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A Review of the geological history of the Evander Basin with new insights into the deposition of the Kimberley Formation

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Abstract

The deposition of the Witwatersrand Supergroup commenced with a major marine transgression across the granite/greenstone terrain of the Kaapvaal Craton, depositing the predominantly marine West Rand Group. Possibly as a consequence of continental convergence the craton became subject to regional transpression, which began to fragment the widely distributed West Rand Group into a number of separate sub-basins, flanked by uplifts. The sedimentation style changed from shallow marine to fluvial, initiating the deposition of the Central Rand Group. The sub-basins in which sedimentation took place were separated by faults, anticlines or monoclines. In the Far East

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Rand these sub-basins included the Evander, Delmas, South Rand and East Rand Basins. Complete separation of these sub-basins only occurred after deposition of the Kimberley Reef.

Left lateral transpression caused syn-depositional periclinal folding of Witwatersrand strata trending northwest-southeast. Important structures that developed at this stage include the Springs Monocline, which formed a ledge separating the East Rand from the main Witwatersrand Basin, and the Fold-Fault, which formed a ridge dividing the Evander Basin into two. Contrary to previous interpretations, the Fold-Fault is not a basin margin structure because the Evander Basin continues to its northeast, and hence it is an intra-basinal fold.

During the early phases of Central Rand Group deposition in the East Rand Basin, sediments were derived from greenstone poor granitic source rocks in the north and northwest. In contrast, in the adjoining Evander area, pre-Kimberley sediment was derived from greenstone-dominated terrain to the northeast.

Underground mapping of the immediate footwall strata of the Kimberley Reef at Evander has provided unambiguous evidence for glacial activity at that time. It is unclear whether glaciation was involved in the formation of the Kimberley Reef itself. However, glacial activity was responsible for the deposition of extensive glaciogenic sediments across the Far East Rand in the form of diamictites (termed puddingstones in the older literature) and associated channel deposits (MK1, eskers?).

A period of erosion followed this glacial episode and gave rise to an extensive gravel lag across the erosion surface, which constitutes the Kimberley Reef at Evander. The erosion surface on which the reef lies is thus a large pediment. The palaeocurrents responsible for this degradation flowed from the west and southwest and thus indicate a reversal of the local palaeoslope relative to pre-Kimberley Reef times. Palaeocurrent measurements in the Kimberley Reef and its hangingwall are consistent in their azimuths suggesting that flow was dispersed across the pediment rather than originating from a local point source.

The sources of gold which became concentrated in the gravel lag appear to have been predominantly the LK1 and MK2 conglomerates and possibly gold present in the diamictites. The footwall strata had been derived from a greenstone-rich source in the east. Their greenstone signature was carried over into the Kimberley Reef, notably the presence of banded iron formation clasts and high concentrations of osmiridium and chromite.

Northwest-southeast folding continued during Kimberley Reef formation. A synclinal trough bounded along its northeastern flank by an anticline, the Fold-Fault, developed across the pre-Kimberley surface. This structure created accommodation space, which caused local thickening of the Kimberley Reef package. Thickening of the reef in the Fold-Fault area is therefore not a consequence of fluvial channelisation but a result of thickening due to syn-sedimentary warping. Palaeocurrent directions in this trough continued in a northeasterly direction, perpendicular to the warp axis. The synclinal feature associated with the Fold-Fault remained active after the formation of the Kimberley Reef. As a consequence, isopachs of hangingwall strata also thicken towards the trough.

The gold grade in the Kimberley Reef is inversely related to reef thickness: where the reef is thick, the gold grade is generally low. Most of the gold was scavenged from the footwall. The scavanged material was winnowed on the erosion surface, producing the high grades characteristic of the thin Kimberley Reef present at the southwestern and northwestern margins of the basin. In the trough which borders the western flank of the Fold-Fault, grade is lower due to an increase in quartzite partings. The Fold-Fault is a syn- to post depositional anticline and it is expected that the reef will thin onto the structure. Palaeocurrents are perpendicular to the anticline and therefore gold grades are expected to increase as the reef thins.

Because of the local derivation of much of the Kimberley Reef, the proximal to distal indicators such as changes in pebble size, U/Au ratio and gold fineness are weakly developed to absent. Carbon is often associated with gold in the Witwatersrand Basin but in the case of the Evander Goldfield, carbon does not appear to have played a significant role in gold enrichment on a regional scale. However, there is anecdotal evidence of gold being associated with carbon on a local scale.

We suggest that the burial of the Kimberley Reef occurred as a result of an increase in sediment supply to the depository. Distal deposits which characteristically contain a high proportion of quartzite partings (HW1 and HW2), transgressed across the palaeo-plain and buried the Kimberley pediment surface.

Introduction

The Evander Goldfield (Figure 1) is located in the Mpumalanga Province, 120 km east-southeast of Johannesburg. The presence of Witwatersrand strata in this area was suspected following the discovery and development of the East Rand Goldfield. The earliest drilling was carried out in 1903, but without success. The first modern exploration was undertaken in 1930 and involved a ground magnetic survey employing the vertical magnetic field balance as was being employed to locate and define the Carletonville and Welkom goldfields (Leeb-Du Toit, 1986). This was followed by 17 000 m of diamond drilling but no payable conglomerates were intersected. Consequently this project was abandoned. In 1949, a subsidiary of Union Corporation returned to the area and undertook the first airborne magnetic survey. Union Corporation commenced drilling in 1950 and intersected

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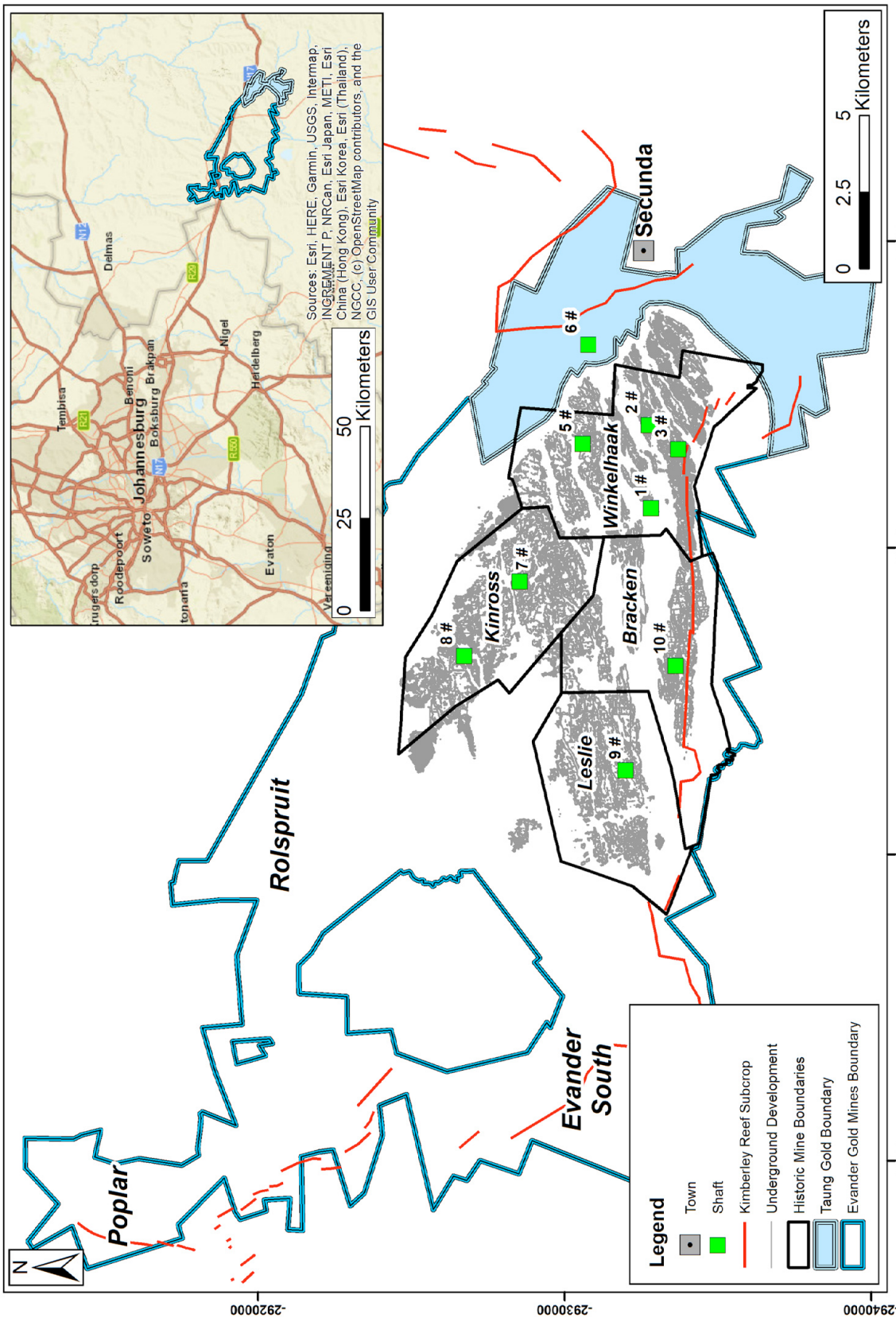


Figure 1. *Locality of the Evander Gold Mines, in relation to the Witwatersrand geographic region. Shaded areas represent mined out areas. The outlines of the historical and present mine boundaries are also shown. The coordinates on the map are based on the South African Local Grid System, Cape Datum (Clarke 1880 ellipsoid; Gauss conform projection). The coordinate numbers are metres south of the equator and east of LO29. This applies to all of the maps shown in this article.*

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significant values on the farm Winkelhaak. By 1955 sufficient drilling had been undertaken to define a resource and Winkelhaak Mines Ltd was incorporated during 1956. The first gold was poured on the 1st of July, 1958. Exploration in the region continued and Leslie and Bracken mines were established in April 1959, followed by Kinross Mines in 1964 (E.B. Tweedie, 1986; Leeb-du Toit, 1986; Figure 1). Subsequently exploration in the surrounding areas resulted in the extension of the mining lease (Figure 1) and the incorporation of the original four mines into the larger Evander Gold Mines. As a result of various phases of restructuring of the gold mining industry, ownership of the Evander Mines passed to Harmony Gold. In 2013 Harmony sold the majority of Evander Mines to Pan African Resources and the southeastern portion of the mine (6 Shaft) to Taung Gold.

Notwithstanding the mines' relatively recent establishment, the body of public domain geological literature on the goldfield is limited when compared to that for other Witwatersrand goldfields. The most important compilations of the geology were carried out by E.B. Tweedie (1981, 1986). Although minor modifications have since been made, E.B. Tweedie's pioneering work remains the cornerstone of the currently accepted concept of the origin and distribution of the mineralisation in the goldfield. Since E.B. Tweedie's work a considerable number of additional geological investigations have been undertaken but very little has been released into the public domain. Moreover, vast improvements in data processing software have become available in recent years, which have enabled the goldfield to be analysed in ways that were not previously possible.

Sources of information employed during the present investigation

The investigation described in this document was carried out by a multidisciplinary team at Shango Solutions (Shango) at the request of Pan African Resources plc. The latter provided access to all of the geological information pertaining to the goldfield. This included a significant amount of data which were not available to E.B. Tweedie (1981) at the time of his investigation. Amongst the data was the Evander master borehole database which contains stratigraphic thicknesses recorded in all surface boreholes, associated grades and channel widths (note, in this paper the word channel is employed in both the sedimentological context, e.g. a stream channel, and in the mining context where it refers to reef thickness). Access was also provided to the original borehole logs. The lithological characteristics of the Kimberley Reef interval were digitally captured for a subset of these boreholes along east-northeast striking transects across the goldfield (Figure S1). (Supplementary data files are archived in the South African Journal of Geology repository (https://doi.org/10.25131/sajg.127.0020.sup-mat)). These characteristics included sorting, pebble shape, packing, type of mineralisation (e.g. size, sulphide distribution and type), maturity, matrix type and nature of carbon, if present.

Stope elevation pegs were either obtained from the mine in digital format or were digitised from mine plans by Shango. A total database of 190 566 data points was assembled. Reef thickness, gold and uranium grades from the stope sampling as well as the boreholes were captured for this dataset (Figures S1 and S2).

Extensive use was made of published articles and unpublished reports compiled by Union Corporation personnel and academic researchers. Most important of these were the papers and reports written by K.A.M. Tweedie between 1954 and 1968, E.B. Tweedie (1981 and 1986) and the Ph.D. thesis of W. Hirdes (1979).

Information on the regional geology was obtained from published papers, reports and theses, notably those by Ferraz (1989), Button (1968) and Cadle (1976) and papers by Borchers (1964), Pretorius (1986), Brandt (1986) and Antrobus and Whiteside (1964).

In addition a complete set of the Union Corporation geological bulletins for the four mines was made available which also included large areas of detailed underground mapping. These bulletins provided invaluable information which had never been released into the public domain.

Regional stratigraphy

The area is underlain by rocks of the Karoo Supergroup, which unconformably overlie the Transvaal, Ventersdorp and Witwatersrand supergroups (Figure 2) and basement rocks which include Archaean granodiorites and greenstones. There are no surface outcrops of the pre-Karoo lithologies and knowledge of these is derived entirely from drilling and geophysical studies.

The Evander Goldfield represents one of a cluster of depressions (commonly referred to as basins) surrounding the Devon Dome in which Central Rand Group rocks are preserved (Figure 3). This region constitutes what we refer to as the Far East Rand (Figure 3). The basins had a similar geological history which is reflected in their respective stratigraphic columns, especially evident in the Central Rand Group. The total thickness of the Witwatersrand Supergroup varies substantially across the region, partly due to thinning of individual stratigraphic units, but also because of the presence of major disconformities, especially in the West Rand Group (Figure 4). As a consequence of these erosional truncations, the Jeppestown Subgroup is absent in the Evander area.

The Kimberley Reef is developed in all of these basins with active mining of this reef occurring in three of them (East Rand, Evander and South Rand/Burnstone). The stratigraphic characteristics of the Kimberley Reef interval in the basins are compared in Figure 5.

Regional structure

Pre-Karoo surface

Large portions of the Far East Rand are covered by horizontally bedded Karoo Supergroup strata. The underlying geology is detailed in Figure 6. Examination of this map provides insight into post-Transvaal, pre-Karoo events.

The northern portion of the region is dominated by Transvaal Supergroup rocks which lie unconformably on Ventersdorp and Witwatersrand supergroup strata as well as

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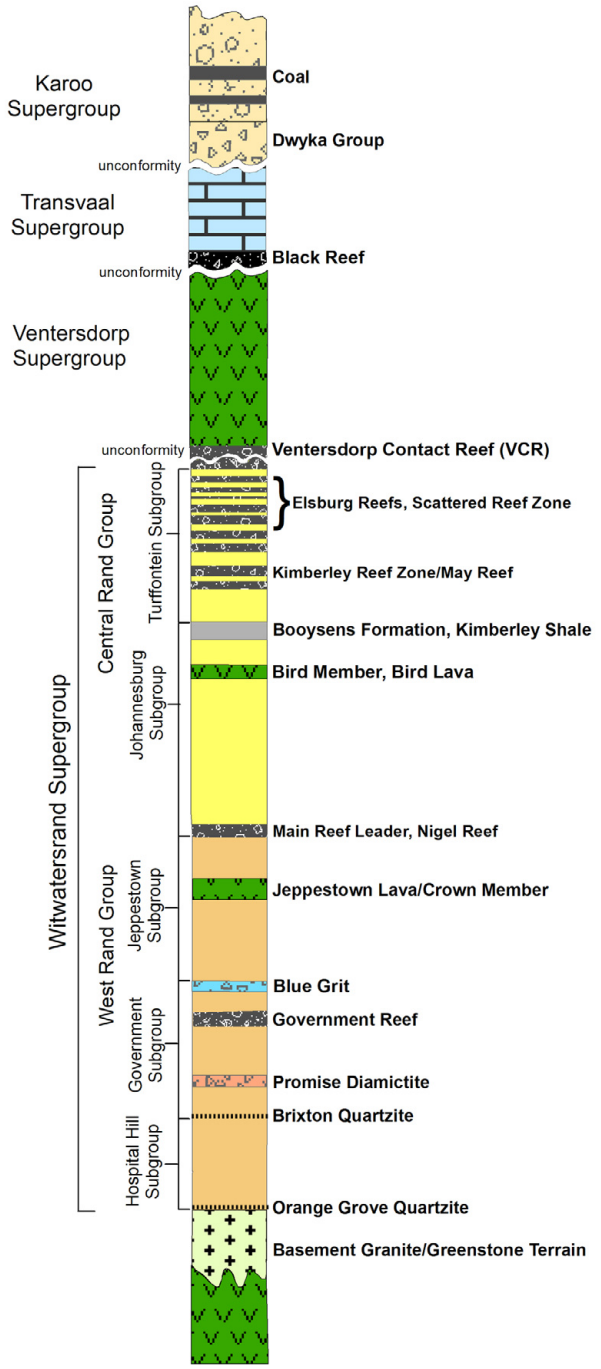


Figure 2. *Regional stratigraphic column for the East Rand area.*

basement granitoid and greenstone. The Transvaal Supergroup, represented primarily by the Malmani dolomite surrounds and dips away from the Devon Dome indicating that this basement dome experienced post-Transvaal diapiric uplift. In addition, the Transvaal succession exhibits evidence of two major deformational events: a northwest-southeast striking set of periclinal folds, which occur particularly in the northwest and west, and a regional tilt to the northeast in the northeastern portion of the map area. The former event has been previously identified as being a consequence of the emplacement of the Vredefort Dome (McCarthy et al., 1986), whereas the latter is ascribed to regional tilting induced by the intrusion of the Bushveld Complex (E.B. Tweedie, 1986). At the scale of the reconstructed pre-Karoo geological map, there is no evidence of significant post-Transvaal faulting.

Pre-Transvaal surface

The geology of the pre-Transvaal surface is illustrated in Figure 7. This map reveals several important pre-Transvaal structural features. The Devon Dome remains at the core of the Far East Rand with Central Rand Group and Venterdorp Supergroup strata dipping radially away from the dome. This indicates that the diapiric rise of the dome had already commenced prior to the deposition of the Transvaal Supergroup. The ovate distribution of the Central Rand Group and Ventersdorp sequences reveals the existence of a prominent set of northwest-southeast striking periclinal folds which are coincident with the post-Transvaal folds referred to earlier. The most prominent of these forms the South Rand basin (Figure 3). The shapes of the East Rand, Delmas and the eastern portions of the Evander basin suggest that they too are a consequence of northwest-southeast periclinal folding. These periclinal folds formed as a result of syn-Witwatersrand regional scale east-west striking wrench faulting which affected the northern portion of the Witwatersrand Basin (Stanistreet et al., 1986). There are two periods of periclinal folding which are coincident in the East Rand but cannot be distinguished on the maps reproduced here. However, further to the west they exhibit distinctly different orientations. The pre-Transvaal folds strike northwest-southeast, as in the East Rand area, whereas the post-Transvaal folds strike east-west (McCarthy et al., 1986).

The South Rand and Evander basins have been transected by east-northeast striking faults. Most of these seem to be normal faults, down-throwing to the south. However, the larger faults, such as the Sugarbush Fault (Figure 7) in particular, may have a component of left lateral strike-slip motion (Myers et al., 1987; Stanistreet et al., 1986). A few prominent easterly striking strike-slip faults are developed in the East Rand basin, but normal faults are rare (see McCarthy, 2006 for a brief review).

Geology of the Evander Goldfield

Stratigraphy

The stratigraphy of the Central Rand Group in the Far East Rand is illustrated by the Evander stratigraphic column (Figure 8) (E.B. Tweedie, 1981, 1986). This profile is macroscopically reasonably representative of the entire region. Prior to the onset of Central Rand Group sedimentation, the region began to experience gentle warping with a prominent northwest-southeast strike. This tectonism has been well documented in the East Rand basin (see McCarthy, 2006 for a review), but its role elsewhere in the Far East Rand is less well known. Sedimentation of the lower Johannesburg Subgroup commenced with deposition of the Main Reef (or Nigel Reef), which was the primary economic horizon in the East Rand Goldfield. This reef is poorly developed in the other outlying basins shown in Figure 3. The overlying

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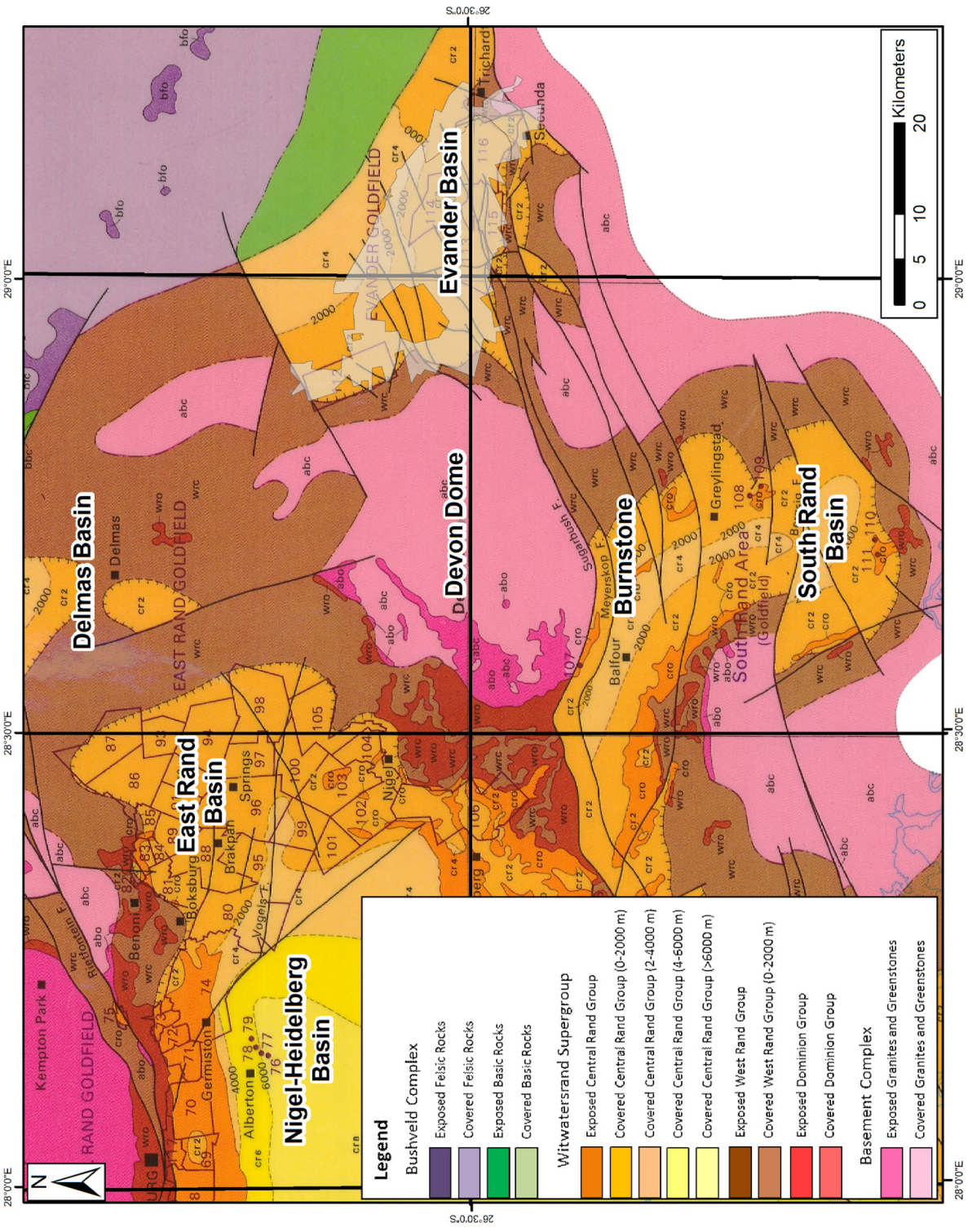


Figure 3. *The distribution of the Witwatersrand Supergroup in the Far East Rand (modified after Pretorius, 1986). The cover rocks (Ventersdorp, Transvaal and Karoo supergroups) have been removed.*

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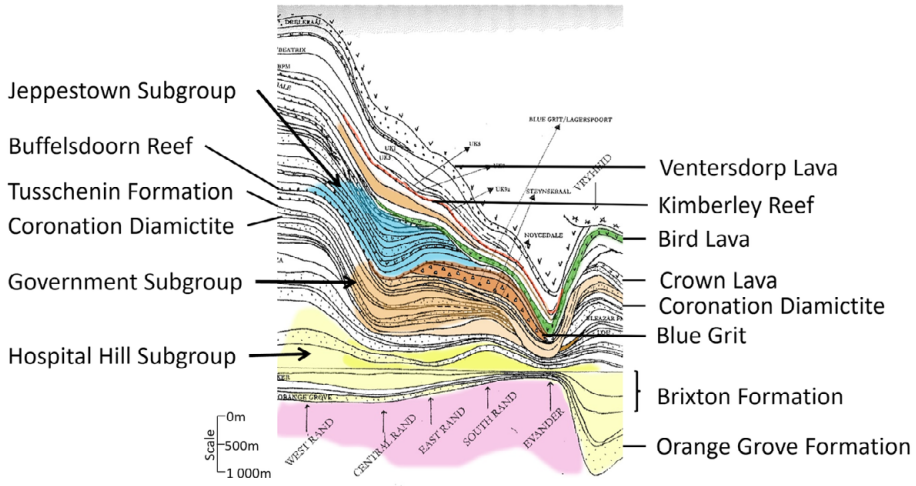


Figure 4. *Diagram illustrating the thinning of the Witwatersrand Supergroup from west to east into the Evander area (modified after Nelson and Beukes, 2004).*

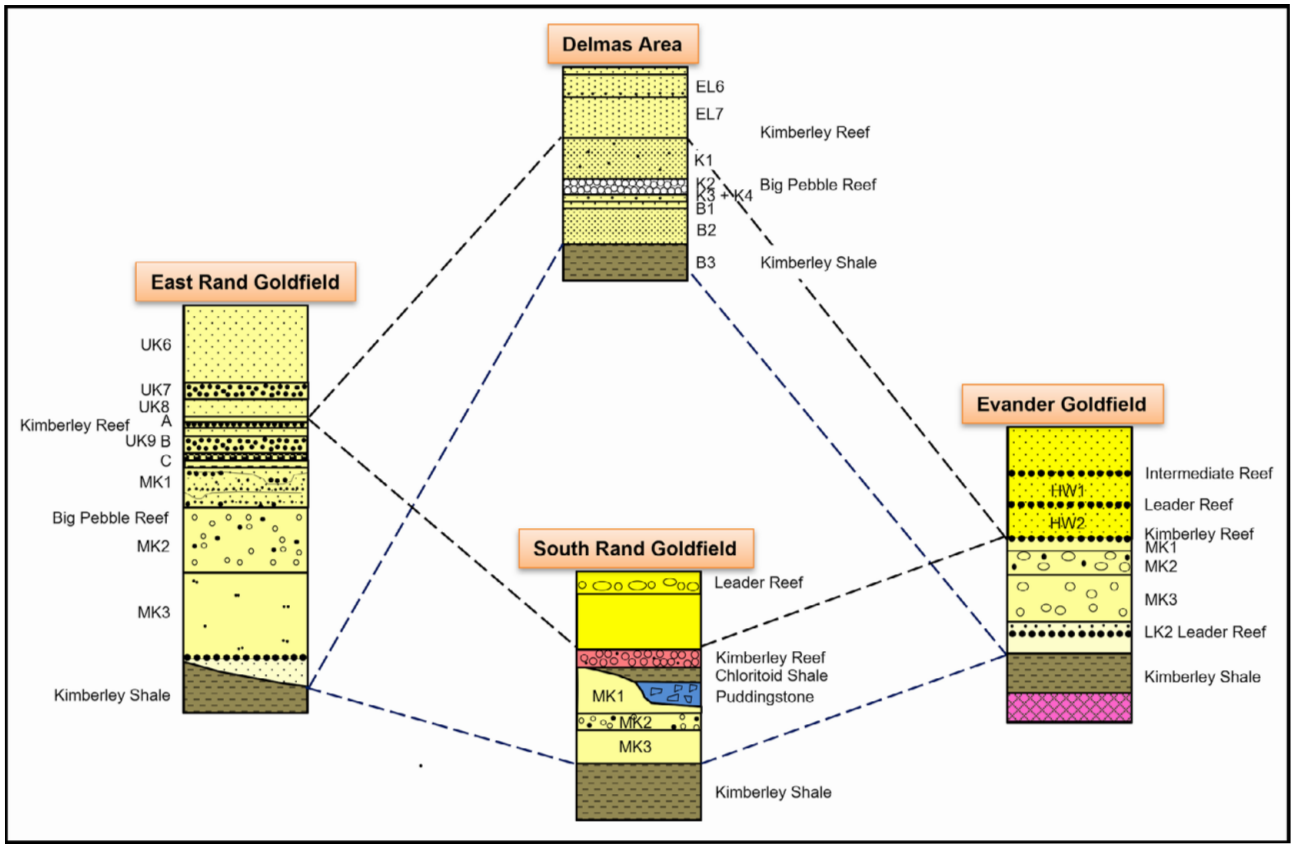


Figure 5. *Stratigraphic correlation of the Kimberley package across the Far East Rand (compiled from Antrobus, 1964; Button, 1968; E.B. Tweedie, 1981 and Great Basin Gold, 2007).*

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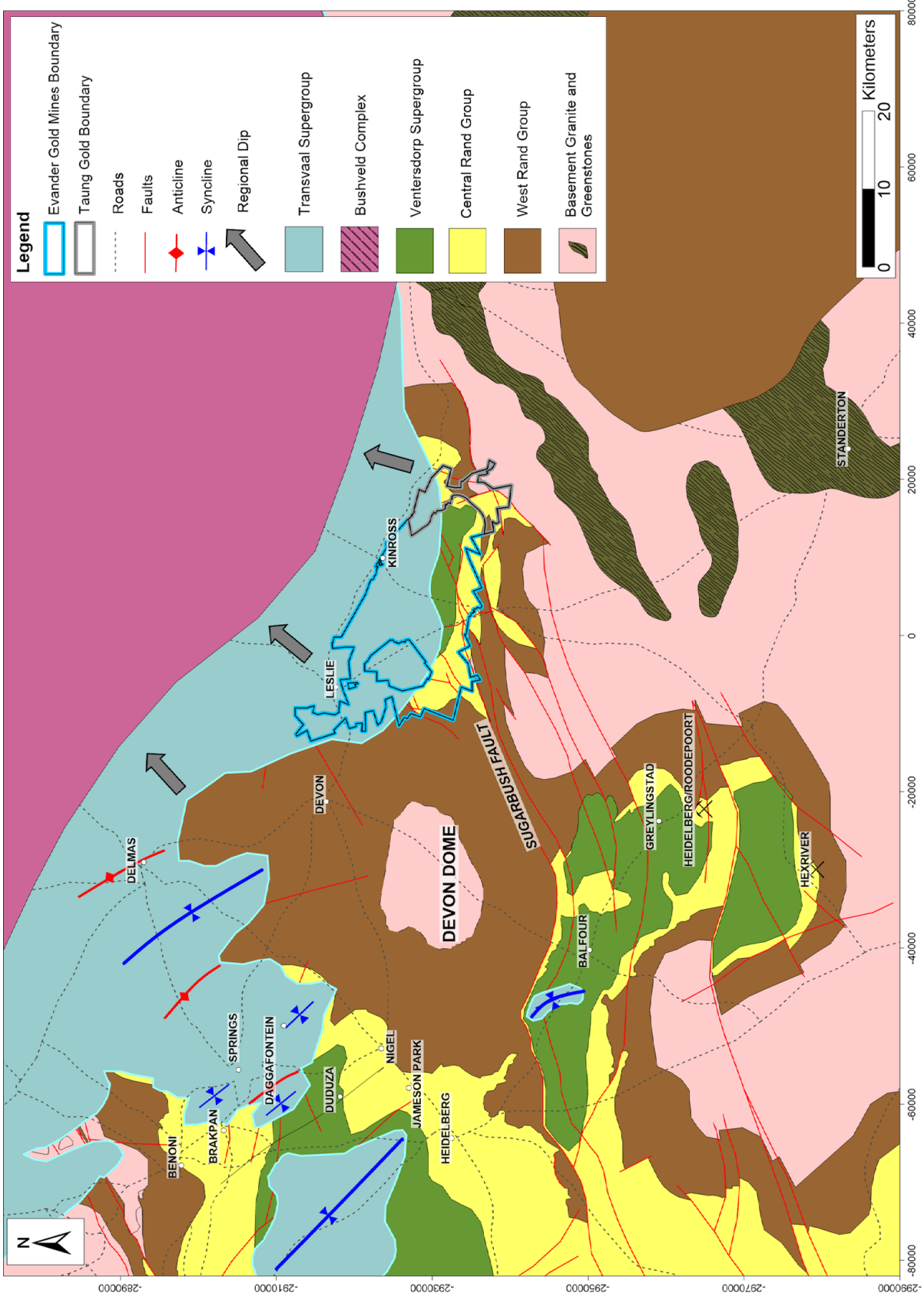


Figure 6. *Pre-Karoo geology of the Far East Rand (map based on information from Borchers, 1964; Pretorius, 1986; Ferraz, 1989; Button, 1968; Brandt, 1986; Cadle, 1976 and Antrobus and Whiteside, 1964).*

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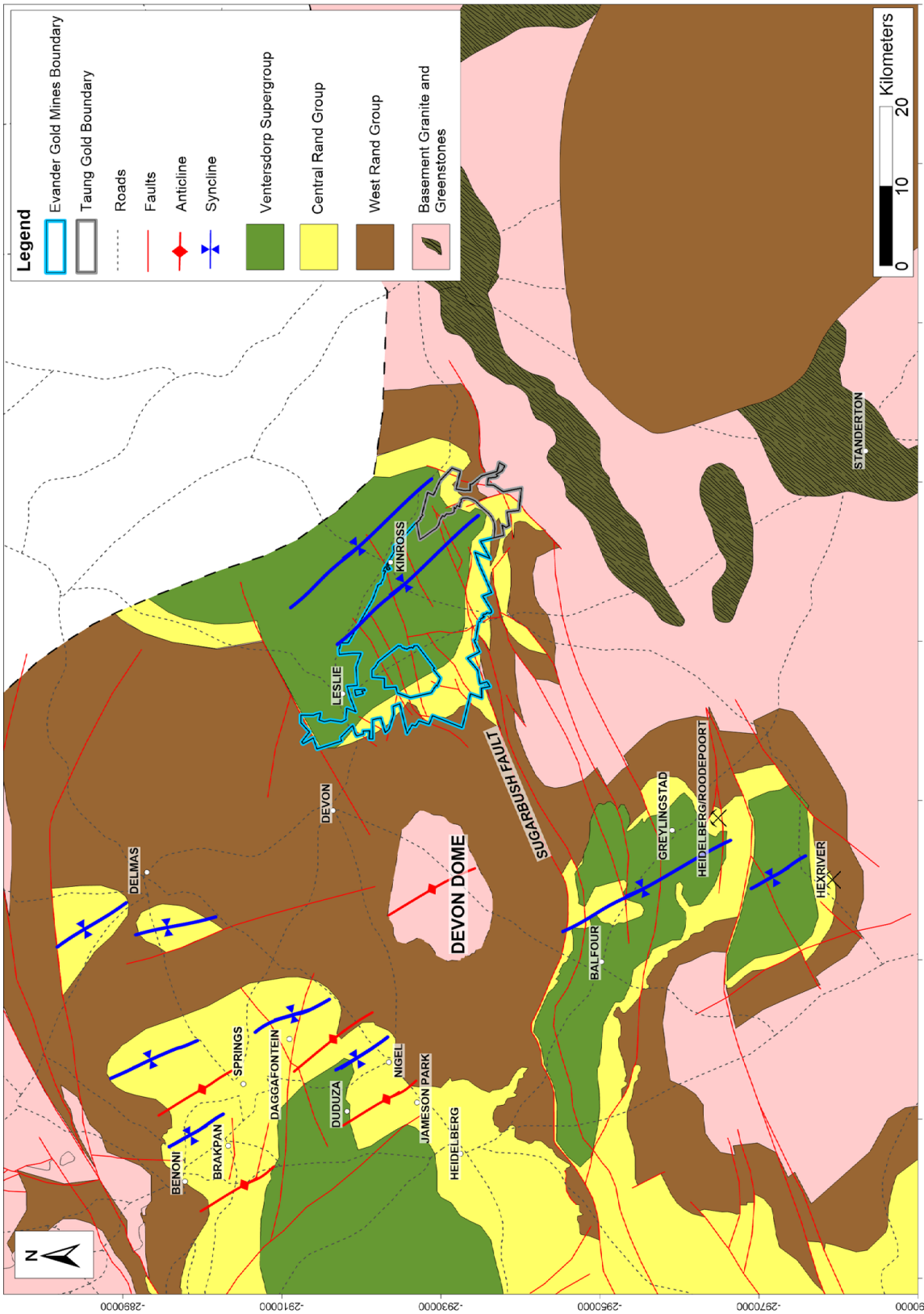


Figure 7. *The pre-Transvaal geology of the Far East Rand (map based on information from Borchers, 1964; Pretorius, 1986; Ferraz, 1989; Button, 1968; Brandt, 1986; Antrobus and Whiteside, 1964; Cadle, 1976 and the Evander Gold Mines wireframe). Note that the extent of the Devon Dome has been reduced to compensate for post-Transvaal erosion. The major faults strike east/northeast and are post-Ventersdorp, pre-Transvaal in age.*

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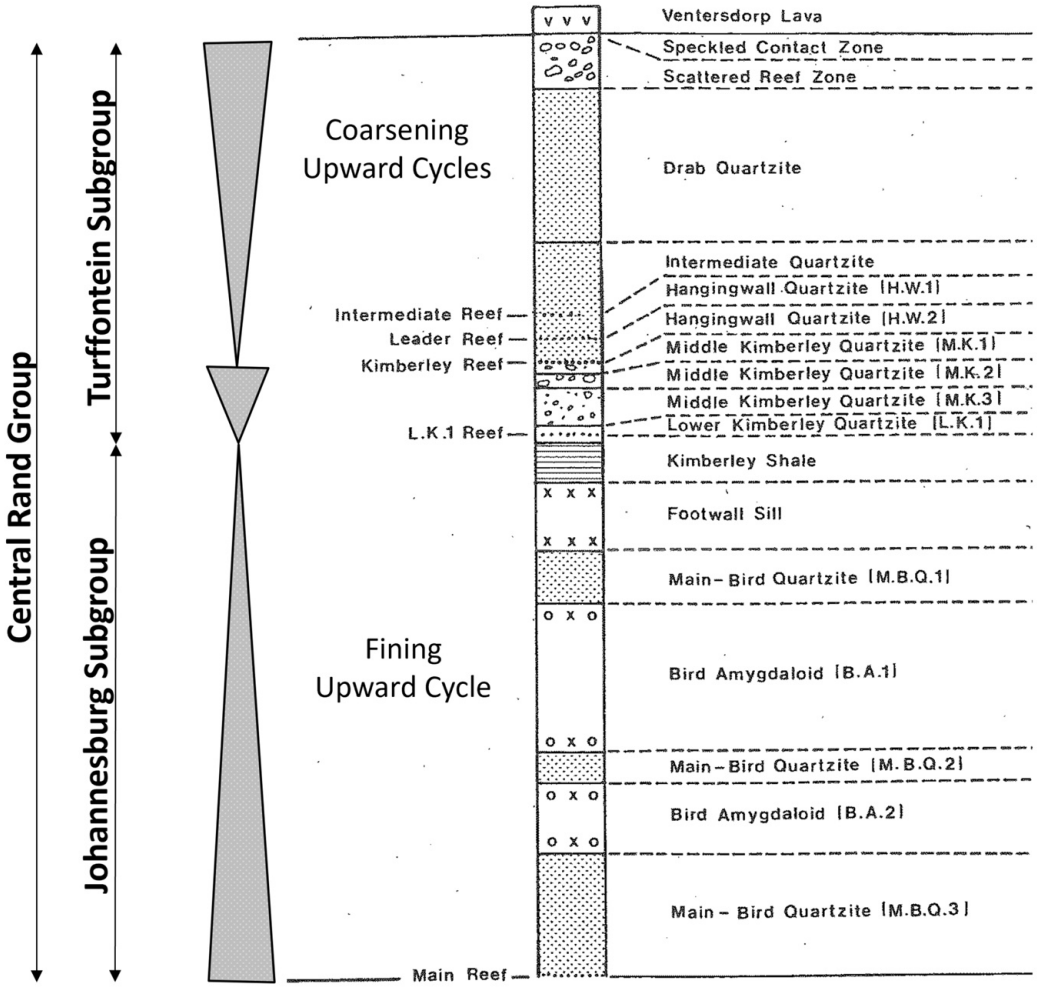


Figure 8. *Schematic stratigraphic column for the Central Rand Group in the Evander area (reproduced from E.B. Tweedie, 1981). The West Rand stratigraphy is illustrated in Figures 2 and 4.*

strata form a broadly upward fining sequence which culminates in the Booysens Shale (Figure 8). In the Delmas and Evander areas, the Bird Member is represented by two eruptive cycles separated by quartzite (MBQ2), whereas elsewhere in the region only a single volcanic cycle is developed.

Deposition of the Turffontein Subgroup commenced with a broadly upward coarsening sequence of arenaceous rocks. At Evander, the conglomerate of the LK1 unit lies at the base (Figure 5 and Figure 8), whereas elsewhere the partly conglomeratic MK3 forms the lowermost unit. This is overlain by the MK2 conglomerate (the so-called 'Big Pebble Marker') which is unconformably overlain by the MK1. The MK1 is heterogeneous across the Far East Rand, consisting of varying proportions of chloritoid-bearing shale, greywacke, conglomerate and diamictite (previously referred to as puddingstone). Internal disconformities are common (de Jager, 1964).

The deposition of the MK1 was followed by a period of erosion across the entire region. The gravel that accumulated on this erosion surface constitutes the Kimberley Reef. It is estimated that up to 200 m of Kimberley Reef footwall was locally removed in the Evander area (E.B. Tweedie, 1981) and possibly even more at Burnstone. The extent of erosion in the East Rand appears to be more modest.

At Evander, the Kimberley Reef is overlain by gritty quartzite (HW2) followed by conglomerate (Leader Reef) and quartzite (HW1) (Figure 8). Similar relationships occur in the East Rand, where the HW2-Leader Reef-HW1 package is termed UK8, UK7 and UK6, respectively (Figure 5; SACS, 2006).

The hangingwall sequence is overlain by the Intermediate Zone at the base of which lies the Intermediate Reef (UK5; SACS, 2006). At Evander, the Intermediate Zone cuts down through the underlying rocks towards the south and west, ultimately truncating the Kimberley Reef. The Intermediate Reef is often economically mineralised down dip of the subcrop of the Kimberley Reef.

The Intermediate Zone is overlain by a sequence of quartzites with occasional conglomerates (the Drab Zone at Evander), which coarsens upwards into the Brendan Conglomerate Formation, consisting of the lower Scattered Reef Zone and the upper Speckled Contact Zone (Figure 8). This conglomeratic zone is

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considered to be the equivalent of the Elsburg conglomerates in the East Rand Basin (SACS, 2006).

The Witwatersrand Supergroup in the Far East Rand is conformably overlain by volcanic rocks of the Ventersdorp Supergroup. The Ventersdorp Contact Reef is absent. A major period of extensional faulting, dominated by east-northeast striking normal faults which down-throw to the south in the Evander and South Rand basins, followed the eruption of the volcanic rocks. Faulting of this type did not occur in the East Rand basin. The Devon Dome appears to have been actively rising during Ventersdorp Supergroup times. Following a period of erosion, the Witwatersrand and Ventersdorp rocks were buried beneath the sedimentary rocks of the Transvaal Supergroup. The Transvaal and older strata experienced tilting towards the northeast after the intrusion of the Bushveld Complex (Figure 3) a short distance to the north of the goldfield. Following a period of erosion, the entire area was covered by the sedimentary rocks of the Karoo Supergroup.

The structure of the Evander Goldfield

The Evander Basin is best known along its southern and southwestern margins as a result of extensive exploration drilling and mining. In contrast, the area to the northeast is poorly known due to limited drilling and significant depth. The wireframe of the Kimberley Reef over the known basin is illustrated in Figure 9. The basin broadly has an oval shape with the major axis trending northwest. It is transected by numerous faults the majority of which trend east-northeast. These are normal faults which dip towards the south-southeast, with upthrow to the

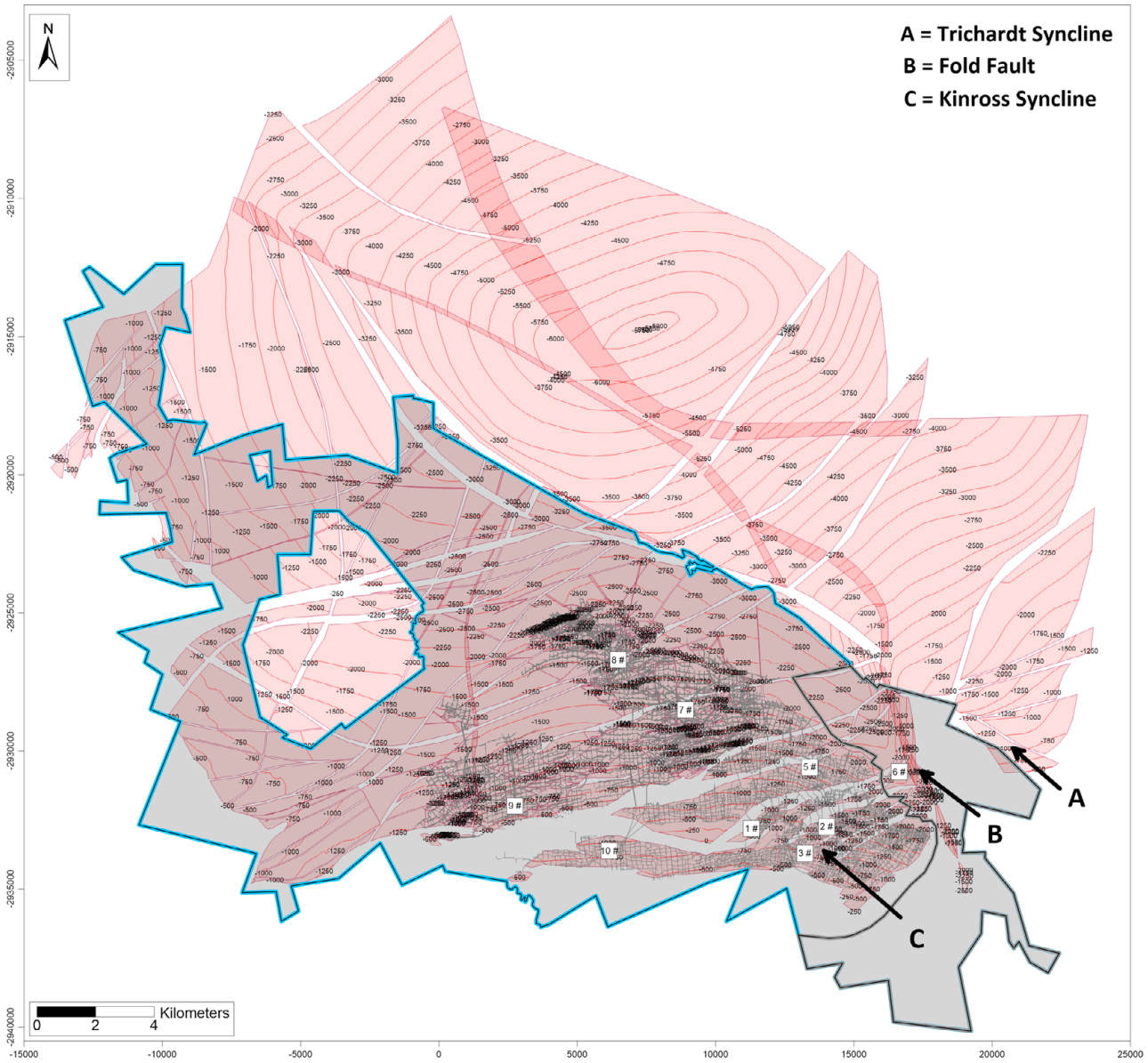


Figure 9. *Wireframe constructed for the Kimberley Reef, Evander basin showing the extent of the lease area and mined out area (red and dark grey). Contours are in metres below datum (1 829 masl).*

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north, and are of post-Ventersdorp age (E.B. Tweedie, 1986). The southeastern portion of the basin is divided into two northwesterly plunging synclines, the Kinross Syncline in the southwest and the Trichardt Syncline in the northeast (Figure 9). These synclines are separated by an anticlinal structure which passes into a zone of reverse faulting to the northwest. This structure is termed the Fold-Fault (E.B. Tweedie, 1981 and 1986). Within this structure the Kimberley Reef and associated sequences have been overturned towards the southwest, dipping towards the northeast.

To obtain additional insight into the nature of the Fold-Fault, a series of northeast-southwest orientated geological cross sections was constructed across a portion of the structure, employing borehole records (Figure S3). The sections reveal a component of compressional deformation verging to the southwest, which was followed by an extensional event that resulted in down faulting towards the northeast. The Fold-Fault was interpreted by E.B. Tweedie (1986) and Myers et al. (1990) to represent a basin margin similar to the large anticlinal structure which bounds the western margin of the Free State (K.A.M. Tweedie, 1986) and other major goldfields. However, the wireframe (Figure 9) indicates that the basin reopens to the northeast of the Fold-Fault into the Trichardt Syncline and beyond, which is not a common feature of a folded basin margin. The most likely analogue of the Fold-Fault structure is the Marievale Anticline of the East Rand Goldfield which was well documented by Whiteside (1964) and Stanistreet et al. (1986). The Marievale Anticline is part of a large monoclinal structure that forms a lip separating the East Rand and Heidelberg-Nigel basins (Figure 3). Mapping by Rogers (1921) revealed that the Marievale Anticline represents a disharmonic fold and the major economic horizons are continuous around the anticline. We therefore conclude that the Fold-Fault is an intra-basinal structure and does not represent a basin margin feature.

Depositional setting

The pre-Kimberley Reef surface

The various basins of the Far East Rand in which Kimberley Reef is preserved most likely became separated from each other as a result of pre-Transvaal erosion. The Witwatersrand and Ventersdorp supergroup rocks had been deformed by prolonged northwest-southeast striking periclinal folding and rise of the Devon Dome. Pre-Transvaal erosion removed the anticlinal features, thus exposing the synclinal keels and the core of the Devon Dome. Prior to this, the Kimberley Reef extended as a more or less continuous layer across the entire Far East Rand.

The Kimberley Reef was deposited on an unconformity. Subcrop maps beneath the Kimberley Reef were prepared from a variety of sources. In the case of the Evander Goldfield, the primary sources were the Master Borehole Database and E.B. Tweedie (1981), which were augmented by several Union Corporation internal bulletins and reports (Theron, 1963; Moubray, 1967a, b; Pritchard-Davies, 1953; K.A.M. Tweedie, 1954). The angles of unconformity were calculated from isopach plans for the thicker footwall units extracted from the internal bulletins. The Kimberley Reef footwall in the East Rand and Nigel areas was reconstructed from maps compiled by Antrobus and Whiteside (1964), de Jager (1952, 1964, 1986a, b) and Armstrong (1965). The footwall geology of the Kimberley Reef at Burnstone was obtained from Great Basin Gold (2007) and at Delmas was reconstructed from isopach plans of the region compiled by Button (1968). The regional pre-Kimberley Reef geological map for the Far East Rand is shown in Figure 10.

The disconformable relationship between the MBQ3 and the Government and Jeppestown subgroups is evident in the centre of the map (Figure 10), and arises from a major disconformity that exists within the West Rand Group in the Far East Rand (Figure 4). The relationships are further clarified by means of a cross section extending from the East Rand to the Evander goldfields (Figure 11). A detailed footwall map of the Kimberley Reef in the Evander Goldfield is shown in Figure 12.

Several inferences can be made from Figure 10, Figure 11 and Figure 12:

- It is evident that although the Devon Dome had been rising since at least Johannesburg Subgroup times, the basement rocks of the Dome were still deeply buried at the time of deposition of the Kimberley Reef in the Evander and East Rand basins. Consequently, the Devon Dome did not contribute any detritus to the Kimberley Reef;
- The footwall strata had been gently folded about northwest-southeast striking axes prior to deposition of the Kimberley Reef. The folding was periclinal in nature and the folds exhibit gentle plunges to the northwest and southeast. For example, this is illustrated by the distribution of MK1 strata in the footwall of the Kimberley Reef (Figure 12);
- The Evander Basin is characterised by two closely spaced synclines; the Kinross and Trichardt synclines (Figure 10), separated by an anticline; and
- The folded footwall rocks were bevelled by erosion prior to deposition of the Kimberley Reef. The folding continued after deposition of the reef.

Characteristics of the pre-Kimberley sequence

The Kimberley Reef unconformably overlies an upward coarsening sequence above the Booysens Shale (Figure 8). K.A.M. Tweedie (1968) and E.B. Tweedie (1981 and 1986) described the sedimentological characteristics of the footwall (shale, diamictite, quartzite and conglomerate), Kimberley Reef (conglomerate) and hangingwall (pebbly quartzite). K.A.M. Tweedie (1968) also described the Kimberley (Booysens) Shale in considerable detail. Its composition ranges from a black mudstone to a calcareous siltstone. Palaeocurrent structures indicate a consistent west-southwest flow direction. Similar flow directions are present in the overlying pebbly quartzite of the LK1 and MK3 (Figure 13).

Several features of the MK2 and MK1 footwall rocks in the Far East Rand are diagrammatically illustrated in Figure 14. Palaeocurrent indicators in the Delmas and Evander basins reveal that flow was from the northeast, whereas the East Rand basin received sediment from the northwest. There may have been some southward convergence of these flow directions in the South Rand because Antrobus (1986) recorded southward

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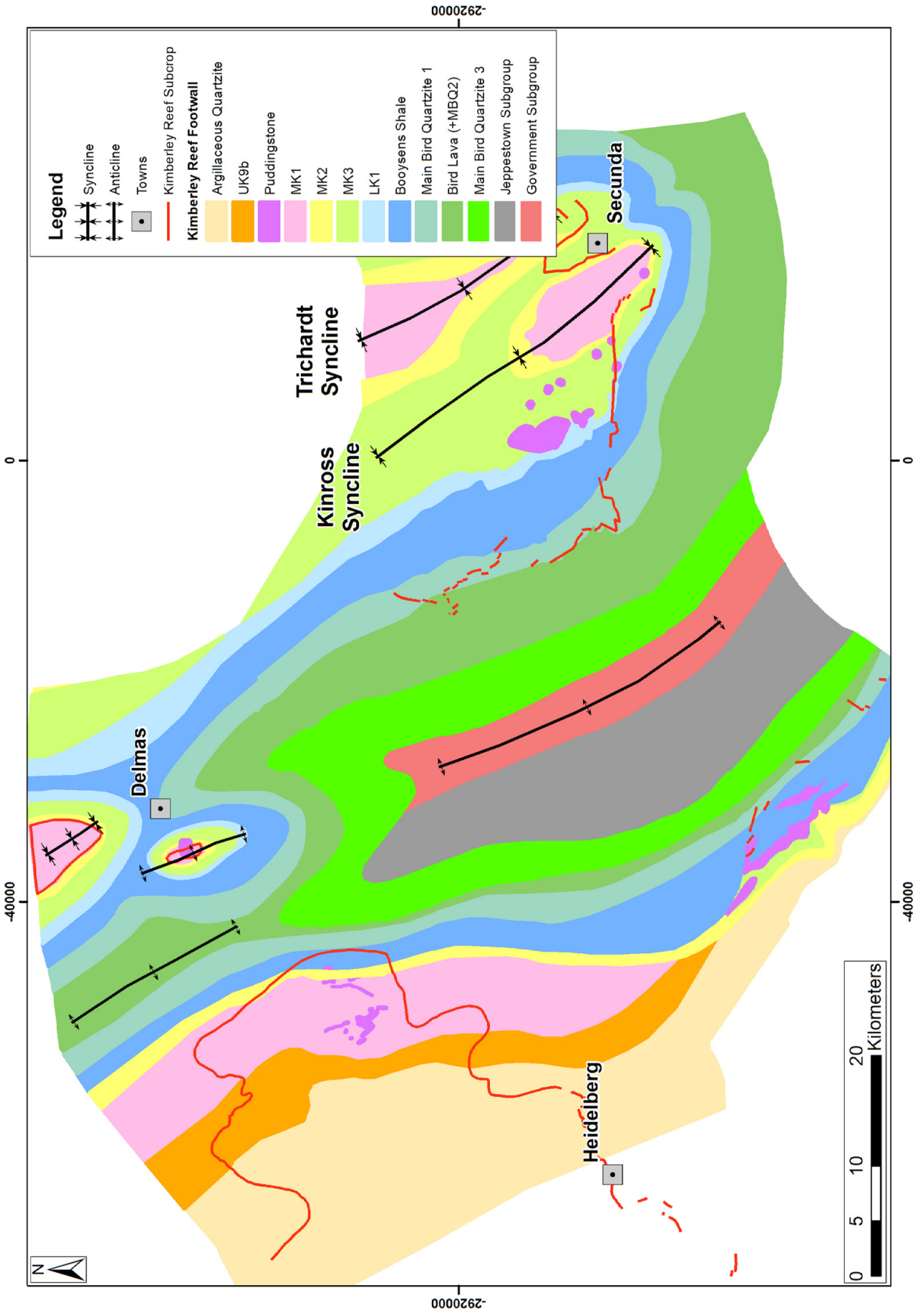


Figure 10. *The pre-Kimberley Reef geology of the Far East Rand.*

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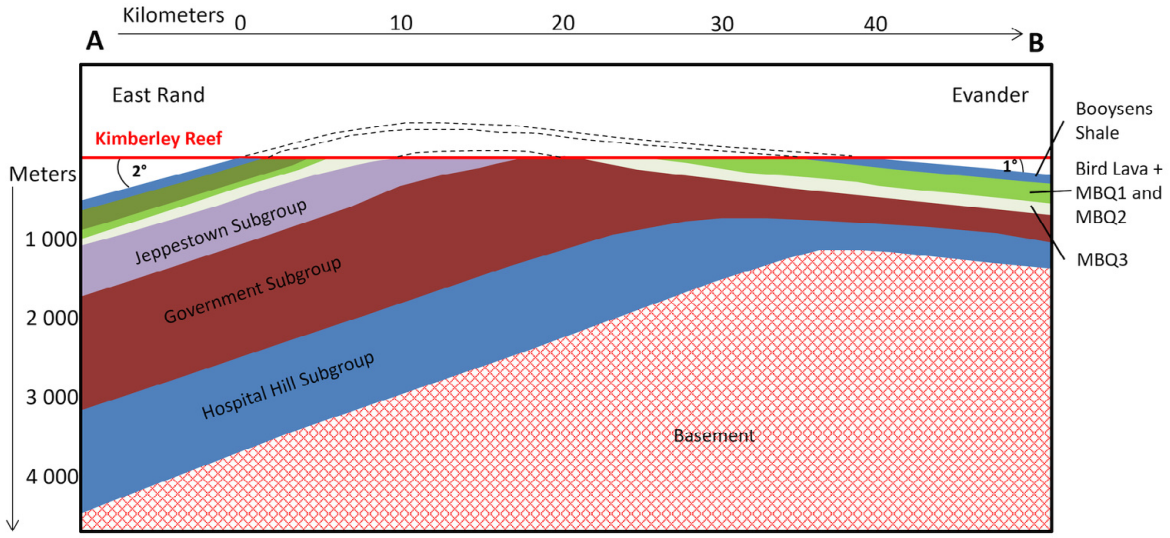


Figure 11. *Geological cross section from the East Rand to Evander, assuming that the Kimberley Reef is horizontal. Note the vertical exaggeration.*

directed palaeocurrents in pre-Kimberley Reef rocks in the southern portion of this basin. Fully quantitative pebble assemblage data for the MK2 and MK1 are only available for the Delmas and East Rand basins (Button, 1968 and Armstrong, 1965, respectively). The majority of pebbles in the East Rand consist of vein quartz. In the southern portion of the East Rand basin, pebbles of both vein quartz and chert occur, but proportions are not provided (de Jager, 1964). In the Delmas area, chert makes up the majority of the pebbles. At Evander, the presence of both chert and vein quartz are mentioned, but again proportions are not provided (E.B. Tweedie, 1981). Jasper is an uncommon clast type in Witwatersrand conglomerates but has been reported from the Evander basin (Hirdes, 1979; E.B. Tweedie, 1981 and 1986). According to E.B. Tweedie (1981), jasper is most abundant in the LK1 conglomerate. However, it is largely absent from the East Rand Basin, except in the south (de Jager, 1964).

The clast assemblages, when viewed in conjunction with the palaeocurrent data, suggest two fundamentally different sources for the footwall sequences in the Far East Rand: one to the northeast which was rich in chert and another to the northwest, poor in chert (Figure 14). This source difference has been noted previously and attributed to differences in the relative proportions of greenstone and granitoid in the respective source areas (Ferraz, 1989). The presence of jasper is indicative of a greenstone-rich source, because the jasper in Evander conglomerates has been shown to have originated from greenstone-hosted iron formations (Hirdes, 1979).

The immediate footwall rocks experienced erosion to varying degrees in the basins of the Far East Rand, prior to Kimberley Reef deposition. The sequence consists of the MK3, MK2 and MK1 in most of the preserved Kimberley Reef basins, but at Evander and Delmas, a lower LK1 unit is present as well (E.B. Tweedie, 1981; Button, 1968). These units, together with the underlying Booysens Shale, MBQs, Bird Member and Jeppestown Subgroup shale and quartzite, would have been exposed by erosion on the denudational surface on which the Kimberley Reef was deposited. However, during initial onset of pre-Kimberley Reef erosion, the region would have been covered primarily by MK2 and MK1 units (Figure 12). The former consists largely of matrix to clast supported, medium to coarse pebble conglomerate (the 'Big Pebble Marker'), whereas the latter is represented by a diverse and heterogeneous assemblage of rock types that unconformably overly the MK2 (de Jager, 1964).

At Evander, the MK1 consists mainly of pebbly greywacke. In the East Rand and Nigel areas, the MK1 often contains diamictite, usually in channel-like features, and occasionally as more laterally extensive bodies. These are often bounded by unconformities and disconformities and the MK1 as a whole is unconformity based (Armstrong, 1965; Antrobus and Whiteside, 1964; de Jager, 1964). Diamictite has also been encountered in boreholes at Delmas (Button, 1968), and locally occurs in channel-like bodies beneath the Kimberley Reef at Evander (E.B. Tweedie, 1981). Products of the reworking of diamictite include conglomerate and quartzite, which are also associated with the MK1.

The final episode that preceded the Kimberley Reef at Evander was the deposition of a sequence of diamictites interlayered with quartzite and conglomerate (Figure 15 to Figure 17). These figures have been reproduced from unpublished company reports and provide unique information which was not previously available to the geological community and hence are reproduced here. In the East Rand, similar lithologies are considered to form part of the MK1 (Antrobus, 1964; de Jager, 1964). The diamictite and associated rocks often occupy channel-like features which in the Evander area have commonly eroded down into the MK3. The mapped occurrences of diamictite channels in the immediate footwall of the Kimberley Reef in the Far East Rand are depicted in Figure 10.

The diamictite typically is composed of dark, silty to muddy material in which pebbles, cobbles and boulders are suspended (Joynson, 1986). The clasts consist of rounded to subangular

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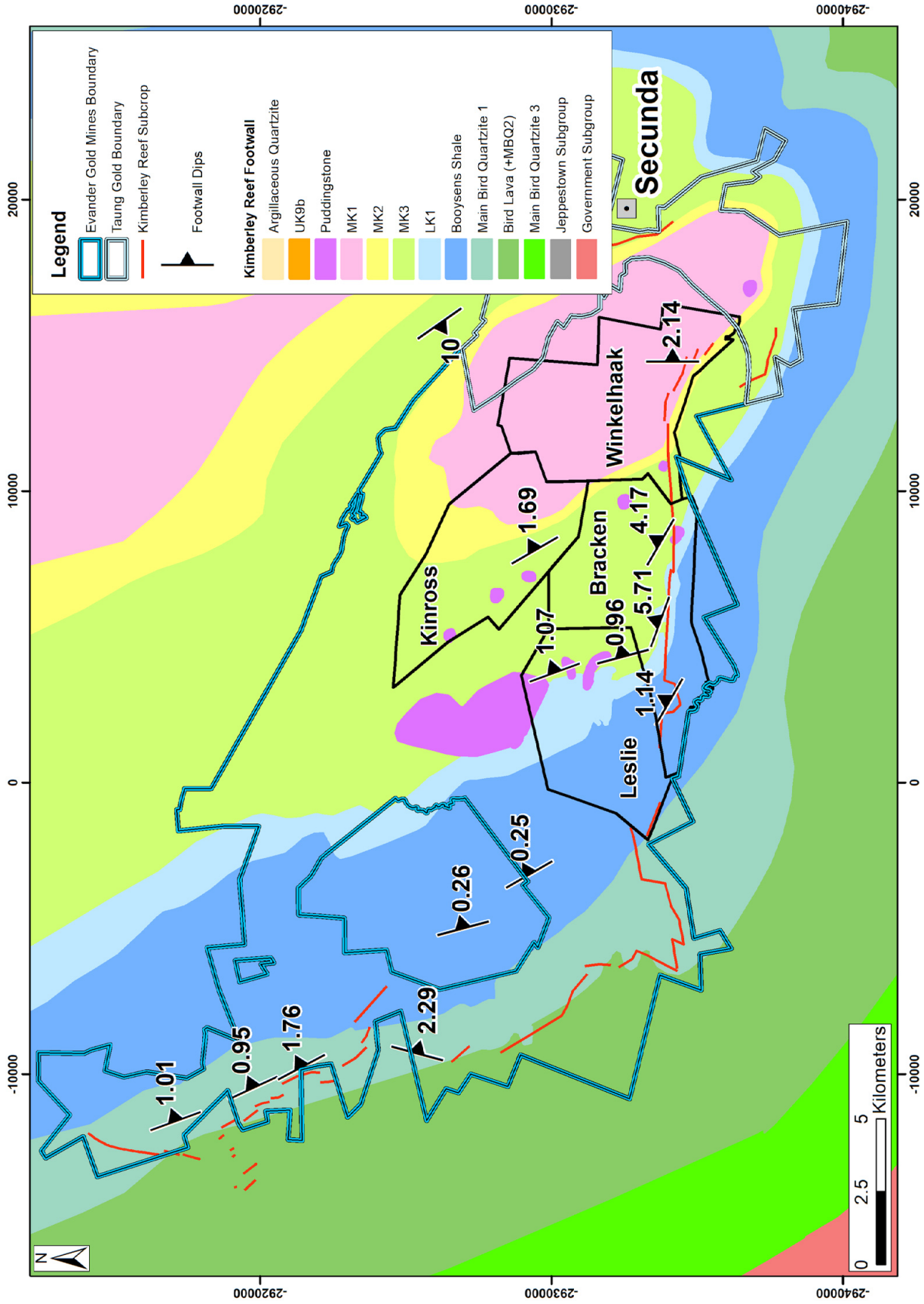


Figure 12. *The geology of the pre-Kimberley Reef surface in the Evander area. The dips refer to the angles of unconformity between the Kimberley Reef and the footwall.*

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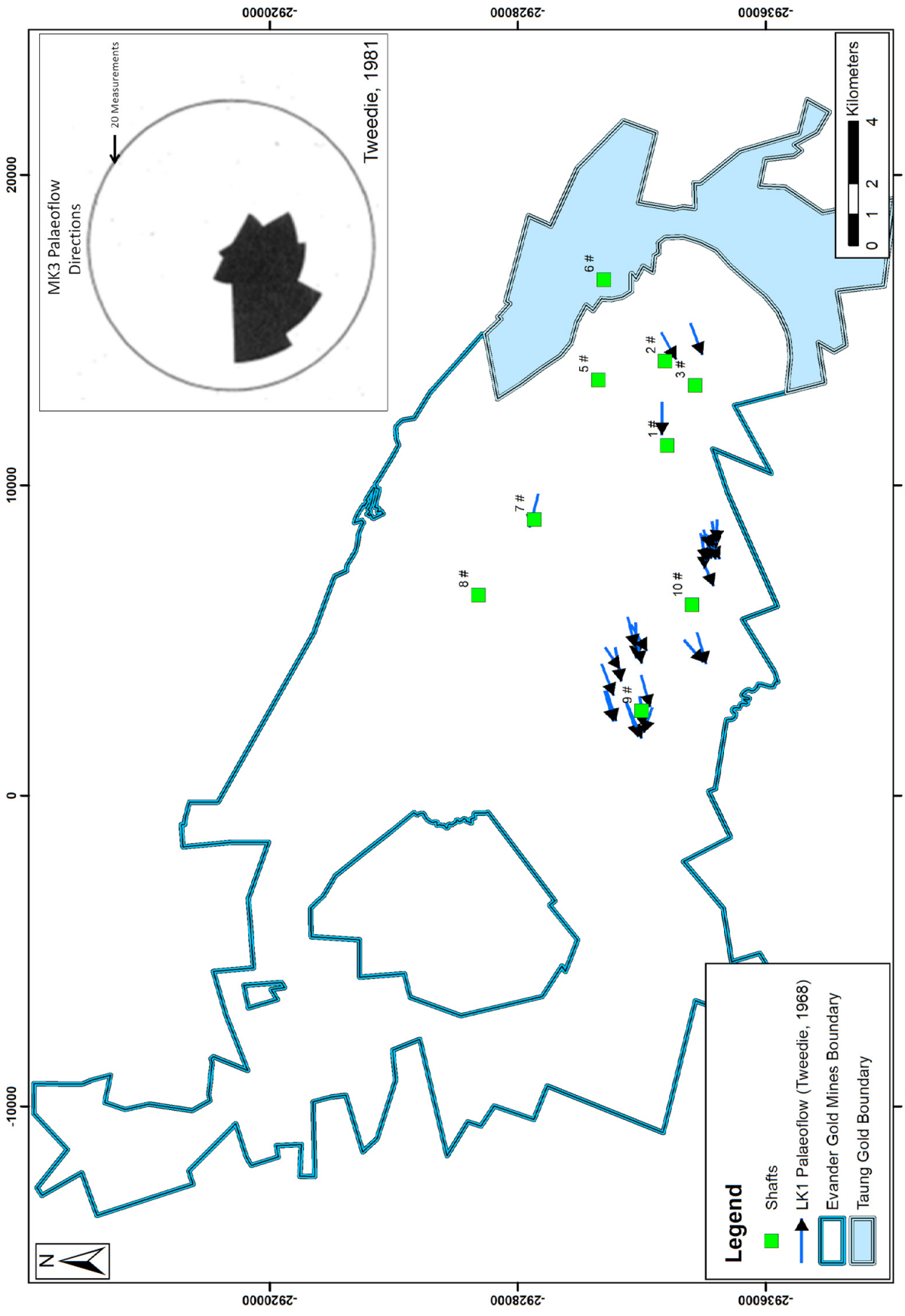


Figure 13. *Palaeocurrent directions during deposition of the LK1 (main figure, after K.A.M. Tweedie, 1968) and MK3 footwall quartzites (insert, E.B. Tweedie, 1981).*

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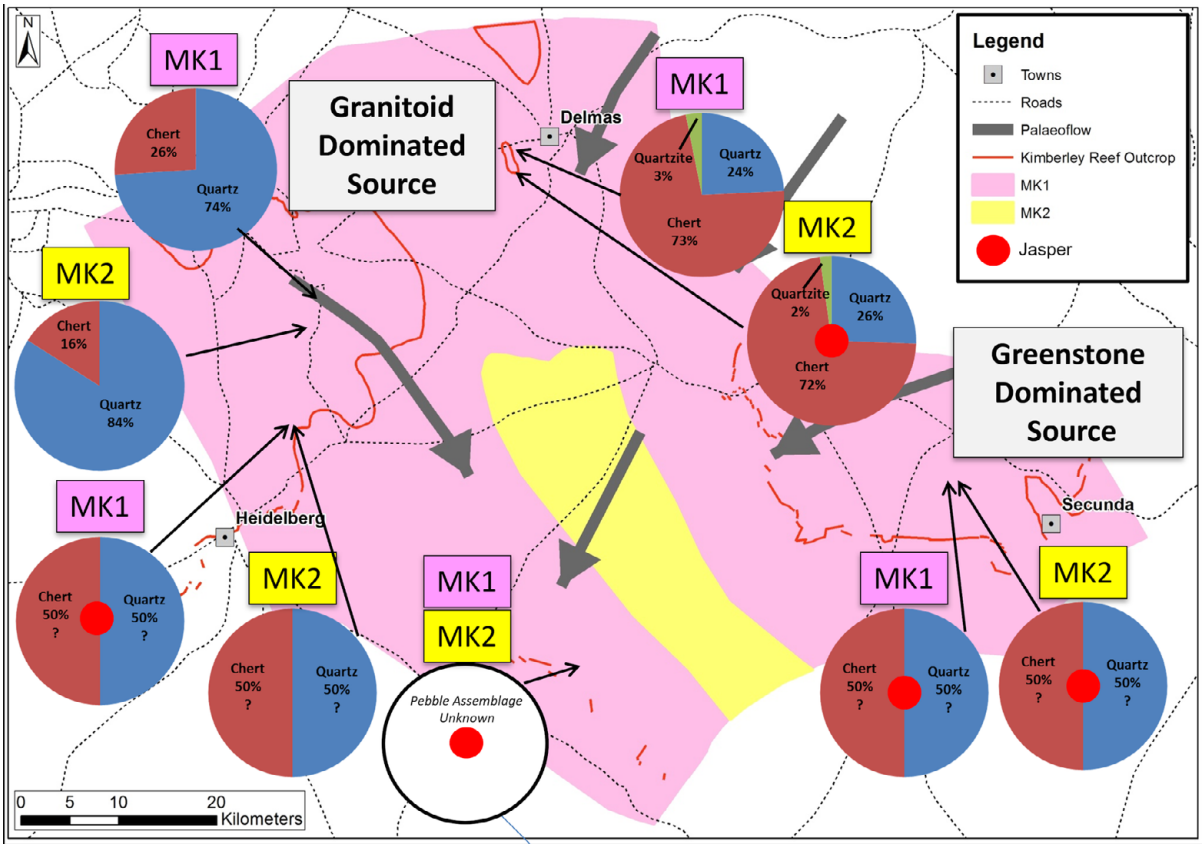


Figure 14. *Schematic diagram summarising some sedimentary parameters of the MK2 and MK1 footwall units. Data compiled from Armstrong (1965); E.B. Tweedie (1981); Hirdes (1979); Button (1968), de Jager (1964) and Muntingh (pers. comm.). This map straddles the region between Secunda, Heidelberg and Delmas, the location of which is shown in Figure 1.*

chert and vein quartz which vary in size up to 10 cm in diameter. Lithic fragments include basaltic lava and quartzite derived from footwall strata. The largest clast recorded was a quartzite boulder one meter in diameter (Theron, 1963; Figure 16). The clasts constitute about 10% of the diamictite. One of the channels mapped at Bracken Gold Mines contains chaotic bedding as well as dismembered blocks of bedded quartzite and conglomerate which were folded prior to incorporation into the stratigraphic unit in which they now occur (Koning, 1965; Figure 17). It is noted that this exposure was mapped in great detail, possibly down to the scale of less than an inch. There is no indication of brecciation or faulting between individual fragments, indicating that the juxtaposition occurred prior to lithification. Moreover, the underlying rocks are tectonically undeformed. All of these channel deposits are unconformably overlain by undisturbed Kimberley Reef as shown in the cross sections.

The features illustrated in Figure 15 to Figure 17 suggest that the pre-Kimberley Reef sequence may have been deposited under glacial conditions. The large boulder illustrated in Figure 16 could be a glacial erratic, possibly a drop stone. The complex combination of disrupted blocks of well bedded and deformed arenaceous rocks together with cross bedded quartzitic material (Figure 17) may be the result of glacial deformation and complex depositional processes which often occur at glacial termini as illustrated in Figure 18 (e.g. Huddart and Humbrey, 1996; Bennediktsson et al., 2010). In Figure 18 the various lithofacies were juxtaposed prior to lithification and we propose that similar processes were responsible for the formation of the complex succession observed in Figure 17.

Diamictites in the Witwatersrand sequence are generally considered to be debris flow deposits (Tankard et al., 1982; Martin et al., 1989), although Wiebols (1955) had proposed that the diamictites were of glacial origin. His interpretation was never widely accepted. We are of the opinion that the evidence for glacial activity prior to the deposition of the Kimberley Reef in the Evander Goldfield is very strong.

Characteristics of the Kimberley Reef sequence

Palaeocurrent directions

The Kimberley Reef itself lies on a major unconformity as described above (examples of this unconformity can be seen in Figure 15 to Figure 17). Palaeocurrents within the reef indicate a northeasterly flow direction (E.B. Tweedie, 1981) (Figure 19). This palaeocurrent direction is sustained in the overlying hangingwall sequence (Figure 20). It is evident that a radical change in the regional topographic slope occurred during the erosional episode that preceded the deposition of the Kimberley Reef (E.B. Tweedie, 1986), i.e. southwesterly palaeocurrents prior to the Kimberley Reef and easterly to northeasterly flow

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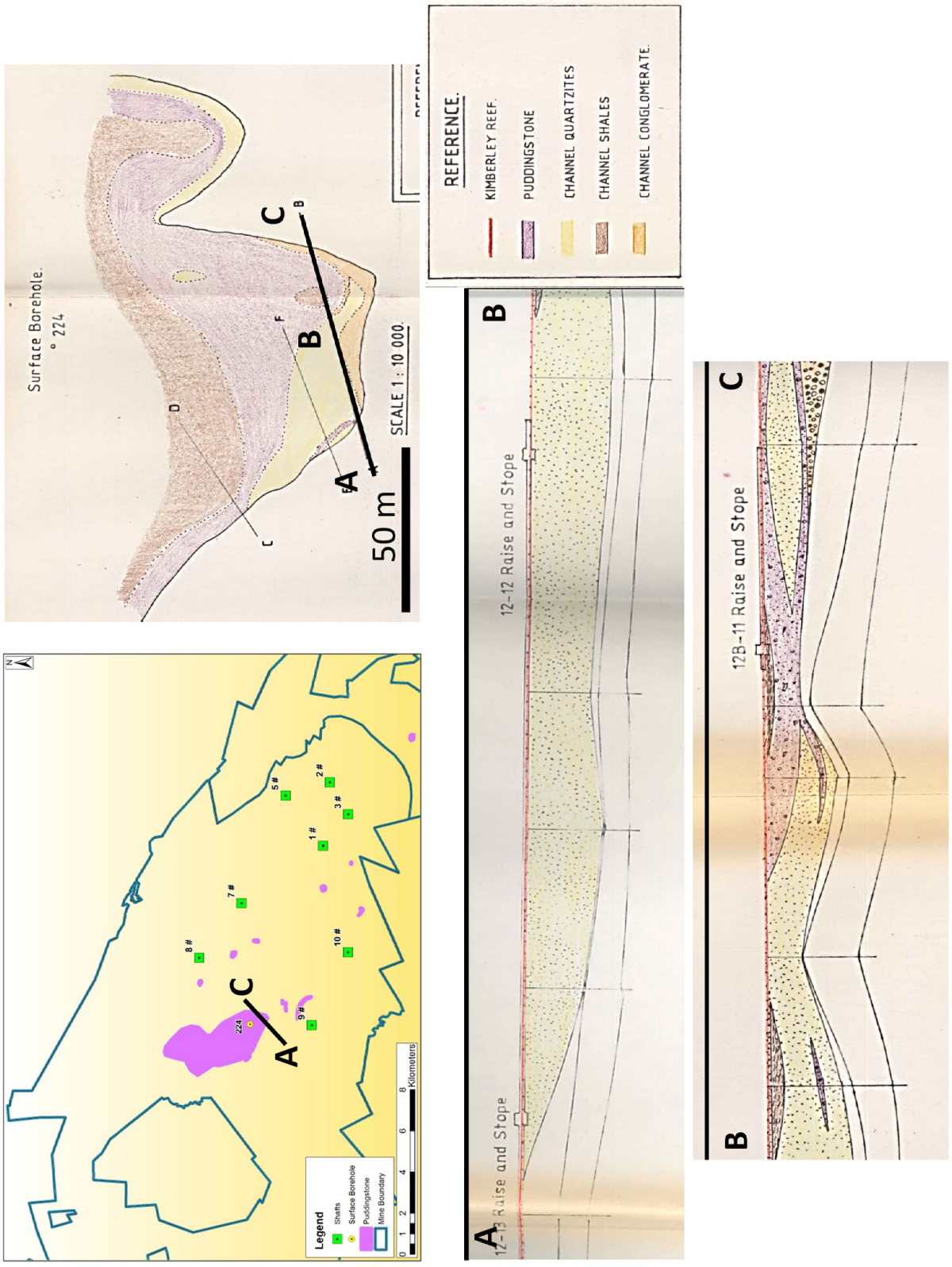


Figure 15. *Geological plan and cross sections of a large diamictite body encountered on Leslie Gold Mines (reproduced from unpublished internal report by Joynson, 1986).*

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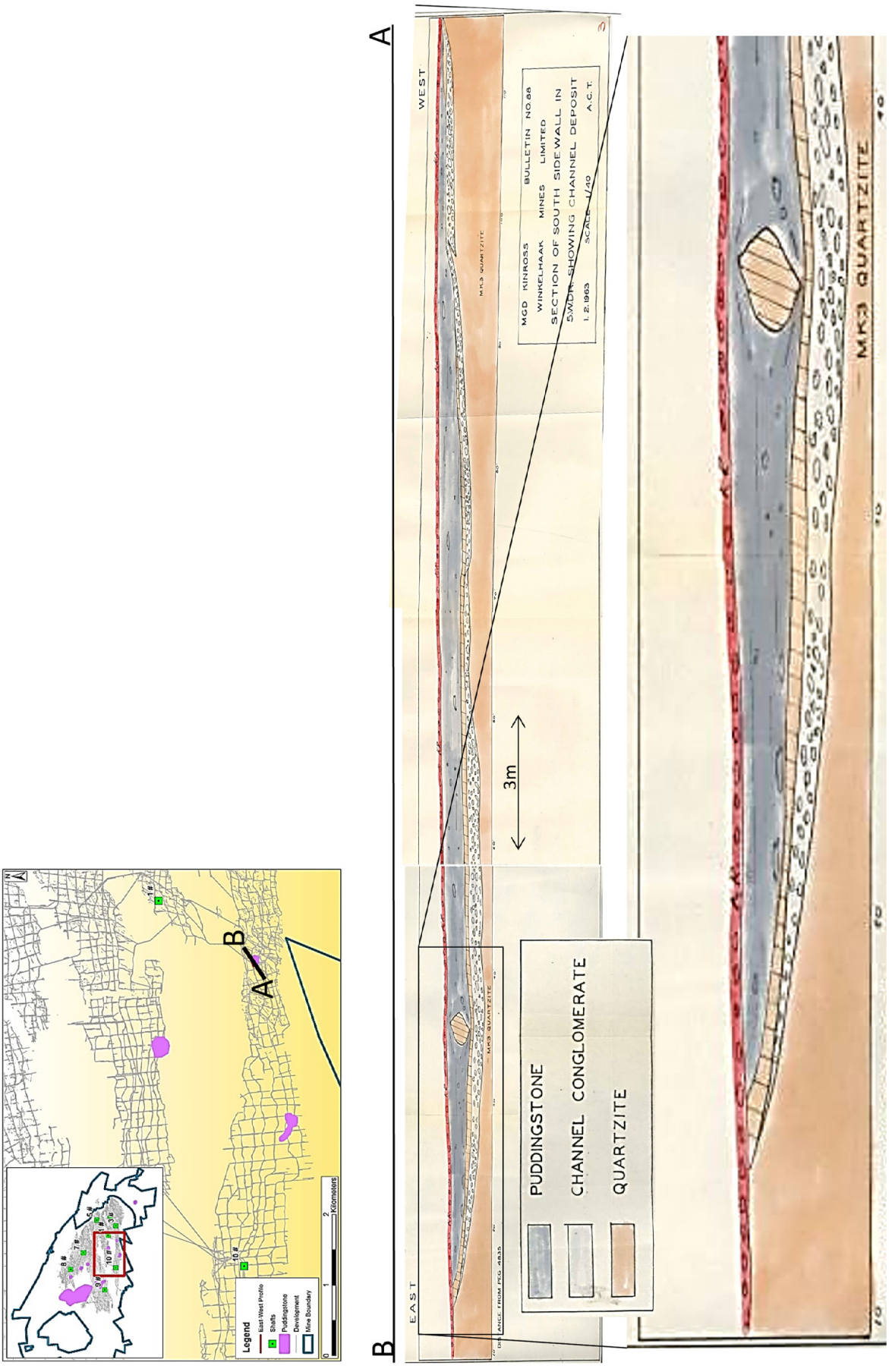


Figure 16. *A diamictite channel encountered on Bracken Gold Mines (reproduced from unpublished internal report by Theron, 1963). This deposit contains a quartzite boulder about 1 m in diameter.*

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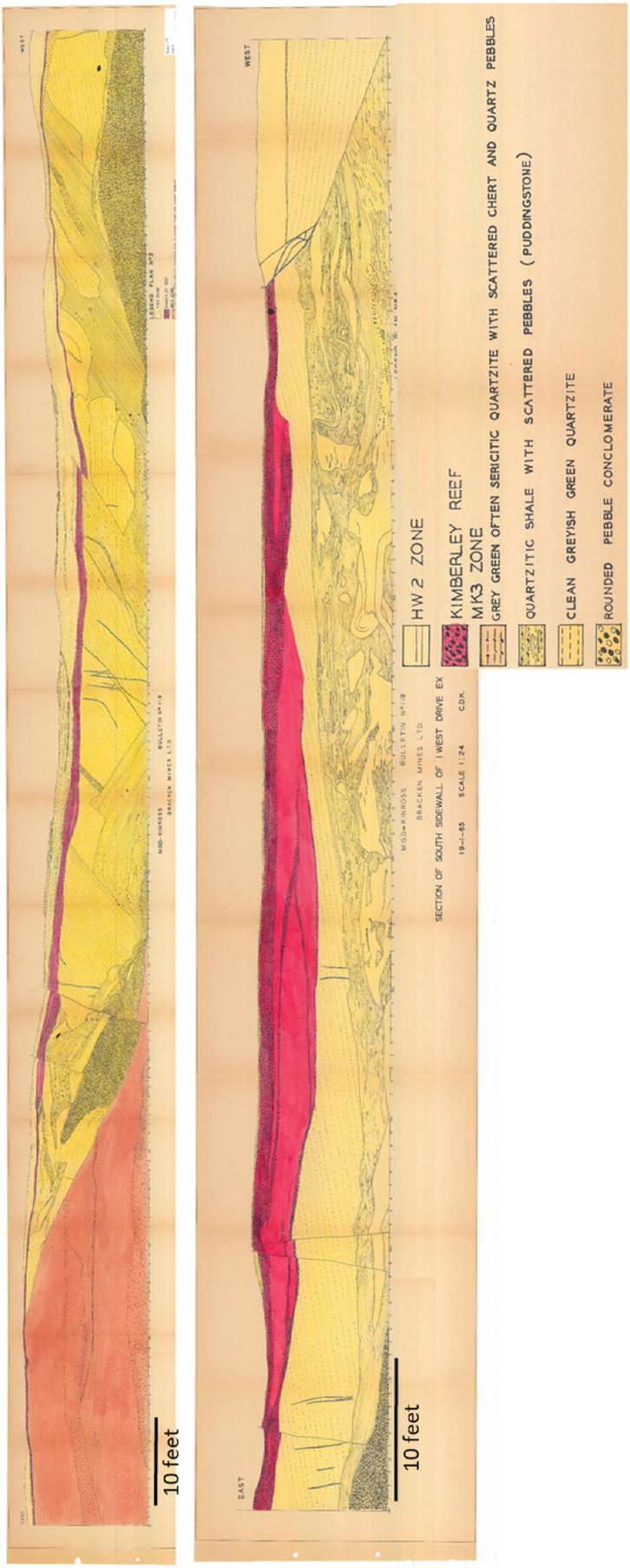


Figure 17. *A diamictite channel encountered on Bracken Gold Mines (reproduced from unpublished internal report by Koning, 1965). This map illustrates disjointed fragments of bedded quartzites which occur within a host consisting of bedded quartzites. Some of the fragments were folded prior to their inclusion in this complex stratum. The lower figure is a continuation of the cross section shown in the upper figure. Vertical and horizontal scales are the same.*

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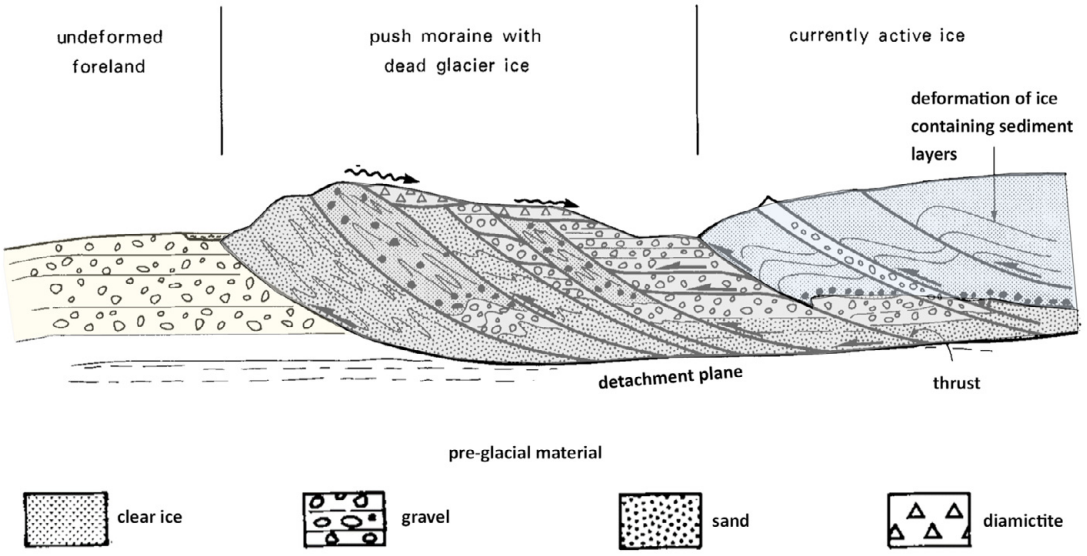


Figure 18. *Schematic cross section showing principal features of a push moraine (modified after Humbrey and Huddart, 1995).*

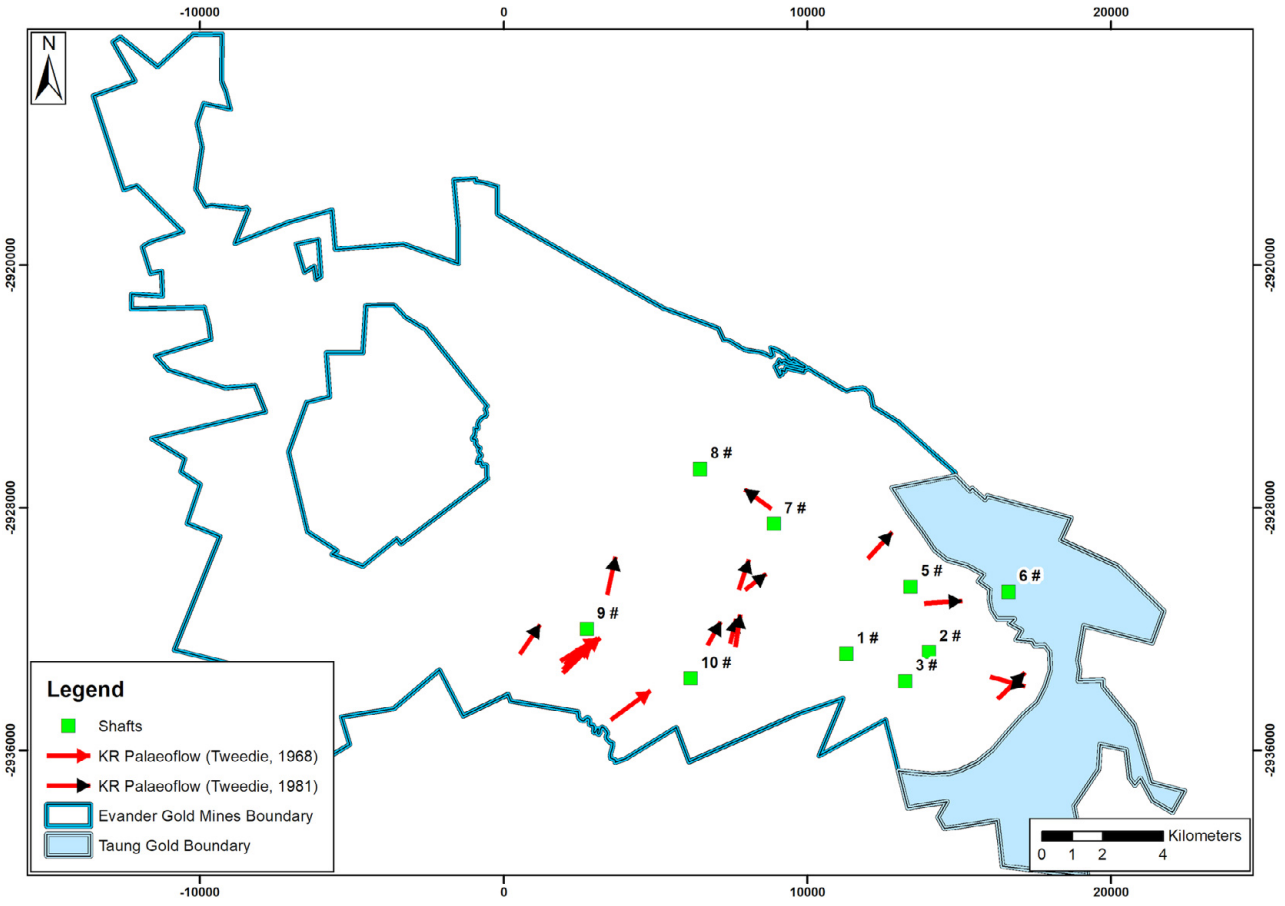


Figure 19. *Palaeocurrent directions measured in the Kimberley Reef at Evander (K.A.M. Tweedie, 1968; E.B. Tweedie, 1981).*

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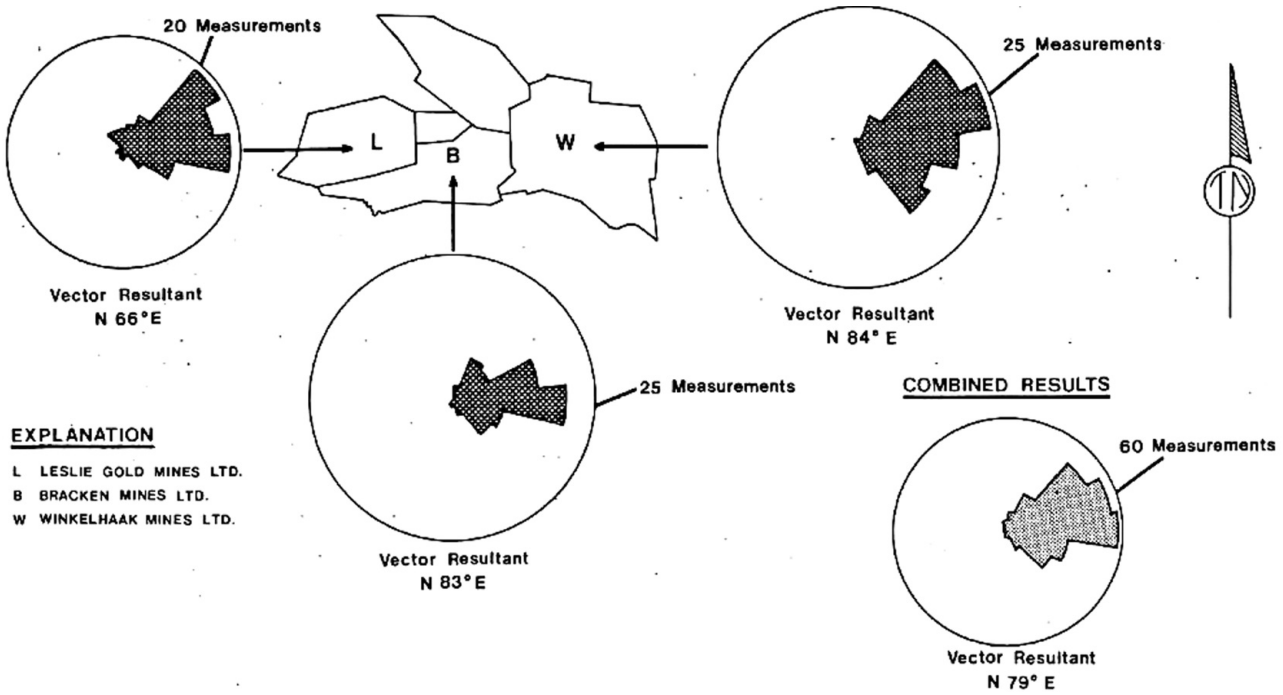


Figure 20. *Palaeocurrent directions in the hangingwall (HW2) of the Kimberley Reef (reproduced from E.B. Tweedie, 1981).*

directions during and after deposition of the Kimberley Reef. During this period of reversal the area appears to have experienced glaciation.

Clast compositions

Clast compositions have been recorded in the Kimberley Reef in the Far East Rand, but only locally in quantitative terms. Quartz tends to be the dominant clast type in the western section of the region, whereas chert becomes more abundant in the east, where an east to northeast palaeocurrent direction prevailed (Figure 21). Banded iron formation and jasper clasts have been recorded in the Evander and Burnstone areas, but are absent in the East Rand.

Hirdes (1979) undertook detailed mineralogical studies of the Kimberley Reef in the Evander Goldfield. He observed that the occurrence of jasper and banded iron formation (BIF) clasts varies systematically across the goldfield. The highest abundance of these clasts occurs along the southern margin of the goldfield. On the basis of geochemical studies, Hirdes (1979) concluded that the iron formation and jasper clasts were derived from greenstone belts (rather than from West Rand Group rocks). Jasper and BIF clasts decrease rapidly to the north, so much so that Hirdes (1979) was able to divide the reef into two broad domains on the basis of the jasper and BIF content (Figure 22). The zone of high jasper and BIF occurrence is situated close to the subcrop of the LK1 (Figure 12). This reef has the greatest abundance of jasper and BIF clasts in the Evander area (E.B. Tweedie, 1981; his page 74) and therefore the Kimberley Reef would have had greater exposure to eroded LK1 material in the southwest. The reef also contains BIF clasts upstream of the LK1 subcrop, but this is not surprising given the low angle of unconformity (Figure 12). The jasper and BIF clasts represent erosional lags of the LK1 conglomerate.

Table 1. PGE content and the chromite/(chromite + zircon) ratio of the Kimberley Reef at Evander compared to abundances in other reefs in the East Rand and Central Rand goldfields (after Viljoen, 1963, Hirdes, 1979, Cousins, 1973 and Lenthall, 1970).

Reef	Goldfield	PGE (ppb)	Chromite/(Chromite+Zircon)
Main Reef Leader	Central Rand	1.9	0.114
Nigel Reef	East Rand	4.3	0.418
Main Reef Leader	Central Rand	2.4	0.278
Kimberley Reef	East Rand	-	0.884
Kimberley Reef	Delmas	-	0.66
Kimberley Reef	Burnstone	-	0.731
Kimberley Reef	Evander	93	0.794

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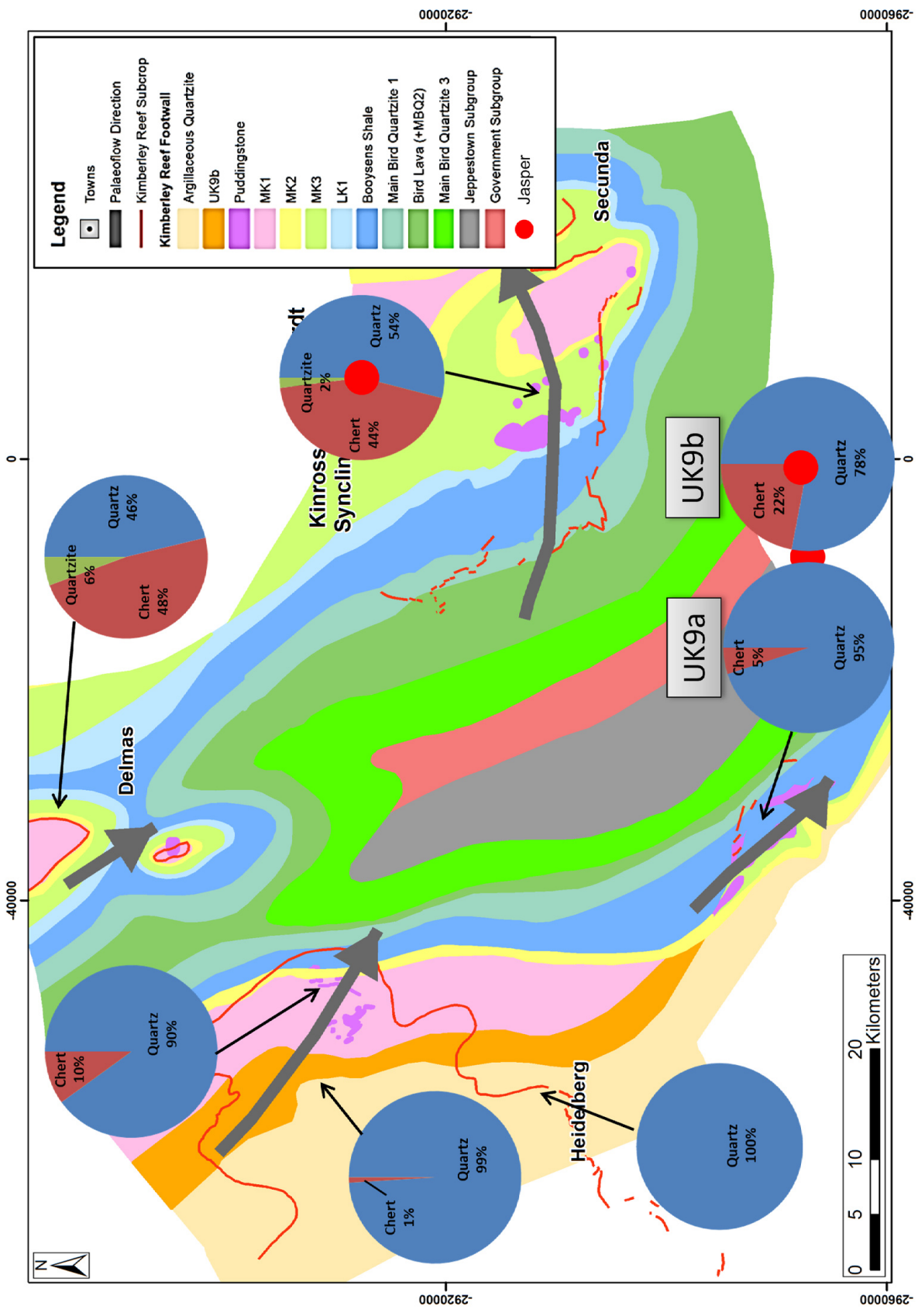


Figure 21. *Clast compositions and palaeocurrent directions in the Kimberley Reef of the Far East Rand (E.B. Tweedie, 1981 and 1986; Button, 1968; Armstrong, 1965; de Jager, 1964; Muntingh, 2016, pers. comm.). This map straddles the region between Secunda, Heidelberg and Delmas, the location of which is shown in Figure 1.*

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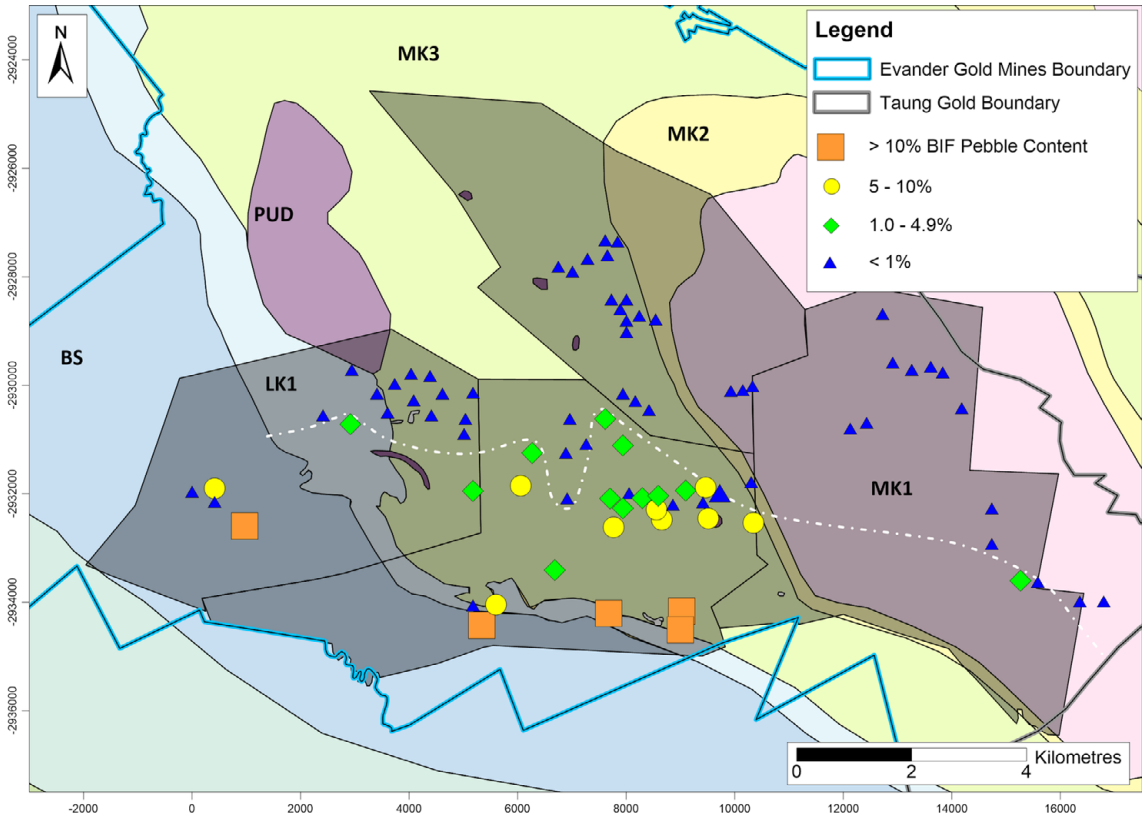


Figure 22. *The abundance of jasper and banded iron formation (BIF) clasts in the Kimberley Reef at Evander (Hirdes, 1979).*

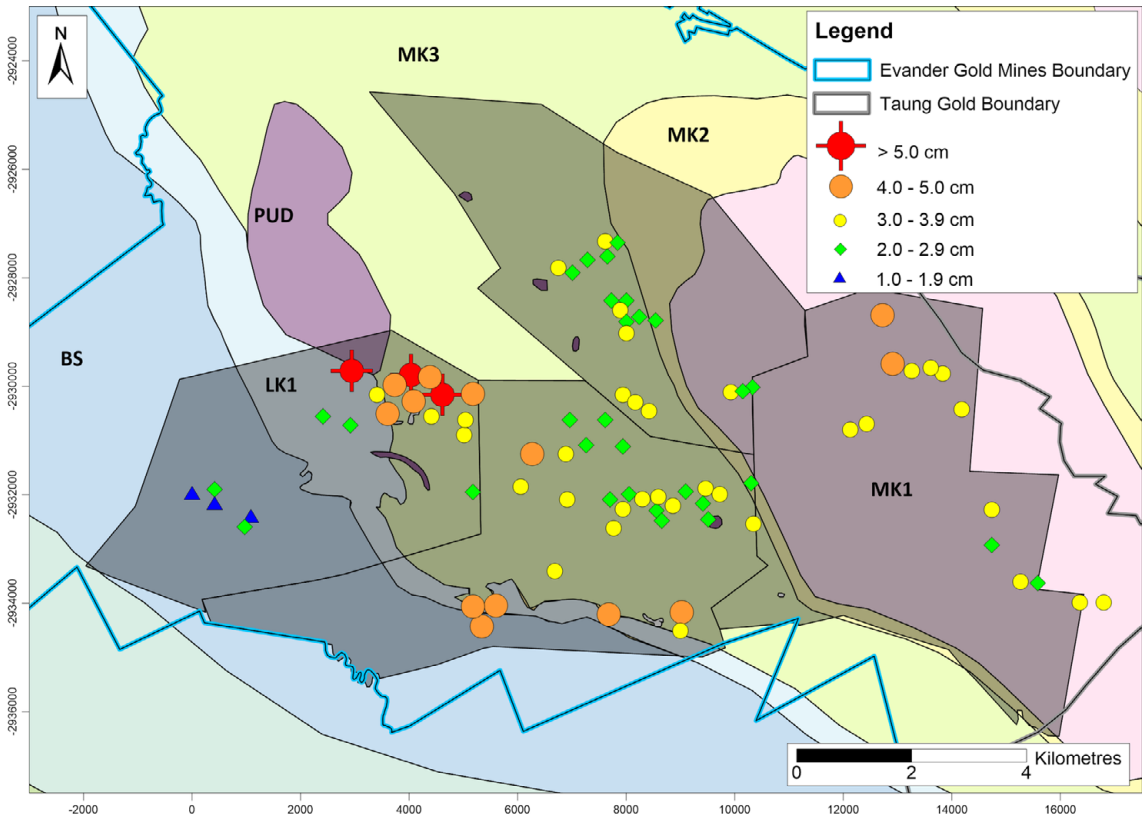


Figure 23. *Pebble size distribution across Evander Mines (modified after Hirdes, 1979).*

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We deduce that the Kimberley Reef at Evander was derived by erosion of the footwall by northeasterly flowing streams on an erosional pediment. The reef therefore retains the characteristic greenstone signatures of a high chromite/(chromite + zircon) ratio and high platinum group metal abundance (93 ppb compared to 2 to 3 ppb for other Witwatersrand reefs; Cousins, 1973) (Table 1). The implication is that this provenance signature reflects erosion of footwall rocks, derived from a northeasterly source, which contained abundant greenstone material (Figures 13 and 14), (Ferraz, 1989).

Clast sizes

Hirdes (1979) collected slab samples of the Kimberley Reef and measured the largest pebble in each 10 x 10 cm area on the slabs, which he then averaged. His slabs were large, so that each average included at least five individual pebble measurements. The outcome of his investigation is illustrated in Figure 23. The pebbles are generally larger along the southwestern fringe of the Kimberley basin where the reef lies in close proximity to the LK1 conglomerate and the footwall diamictites.

Pebble sizes in the logs of historical boreholes that intersected the Kimberley Reef were simply described as large (15 to 32 mm), medium (10 to 15 mm) or small (5 to 10 mm) by the mine geologists. Mean pebble sizes in boreholes are shown in Figure 24. These are not quantitatively comparable to Hirdes (1979) due to the different methodologies applied. Nevertheless, the pebbles appear to be larger in the southwestern portion of the mined out area as reported by Hirdes (1979, Figure 23). The northwestern area of the mine tends to have smaller pebbles.

In the Rolspruit and Poplar areas (Figure S4), actual pebble dimensions were measured by mine staff on core. Palaeocurrents at Poplar are interpreted to have flowed from the southwest to the northeast (King, 1990) and at Rolspruit from west to east (Els and King, 1989). Pebbles from these areas fall into two groups on a scatter plot of average size against chert content (Figure S5). The Kimberley Reef at the Poplar prospect is situated primarily on MBQ1 footwall, whereas in the Rolspruit area it overlies the LK1 and MK3 (Figure S4).

The pebble characteristics (composition and size) are projected onto a plane perpendicular to the strike of the footwall and parallel to the palaeocurrent direction in Figure S6. These plots reveal changes in pebble composition and size down the palaeoflow direction which appear to be related to varying footwall types. The introduction of pebbles from the footwall could also account for the lack of systematic variation in maximum pebble size (Figure S6). The angle of unconformity of the footwall strata is very small (Figure 12). The clasts eroded from footwall strata would have been left as a lag on the erosion surface and therefore also occur upstream of the source lithology, beyond the subcrop. The pebbles would have been derived from the LK1, MK2 (Big Pebble Marker) and the diamictites (which contain some very large pebbles).

Isopachs

Cross bedding measurements and other palaeocurrent indicators reveal that the Kimberley Reef palaeosurface sloped towards the northeast, with palaeoflow from the west and southwest (Figure 19). The pebbles constituting the reef were derived primarily from the footwall. In the far west, the reef consists of a parting, often with no pebbles at all (waste on contact). Such surfaces nevertheless exhibit high but variable gold grades (trace to >5 000 cmg/t). The reef thickens to the northeast and east (Figure 25), towards the Fold-Fault structure and its northwesterly continuation. Quartzite partings constitute a significant proportion of the thicker reef (Figure 26).

The processes leading to increased reef thicknesses in the east are schematically illustrated in Figure 27. Footwall rocks in the west contain few and small pebbles and hence the overlying Kimberley Reef is thin with very poorly developed conglomerate. Diamictite, LK1, MK3 and especially MK2 contain abundant pebbles of sizes and types similar to those in the Kimberley Reef. These were released into the gravel mantle overlying the erosion surface, which became the Kimberley Reef (Figure S6). Synchronous folding led to thickening down the palaeoslope. Eroded material accumulated on the MK1 footwall along with sand which gave rise to quartzite partings in the distal portions of the gravel mantle (Figure 26). The zone of thickest reef coincides with a synclinal axis in the footwall (Figure 12) which reflects the creation of additional accommodation space by syn-depositional folding (Figure 27). Where the Kimberley Reef is thin the immediate footwall will be a major detritus contributor to the reef. However, as the reef thickens, a larger range of footwall pebble types will be present in the reef.

The trend of increasing thicknesses towards the northeast of the basin, which is evident in the Kimberley Reef, is also seen in the isopach plans of the overlying stratigraphic units (Figures S7 to S11). It is evident that a northwest-southeast trending depositional axis is developed across the goldfield, extending from the Fold-Fault in the southeast towards the northwest, which persisted throughout the deposition of the Turffontein Subgroup.

Gold distribution

Gold grades are routinely measured during mining. Profiles of reef samples, each about 15 cm-thick, are collected and assayed for gold. The gold grades are averaged, weighted according to the sample thickness. The profiles are commonly 5 m apart.

The distribution of gold contained in the Kimberley Reef across the Evander Goldfield is shown in Figures 28 and 29. Figure 28 emphasises face sampling data whereas Figure 29 is based on the entire dataset (boreholes and face sampling) and consequently is of lower resolution. The highest gold grades occur along the western and northwestern portions of the goldfield. These high grade areas coincide with the occurrence of thin reef (Figures 25 and 30).

The relationship between grade and channel width is illustrated in Figure 31. Reef characterisation was undertaken by employing K-means partitional clustering. Partitional clustering

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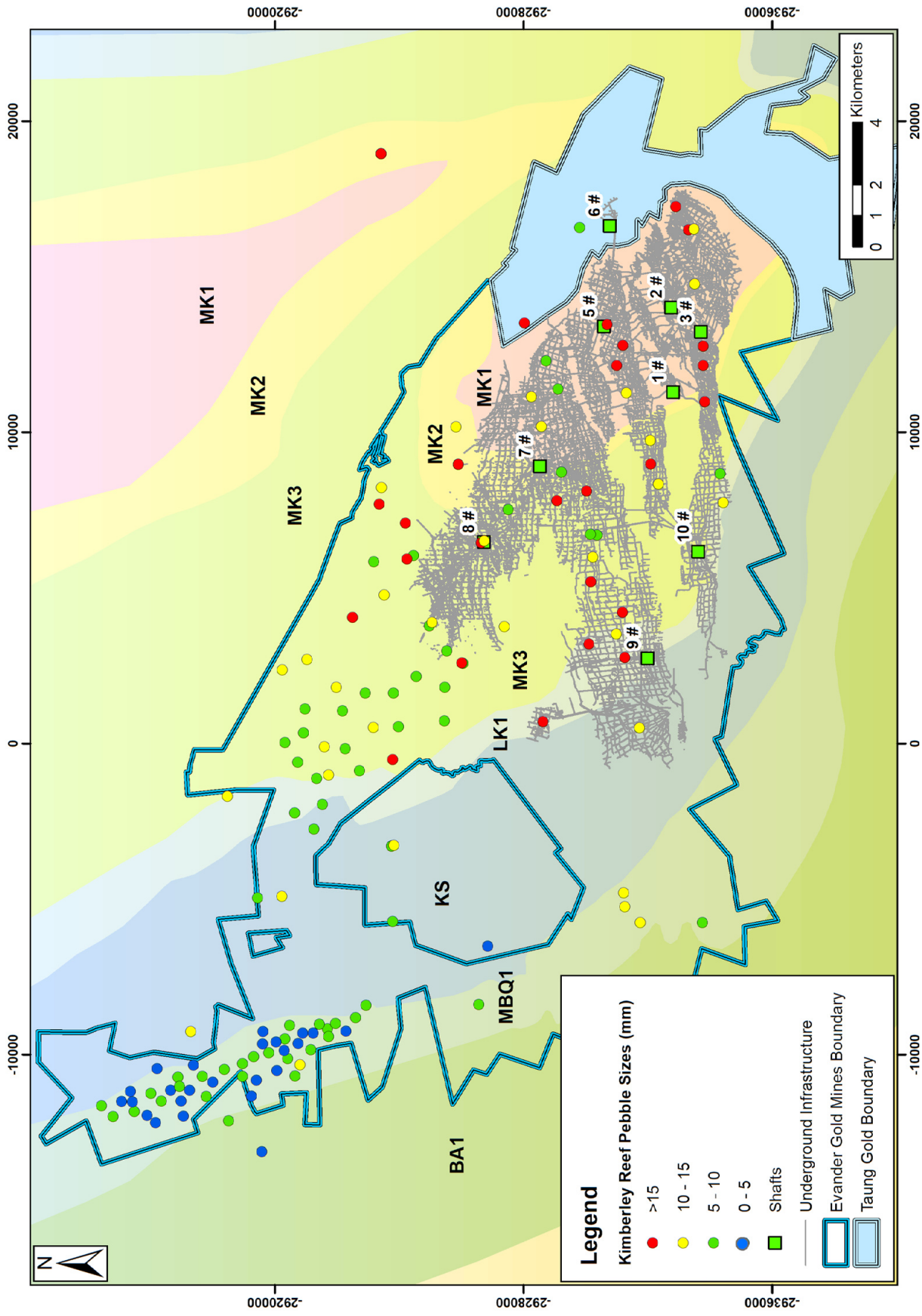


Figure 24. *Map showing mean pebble sizes in the Kimberley Reef as observed in boreholes by mine geologists.*

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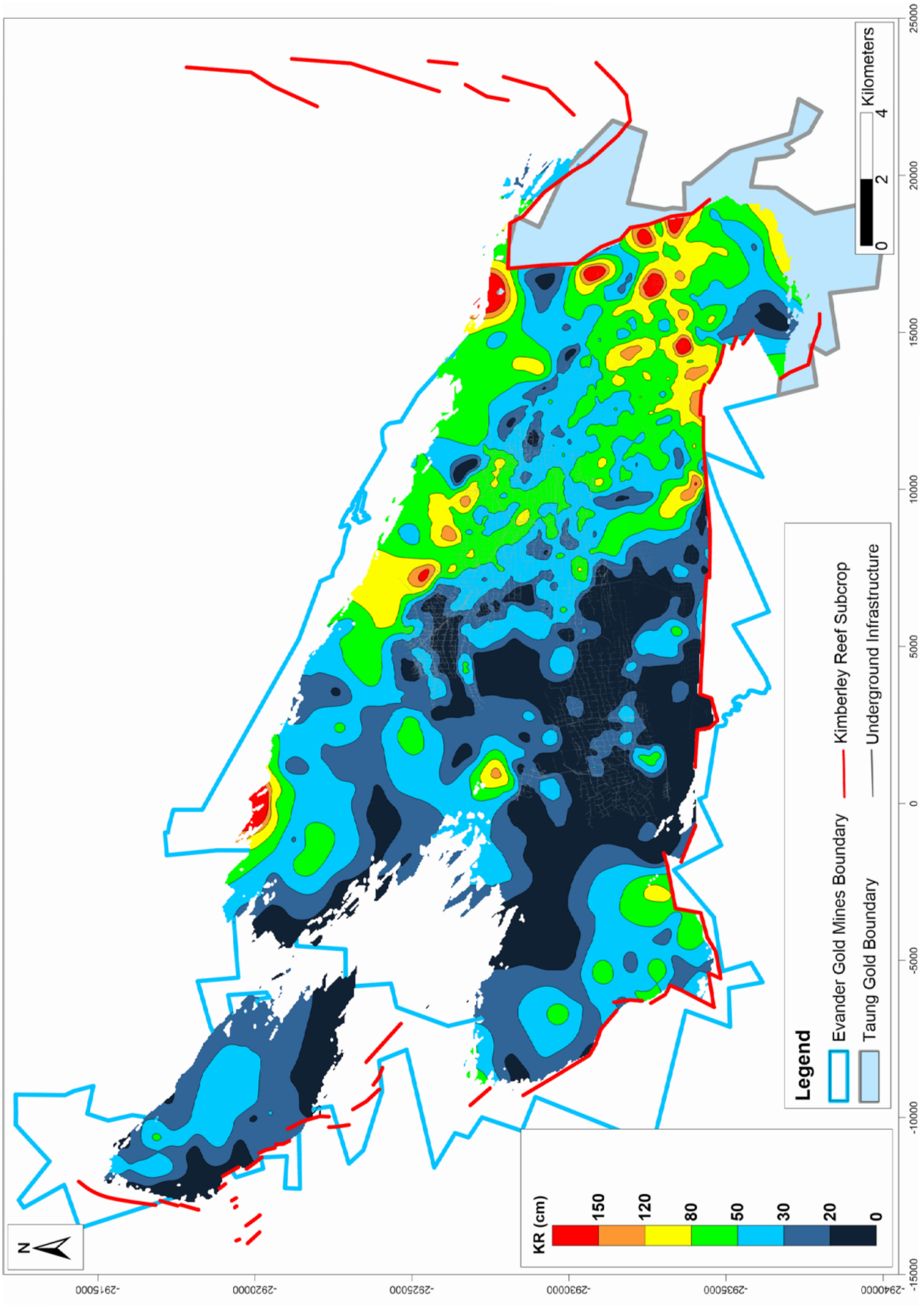


Figure 25. *Kimberley Reef isopach map. The isopachs extend beyond the subcrop due to the presence of narrow fault blocks and the smearing effect of the contouring software.*

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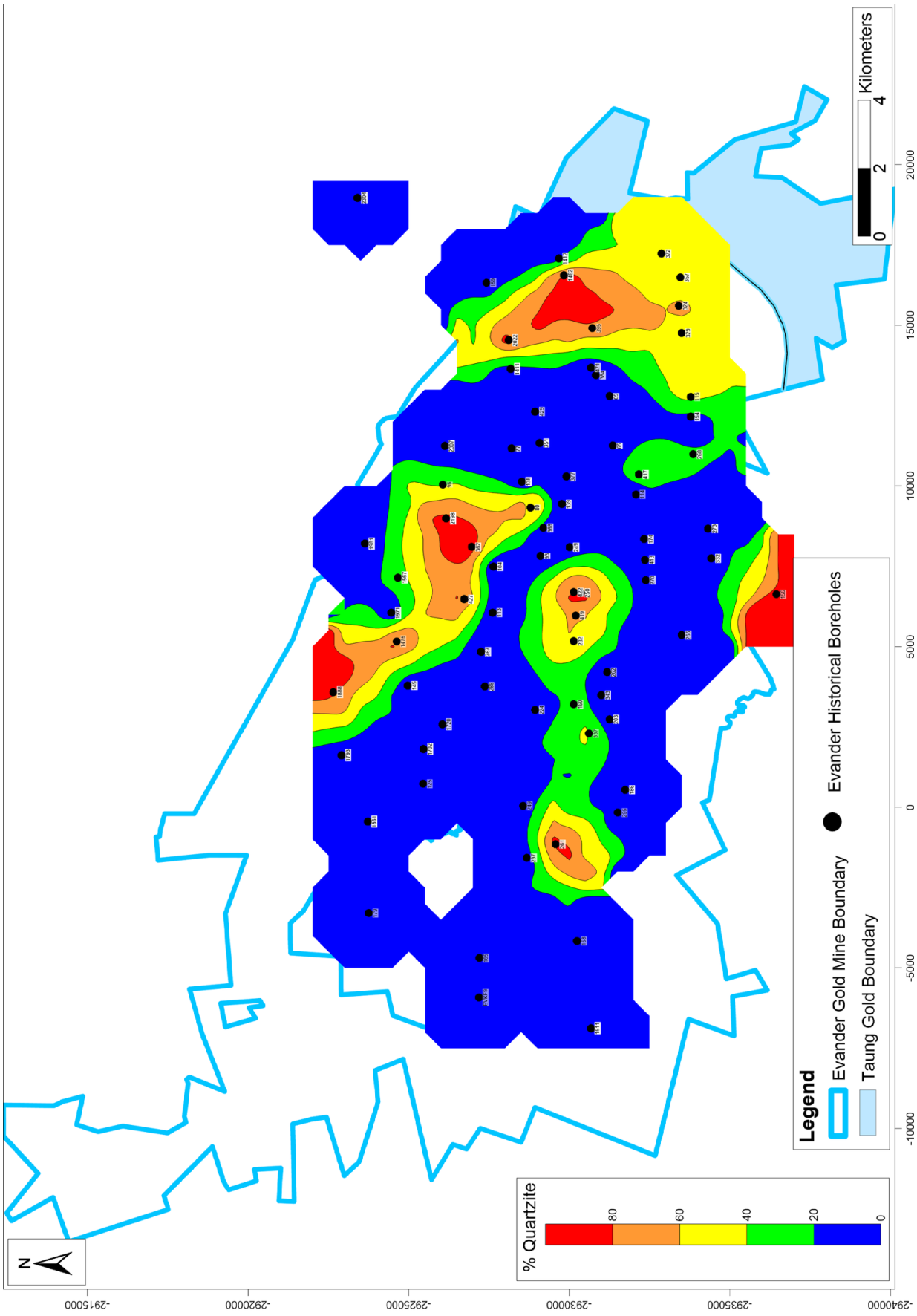


Figure 26. *Percentage quartzite partings in the Kimberley Reef.*

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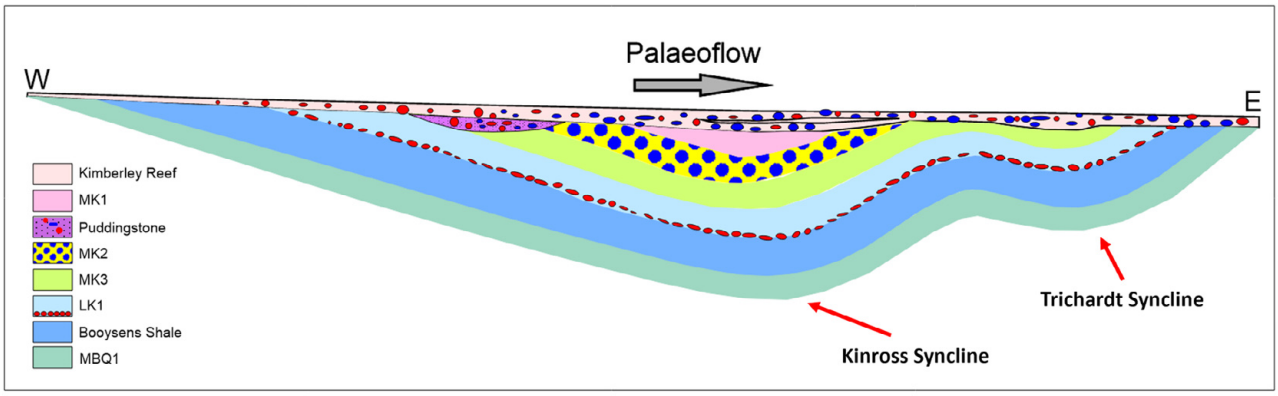


Figure 27. *A schematic section across the Evander Goldfield showing the thickness of the Kimberley Reef and its pebble content in relation to the regional folding and footwall lithologies. The interval between the base of the Booysens Shale and the Kimberley Reef is approximately 150 m. The lateral distance is in the region of 25 km.*

divides a dataset into non-overlapping subsets (MacQueen, 1967). The Kimberley Reef chip and borehole data (50 x 50 m blocks) were declustered according to channel width (reef thickness) and grade (g/t). The method entails selecting a set of initial cluster centroids, in this case eight. Each point in the dataset is then assigned to the cluster with the closest centroid. This process is repeated iteratively until the distance between cluster centroids is maximised. The result is shown in the inserted table in Figure 31.

The spatial distribution of the eight clusters, utilising the face sampling data is illustrated in Figure 32. Clusters of similar characteristics are spatially grouped together. The high grade, thinner reefs occur in the southwestern and western portion of the stoped-out area. This indicates that the individual clusters are not randomly distributed but are grouped together, implying an underlying geological control.

The vertical distribution of gold has been studied at many mines and typically occurs at the top or, more commonly at the bottom of the reef. Reef sampling is performed by collecting multiple samples along vertical profiles through the reef. Both conglomerates and quartzite bands are sampled. The concentrations of gold in the Kimberley Reef in individual reef samples were plotted as a function of their distance from the base of the Kimberley Reef for about 60 boreholes. The pattern of gold distribution varies widely from borehole to borehole (Figure 33). The distribution was grouped into five types, named A to E:

- Category A: Top enriched (30% of the 60 boreholes);
- Category B: Bottom enriched (20%);
- Category C: Erratic (20%);
- Category D: Bottom and top enriched (20%); and
- Category E: Middle enriched (10%).

Representative examples of the profiles are shown in Figure 33. The vertical gold distribution pattern appears to be random and even mother holes and deflections exhibit no correspondence. The gold distributions are unrelated to the footwall type.

The absence of a spatially coherent pattern suggests the following:

- The nugget effect significantly influences the grade of individual samples;
- Fifty percent of the profiles contain only a few (<4) assays (Figure 33) and most are likely not to be representative;
- The processes that concentrated the gold may have varied across the depositional surface resulting in very variable vertical and spatial distributions and;
- The sample size taken from the core may be insufficient for the natural gold distribution in the material.

As a consequence no firm conclusions regarding the gold concentration mechanisms can be drawn from the vertical reef gold profiles.

Uranium/gold ratio

The ratio of uranium to gold in Witwatersrand conglomerates has been found to vary systematically down the palaeoslope (Minter, 1978). Low ratios are typical of proximal settings, but the ratio increases towards the more distal parts of a placer. The spatial variation in the U/Au ratio across the Kimberley Reef in the Evander Goldfield is illustrated in Figure 34. There does not appear to be any systematic variation in the ratio, which we interpret as a consequence of variable U/Au ratios in the footwall rocks that have been inherited by the Kimberley Reef. For example, the LK1 conglomerate may show a systematic increase in the U/Au ratio from its source in the east and the MK2 conglomerate may likewise show an east to west change in the U/Au ratio but possibly at a different rate. Reworking of these two units into the Kimberley Reef would result in heterogeneous U/Au ratios. The apparent randomness of the U/Au ratio across Evander Mines implies that a point source was not present and that the gold and uranium were derived across a broad erosional surface.

Carbon

During the course of this investigation, selected features of the Kimberley Reef interval of 117 boreholes and 203 deflections

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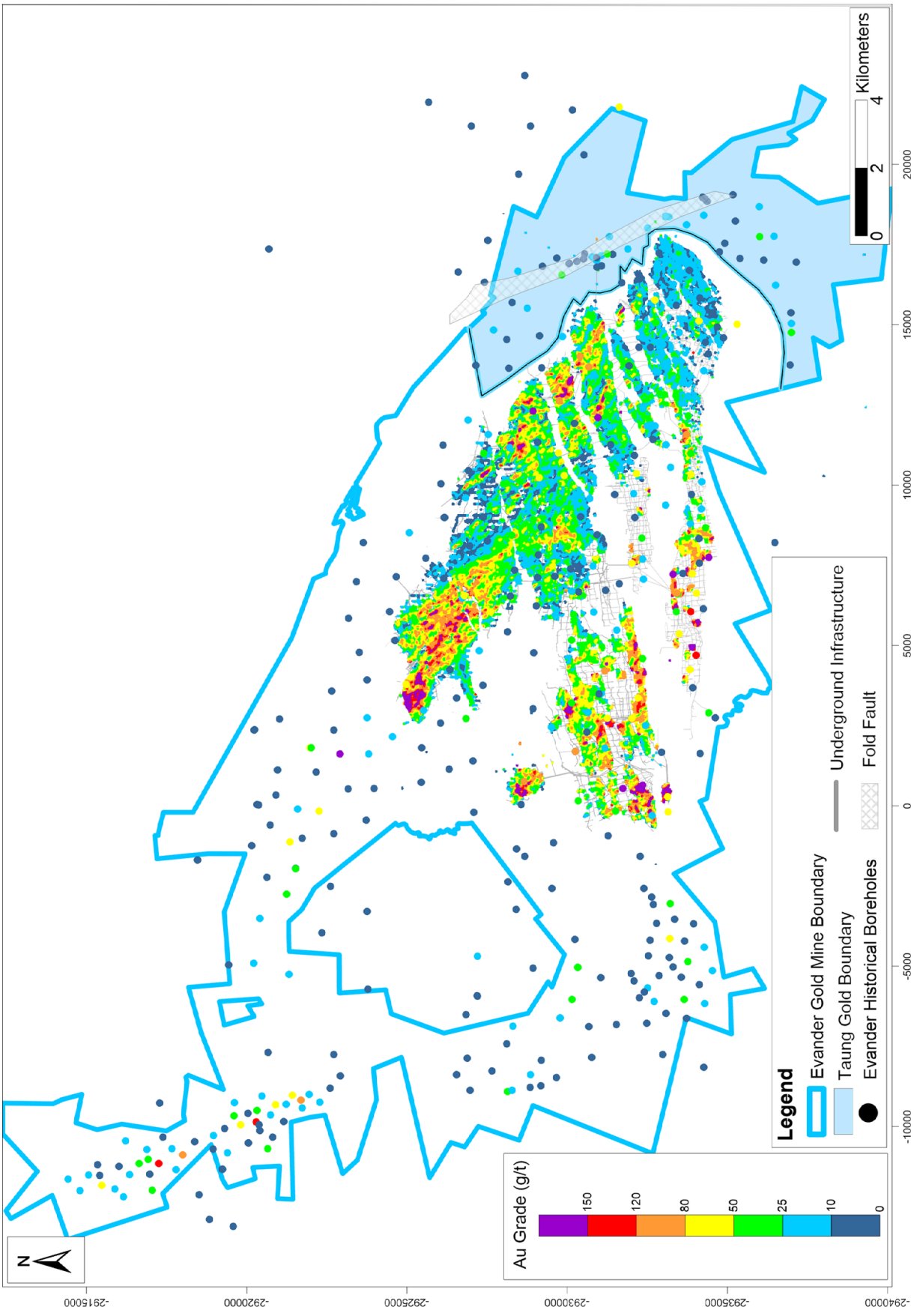


Figure 28. *Gold grades in the Evander area based on face sampling data.*

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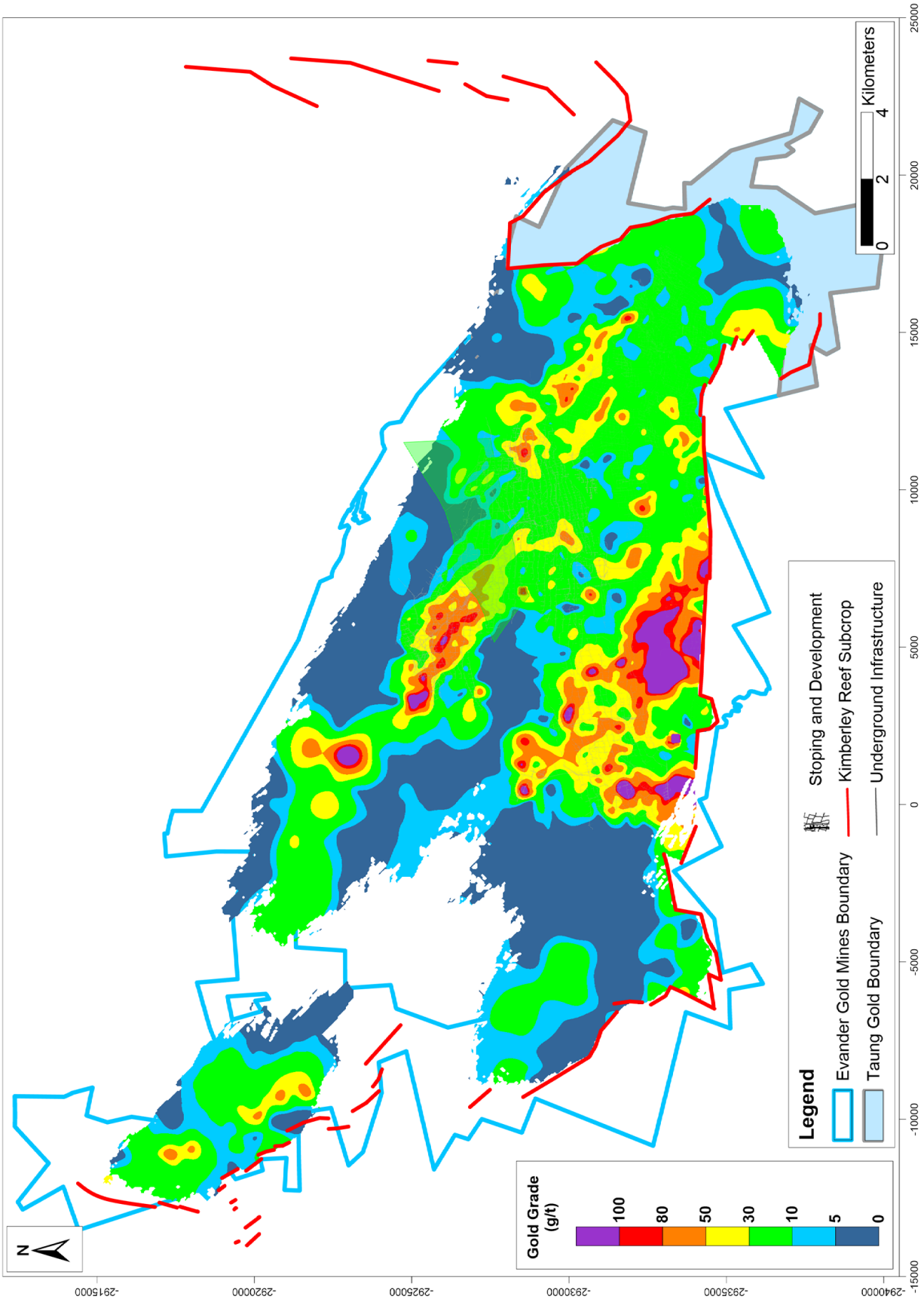


Figure 29. *Gold distribution across the Evander Goldfield incorporating borehole and face sampling.*

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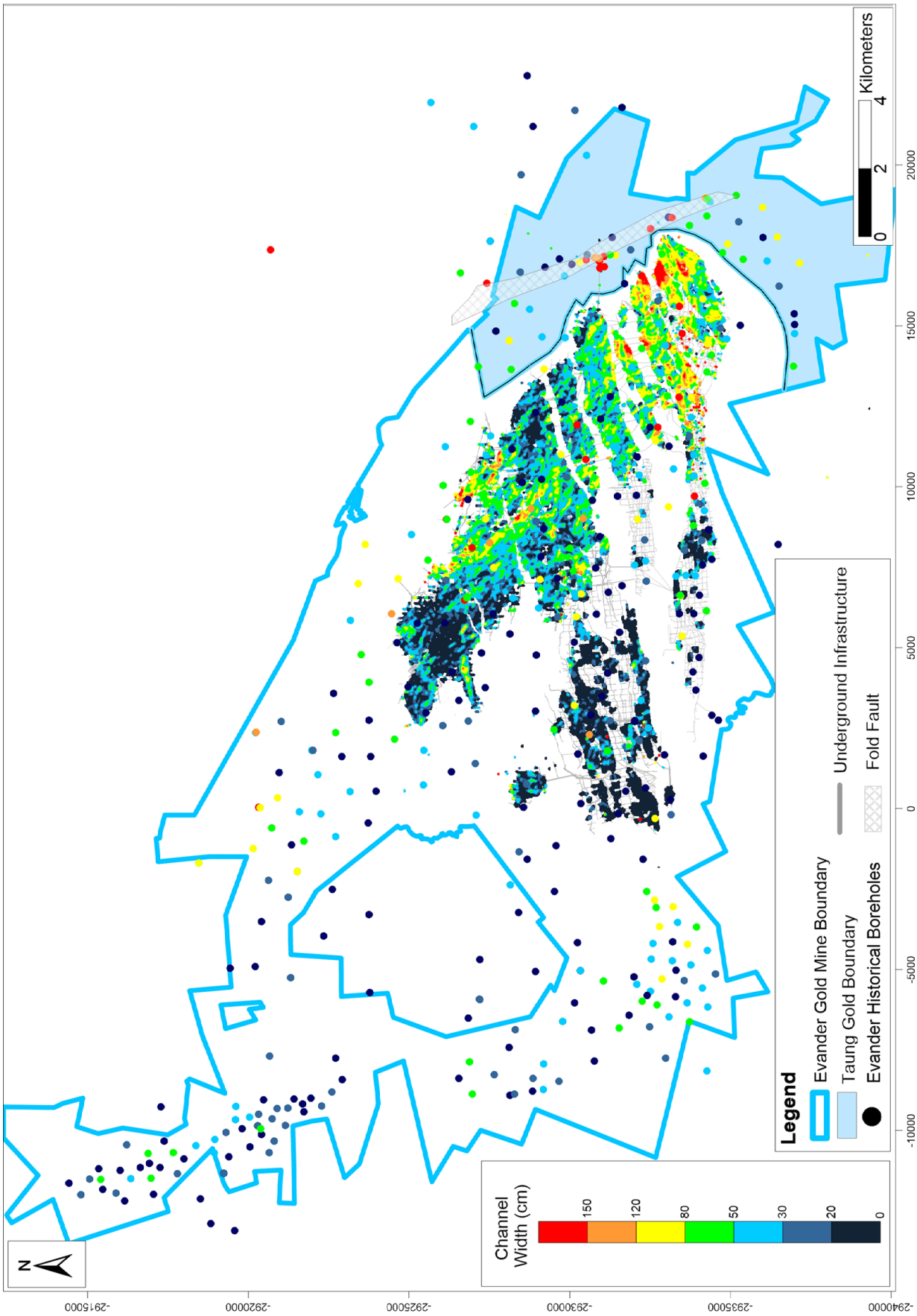


Figure 30. *Channel width in the Evander area, based on face sampling data. Channel width incorporating the borehole data is shown in Figure 25 (reef thickness is synonymous with channel width).*

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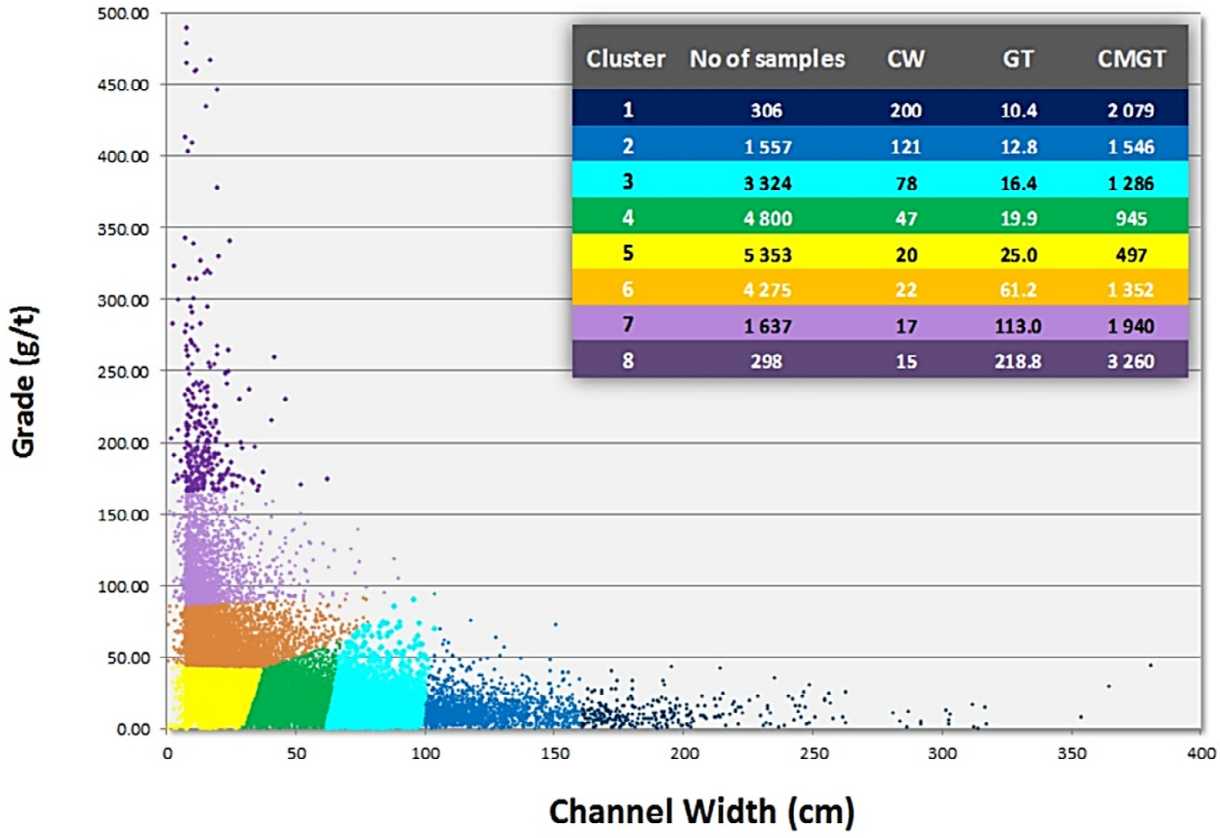


Figure 31. *A plot of grade versus channel width reveals an inverse relationship. The data were subjected to cluster analysis based on eight subpopulations, which are shown in different colours. The characteristics of each cluster are summarised in the inserted table. Refer to text for further detail.*

were captured. The occurrence of carbon in the Kimberley Reef formed part of the captured data. Only one of the intersected footwall conglomerates was logged as containing flyspeck carbon. It is consequently indicated that the carbon contained in the Kimberley Reef was not derived from the footwall and was consequently acquired during the deposition of the Kimberley Reef itself, suggesting an *in situ* origin.

It has been widely observed that the presence of carbon seams in Witwatersrand conglomerates is associated with high gold content (e.g. Feather and Koen, 1975). In the Evander Basin, carbon seams are uncommon.

Borehole logs and Evander Gold Mines bulletins were searched for references to the presence of carbon in the Kimberley Reef. In the majority of boreholes carbon was either not mentioned (i.e. was not present) or recorded as present, generally described as flyspeck carbon. In the case of the bulletins, the reports were more detailed and the quantity and type of carbon was described. In the southwestern portion of the Evander Mine, carbon was differentiated as either veins (seams) or flyspecks.

The results of the investigation into the distribution of carbon are shown in the form of a carbon occurrence and distribution map in Figure 35. The most common form of carbon occurs as scattered flyspeck carbon with generally low abundance. Carbon seam development is patchy and is most prominent in the southwestern portion of the lease area. The map furthermore reveals that carbon, when viewed on a regional scale, is randomly distributed across the goldfield. However, anecdotal information suggests that carbon-gold correlations exist locally on the mine (e.g. 8 Shaft).

The gold accumulation (reef thickness times gold grade) in boreholes which contained carbon was calculated and is shown in relation to the type of carbon in Figure 36. It is evident from this diagram that there is no simple relationship between carbon type, the abundance of carbon and gold content. A carbon-gold correlation could be obscured as a result of the different sample sizes involved: carbon abundance was assessed visually over the entire reef thickness, whereas gold content was determined on specific lengths of core.

Discussion and conclusions

- The deposition of the Witwatersrand Supergroup commenced with a major marine transgression across the granite/greenstone terrain of the Kaapvaal Craton depositing initially the predominantly marine West Rand Group.
- Possibly as a consequence of continental convergence the craton became subject to regional compression, more likely transpression which began to fragment the widely distributed West Rand Group into a number of separate basin-like structures. The sedimentation style changed from shallow marine to fluvial initiating the deposition of the Central Rand Group (Myers et al., 1990).

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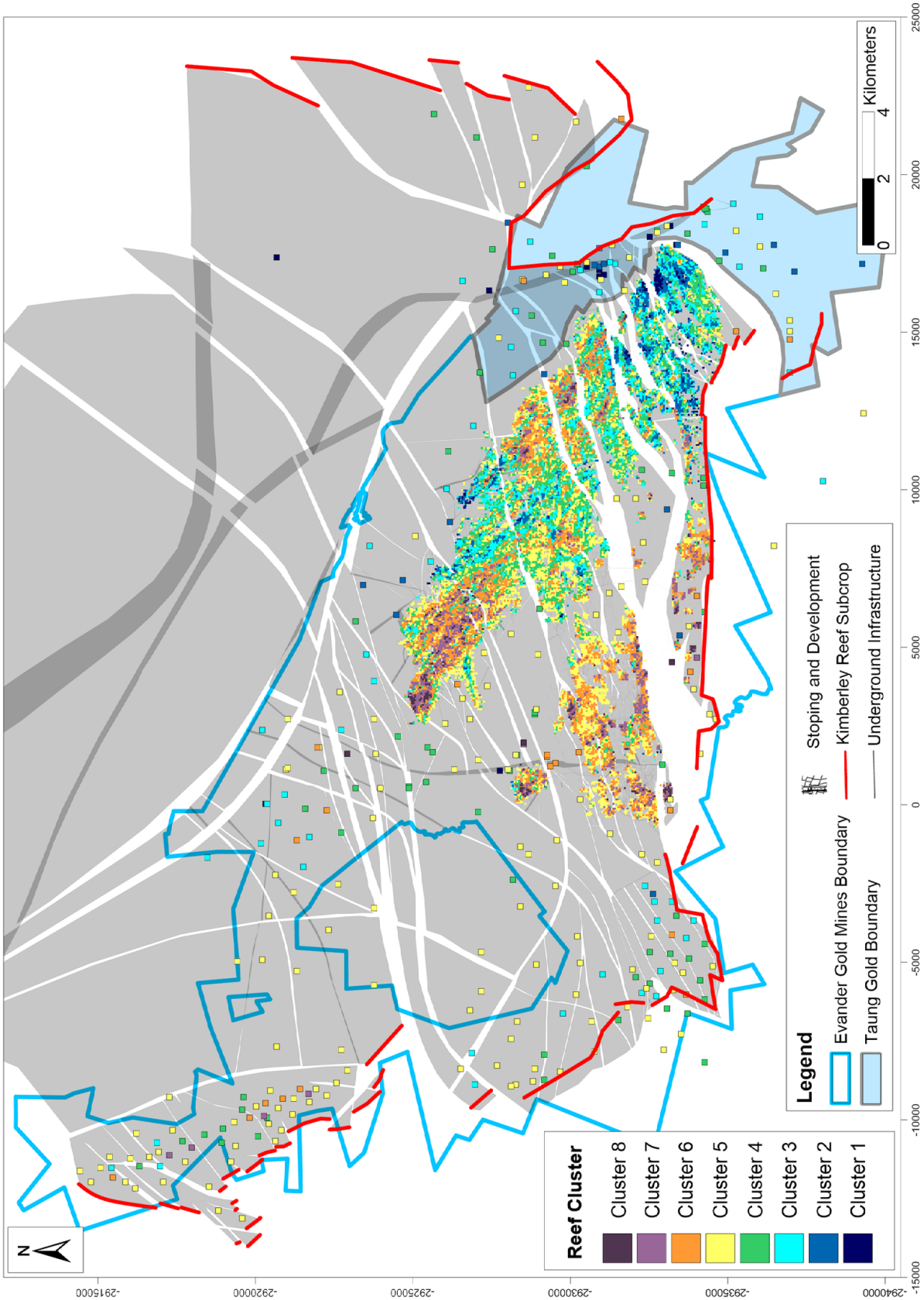


Figure 32. *Reef cluster distribution throughout the Evander Goldfield based on face sampling data.*

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- The depressions in which sedimentation occurred were separated by faults, anticlines or monoclines. Separation of the depressions took place at varying times in different areas.
- In the Far East Rand these structures divided the Central Rand Group into separate structural domains including the Evander, Delmas, South Rand and the East Rand basins (Figure 3). The Kimberley Reef was deposited as a single laterally continuous unit across all of these domains and separation occurred after deposition of the Kimberley Reef.
- Left lateral transpression caused periclinal folding trending northwest-southeast (Figure 7).
- Important amongst these fault structures was the Springs Monocline in the East Rand Goldfield, which formed a ledge separating the East Rand from the main Witwatersrand Goldfield. A similar structure gave rise to the Fold-Fault, which divides the Evander Goldfield into two (Figures 9 and S3).
- During the early phases of Central Rand Group deposition, sediments entering the northern section of the Witwatersrand depository were derived from predominantly granitic terrain to the north and northwest. In the Evander area, sediment originated from granite-greenstone terrain to the east (Figure 14). Gentle folding about northwest-southeast axes accompanied sedimentation. This is attributed to regional left lateral transpression (Figure 10). However, an event of unknown origin caused reversal of the drainage system and palaeocurrents commenced flowing from west to east shortly before the deposition of the Kimberley Reef (Figure 21).
- Continental glacial conditions prevailed during this palaeocurrent reversal. It is unclear whether glaciation was involved in the formation of the Kimberley Reef itself. However, glacial activity was most likely responsible for the deposition of extensive glaciogenic sediments across the Far East Rand in the form of diamictites and associated channel deposits. These lithologies contributed significant amounts of detritus to the Kimberley Reef (Figures 12, 15, 16 and 17).
- The Kimberley Reef deposition was preceded by erosion of the pre-Kimberley Reef strata. Material eroded from the footwall was a major contributor to the reef. This includes the precious and heavy metals and the clasts, notably those derived from greenstone iron formations (Figure 12).
- Water appears to have been abundant with detritus being in short supply. This enhanced erosion of the footwall and gave rise to an extensive gravel lag across the erosion surface which became the Kimberley Reef. Unlike most of the Witwatersrand placers described by Minter and Loen (1991), the Evander Goldfield does not appear to have had a specific entry point. Rather, water and sediment were derived across a broad front extending at least from Poplar to Leslie (Figure 1).
- Northwest-southeast folding continued during Kimberley Reef formation, creating a synclinal trough and therefore accommodation space along the Fold-Fault, which resulted in the accumulation of a thicker Kimberley Reef package. An important implication of this is that the thickening of the Kimberley Reef in the Fold-Fault area is not the consequence of fluvial channelisation but a result of thickening due to syn-sedimentary warping. Palaeocurrent directions continued in a northeasterly direction almost perpendicular to the axis of the trough (Figure 19).
- The synclinal feature associated with the Fold-Fault continued to develop after formation of the Kimberley Reef. As a consequence, isopachs of hangingwall strata continued to thicken towards the trough (Figures S7 to S11).

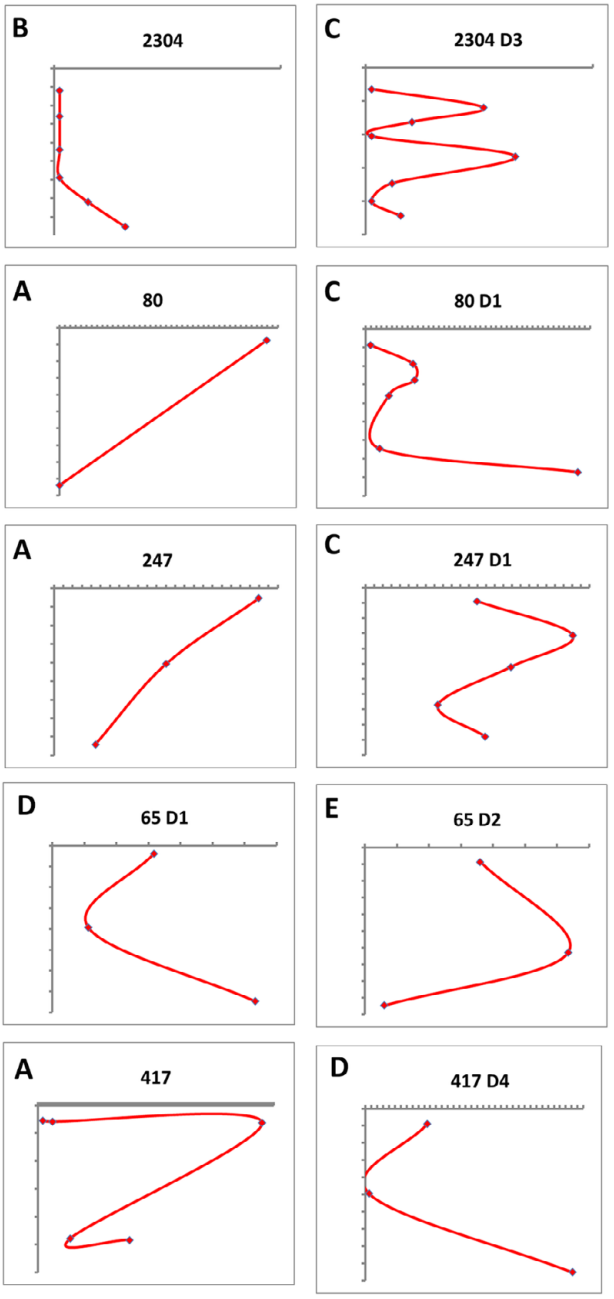


Figure 33. *Vertical gold concentrations in mother holes and corresponding deflections. The vertical and horizontal scales have been normalised in order to make the shapes of the various distributions comparable. The borehole numbers are shown above each profile, D denoting deflections. The letters in the top left corner refer to the profile classification. Refer to text for further detail.*

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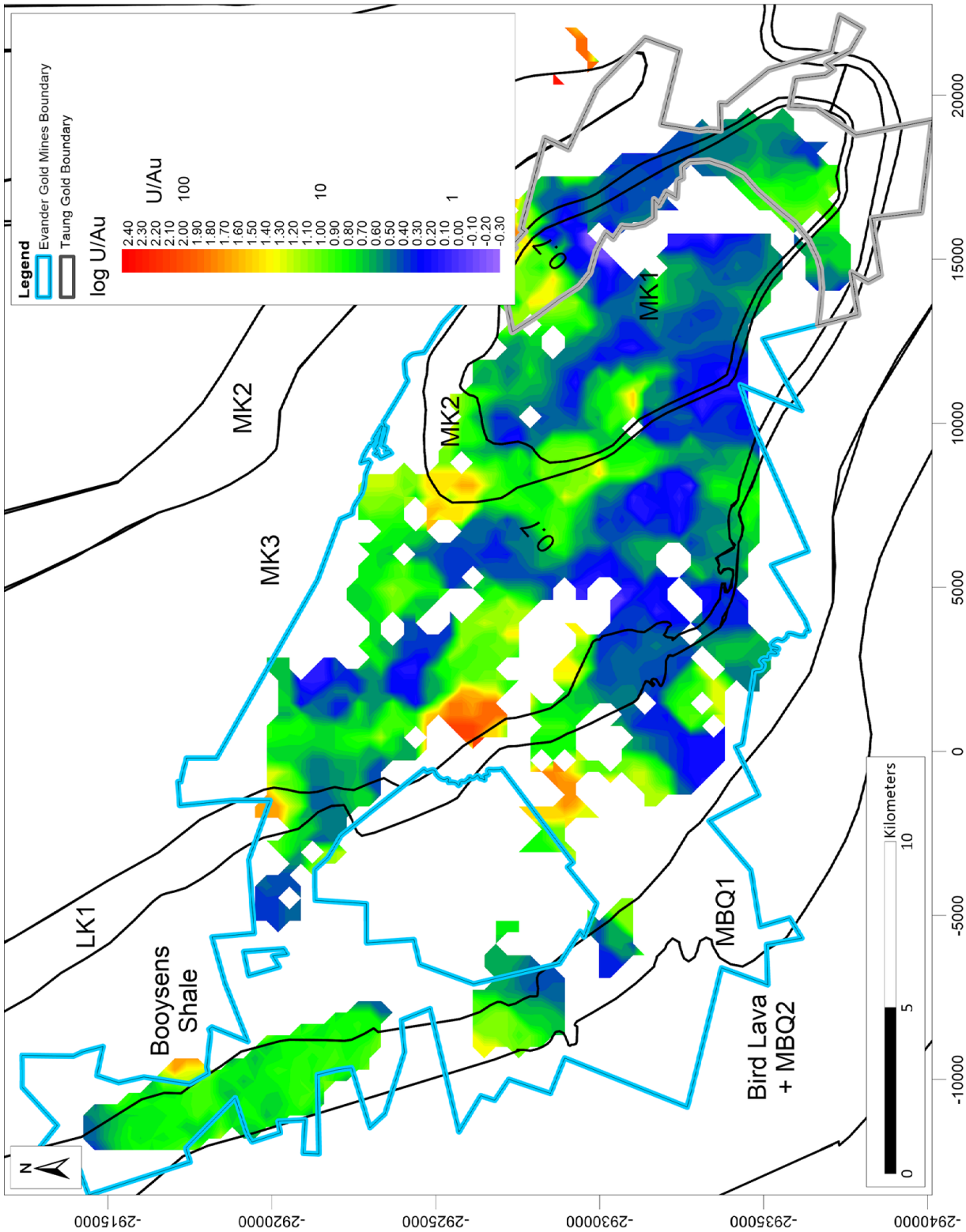


Figure 34. *Spatial variation of the U/Au ratio in the Kimberley Reef at Evander.*

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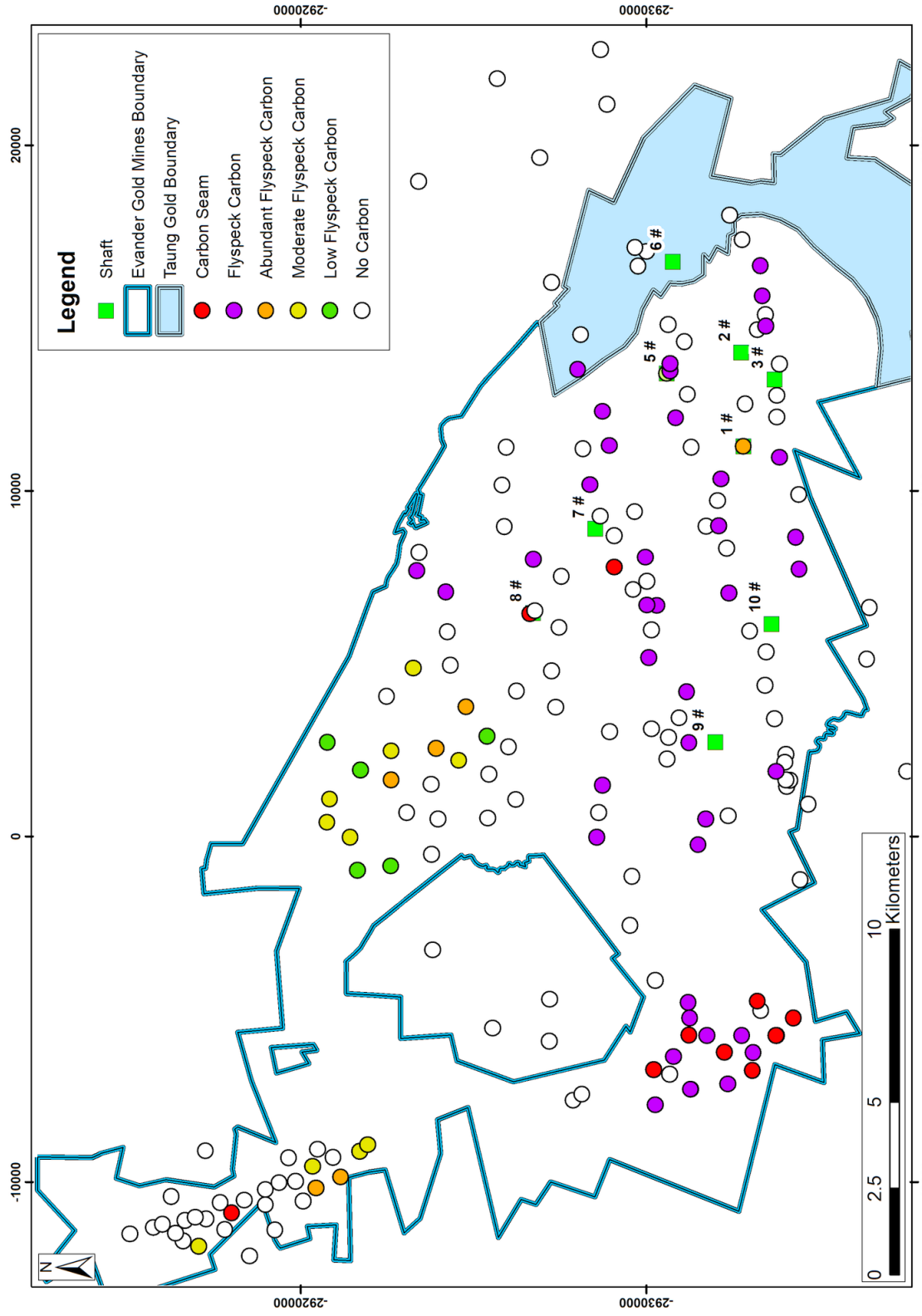


Figure 35. *Carbon occurrences in the Kimberley Reef.*

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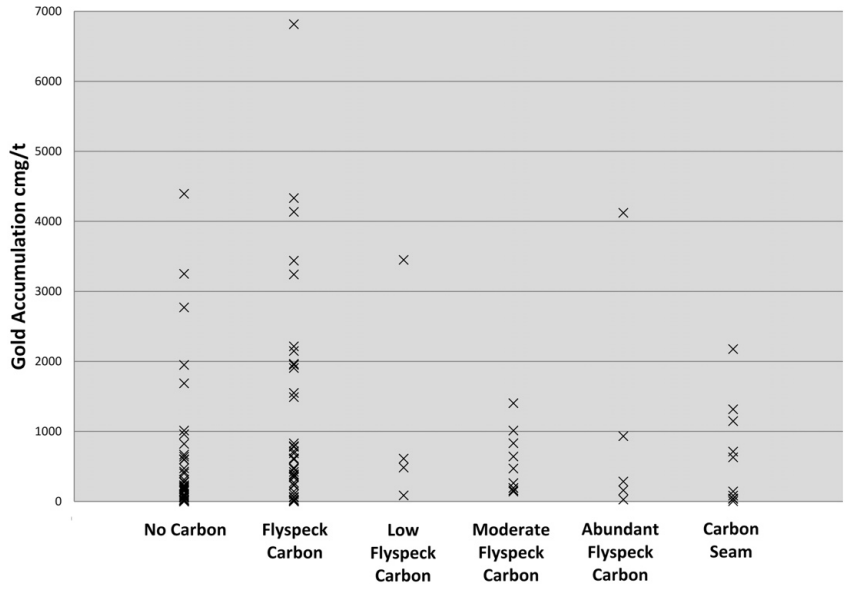


Figure 36. *Gold accumulation in relation to the type of carbon in the Kimberley Reef.*

- It is evident that the Fold-Fault does not represent a basin margin as previously postulated. The Evander Basin is developed extensively to the northeast of this structure.
- The gold grade in the Kimberley Reef is inversely related to reef thickness. Where the reef is thick, the gold grade is generally low. This is particularly prominent in the trough which flanks the Fold-Fault to its west. The lower grade is primarily due to the increase in quartzite partings in the reef horizon in this region (Figure 26).
- The Fold-Fault is flanked towards the northeast by an anticline (Figure 19) which separates the Kinross Syncline from the Trichardt Syncline. Therefore it is expected that the reef will thin onto the anticline. Palaeocurrents were perpendicular to the anticline and therefore gold grades should increase as the reef thins.
- Most of the gold was scavenged from the footwall in particular the LK1, MK2 and possibly the glacial deposits. This material was winnowed on the erosion surface, producing the high grades characteristic of the thin Kimberley Reef present at the southwestern and northwestern margins of the basin.
- Because of the local derivation of many of the clasts the proximal to distal indicators are weakly developed to absent such as changes in pebble size, U/Au ratio and gold fineness.
- Carbon is often associated with gold in the Witwatersrand Basin but in the case of Evander carbon does not appear to have played a significant part in gold enrichment. Carbon formed in situ, and is only locally related to gold content.
- We suggest that the burial of the Kimberley Reef and its underlying unconformity occurred as a result of an increase in sediment supply to the depository. More distal conditions, characteristically containing a high proportion of quartzite partings (HW2 and HW1), transgressed across the Kimberley Reef.
- The Kimberley Formation, which is typically 200 m-thick, has been shown to exhibit lateral continuity and can be correlated internally over a strike distance of 400 km (SACS, 2006). The depositional processes that gave rise to the Kimberley Formation in the Evander area may therefore have basin-wide significance.
- The Kimberley package in the Far East Rand consists of a number of laterally extensive gravel sheets most of which lie on unconformities. In the case of the MK's two fluvial systems were involved, one sourced from the northwest and the other from the northeast, which merged on the South Rand Goldfield. The Kimberley Reef and the overlying hangingwall sediments were primarily sourced from the west and northwest. These fluvial systems had significant aerial extent (*ca.* 7 000 km^2).

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