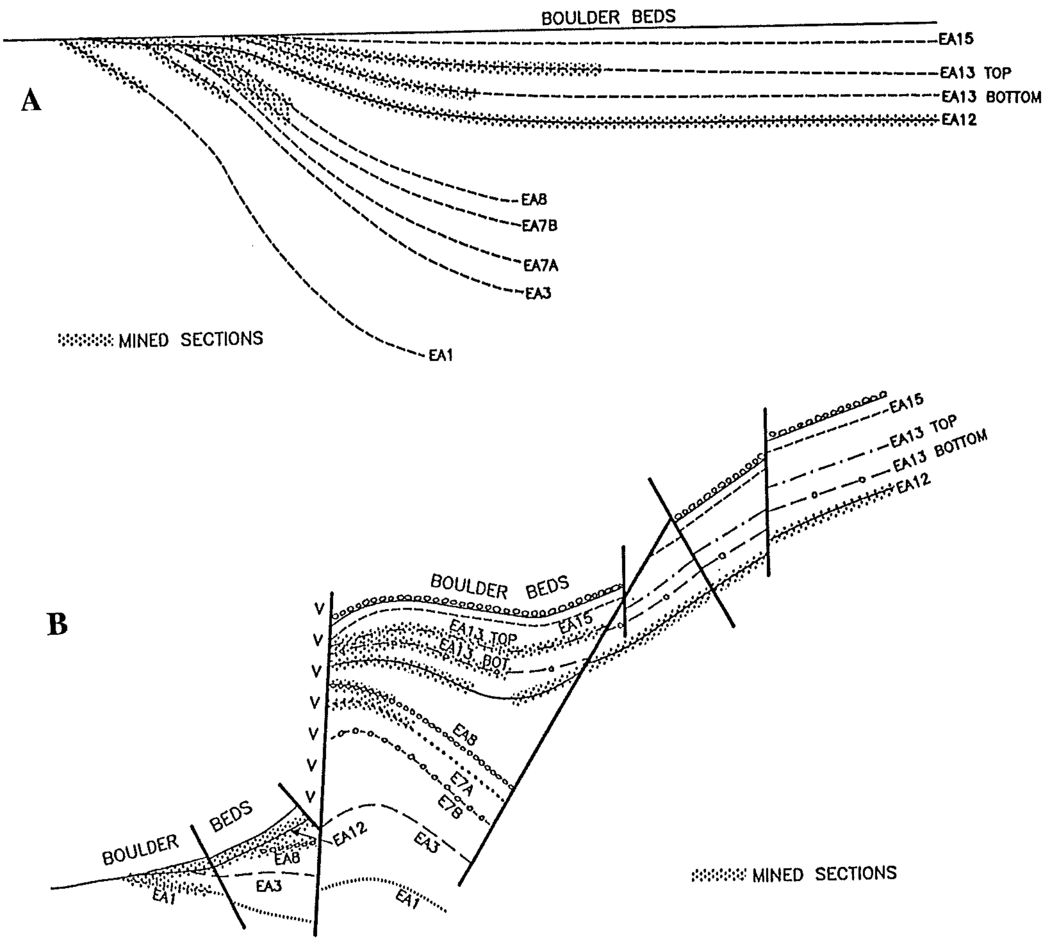


Figure 7A: East-west geological section through the Eldorado Reef on the northern portion of Loraine Gold Mine (from Tracey and Wuth, 1987).
7B: Palinspastic reconstruction of the section shown in Figure 7A, using the base of the Uitkyk Formation as datum.

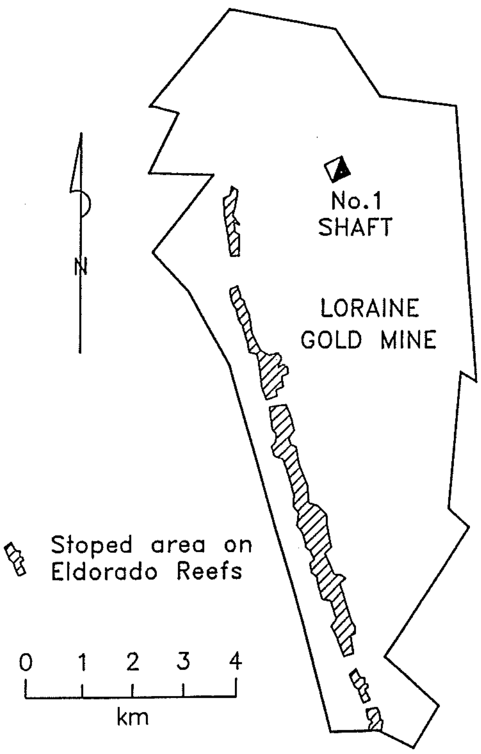


Figure 8: Plan of Loraine Gold Mine showing the extent of mining of the Eldorado Reefs.

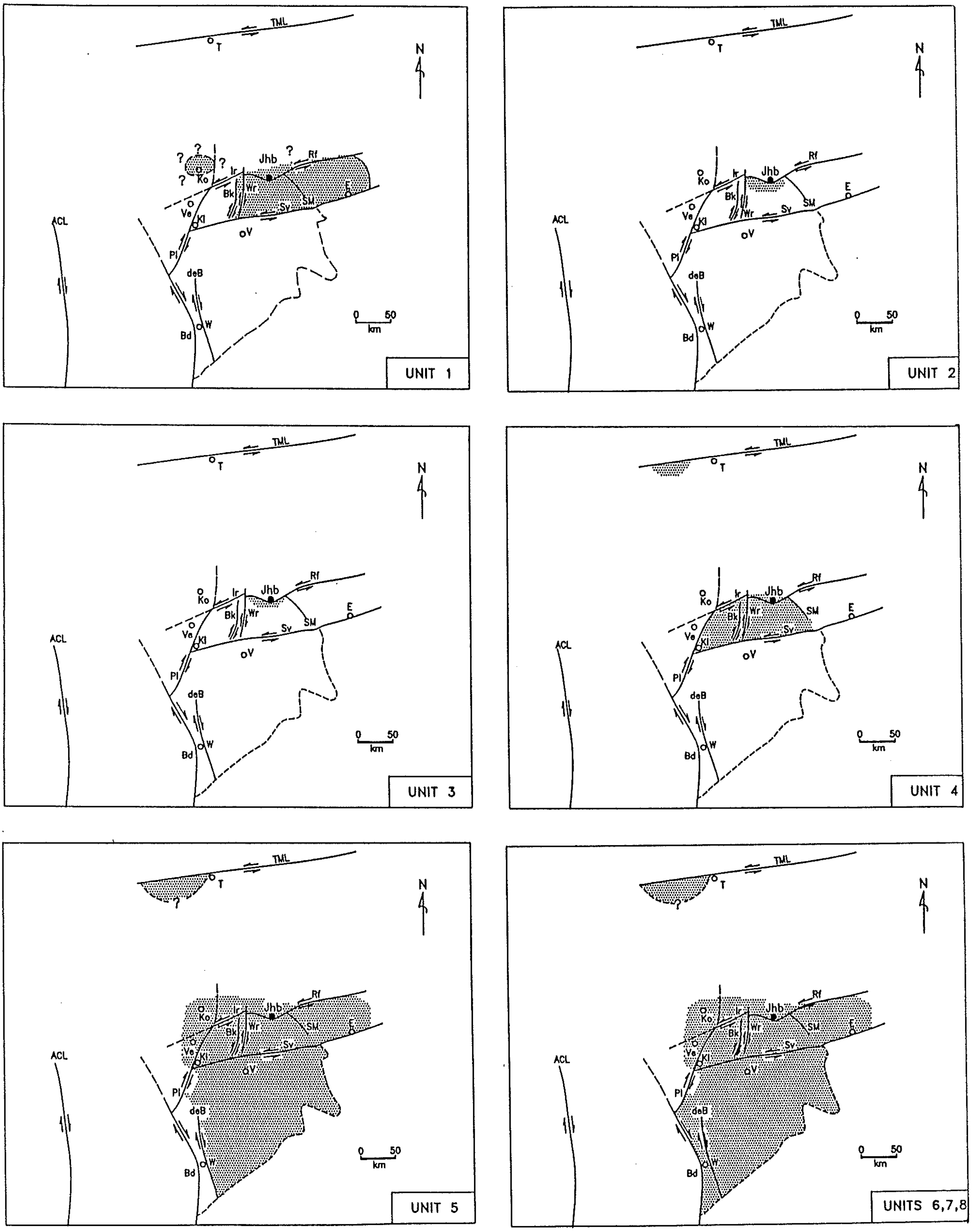


Figure 9: Maps showing the aerial extent of the lower eruptive units of the Klipriviersberg Group volcanics (from Linton et al., 1993).

sediments accumulated in the resulting localized grabens forming the Platberg Group (Buck, 1980., Myers et al., 1992; Stanistreet and McCarthy, 1991). Roll-over anticlines developed along many of the former marginal synclines due to the activation of normal faults along these tectonic margins. These can be seen at Cooke Section of Randfontein Estates Gold Mine (Fig. 6) and at Loraine Gold Mine (Fig. 10). This phase of rifting has been interpreted as a consequence of the impact of the Zimbabwean and Kaapvaal Cratons (Stanistreet and McCarthy, 1991).

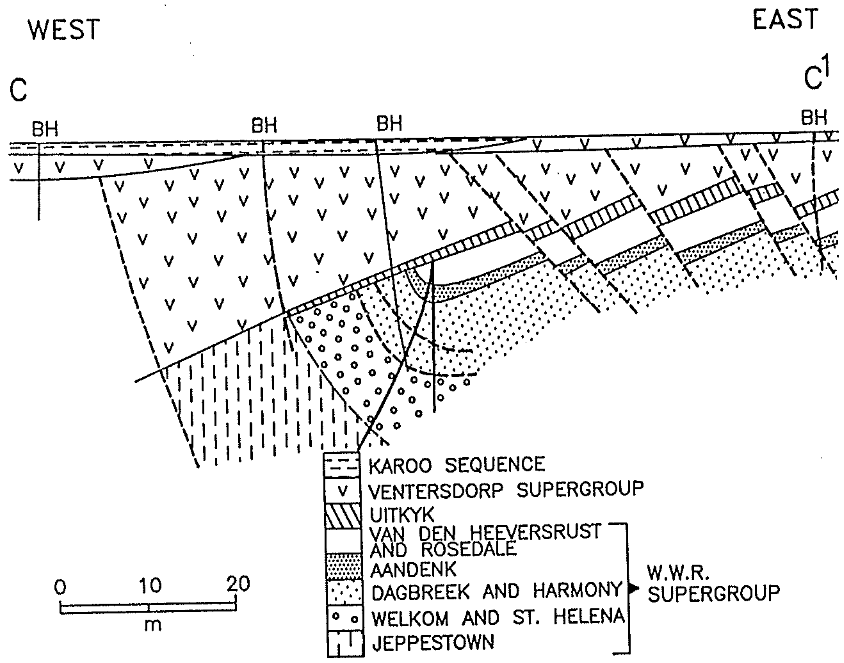


Figure 10: East-west geological section across Loraine Gold Mine.

THE NATURE OF THE VCR

De Kock (1941) first recognized the VCR to be a degradational feature, having a marked unconformable relationship with the underlying Witwatersrand Supergroup strata. He noted, however, that the overlying Klipriviersberg Group was completely conformable with the Witwatersrand over large areas. De Kock (1941, 1964) also noted the effect of bedrock and local palaeotopography on the morphology and character of the VCR conglomerates. Detailed work by Thomas (1979) in the western portion of the Klerksdorp Goldfield (Vaal Reefs Gold Mine) revealed the VCR to be a degradational surface consisting of gravel-draped terraces and intervening broad, shallow, valley-like depressions containing more robust conglomerates. He showed that grade was directly related to conglomerate facies, but that locally bedrock influence was important. Els (1989) identified similar features in the VCR along the northern margin of the Klerksdorp Goldfield on Stilfontein Gold Mine.

Krapez (1979, 1985) examined the relationship between conglomerate facies and palaeotopography in more detail in the Carletonville Goldfield and, like Turner (1979), recognized the VCR as being a gravel mantle lying on a variably incised pediment. Locally, palaeotopography had a strong influence on facies. Degradation characterized palaeohighs while aggradational sequences characterized many of the intervening channels. In other areas, notably the West Rand, aggradational features tend to become dominant (Chapman and Briggs 1989; Minter, 1970; Mullins, 1993).

McWha (1988, 1993), McWha et al.(1990), Schweitzer et al. (1993) and Henning (1993), following Turner (1979), examined in detail the palaeogeomorphology of the VCR in portion of the Carletonville Goldfield, as well as its relationship to conglomerate facies. The important geomorphic elements they recognized were: terraces, which occurred at several discrete elevations, slopes or risers, channels, and embayments (Fig. 11). As much as 30m of palaeorelief was recognized. Trellised drainages were identified, with palaeostream courses often rising in theatre-headed valleys, suggesting bedrock control on drainage and the influence of palaeogroundwater seepage, respectively.

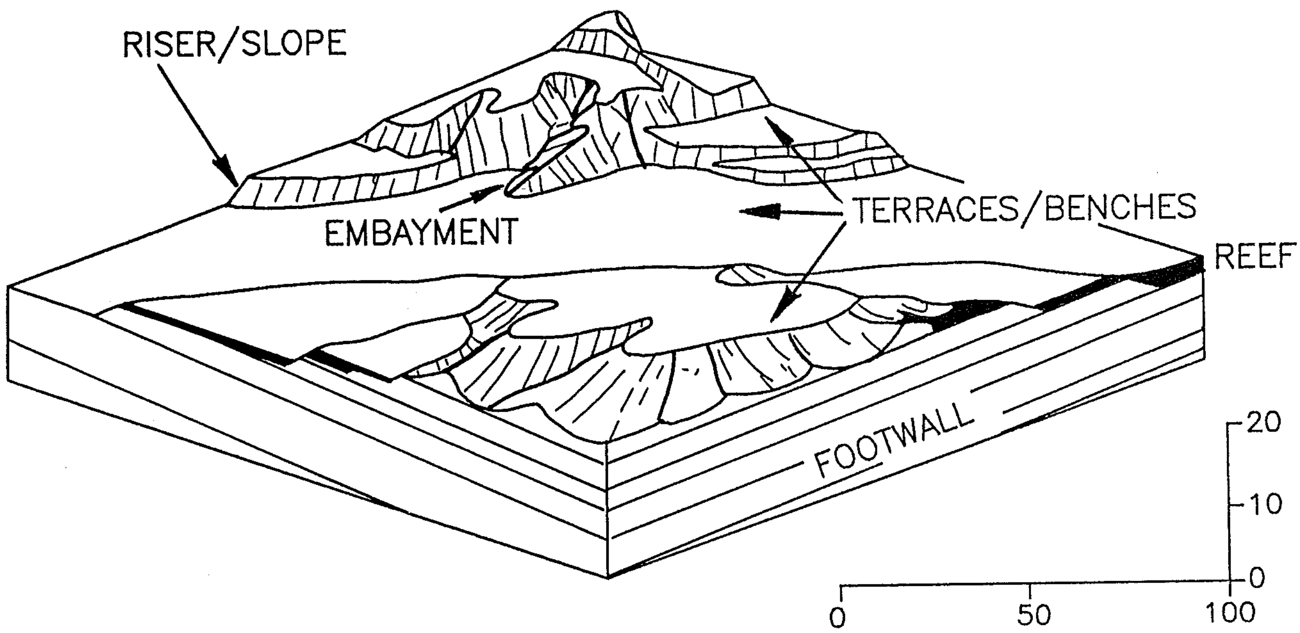


Figure 11: Palaeotopographic reconstruction of a section of the VCR on Western Deep Levels Gold Mine (from McWha, 1988).

McWha (1988) identified three basic conglomerate facies. Terrace reefs vary between 70 and 150cm in thickness and are generally uniform in character over a particular terrace. Conglomerate on intermediate terraces is often overlain by an apple-green quartzite. Conglomerate located on higher-lying terraces commonly exhibits a vertical zonation, with the upper portion being oligomictic, possibly due to palaeoweathering processes. These may be ancient analogues of the oligomictic "derived gravels" which commonly overlie high-level polymictic gravels along the modern-day Orange River (McCarthy, 1983). Slope reef is generally less than 30cm thick and appears to represent colluvial reworking of the terrace above. Outwash conglomerate is developed on the valley floors and in tributary sub-channels and is highly variable, ranging from clast-to matrix-supported types and is associated with lime-green quartzite. Certain footwall lithologies, notably the Booysens Shale, tend to be dominated by slopes, whereas others are incised and form valley floors (Schweitzer et al., 1993).

In contrast to the above, the more distal "Green VCR" (western and eastern facies of Mullins and Martin, 1986), on Deelkraal Gold Mine, apparently does not show the pronounced palaeorelief seen to the northeast. Channels in this region appear to have formed alluvial ridges, slightly elevated above the surrounding terrain (Van der Heever, 1993), suggesting an anastomosed channel system on the distal reaches of the pediment.

The VCR in the Klerksdorp and Carletonville Goldfields described above are clearly very similar in style and overall form. Both have low angles of unconformity ($<4°$) with pronounced bedrock control on palaeotopography and on grade. Although the grade is locally variable, the horizon is payable over large areas, as is indicated by the extent of stoping of the reef (Fig. 12).

Recently details of two new VCR discoveries have been released, namely in the area south of Western Areas Gold Mine and referred to as the South Deep Project Area (JCI, 1990; Fig. 1) and in the area to the north of Loraine Gold Mine in the Welkom Goldfield, referred to as the Sun-Target Project Area (Anglovaal, 1992; Fig. 1). Although information is limited to drill intersections, it is evident that the VCR in these two areas differs substantially from VCR presently exposed by mining.

At South Deep, as well as the area to the north (Western Areas Gold Mine and Cooke Section of Randfontein Estates Gold Mine), the distinction between the VCR and the underlying Elsburg Reefs is less clearly defined than in other areas - the VCR being generally conformable with the underlying reefs (Tucker and Viljoen, 1986). Towards the west, however, an unconformable relationship develops, but the VCR thins to a narrow parting. A similar situation is developed at South Deep (JCI, 1990). Here, the VCR conglomerate also thins to the west. Maximum development of reef and its contained gold mineralization is confined to a narrow north-south trending zone (Fig. 13), which strikes parallel to the major compressive Witwatersrand age West Rand Fault and Bank structure.

The VCR in the Sun-Target Area has a very similar character, being confined to a narrow zone along which most of the mineralization occurs (Fig. 14). This mineralized zone lies on the north-west extension of the mineralized section of the Eldorado Reef zone and suggests a similar mechanism of formation.

Both types of VCR probably grade basinward into laterally extensive sand bodies which conformably overlie the Central Rand Group and the VCR, as such, is not recognized. In these areas, Klipriviersberg volcanics lie conformably on the Central Rand group, with the occasional development of a mixed lithology on the contact (the "lithic tuff" of Wyatt, 1976).

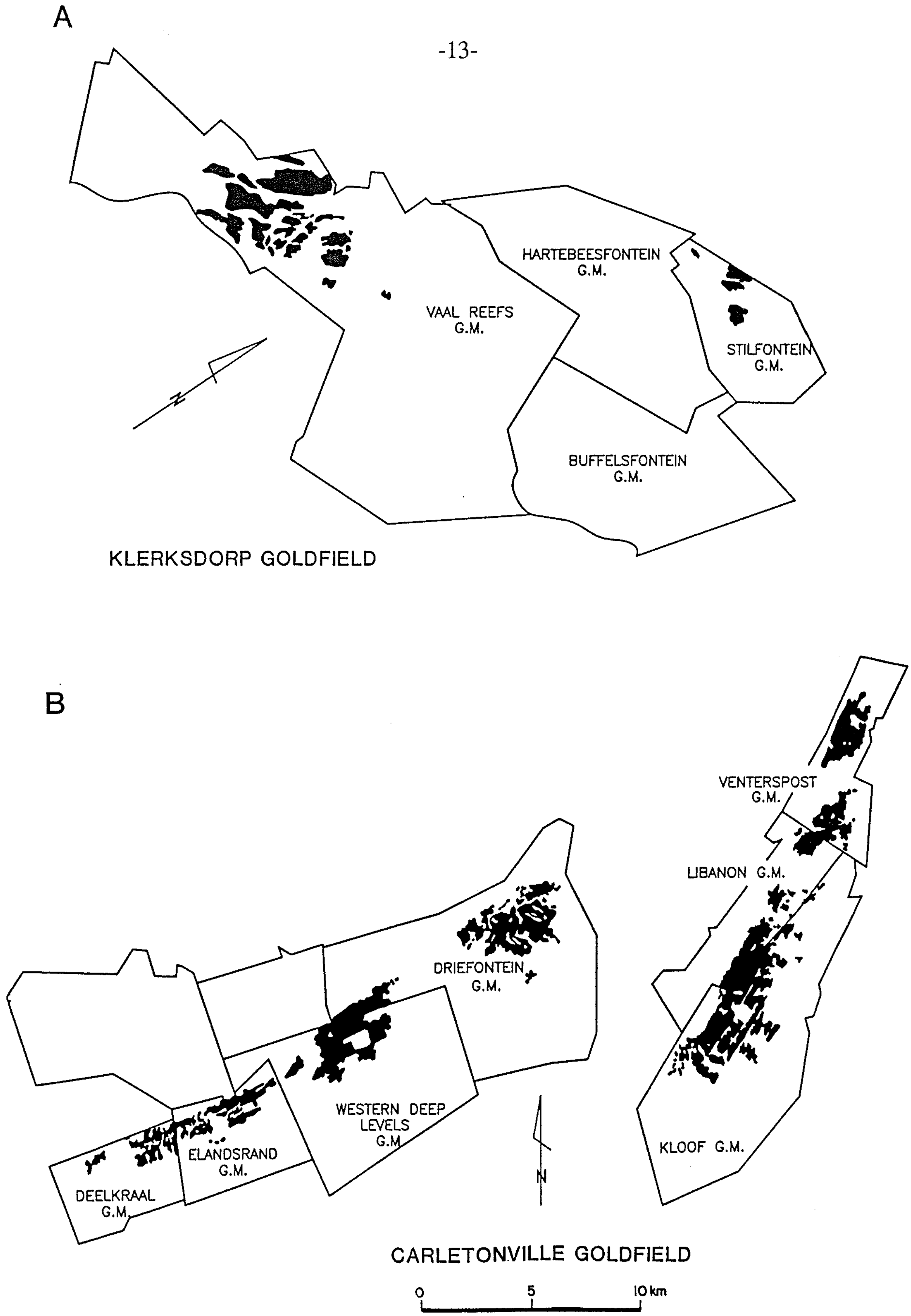


Figure 12: Maps showing the extent of mining (in 1991) of the VCR in the Klerksdorp (A) and Carletonville Goldfields (B).

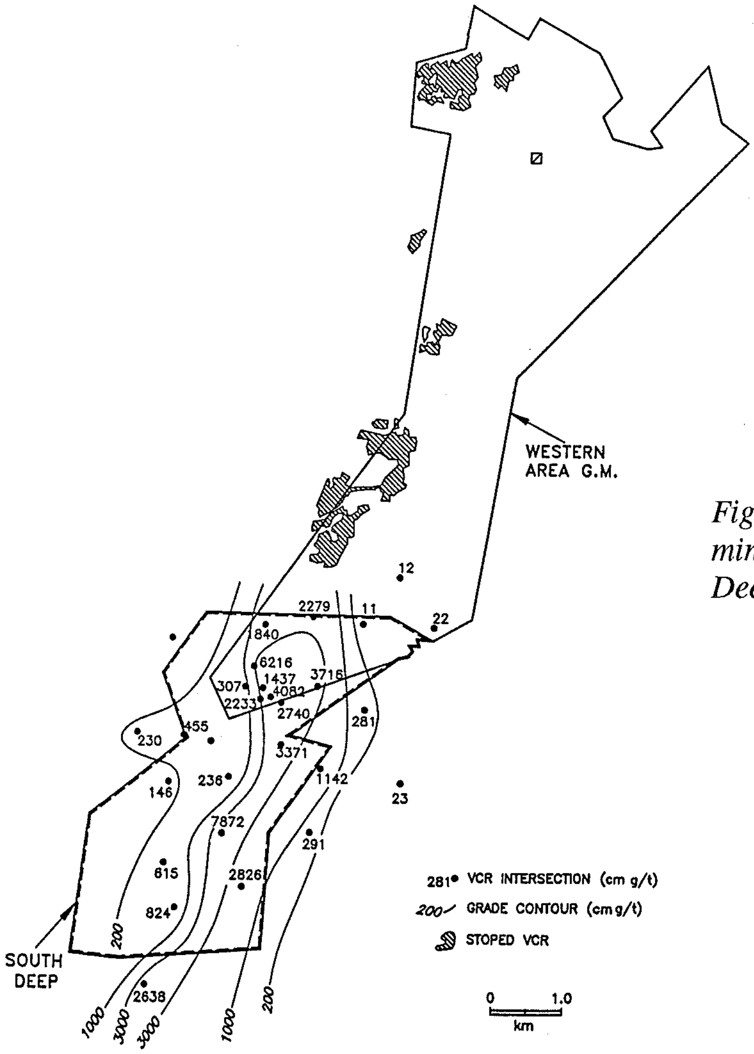


Figure 13: The distribution of gold mineralization in the VCR in the South Deep Project area.

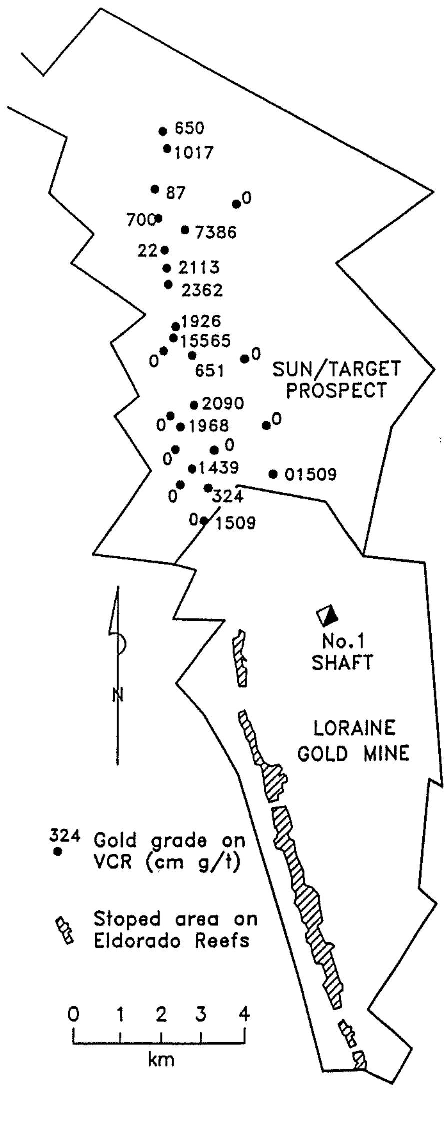


Figure 14: The distribution of gold in the VCR in the Sun/Target Project area and its relationship to mining in the Eldorado Reefs on Loraine Gold Mine.

DISCUSSION

The VCR, described as the "Pompeii of Placers" by I.C. Rust (pers.comm.) because of its rapid preservation beneath volcanics, has afforded a unique opportunity to examine placer formation in the late Archaean. The relevance of these processes to the Central Rand Group placers needs, however, to be demonstrated.

Although the alluvial fan model for Witwatersrand placers is well entrenched, the characteristics of the VCR are not those of alluvial fans. Alluvial fans are aggradational and while erosional unconformities may develop on alluvial fans due, for example, to fan head incision, these develop within the fan succession. In contrast, the VCR erodes well down into the footwall succession, even as far as the Jeppestown Formation and is clearly primarily a degradational feature. This is further emphasized by the palaeorelief of the VCR surface as well as by the material on this surface. Locally, aggradational sequences occur, but these represent accumulations in palaeodrainage channels and most probably reflect eroded material in transit across an essentially degrading surface (Rust, 1993). These considerations led Turner (1979) to propose a pediment model for the VCR.

The essentials of Turner's model, which is derived from the work of Denny (1967) are illustrated in Figure 5. According to Denny "where a large basin adjoins highlands of resistant rock, fans may form only part of the neighbouring piedmont; on the remainder of the piedmont, streams will carve broad pediments veneered with gravel" (page 103). The streams rise both within the highland and on the piedmont itself. The relative sizes of pediment and fan vary. Rapid uplift of the highland will result in progradation of the fan across the pediment whereas, in contrast, protracted denudation of the highland will result in destruction of the fan and expansion of the pediment.

Two distinct types of VCR are developed in the Witwatersrand Basin: (1) extensive, planar surfaces, with low angles of unconformity, which are mineralized over much of their extent. In more proximal areas, these surfaces show pronounced palaeorelief (e.g. Western Deep Levels Gold Mine), but this decreases down the palaeoslope (e.g. Deelkraal Gold Mine); and (2) narrow, linear zones of placer development, with pronounced angular unconformities in the footwall (e.g. South Deep area). Both types grade basinward into sandy braidplains. The former type, here referred to as the Western Deep Levels Type, is developed in the Carletonville and Klerksdorp Goldfields and occurs within large tectonic blocks (Blocks 4 and 10, Fig 2.) where gentle rotation and uplift of the block has produced a broad pediment. The latter type of VCR, here referred to as the South Deep Type, occurs immediately adjacent to compressive fault zones along block margins where continual uplift and erosion of the basin margin has produced a narrow erosional pediment.

Both types appear to have analogues within the Central Rand Group. The Western Deep Levels type is akin to the extensively mineralized horizons such as the Vaal Reef or Carbon Leader, which occur within tectonic blocks. The mode of preservation differs, however, and reworking during subsequent transgression has led to planation of the palaeotopography in the case of the Central Rand horizons. Moreover, the most proximal reaches of these pediment surfaces have, in all cases, been removed by subsequent erosion. The South Deep Type, in contrast, has a parallel in the Eldorado Reefs. Preservation in this latter example resulted from progradation of proximal alluvial fans. It is thus evident that the processes which produced the VCR placers, including the tectonic controls, were no different from those which produced mineralized horizons in the Central Rand Group. Thus, while a distinction is often made between the VCR and economic horizons of the Central Rand Group, it appears that the VCR is, in reality, a product of continued development and an integral part of the Witwatersrand Basin.

Economically mineralized VCR only occurs in those areas where underlying reefs contain significant mineralization suggesting that erosion of footwall lithologies played an important part in enriching the VCR erosion surface. However, while gold contained in Central Rand Group reefs usually shows evidence of a detrital origin, this is not the case for gold in the VCR where petrographic evidence for a secondary origin predominates (Smits, 1993; Martin, 1988). The significance of this is presently unresolved, but given that the VCR surface was buried by lavas while still in an unconsolidated state, local remobilization of gold during diagenesis would be expected.

CONCLUSIONS

Two fundamentally different styles of mineralized VCR are developed in the Witwatersrand Basin, here termed the Western Deep Levels Type and the South Deep Type. The Western Deep Levels Type is characterized by widespread mineralization developed in extensive conglomerate sheets. The surface on which the conglomerate is developed shows variable palaeotopographic relief. Footwall lithologies strongly influenced the palaeotopography and hence the grade of the mineralization. Angles of unconformity in the footwall are generally only a few degrees or less. These deposits are confined within large, fault-bounded, intra-basinal tectonic blocks. This type of VCR is developed in the Carletonville and Klerksdorp Goldfields and its mode of formation is probably analogous to the underlying Carbon Leader and Vaal Reef conglomerates. The South Deep Type is characterized by a narrow zone of mineralization striking parallel to the basin margin. Basinward of this zone, the conglomerate degenerates and sand partings become common, while towards the hinterland the conglomerate thins to an unmineralized parting. Angles of unconformity in the footwall are generally of the order of 10° or more. This type of VCR occurs along tectonically active basin margins and is generally associated with monocline development. It is developed to the north of the Welkom Goldfield along the Border Structure and to the south of Randfontein along the West Rand Structure. Its mode of formation is analogous to the Eldorado Reefs in the Welkom Goldfield or the Elsburg Massives in the West Rand Goldfield. It is thus evident that the tectonic controls which shaped the Witwatersrand Basin also had a profound influence on the character of the VCR.

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