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by

R.E. MYERS, I.G. STANISTREET and T.S. McCARTHY

*(Economic Geology Research Unit, Department of Geology,
University of the Witwatersrand, P.O. WITS 2050,
Johannesburg, South Africa)*

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ABSTRACT

The relationship between a convergent continental margin on the northern edge of the Kaapvaal Craton (Limpopo Belt) and the development of the Late Archaean Witwatersrand Basin has recently been proposed. The resulting tectono-sedimentary style within the Basin has, however, not been assessed and is consequently misrepresented. If "thin-skin" structures (folds, thrusts, regional cleavage) resulting from the Middle Proterozoic emplacement of the Vredefort Dome are backstripped, a two-stage tectonic model for the Witwatersrand Basin can be recognized:

(1) a syn-Witwatersrand 2800Ma craton-wide compressional event culminating in the outpouring of Klipriviersberg flood basalts; and
(2) a post-Witwatersrand 2700Ma extensional event which relaxed the major oblique-slip reverse fault zones of the earlier event to develop grabens and half-grabens in which Platberg Group sediments accumulated. A reconstruction of the Witwatersrand Basin shows an E-W through-going set of left-lateral faults interacting with northerly connecting right-lateral faults to define individually moving fault blocks consistent with a NE-SW regional compression. Synsedimentary monoclines developed during deposition of the auriferous Central Rand Group as the surficial expression of the basement block faulting. This was associated with the development of gold placer-based, unconformity-bound, tectonostratigraphic packages, comprising mainly braided fluvial sediments, which repeatedly overstep older packages and basement across the block fault margins. Deformation culminated in thick alluvial fan sequences developed against fault scarps which caused prominent topographic highs. The Klipriviersberg flood basalts abruptly terminated sedimentation. The craton-wide extensional event associated with the deposition of the Platberg Group followed. This sequence of events may have Phanerozoic parallels in the rise and collapse of basement blocks in the Laramide province of North America.

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INTRODUCTION

Several authors have recently suggested that the Witwatersrand Basin formed in response to the convergence and collision of the Zimbabwe Craton with the Kaapvaal Craton, both of which acted as microcontinents (Burke *et al.*, 1986; Stanistreet *et al.*, 1986; Winter 1987; Clendenin *et al.*, 1988). Geophysical studies (Fairhead and Scovell, 1976) suggest that the Zimbabwe cratonic crust was partially subducted beneath Kaapvaal cratonic crust in this process which caused the culmination of the Limpopo orogenic belt.

Most authors view the Witwatersrand Basin as a sag response to the developing thrust fold belt, emphasising a "thin-skinned" structural style of deformation in the Kaapvaal Craton foreland. Recent studies of the Witwatersrand Basin by the writers, and synthesis of available structural, stratigraphic, and sedimentological information, derived mainly from mining activities, suggest that such a sag response was not the tectonic style of the Witwatersrand Basin at all, but that the basement became intricately involved with sedimentation through the development of large fault-bounded basement blocks which controlled sedimentation, particularly in the last stages of the Basin history (Myers *et al.*, 1990).

GEOLOGICAL SETTING OF THE WITWATERSRAND BASIN

The Late Archaean Witwatersrand Basin (3050 - 2708 Ma) (Fig. 1) has been preserved as a triangular-shaped structural entity (Pretorius, 1986) which has been largely covered by Proterozoic and Phanerozoic sequences. During its early history the area of the Witwatersand Basin was covered by a widespread epicontinental sea, which was much more widespread than the present basin itself, and in which the West Rand Group of the Witwatersrand Supergroup was deposited. The sediments represent subtidal deposits (Eriksson *et al.*, 1981) in which thick, subtidal, supermature, sand sheets tens of metres thick were intercalated with offshore basinal ferruginous mud deposits and pelagic ironstones.

In contrast, the Central Rand Group was deposited in a shrinking basin whose geometry evolved during deposition until it became close to its present configuration. Such basin shrinkage has been proposed previously (Pretorius, 1976; Vos, 1975) but not to the extent envisaged here. The sedimentary response to this tectonic evolution was a less mature suite of sediments, which now comprise conglomerates and meta-arkoses of fluvial origin. These are intercalated with several transgressive sequences, represented in one extreme case by a thick interbedded mudstone and siltstone unit, the Booysens Shale Formation. The finale in the development of the Witwatersrand Basin was the outpouring of the Klipriviersberg Group lavas; a $>$2km thickness of tholeiitic flood basalts. Zircons from these lavas have recently been dated by ion-microprobe at 2708 Ma (R.A. Armstrong, pers.comm.).

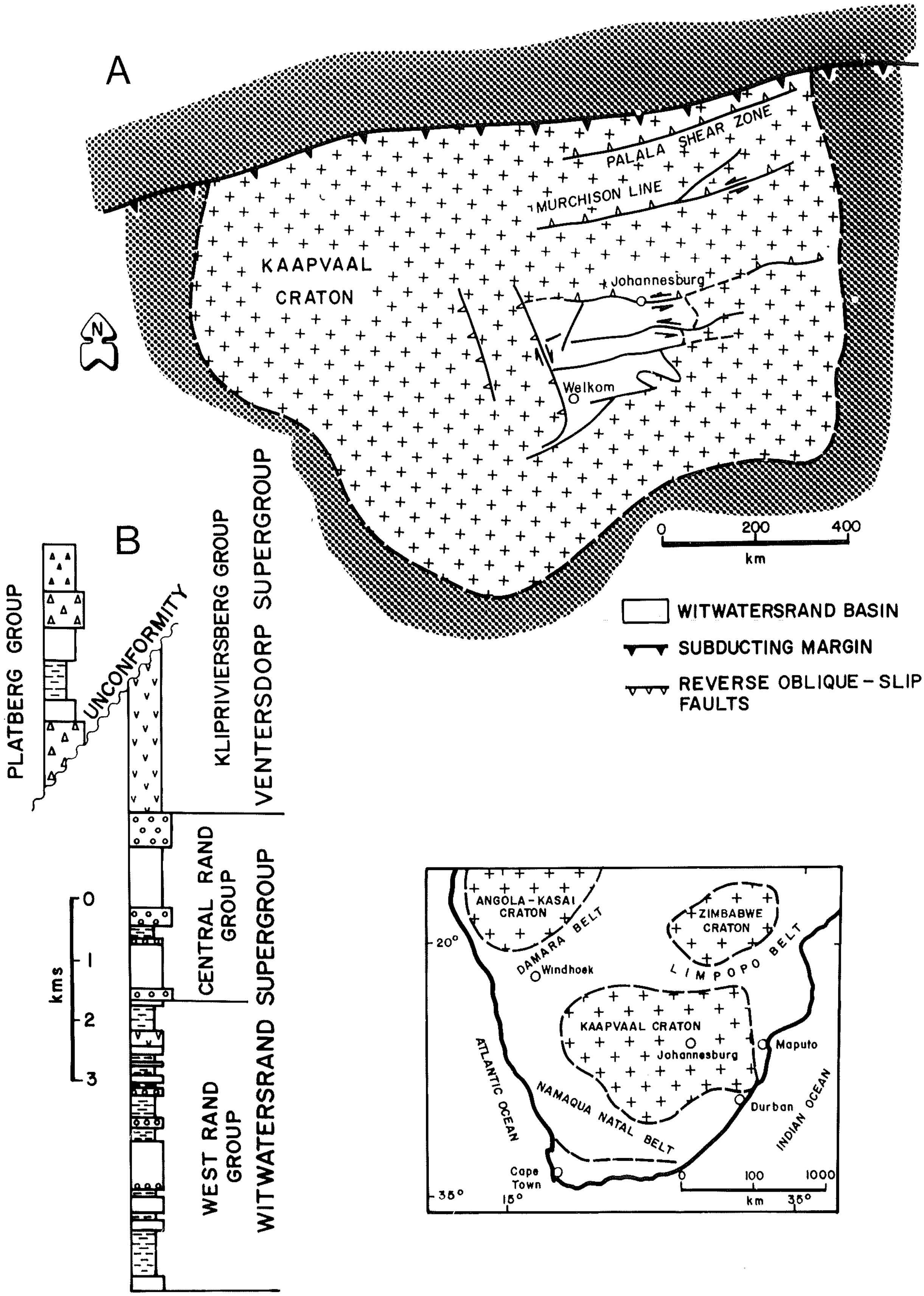


Figure 1: *(A) Location of the Witwatersrand Basin, and (B) the stratigraphy of the Late Archaean within the Kaapvaal Craton. In the stratigraphic column open circles = conglomerate units; dashes = mudstone units; blank = sandstone units; v's = lavas; triangles = diamictites/ paraconglomerates.*

After the eruption of the Klipriviersberg Group lavas, Platberg Group (Middle Ventersdorp) rocks were deposited in small, fault-related depositories in the area of the basin itself and, more substantially, in a large extensional rift basin just to the west of the Lichtenburg Basin (named here).

STRUCTURAL BACKSTRIPPING

Central to recent studies by the writers is the philosophy that in order to understand the development of the Witwatersrand Basin, subsequent structural events which have had a major effect on the Basin must firstly be stripped off in order to "see through" to the syn-sedimentary tectonism. Figure 2 summarises this process. Figure 2a shows major structural features associated with the emplacement of the Vredefort Dome (Simpson, 1977; McCarthy *et al.*, 1986). These include the Potchefstroom Synclinorium, the Rand Anticline and numerous circum-ferentially disposed thrusts such as the Westonaria thrust (Killick *et al.*, 1986) and the Master Bedding Plane Fault (Fletcher and Gay, 1972, McCarthy *et al.*, 1986). This phase of deformation represents a "thin-skinned" tectonic response which has been age-bracketed as Middle Proterozoic (McCarthy *et al.*, 1986).

When this youngest event has been stripped off, two other tectonic phases can be recognised which are both intimately related with the development and termination, respectively, of the Witwatersrand Basin itself.

The younger of the two is that which controlled the development of the Lichtenburg Basin, an extensional rift basin which accepted large volumes of mafic and felsic volcanics and sediments of the Platberg Group (Ventersdorp Supergroup). Early sedimentation comprised debris-flow dominated fans which prograded into lakes (Buck, 1980). The development of felsic volcanic centres in the basin appears to have been controlled by the same faults which controlled alluvial fan sedimentation (J.M. Myers, in prep.). Faults, such as the Rietfontein and Ireton Faults within the area of the Witwatersrand Basin, relaxed at this stage under left-lateral strike-slip movement (Stanistreet *et al.*, 1986) to develop small half-graben-like pull-apart basins in which a similar suite of sedimentary environments were developed. Very little volcanic material accumulated in these collapse basins compared with the main Lichtenburg Basin (Stanistreet and McCarthy, 1990).

To "see through" this tectonic phase (during the deposition of the Platberg Group) to the earlier syn-Witwatersrand deformation is a relatively straightforward procedure. Most of the structural lineaments which were acting with a normal component during the syn-Platberg Group basin development, were acting with a reverse component during Witwatersrand deposition. Accordingly, areas which were subsiding depositional areas during the development of the Platberg Group (Lichtenburg Basin, Ireton half-graben, Bezuidenhout Valley half-graben) were acting as topographically positive source areas during the deposition of the earlier Central Rand Group. This is an example of tectonic inversion. It has, however, an opposite polarity to other cases of tectonic inversion cited in the literature (e.g. Stoneley, 1982; Etheridge, 1986). Most reported cases refer to extensional basins, with faults generally having a normal component, inverting to a phase of compressional

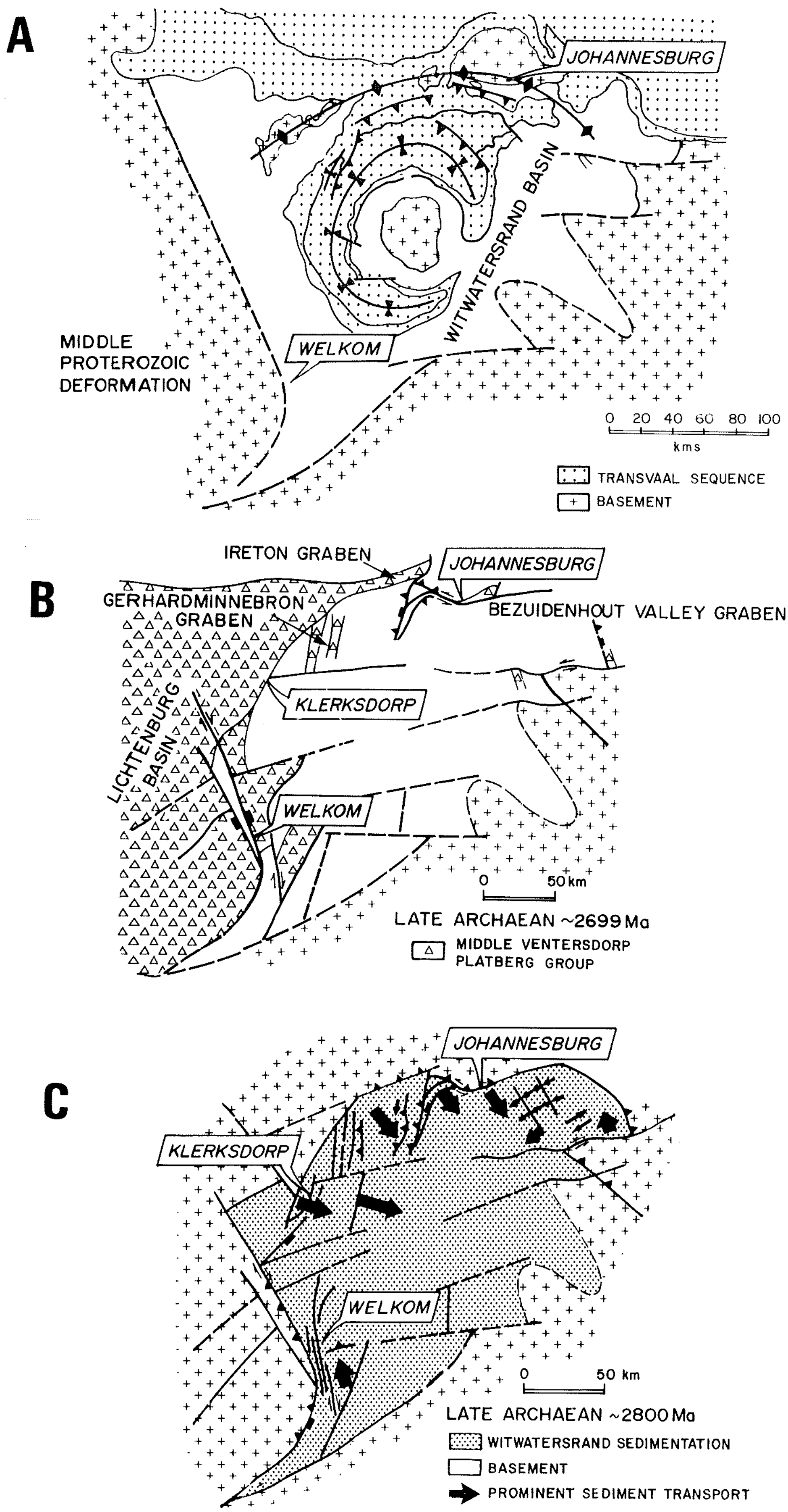


Figure 2: *Structural backstripping of structural events affecting the Witwatersrand Basin: (A) Proterozoic "thin-skinned" deformation associated with the emplacement of the Vredefort Dome. (B) the extensional rift phase which gave rise to the Lichtenburg rift Basin; and (C) the syn-Witwatersrand compressive deformation.*

tectonics in which faults are reactivated in a reverse sense. The present example is the exact opposite and might be considered as negative tectonic inversion, whereas the more commonly referred to situation might be regarded as positive tectonic inversion.

THE SYNSEDIMENTARY TECTONIC STYLE OF THE WITWATERSRAND BASIN

The map shown in Figure 3 has been compiled by Myers *et al.* (1990). It is based primarily on magnetic and gravity maps of the Witwatersrand Basin published by Corner *et al.* (1986), but also incorporates the principles discussed above in order to identify major syn-Witwatersrand, mainly compressional, structural features, through their control on sedimentary facies and stratigraphic thickness. It should be noted that the writers' resolution of knowledge is high where mining and exploration activity have been at a maximum. This resolution decreases markedly when moving into areas where depth has constrained such activity, particularly so in the area surrounding the Vredefort Dome and to the southeast of this structure.

Information in high resolution areas is adequate, however, to indicate that the sedimentation of the Basin has been controlled by rising fault-bounded basement blocks, of which nineteen have so far been identified, although more will undoubtedly be recognised in the future. As an illustration of the way in which these blocks interacted with sedimentation details will be given of Block 5, the Meyerton Block, together with its neighbours. In addition, some features of Block 15, the Welkom Block, together with a neighbouring block, will also be highlighted.

The Meyerton Block is located to the south of Johannesburg. It is bound on the north by the Rietfontein Fault and on the west by the West Rand Fault. Figure 4a shows a structural cross-section across the Rietfontein Fault, indicating that Witwatersrand Supergroup rocks have been folded upwards into a monoclinal structure by reverse motion on the fault. That this structure formed during sedimentation is shown by the overstepping of the Elsburg conglomerate across the upturned monoclinal limb, and also by the way the Klipriviersberg Group lavas overstep the structure to rest on top of lower Witwatersrand and basement rocks to the north of the fault. After this reverse component the Rietfontein Fault relaxed and collapsed, causing the Bezuidenhout Valley half-graben which filled with Platberg Group sedimentary rocks as described earlier.

The syn-Witwatersrand nature of the Rietfontein Fault is confirmed by the stratigraphic profile of Figure 4b. This shows that the Johannesburg Subgroup maintains an almost constant thickness within the Meyerton Block along a section parallel to the Rietfontein Fault, but thins dramatically along stratigraphic profiles measured towards this fault into the monocline. Myers *et al.* (1990) have also shown that the West Rand and Bank Faults, defining the western margin of the block, were syn-Witwatersrand faults downthrown on their eastern sides. This caused erosion and elimination of the entire Central Rand Group in related monoclinal structures before relaxing with a normal component during the deposition of the middle Ventersdorp (Platberg) strata. The Meyerton Block was, therefore, tilted and rotated under the compressive stresses which affected the entire Witwatersrand Basin but returned to its original position during the Ventersdorp relaxation phase.

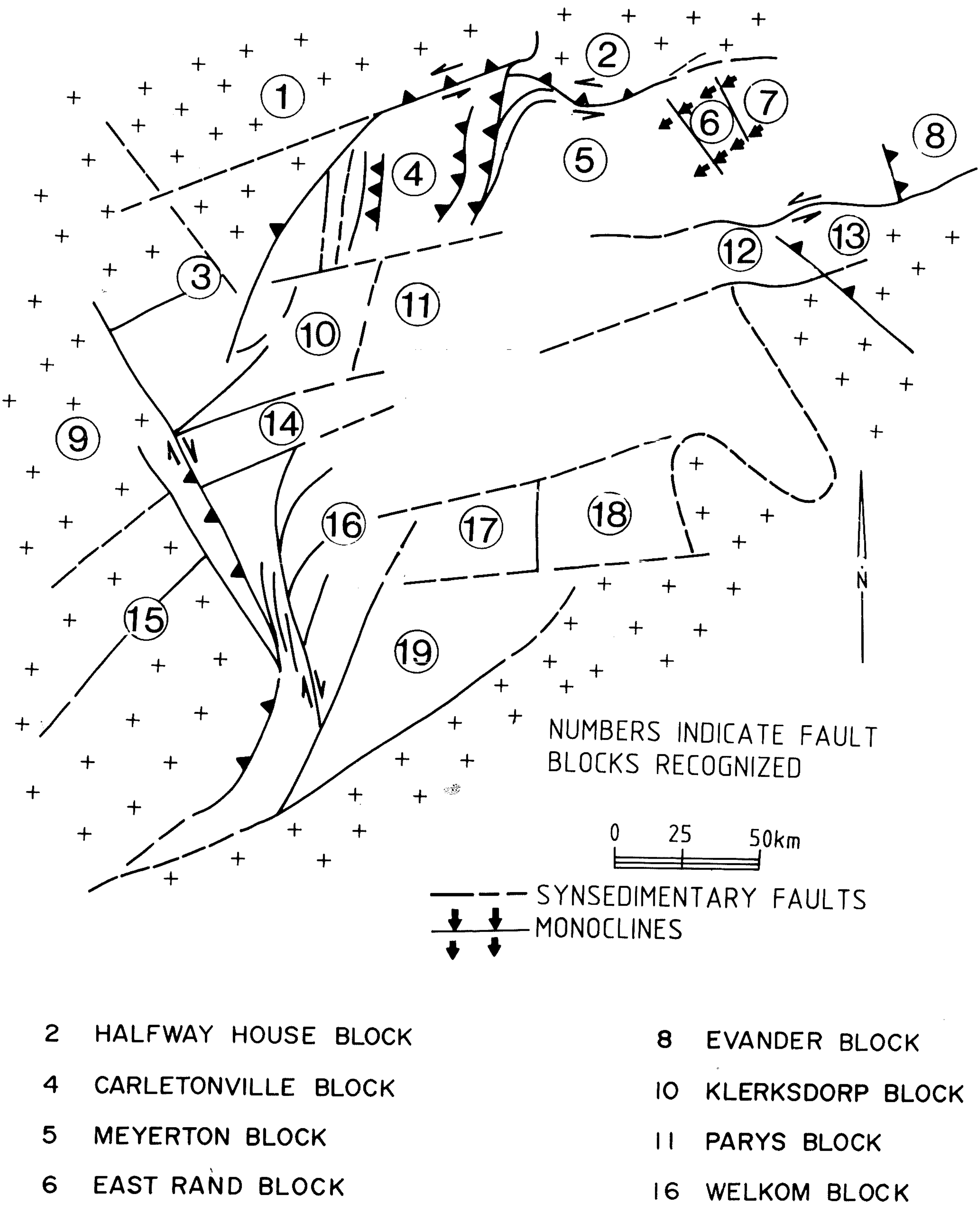


Figure 3: Structural map of the Witwatersrand Basin showing the major synsedimentary faults (or deformation zones) which define the edges of basement fault-blocks. Named blocks are listed on the diagram.

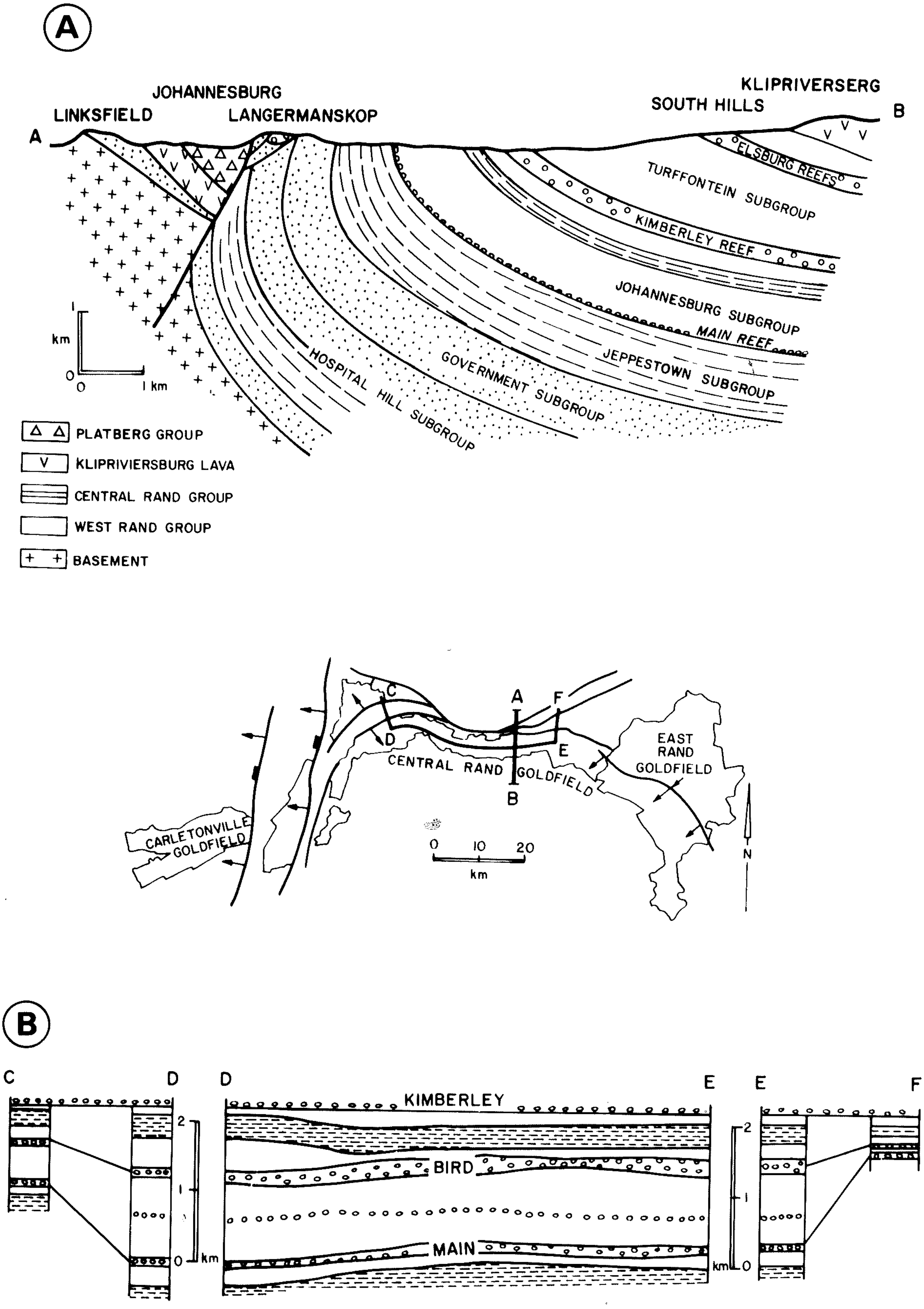


Figure 4: Structures and stratigraphic changes associated with the Rietfontein Fault: (A) a structural cross-section showing the synsedimentary monocline associated with syn-Witwatersrand reverse movement on the fault. Note the presence of a half-graben filled by Platberg Group sediments during the later relaxation phase; and (B) variations in stratigraphic thickness parallel and perpendicular to the block margin fault structure.

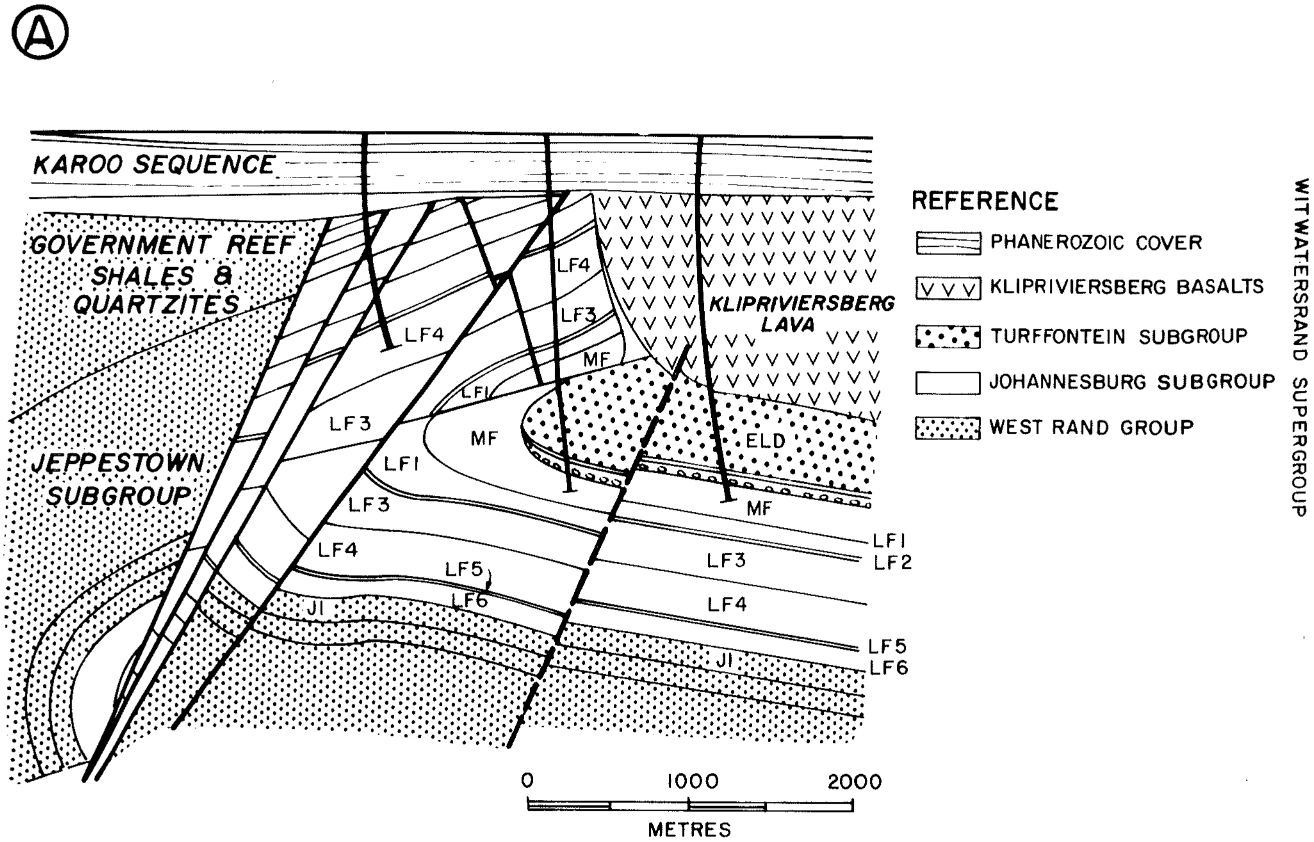
Similar events affected Block 16, the Welkom Block. During the deposition of the Central Rand Group, reverse motion on the Border Structure, (its western bounding fault), caused monoclinal folding (locally overturned), analogous in scale and type to the one just described. The structure is now covered by Phanerozoic rocks, but has been delineated by gold exploration boreholes. This monocline also developed during Witwatersrand sedimentation. At Loraine Gold Mine, Olivier (1965) documented the overstepping of the Johannesburg Subgroup by the younger Turffontein Subgroup reefs across the developing monocline. At Beisa Mine, Tweedie (1984) documented the same overstepping relationship across the monocline, which is overturned in this area. This relationship is shown in Figure 5a. The Border Structure also collapsed following the eruption of the Klipriviersberg Group lavas with normal fault movement truncating the closure of the monocline as shown in Figure 5. It was during this collapse that the large Lichtenburg grabens developed to the west of the then defunct Witwatersrand Basin (Figure 2b).

SYNTHESIS AND DISCUSSION

Both the examples described in the preceding sections show that the block faulting in the Witwatersrand Basin, during its late stage evolution, had a two stage history. A compressive first stage occurred during Central Rand Group deposition in the Witwatersrand Basin, when blocks were inclined and rotated causing block-marginal monoclines which are exemplified by successive elimination and overstepping of strata into the structure. This was followed by a Platberg Group relaxation stage during which blocks collapsed back in association with the newly developing Lichtenburg Graben forming localised half-grabens along block edges.

This style of basement uplift coinciding with the compressive phase has its Phanerozoic analogue in the formation of Laramide block faulting during the Cretaceous Period when the Rocky Mountains developed in the western U.S.A. Fault-bound basement blocks were also inclined and rotated (Matthews, 1978) during a compressive stage associated with the Laramide orogeny which developed in a foreland setting during the convergence of the Farallon and North American plates. Other similarities are apparent. Like the Witwatersrand examples, the Laramide blocks also suffered a later collapse stage during the Tertiary extensional tectonic regime which resulted in the formation of the grabens and half-grabens of the Basin and Range Province. Sales (1983) described how such half-grabens formed as structures between two neighbouring blocks. One of the examples, from the Seminoe Mountains of Wyoming, is reproduced in Figure 5b. The fault-related fold structure is remarkably similar in both size and style to that reproduced in Figure 5a and to those described by Tweedie (1984) from the Beisa area of the Welkom Goldfield. The Bezuidenhout Valley half-graben collapse which developed along the Rietfontein Fault, as shown in the section in Figure 4a, is analogous in its style and timing to the Tertiary half-graben which developed from the Seminoe Mountains structure.

The two-stage development of the Witwatersrand Basin fault-blocks is, therefore, paralleled by the Laramide structures. Even the size of the main Witwatersrand Basin is more consistent with that of basins between Laramide basement uplifts (e.g. the Green River and Washakie basins; Matthews, 1978) than it is with the foreland basins suggested by Burke *et al.* (1986) and Winter (1987). The only element not so far discussed is the outpouring of the Klipriviersberg Group flood basalts between the compressive stage and the extensional stage. This phenomenon also has its



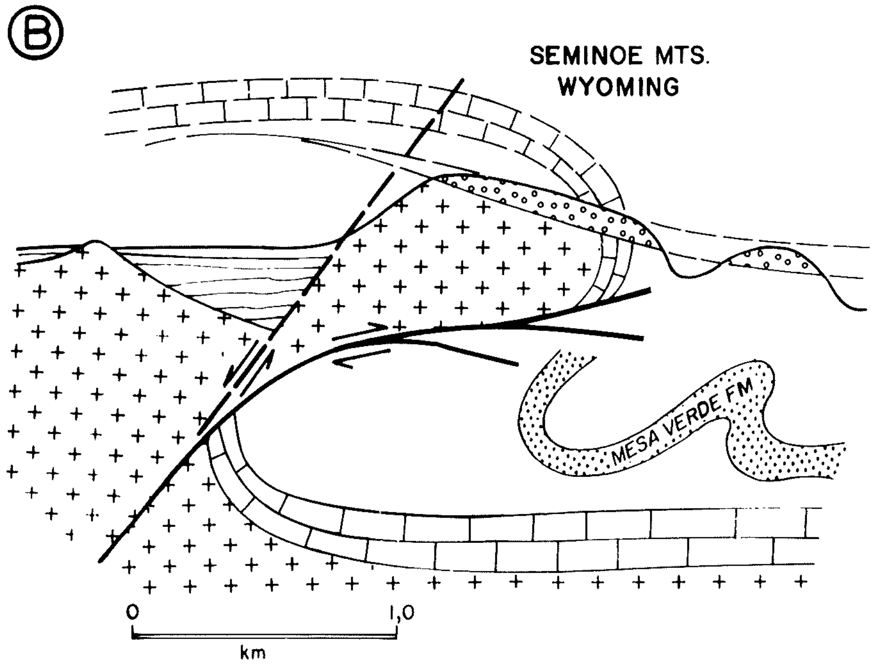


Figure 5: *(A) Overturned monocline developed on the Border Structure in the southern Welkom Goldfield during the syn-Witwatersrand compressive phase. Note the backward collapse of the structure truncates the hinge of the fold. (B) A comparable synsedimentary structure to that shown in (A) of Cretaceous age from the area of the Laramide Orogeny. Notice the backward collapse of this structure during the Tertiary.*

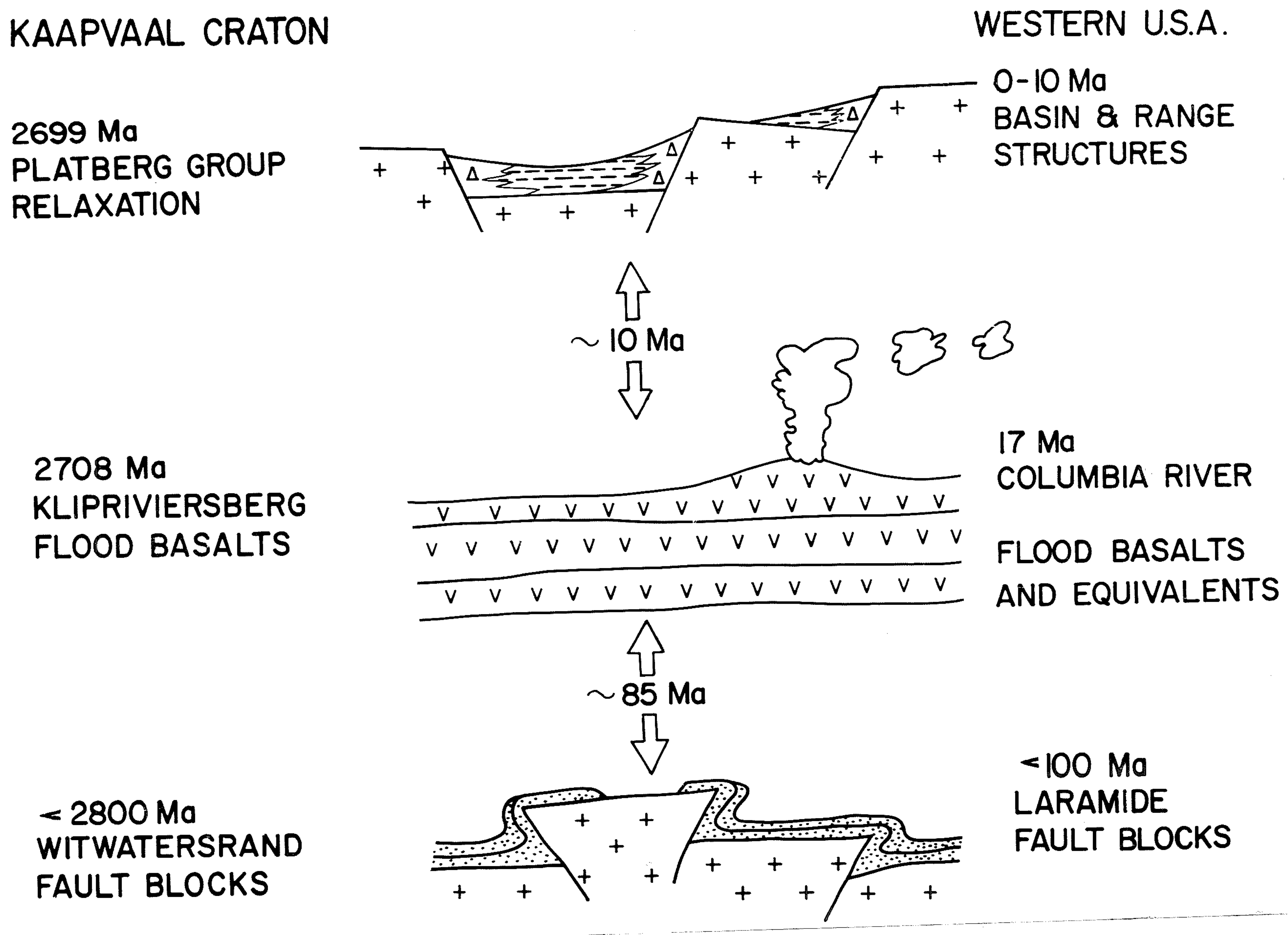


Figure 6: *Cartoon showing the possible comparable development of: compressive phase: extrusion of flood basalts; and extensional phase between the Late Archaean Kaapvaal Craton and the western United States.*

parallel in the evolution of the Rocky Mountains. Both in the northern and southern Rocky Mountains flood basalts were extruded (the Columbia River Group and its lateral equivalents e.g. Mangan *et al.*, 1986) after the compressive tectonics which caused the Laramide orogeny and before the extensional tectonics associated with the development of the Basin and Range Province (Figure 6). With the newly discovered precision of the zircon ion-microprobe dating technique comparison can also be made between the relative timing of the three events. The Laramide basement block fault style developed over a time period of at least 80Ma. The Dominion, West Rand, and Central Rand Groups, together, developed over a period of 350 Ma, during which the Central Rand Group portrays the sedimentation style which related to basement block faulting, perhaps over a time period of circa 100 Ma (Figure 6). The outpouring of the Columbia River Basalts and its lateral equivalents occurred during a period of about 7Ma before Basin and Range extension, compared with a period of about 9Ma (Figure 6) between the start of the Klipriviersberg Group extrusion and the development of the Platberg Group grabens (Armstrong *et al.*, 1986, R.A. Armstrong, pers.comm.). The time periods appear, therefore, to be of a similar order of magnitude in both cases.

There are thus definite similarities between the stages in the evolution of the Kaapvaal Craton during the Late Archaean and the evolution of the Western United States during the Cretaceous and Tertiary and the respective occurrence of flood basalts. The important feature about the later extensional phase (in the case of the Kaapvaal Craton) was that it collapsed along the same lines of weakness which accommodated the compressive phase (negative tectonic inversion). Is such a collapse feasible if "thin-skinned" tectonic effects dominated the cratonic response? It is more likely that the Witwatersrand Basin was dominated by a "thick-skinned" style of deformation causing the basement block-faults described and allowing negative tectonic inversion to take place. "Thick-skinned" continental responses to compression of Phanerozoic age have recently been detected by deep seismic studies within cratons in Australia (Goleby *et al.*, 1989). Evidence presented in this paper would seem to point to such a response to compression in the Kaapvaal Craton during the Late Archaean.

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