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MORPHOTECTONIC ANALYSIS OF THE WESSELSBRON PANVELD

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ABSTRACT

The Vet-Sand River-system of the western Orange Free State flows west-northwestwards across a semi-arid, Miocene planation-surface with an average gradient of $0^\circ 0' 5''$. The longitudinal profile of this stream does not reflect the expected smooth, almost-logarithmic profile of a river that has attained base-level equilibrium. The profile is interrupted by a central, flat section which lies adjacent to the Wesselsbron panbelt. Associated with the flat longitudinal-profile are broad, shallow cross-profiles, extensive marsh-development, and flying levees, as opposed to the v-shaped, often-incized profiles found up- and down-stream. A comparison of these features with those found in the salt-dome areas of Louisiana, around New Orleans, implies that the river-system has been affected by slow, diapiric uprising of a subsurface feature. Geophysical (gravity) data, boreholes, and mining operations in the nearby Welkom Goldfield reveal this to be a fault-bounded, granitic dome.

Morphological reconstruction of the drainage of the adjacent Wesselsbron panbelt shows it to be a tectonically-disrupted palaeo-river-system. The longitudinal profile of this stream shows the same anomaly as the perennial Vet-Sand system, implying disruption by the same mechanisms. However, the geometry within the disruption of the panbelt implies a down-warp or graben-like feature on the northern flank of the dome, a conclusion subsequently verified by drillhole information. Further comparisons of surface drainage with known subsurface structure have revealed that the granitic Wesselsbron dome has been periodically remobilized, from the Pre-cambrian to, at least, the Miocene.

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INTRODUCTION

Since the discovery of the Welkom Goldfield, many geological and geophysical exploration methods have been used in an attempt to locate further extensions to the Witwatersrand Basin. Although having had certain success, these methods are both costly and time-consuming. Morphotectonic analysis is an alternate exploration method that is relatively inexpensive, and that relies on direct observation. Morphotectonics is the branch of earth science that studies the influence of tectonics and structures on large elements of relief. A detailed study of surface-drainage and landscape-analysis can reveal the presence of reactivated fault-zones, domes, and grabens in the underlying basement rocks.

A morphotectonic analysis was undertaken of the area immediately to the west of the Welkom Goldfield and between the Vet-Sand River and the Sandspruit, in order to show empirically how a study of drainage-characteristics can be used to predict certain subsurface, structural features.

GENERAL SETTING OF THE WESSELSBRON PANVELD

The Vet-Sand river-system is a left-bank tributary-system to the Vaal River and flows across the flat Post-African I surface in the Orange Free State (Fig. 1). On the northern bank of the river is an anomalous concentration of pans of unknown origin. Climatically, this area is semi-arid, receiving less than 600mm of rainfall per annum. The combination of low precipitation and high evapo-transpiration rates has resulted in the predominance of dry *Cymbopogen-Themeda* veld grass. Much of the area is irrigated for crop-farming activities.

DRAINAGE ANALYSIS

The Wesselsbron panveld occurs between the Welkom Goldfield and the Vaal River and between the Vet-Sand River and the ephemeral Sandspruit. The contouring of the pans, both by percentage area and frequency distribution, highlight essentially the same features (Figs. 2a and b). The highest concentrations occur near the town of Wesselsbron, and there is a decrease concentrically outwards in all directions. The implication is that there is a decrease in the slope or gradient of the land, from all sides, in toward a centre focussed at, or near, Wesselsbron, suggestive of downwarping or back-tilting in this area.

Reconstruction of the palaeo-drainage shows that the pans represent the disrupted remains of a well-integrated stream-system (the Wesselsspruit). The main Wesselsspruit has been beheaded in the vicinity of Wesselsbron, as indicated by a windgap and several reversed and barbed tributaries (Fig. 3). The nature of the disruption indicates a basining or back-tilting, which has caused a reversal of the drainage and the conversion of an initially-dendritic drainage-pattern to a centripetal one. The streams converge at the point of maximum pan-development around Wesselsbron. This drainage configuration may be compared with that of lakes Victoria and Kioga in the African Rift Valley (Ollier, 1981).

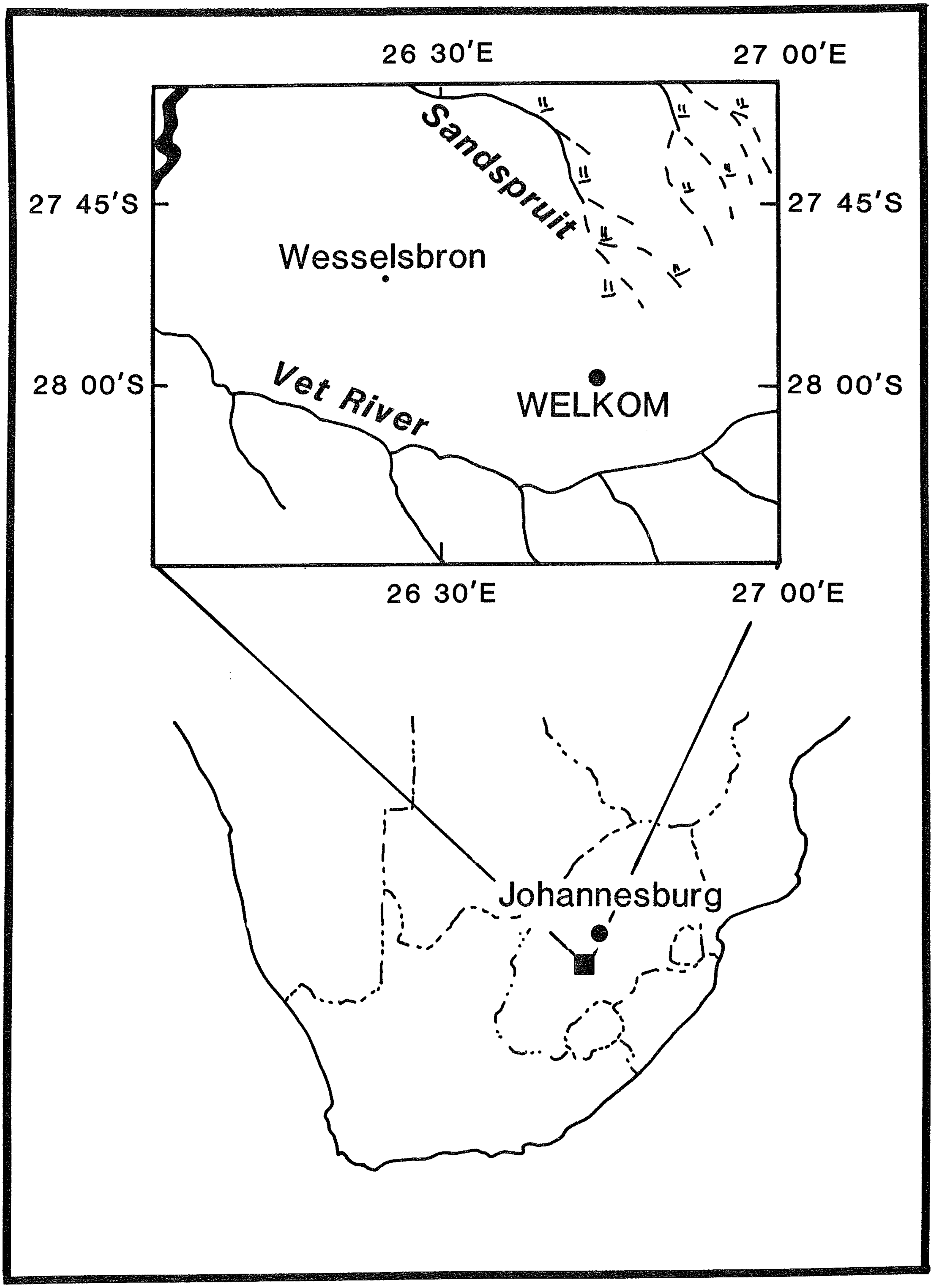

Figure 1 : Locality map of the Wesselsbron panveld

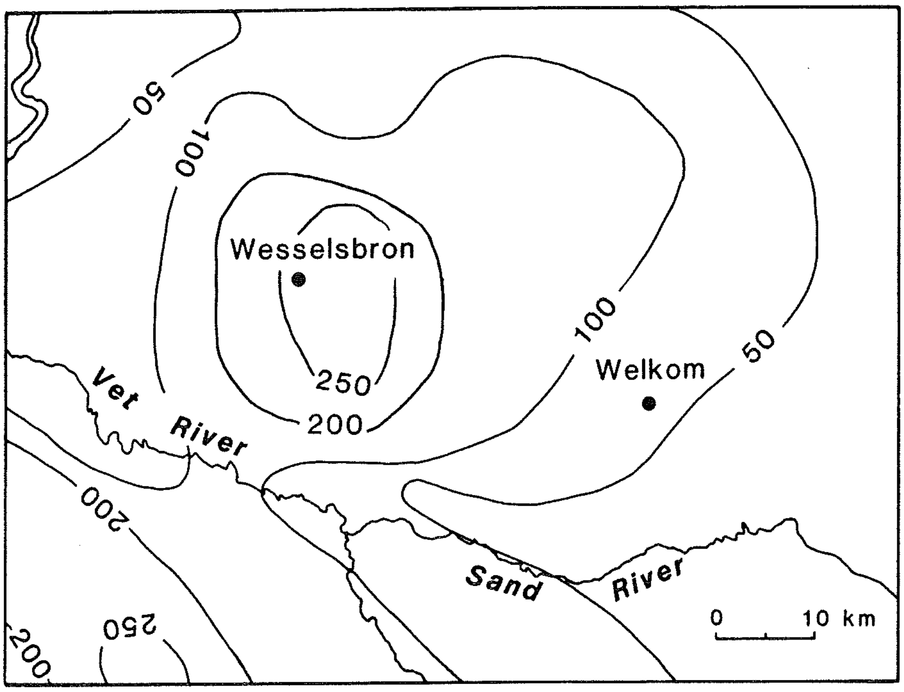

Figure 2(a) : *Frequency-distribution of pans.*

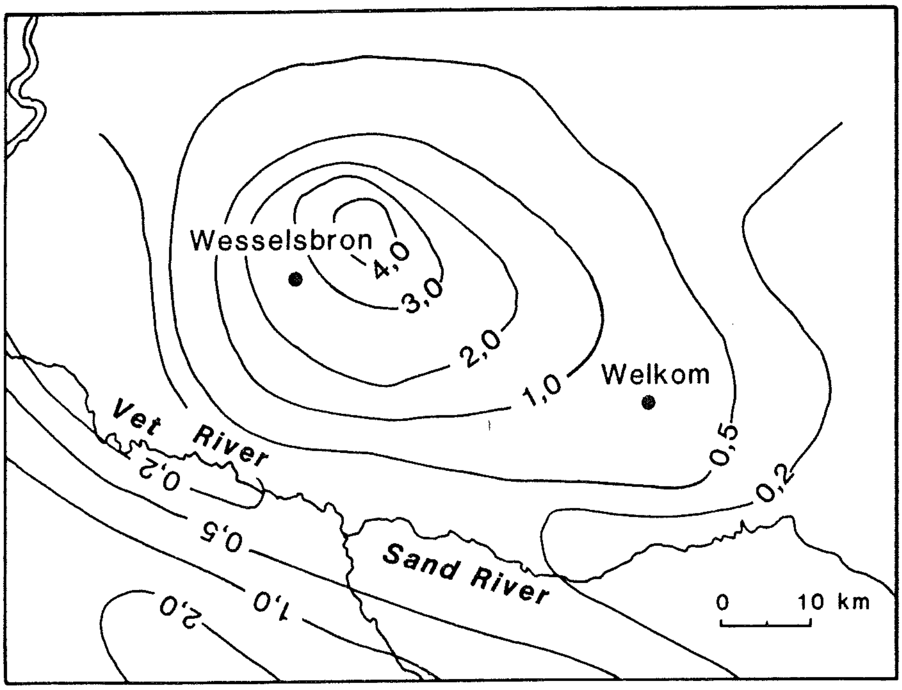

Figure 2(b) : *Percentage-areal-distribution of pans (contours in km^2/km^2).*

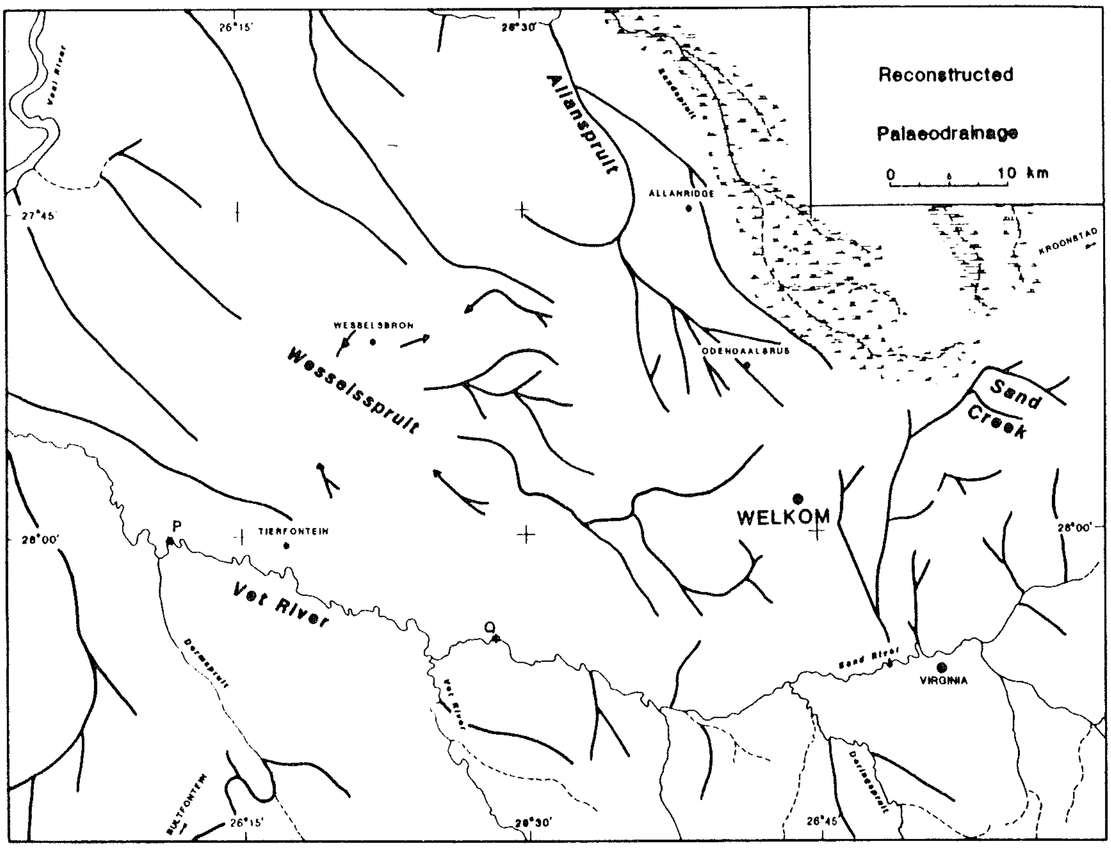

Figure 3 : Reconstructed palaeo-drainage of the Wesselsbron pans.

Parallel to the Wesselsspruit is a second palaeo-drainage system, the Allanspruit. At least two of the tributaries of this system have been re-orientated by uplift along the drainage-divide between the Allanspruit and Wesselsspruits. To the east of Welkom, the initial NW-SE-orientated tributaries of the Sandspruit have been captured by the Sand Creek and re-orientated southwards into the Sand River, near Virginia. This is the result of uplift to the north of a line trending ENE through Welkom and the elbows of capture of the Sand Creek-system.

The longitudinal profile of the Sandspruit (Fig. 4) is a smooth, exponential curve, with no point of inflection of irregularities. This curve approximates the ideal, graded profile of a river in equilibrium. The stream-profile is undisturbed by surface geology or palaeo-climatic changes and has adjusted to the sediment-load and discharge-characteristics of the basin, as well as to the time that it has taken to evolve to this stage of materials. Here, maturity is not used in the Davisian sense of cyclic evolution. For this reason, the Sandspruit is taken as a standard against which the Vet Sand system and the Wesselsspruit are analysed. The smooth profile of the Sandspruit indicates that, whatever the effects of palaeo-climate or changes in sediment-load and -discharge might have been, the streams in the Wesselsbron vicinity have had sufficient time to overcome them. This being the case, any irregularities in the profiles of the other two rivers have to be explained by changes in base-levels, which are the result of either sea-level fluctuations or local, tectonic movements.

In comparison with that of the Sandspruit, the longitudinal profile of the Vet-Sand river-system deviates quite considerably from the norm.

From its source, the profile of the Sand River is relatively asymptotic, until point Q, 40-50km upstream from its confluence with the Vet River (Figs. 3 and 4). At this point, the profile becomes steepened and then flattens out rapidly, forming a nick-point. Downstream of this nickpoint, the gradient of the profile is almost completely flat for approximately 150km (Q-P on Figs. 3 and 4). At Q, another nick-point occurs, and downstream of this point, to the confluence of the Vet with the Vaal River, the gradient is once again relatively asymptotic. The profile of the Vet-Sand River can thus be divided into three sections - two asymptotic sections, separated by a flat portion, bounded by two nick-points. A similar pattern is evident in the longitudinal profile of the reconstructed Wesselsspruit.

In this case, however, the central portion of the Wesselsspruit-profile shows a greater degree of disruption than that of the Vet-Sand River, and the river gradient is often negative or reversed. The reversed gradients prohibit the through-flow of runoff and thus promote the development of pans.

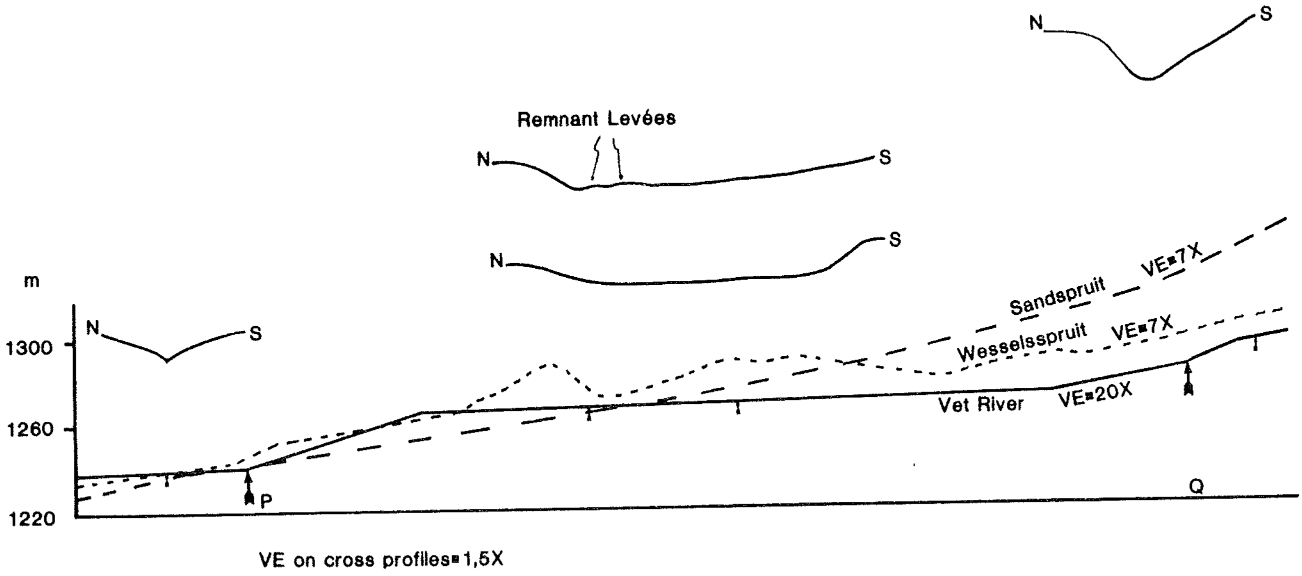

Figure 4 : Longitudinal- and cross-profiles of the Vet River, the Sandspruit, and the reconstructed Wesselsspruit.

A comparison of the longitudinal profiles of the three rivers indicates that the disrupting feature must be local and cannot be attributed to continental-scale isostasy or sea-level change. If this were the case, it would be expected that the Sandspruit would show similar nick-points to those of the other two rivers, which it does not. Furthermore, a rise in, or lowering of, sea-level and its accompanying levels of erosion-surfaces would not produce the negative gradients exhibited by the Wesselsspruit. Rather, if the nick-points were related to Post African incision, the two nick-points would be separated by a gently-decreasing slope. Whatever the nature of the disruption, it must be local, affecting only the central portions of the Vet-Sand river-system and the Wesselsspruit. Furthermore, the disruption must either have been more intense beneath the Wesselsspruit or have been of a different nature, in order to have reversed the river-gradients, instead of merely flattening them, as in the case of the Vet-Sand River.

Cross- or valley-profiles of graded- or equilibrium-rivers tend to have a characteristic trend from source to mouth (Davis, 1899 and 1902): near its source, the cross-profile of a river is usually V-shaped, with relatively steep sides and a narow valley; downstream, the valley-profile flattens out, until, near the river-mouth, it becomes broad and shallow. Once again, deviations from the ideal are usually explained in terms of changes in lithology or in load and hydraulic characteristics. The cross-profiles of the Vet-Sand River (Figs. 3 and 5) indicate a distinct flattening between P and Q. Outside of these two points, the river shows the relatively steep-sided profile expected of a river far from its mouth. Between the two points, however, the valley-profile is broad and shallow. The river-valley is marshy, and there is an anomalous development of levees immediately downstream of the confluence of the Vet and Sand rivers. Normally, there should be incision downstream of a confluence of two large rivers (Schumm and Mosley, 1973). Therefore, these localized or flying levees are indicative of a local structure that is overriding the effect of fluvial incision. This is further suggested by the flared valley that emerges as a result of the local flattening and widening of the Vet-Sand river-valley.

DISCUSSION

Reconstruction of the palaeo-drainage of the Vet-Sand-Wesselsspruit rivers has indicated that major changes have occurred in the system since the Cretaceous. The palaeo-drainage-pattern indicates that the initial, post-Karoo drainage was oriented in a northwesterly (130°) direction. The Wesselsspruit may represent the lower segment of the Doringspruit (Fig. 3) that was pirated by the Sand River, either as a result of movement along the line through Welkom and the Sand Creek or as a result of Cretaceous-Tertiary uplift along the Natal moncline (Matthews, 1968). However, another, local, structural feature appears to have played a more direct role in the subsequent evolution of the Vet-Sand and Wesselsspruit drainage-systems. Such locally-flared valleys and negligible gradients, as are present in the Vet-Sand and Wesselsspruit profiles, are also found to be invariably associated with the diapiric action of salt-domes in Louisiana and Texas (de Blieux, 1949; de Blieux and Shepherd, 1951). Slow upward movement of these domes has had the effect of flattening the gradients of nearby streams marginally, causing a decrease in stream-velocity and forcing the streams to drop some of their load. Subsequent unequal basin subsidence has resulted in the preferential preservation of levees near the highest point of the buried structures.

A direct comparison may be drawn between the fluvio-morphic features developed over salt-domes and those present in the Vet-Sand and Wesselsspruit rivers. By implication therefore, it seems likely that the disruption of these rivers is tectonic, in the form of diapiric uprising of a dome. The highest point of the suspected Wesselsbron dome would be located near the confluence of the Vet-Sand river, as this is where the

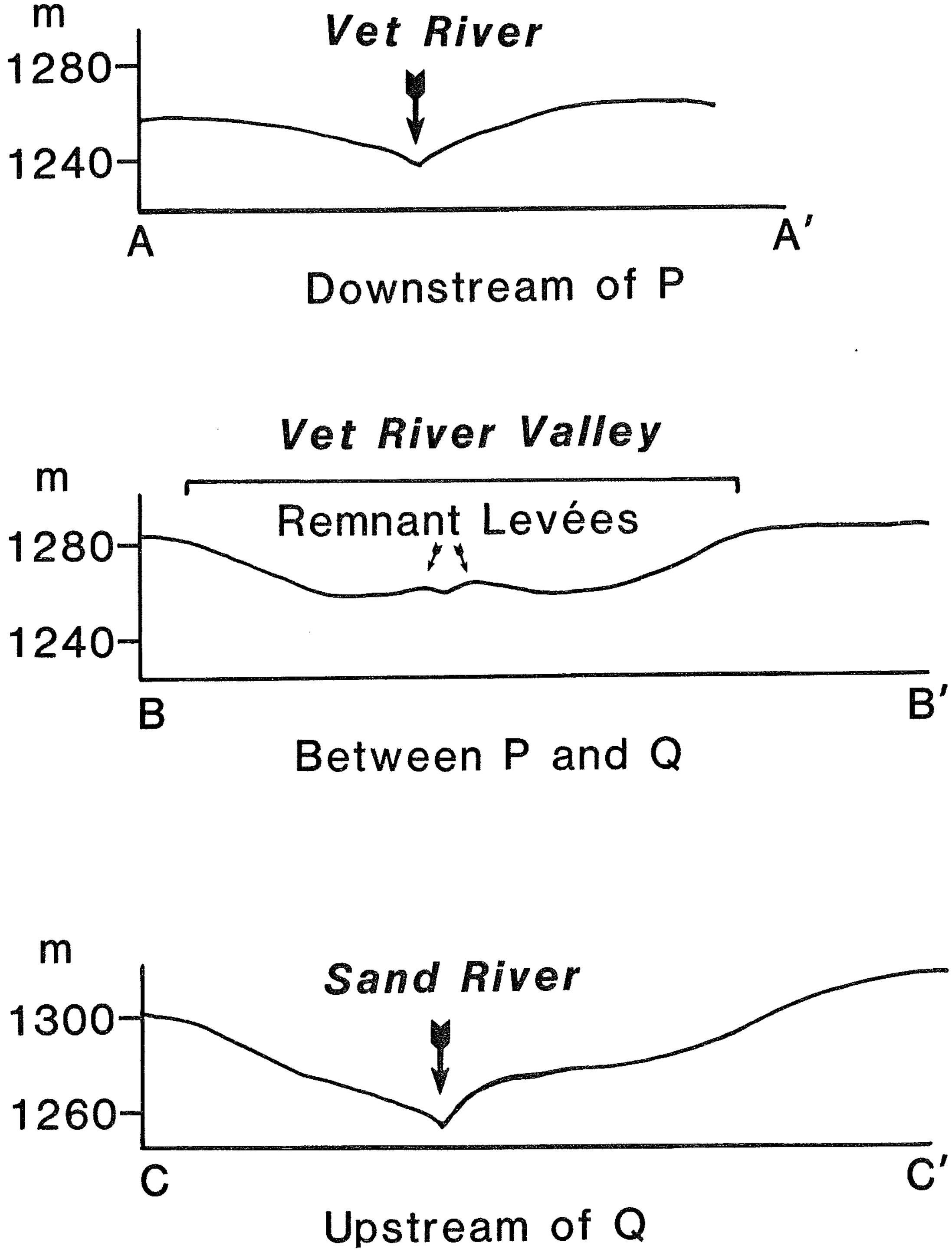

Figure 5 : *Cross-profiles of the Vet-Sand River.*

flying levees are preserved. The presence of pans on what would be the northern flank of the dome introduces further complexity into the situation. The distribu- tion-patterns of the pans and the reconstructed drainage-lines have been used to indicate a downwarp or graben-type feature over the point of highest pan-concentration. The model that would best explain all the above features is that of a peripheral graben, developed on the flank of a rising dome. The diapiric action of the dome would be responsible for the flattening of the river-gradients, the local flaring of the valley, and the flying levees. Collapse of a segment of the dome would provide the reversed gradients essential to the development of a panveld. Subsequent to this disruption, which must have been slow and non-catastrophic, the panveld has been modified by modern agents of mind-erosion and salt- accumulation (de Bruijn, 1971; Geyser, 1947 and 1950; le Roux, 1978).

The subsurface geology of the Wesselsbron pilot-study area is relatively well known, due to the presence of numerous boreholes associated with local mining and exploration activities. Further information has also been gleaned from both the regional gravity field (1:1000 000 Geological Map of South Africa, 1984 Gravity Edition) and unpublished, detailed, local, Bouguer anomalies (Anglo American Corporation of South Africa Limited, 1985).

The regional gravity data indicate the presence of a closed gravity-low, situated downstream of the Vet-Sand river-confluence, flanked by a gravity-high, around the town of Wesselsbron. The gravity-low indicates light, granitic material, while the high represents heavier, possibly-Ventersdorp, volcanic material. The more detailed Bouguer-anomaly

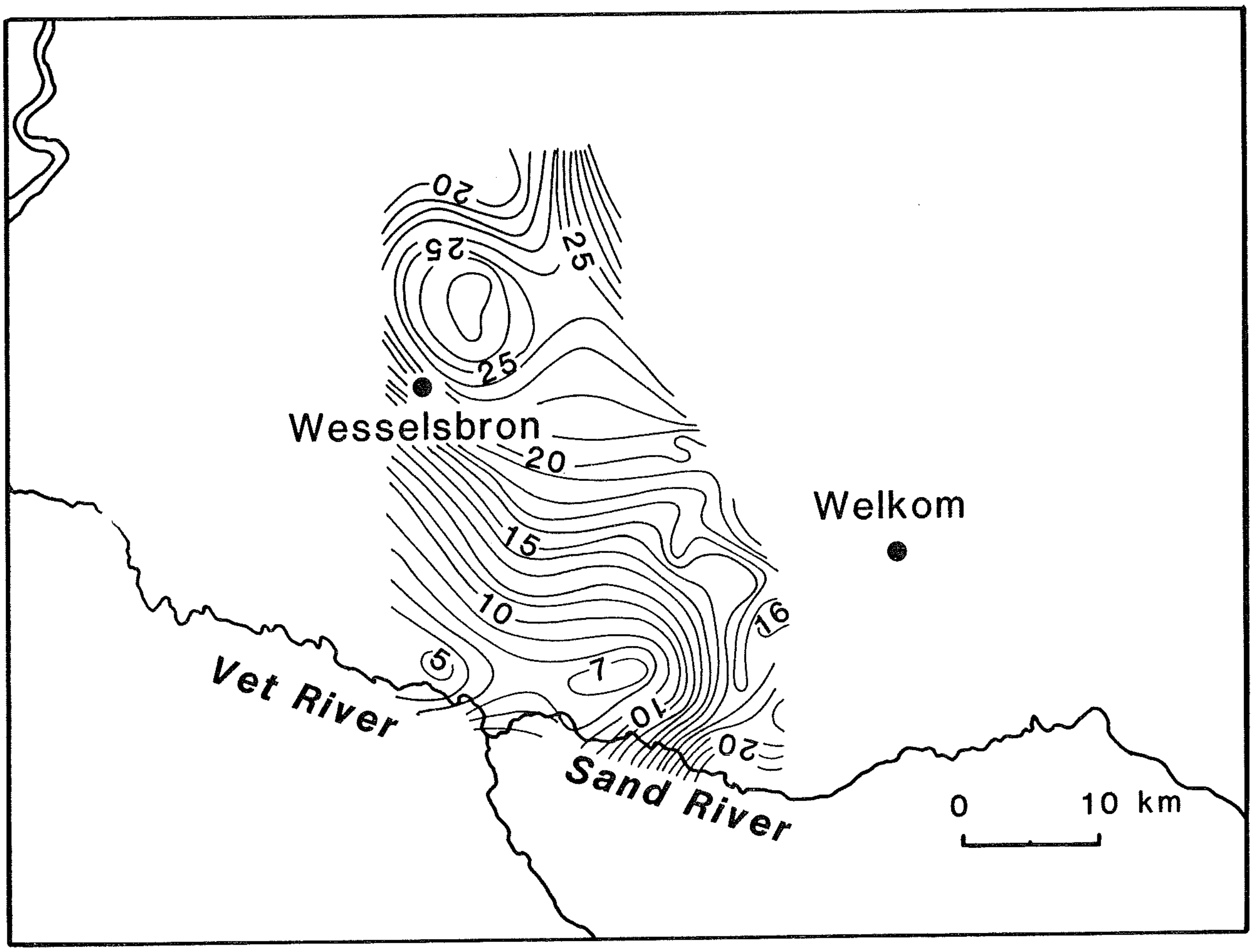

Figure 6 : *Bouguer gravity anomalies over the Wesselsbron dome (source : Anglo American Corp.).*

data (Fig. 6) reveal that the highest point of the granitic dome (the Wesselsbron dome) occurs immediately downstream of the confluence of the Vet-Sand river. The gravity-high, on the northern flank of the dome, is further refined to a small feature, situated north-northeast of the town of Wesselsbron.

Boreholes verify the existence of a dome beneath the Karoo and Ventersdorp cover (Fig. 7). The dome is bounded by major faults that are parallel to those found in the neighbouring Welkom Goldfield. The eastern-boundary fault is parallel to the Border Fault and probably forms part of the same fault-zone. The southeastern sector of the dome is affected by a southwesterly extension of the Geduld Fault and by an 070°-tending fault which has juxtaposed West Rand Group sediments and the granite dome. The later, W-E -trending fault has effect the Geduld Fault-extension, as well as the dome, approximately 10km to the West. The Geduld Fault-extension is also parallel to the boundary fault to the northwest of the dome.

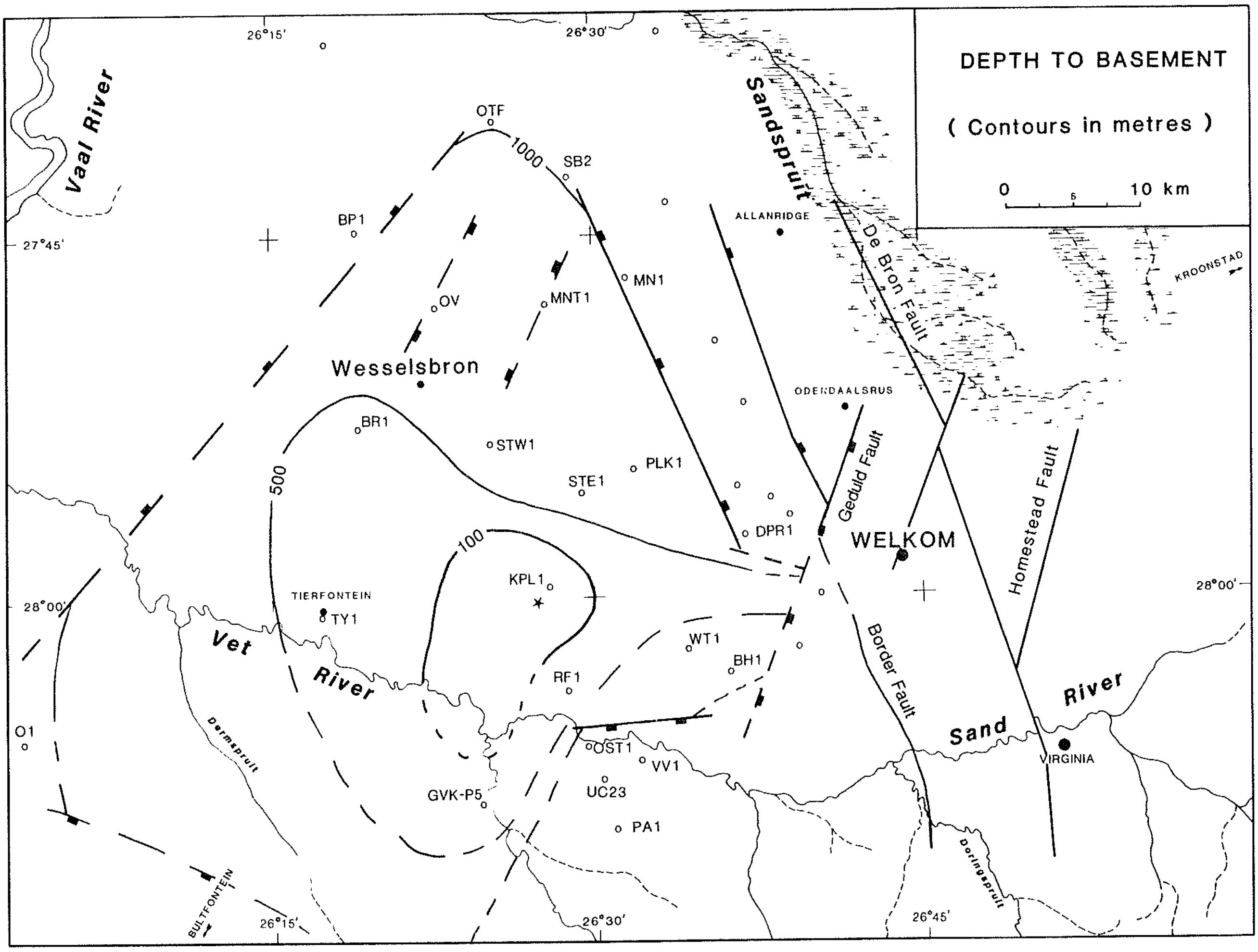

Figure 7 : *Depth to basement-granite (contours in metres below surface).*

The gravity-high on the northern flank of the dome represents a Ventersdorp-lava-filled graben, over 2000m deep. Although it has not been possible to deduce the exact shape of the graben, it is likely that is parallels the main fault-directions present on the dome.

Comparing the drainage characteristics (Fig. 3) with the geology (Figs. 7 and 8), four cause-effect relationships occur between surface and subsurface features:

(a) The flattened profile of the Vet-Sand River (P-Q) occurs near the top of the granite dome. This would indicate post-Karoo reactivation of the dome. The consequent uplift has not been sufficient to induce fluvial incision, but it has been responsible for the flattening of the river-gradient. This has, in turn, resulted in the local flaring of the valley and the preferential development and preservation of levees downstream of the Vet- Sand river-confluence.

(b) A peripheral collapse-graben of pre- or syn-Ventersdorp-age on the northern flank of the dome can be correlated with the disrupted portion of the Wesselsspruit-profile, the centripetal palaeo-drainage-pattern, and the maximum development of pan-frequency and-size.
The implication, thus, is that the early fault-planes have been re-activated in Tertiary-times, to give rise to the present drainage-features.

(c) Tertiary movement on the boundary faults of the dome has resulted in the beheading and piracy of some of the drainage-lines. Uplift on the dome, to the west of the eastern-boundary fault, between Odendaalsrus and Allanridge, could have been responsible for the configuration of the Allanspruit tributary. The uplifted block would, therefore, have separated two grabens - the Witwatersrand-bearing, Odendaalsrus graben, to the east, and the Wesselsbron graben, to the west. The possibility then exists for the presence of Central Rand Group sediments below the Ventersdorp lavas in the Wesselsbron graben. To the east of Welkom, the Sand Creek has been diverted from flowing northwards, into the Sandspruit, into a palaeo-Sand River tributary. This can be shown to be the result of movement along the Homestead Fault. Uplift of the De Bron horst would have initiated headward-erosion of the Sand River-tributary and would have results of finally, in the capture and diversion of the Sand Creek.

(d) There is a distinct parallelism of present- and palaeo-streams with the major, Witwatersrand faults. The tributaries of the Vet-Sand Rivers and the Sandspruit appear parallel to the dominant NW-SE fault-trend. The implication is that the structural grain association with these faults has permeated through the Ventersdorp and Karoo cover and has influenced the development of the post-Karoo drainage-system.

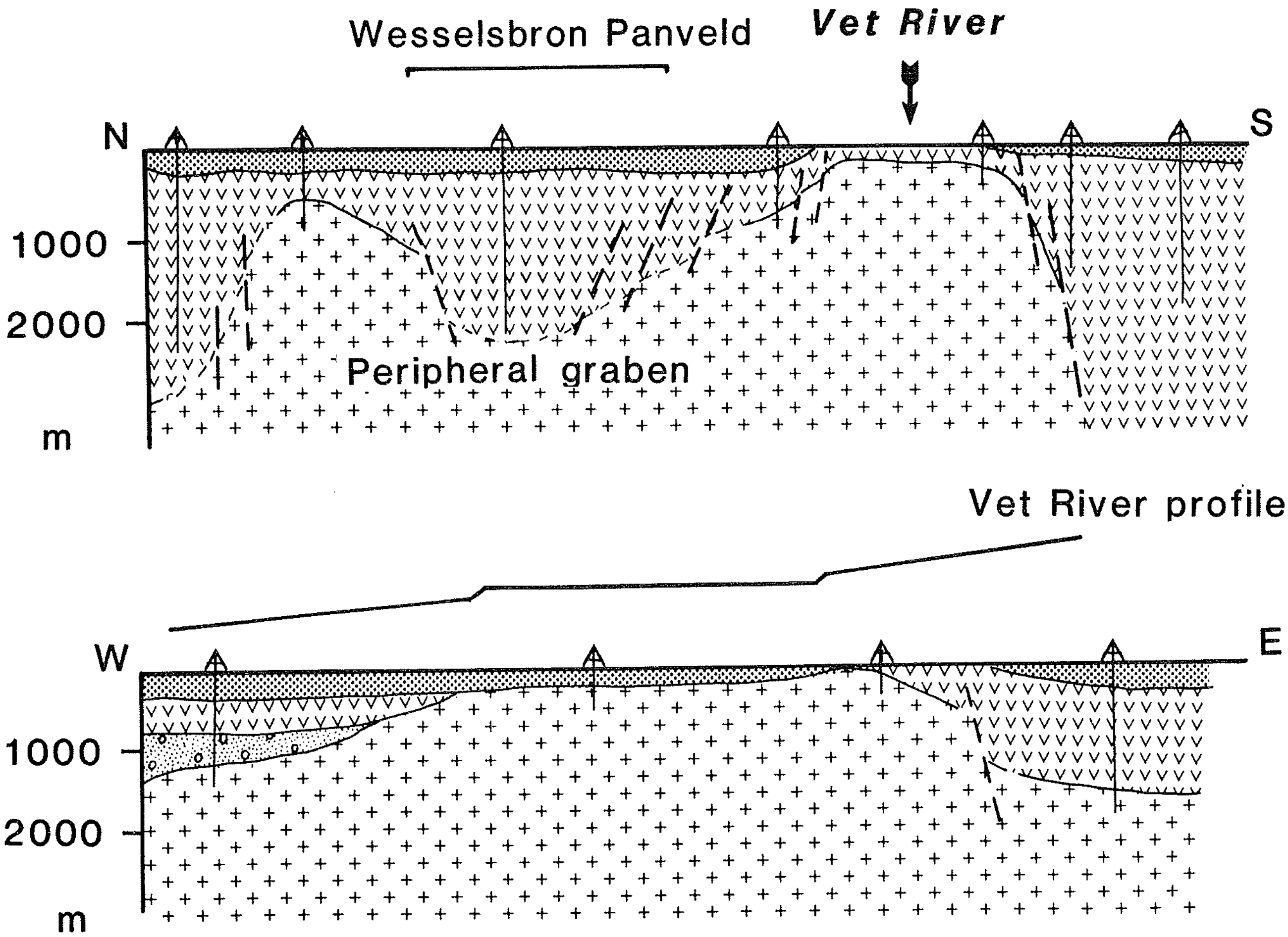

Figure 8 : *Geological cross-sections across the Wesselsbron dome.*

CONCLUSIONS

A comparison of fluvio-morphological and geological data reveals that, both in general and in detail, the subsurface structure is reflected in the morphology of the surface drainage-features. The Wesselsbron pilot-study has shown that the structure of the dome and of the boundary-faults of the Welkom Goldfield has affected the drainage in four, distinct ways:

(a) the reactivated, diapiric action of the Wesselsbron granite dome has caused the flattening of the gradient of the superimposed, Vet-Sand river-system and the Wesselsspruit;

(b) the lowered gradient of the Vet-Sand River has initiated local valley-widening (-flaring) and the preferential development of levees;

(c) the faults bounding the dome on the east have resulted in piracy and redirectioning of the drainage-system; this is seen in the case of both the Allanspruit (Border fault-system) and the Sand River palaeo-tributary (Homestead Fault); and

(d) a peripheral collapse-feature of pre- or syn-Ventersdorp-age, on the northern flank of the dome, has been reactivated and is responsible for the flat and negative gradients of the Wesselsbron panveld; the consequent reversal of gradient allowed for the flooding of the palaeo-drainage-system; subsequent desiccation of the climate transformed the inland lakes into pans, which have been perpetuated and modified by exogenetic (erosion) processes.

Based on these relationships, the following model is proposed for the post-Karoo evolution of drainage of the Wesselsbron panveld. The initial, post-Karoo drainage-pattern formed in response to a regional, NW-SE, structural grain. It was disrupted by an event that caused the large-scale piracy observed in all the rivers between the Modder and the Wilge. This disruption, in the Lesotho Highlands, has been assigned a Tertiary age (Matthews, 1968). Superimposed upon, and possibly simultaneous with, this regional disruption is evidence of local, structural control. Slow, diapiric movement on the Wesselsbron dome (isostatic re-adjustment) has flattened the gradient of the Vet-Sand River and disrupted the Wesselsspruit. The flattening of the Vet-Sand River resulted in the local widening, or flaring, of the valley over the sphere-of-influence of the dome. Downwarping over the peripheral graben partially disrupted the drainage-lines of the Wesselsspruit and the Allanspruit, flattening and reversing river-gradients and causing the development of lakes within the river-channel. Subsequent, late-Tertiary desiccation of the climate resulted in the development of dry lakes or pans. Once the pans had thus been established, external erosion-processes operated upon them, to modify them in the manner described by Lancaster (1978), Le Roux (1978), and others.

The morphotectonic analysis of the Wesselsbron panveld has been instrumental in emphasizing the importance of geomorphology in determing subsurface, structural features. Further morphotectonic studies, in other parts of Southern Africa, might likewise be used to indicate the nature of the subsurface.

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