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ENGINEERING GEOLOGICAL EVALUATION REPORT FOR THE PROPOSED CONSTRUCTION OF A RAILWAY LINE TO KUSILE POWER STATION.

1. Preamble

During August 2009, Ms. J. Hex from Zitholele Consulting invited Africa Exposed Consulting Engineering Geologists to submit a proposal to carry out a geotechnical evaluation on three alternative routes for a proposed railway line from the existing Pretoria- Witbank railway to the Kusile Power Station.

Subsequently on 27th August 2009 a letter of appointment was received from Zitholele Consulting, instructing Africa Exposed to proceed with the geotechnical evaluation.

2. Database

A computer disc was supplied to Africa Exposed, upon which a number of reports and drawings appeared, of which the following documents were perused:

-A report prepared by Mr. P. Van Heerden, entitled "*Kusile Power Station. Report on proposed rail access"* dated 17 March 2009.
-The draft environmental scoping report, prepared by Zitholele Consulting, entitled *"Kusile Railway Project: Proposed construction of a railway line (and associated infrastructure) from the existing railway line (parallel to the N4) to Kusile Power Station.*" dated July 2009.
-A draft report, prepared by Pangaea KV3 Joint Venture, entitled *"Kusile Power Station. Preliminary investigation report on the northern rail line routes for transporting lime"* dated April 2009.

3. Objectives

No excavations and no laboratory soil testing were carried out and this evaluation was confined to a desktop study, complimented by a walk over survey on each alternative route.

The objectives of the evaluation of each route were to provide an assessment of:-

- the nature and extent of near surface soils and outcropping strata.
- likely excavation conditions.
- comment on any geotechnical problems that may impact upon the construction.
- provide recommendations of mitigation.

4. Literature Review

The geological evaluation of the site was based on a literature search and appropriate information was obtained from the following maps:-

- The 1: 250 000 geological map, No 2528 Pretoria, published by The Government Printers, Pretoria 1986.
- The 1 : 50 000 Topo-cadastral maps 2528 DD, published by The Department of Survey and Mapping, Mowbray 1995.
- Aerial photographs obtained from Google.earth, which covers the study area.
- A paper entitled "An insight into the Archaean Geology of Gauteng" by C. McKnight 2003.
- Course notes "Introduction to Ground Water" prepared by the Geological Society of South Africa Ground Water Division, 1992.
- The Johannesburg Groundwater Map 2526, at a scale of 1:500 000, produced by Department of Water Affairs and Forestry, 1999

Further information and data was also obtained from the following sources:-

i. "Engineering Geology of Southern Africa" volume 1 and 3, by A.B.A. Brink (1979), published by Building Publications.
ii. "The Natural Road Construction Materials of Southern Africa" by H.H. Weinert (1980) published by Council for Scientific and Industrial Research, Pretoria.
iii. The "Guidelines for Urban Engineering Geological Investigations" as published by the South African Institute of Engineering Geologists in 1999.
iv. "The geology of South Africa" edited by Johnson, M.R, Anhauesser, C.R. and Thomas, R.T, published by Geological Society of South Africa in 2006.

5. Project Description

The Kusile power station, currently under construction, requires the delivery of sorbent to the plant as a reagent in the air quality abatement processes, from the power generation. This proposed project is to construct a new railway line from the existing Pretoria - Witbank railway line to the Kusile power station and three proposed alternative corridors are currently being assessed through an Environmental Impact Assessment process (see figure 1).

5.1. ***Alternative 1: Kusile – Wilge River interchange shortcut***

The Alternative 1 corridor alignment, which starts at the existing Pretoria-Witbank railway line, heads in a south westerly direction and crosses the N4 highway. Thereafter the corridor follows the course of the Wilge River. This corridor then heads in a south easterly direction and crosses an unnamed tributary of the Wilge River, continuing for six kilometres into the Kusile Power Station. This corridor is approximately 12km in length. (see figure 2).

5.2. ***Alternative 2: Kusile - Wilge River interchange***

The second alternative follows the same initial alignment as Alternative 1, but after crossing the N4 highway the alignment continues in a south westerly direction for approximately 4.5 kilometres. Thereafter the corridor crosses over the Klipfonteinspruit river and turns in a south easterly direction for approximately two kilometres. The corridor then turns south south east for 2.5 kilometres, turns eastward and crosses the Klipfonteinspruit river a second time and then turns to run in a northerly direction for three kilometres before meeting up with alternative 1 approximately 3 kilometres from the Kusile Power Station. This corridor is estimated at 18 km in length (see figure 3).

5.3. ***Alternative 3: Kusile – Wilge River interchange shortcut alternative 2***

The Alternative 3 corridor alignment follows the same initial alignment as Alternative 1 but it crosses the N4 highway 500 meters eastward of the Alternative 1 and 2 crossing (avoiding the farmstead complexes). The alternative rejoins Alternative 1 for approximately seven kilometres before entering the Kusile Power Station. This corridor is very similar to Alternative 1, with some minor deviations, and is approximately 12.2 km in length. (see figure 4).

6. Site Geology

Large portions of the southern side of the study area are underlain by flat dipping sediments that belong to the Dwyka Group of the Karoo Sequence, however the geology of the site changes towards the north, where shale of the Silverton formation, Pretoria Group of the Transvaal Sequence are extensively exposed. These formations are juxtaposed with sandstone and conglomerate of the Wilgerivier formation of the Waterberg Group, which form the prominent ridges north of the R 104 provincial road.

Post Transvaal age (2050Ma) diabase intrusions are identified at the extreme northern limits of the study area in the vicinity of the proposed railway tie in with the existing Pretoria-Witbank railway line and at the southern terminal point at the Kusile Power Station. (see figure 5.)

The geological lithologies identified on the site belong to the following stratigraphic unit:

Lithology	Formation	Unit
Diabase intrusions		Post Transvaal age
Siltstone diamictite	Dwyka formation	Karoo Sequence
Sandstone conglomerate	Wilgerivier formation	Waterberg Group
Shale	Silverton formation	Pretoria Group

6.1. ***Dwyka formation***

The late Carboniferous to early Permian age Dwyka formation in the area occurs beneath approximately the southern two thirds of the area and are characterised by shallow dipping, almost flat sedimentary rocks that consists almost exclusively of shale. The area falls within the stratified mudrock facies, which consists of dark coloured carbonaceous mudrock and shale.

These rocks were deposited unconformably on-top of the older Precambrian formations, and exposures of the older formations are seen to the west and east of the proposed railway alignments. The Dwyka formation in the area rests on a complex pre-Karoo age topography of high relief, with deep valleys and elongated ridges, and therefore this formation is highly variable in thickness that varies from less than 10m thick to an anticipated maximum of less than 100m.

6.2. ***Wilgerivier formation***

The Wilgerivier formation consists of clastic sedimentary rocks, which include sandstone and conglomerate. The rocks form the only stratigraphic unit in the Middelburg basin of the Waterberg group and extend from just east of Pretoria to beyond Middelburg.

The rocks consist of red to red-brown sandstone and quartzite, with grit bands that dip towards the north at angles of 10º to 15º. Cross bedding frequently occurs and is usually well exposed in rock cuttings.

These rocks rest unconformably on the older Transvaal Sequence formations and the age of the Wilgerivier formation is approximately 1920 ±30 Ma.

6.3. ***Diabase Sills and Dykes***

East to west striking post-Transvaal Sequence age diabase dykes traverses across the extreme southern and northern portions of the site. The northern most exposure of diabase represents a dyke that is intruded into the Wilgerivier formation and underlies a very limited portion of the proposed alignments at the northern terminus.

The southern most limit of the proposed route at the position of the Unloading Facility is also underlain by diabase. This represents a sill that has been intruded into the Silverton shales and limited exposures diabase are usually noted and the presence of the intrusive features are alluded to by the accumulation of well rounded igneous boulders at ground surface.

6.4. ***Silverton formation***.

Shale belonging to the Silverton formation of the Pretoria Group, Transvaal Sequence occurs along the northern portions of the site, where the proposed railway alignments cross the N4 freeway and the R104 provincial roads.

These fine grained argillaceous sediments are usually very finely bedded and dip towards the south west at angles of 20º to 30º. The rock is described as comprising alternating light orange brown to dark brown shale and siltstone with subordinate interbedded fine grained sandstone.

7. Geotechnical Considerations

This assessment is based on a review of existing literature of the engineering properties of the soils that are expected to occur in the study area, and are summarised below:

7.1. ***Transported Materials***

The entire area is covered by transported soil which may vary in thickness from a few centimetres up to several metres. Due to the transported origin of the soils the geotechnical characteristics are typically highly variable and difficult to predict.

The transported soils that occur on the lower slopes of the undulating topography are described as silty sand and gravels, of colluvial (hillwash) origin. The soils are generally of loose to medium dense consistency, and are rich in organic matter.

The base of the transported soils is defined by the pebble marker which consists of a thin horizon (usually 20 to 40cm thick) that contains sub-rounded and angular quartz gravels, in a matrix of greyish brown silty sand.

7.1.2 *Alluvium*

Within the low lying portions of the site that are occupied by the Wilgerivier, the Klipfonteinspruit and several un-named tributaries areas of recently deposited alluvial sediments do occur. These soils are derived from the proximal rocks that occur in the area and the soil texture and mechanical properties are characterised by the lithologies from which they are derived. Typically the soils will be characterised by unconsolidated sediments that consist of sandy silt and clay with a high organic content. The thickness of these soils will vary considerably, and it must be anticipated that the soils may be potentially expansive as well as highly compressible.

7.1.3. *Pedogenic Soils*

The base of the transported soils is usually defined by the pebble marker that has been subjected to pedogenesis in places. The degree of cementation of the pedogenic material varies from scattered ferricrete nodules, honeycomb ferricrete to hardpan ferricrete. The consistency of the horizon is dependant on the degree pedogenisis, varying from dense to very soft rock consistency and is approximately from 0.3 to 0.5m thick.

7.2. ***Residual soils***

A brief description of the residual soils derived from each of the geological formations is also presented.

7.2.1 *Diabase Intrusions.*

The post Transvaal age diabase intrusions that occur in the area generally consists of completely weathered, coarse grained, closely jointed, medium hard rock, diabase. In the sub humid and humid warm climatic regions of the country, falling within the Wienert’s climatic N value of less than 5 (Bronkhorstspruit has a value of 2.5) such as the area investigated, the diabase undergoes chemical decomposition, which produces residual soils which are commonly expansive. A particularly interesting feature about the diabase intrusions sills in the eastern parts of South Africa is the extreme variability in the depth and degree of decomposition over a relatively short distance. Within a few meters of an outcrop of solid rock a test pit may disclose a substantial depth of decomposition.

7.2.2 *Dwyka Formation*

The Dwyka Formation (diamictite and shales) sediments have been interpreted as being deposited in a glacial environment. As such the rock consists of a wide variety of rock fragments assembled by the glaciers as they move over the original host rock. Upon melting the fragments which vary in size from clay fraction to boulders are deposited into fluvial and lacustrine environments that ultimately consolidated to form diamictite, conglomerate, varvite and shale and a direct consequence of the environment of deposition, it is not unusual for a lenticular body of competent, shale to occur within a predominantly weaker and weathered diamictite horizon, or vice versa.

This rock type does not generally weather to great depths, however the weathered residual soil is described as a sandy clay or clayey sand that contains gravel of varying proportions, and may be potentially expansive.

Diamictite exposed in cuttings have presented significant slope stability problems in the past. Differential weathering and mechanical disintegration of the rock in humid area falling within the Wienert's N<5 climatic zone (see 4.2.1 above) does result in exposed cut faces constructed within this rock type being subjected to wedge type failure.

7.2.3 *Wilgerivier formation*

The residual sandstone soils derived from the Wilgerivier formation are expected to consist of silty and gravelly sand that typically shows relic jointing and bedding as seen in the parent rock. The residual soil horizon is generally of a suitable thickness and consistency to provide an adequate founding medium for lightly loaded structures, such as single and double storey buildings.

The depth of weathering will be shallow and it may be anticipated that very soft to soft rock consistency material will be exposed within 2.0 to 3.0m of ground surface. The rock within the upper weathered zone will be highly jointed and closely bedded, resulting in a blocky structure that may result in some slope instability, as well as over break during blasting operations.

7.2.4 *Silverton formation*

The residual soils derived from the Pretoria Group shale weather to form fine grained sandy silt and clayey silt that is usually weathered to a shallow depth, grading into very soft rock shale within 1.5 to 2.5m of the surface. These soils are usually described as stiff to very stiff with bearing capacities in the order of 200kPa within the upper 1.0n of the soil profile.

The bedding planes of these rocks are however unusually smooth, which induces a high risk for slope failure, particularly in deep cuttings in which the shale dips into the excavation. Many documented failures are recorded due to an inflow of moisture along the bedding planes. The introduction of the water in some cases occurred at a considerable distance away from the excavation and migration of water along fractures and joints in the rockmass induced instability in the cuttings.

Furthermore, although weathered shale is generally considered to be inert and is not expansive, it is known that residual Silverton shale contain a higher proportion of montmorillonite and lesser amounts of kaolinite, mica and quartz, which imply that these soils may be highly expansive.

8. Impact Assessment

The methodology employed to determine the environmental impact of the geotechnical aspects of the proposed project, is that presented in the Zitholele Consulting letter of appointment, dated 27 August 2009. In summary the method makes provision for the assessment of the impacts against the following criteria:

-significance
-spatial scale
-temporal scale
-degree of certainty

These impacts are assessed in both a qualitative and quantitative method.

8.1 ***Alternative Route 1***

Four areas of potential environmental impact have been identified along the length of this route, which is the shortest of the three routes. It will require a high bridge or embankment at a stream crossing, and two long cuttings of up to 6m and 13 m deep respectively (Pangaea KV3 Joint Venture, Preliminary Investigation Report, April 2009) . Each area has been labelled A to D in figure 2, and are discussed separately below :

8.1.1 *Section A*

In order to meet the technical requirements for the design of the vertical alignment of the railway line, it is proposed that the route will be placed in a cut from chainage 3.1km to chainage 5.9km (total length 2800m) with a maximum depth of 6m. This section of the route is underlain by rocks of the Dwyka formation, which have an almost horizontal attitude, and therefore it is not anticipated that significant slope instability will occur. It is however known that these rocks slake (mechanically break down) upon exposure, and ravelling of exposed cut faces is a geotechnical characteristic of these formations that must be addressed in the design of the cutting. The determined impact assessment is shown in table 1 below.

8.1.2 *Section B*

The proposed alignment crossed an un-named tributary to the Klipfonteinspruit at approximately chainage 7 km. The stream is situated in a deep, narrow valley and in order to accommodate the technical requirements of the proposed railway line, this crossing must be supported on a bridge or a high fill. The maximum height of the crossing will be 30m, and it is therefore considered that an earth embankment will not be a viable solution, and this assessment is based on the assumption that a bridge will be constructed. The determined impact assessment is shown in table 1 below.

8.1.3 *Section C*

In order to accommodate that maximum permitted gradient of 1% of the proposed railway line, a section from approximately chainage 7.4km to chainage 9.0km (total length 1.6km) will be placed in a fill situation, which at its highest will be approximately 13m. The deemed environmental impact of the construction of the fill is shown in table 1.

It has been assumed that the material required to construct the fill will be obtained by balancing the earthworks requirements, i.e. the volume of material obtained from the cuttings will be sufficient to fulfil the fill requirements, and no borrow pits will be used. Should this assumption not be accurate, the spatial impact of haul roads and borrow pits as will be the temporal scale will be increased be one order.

8.1.4 *Section D*

From approximately chainage 9.0km to 11.0km the proposed alignment will be constructed in a cutting that will be up to 13m deep and approximately 2km long.

The entire length of the cutting will be within the shale of the Silverton formation. As discussed previously in this report (see section 7.2.4) the shales are susceptible to slope failure due to the very smooth bedding planes. The rock on the site dip at an angle of some 20º to 30º towards the southwest, which implies that the rock will dip into the proposed cutting which may induce potential slope failure in the eastern face. Significant precautionary measures will be required to stabilise the cuttings, which may include having to reduce the slope angles, construction of temporary support measures.

A further complicating factor is the crossing of the proposed cutting with a small un-named stream at approximately chainage 10.2 km. It will be required that the stream is canalised around the cutting or directed into an aqueduct over the railway cutting. Both options will have a significant impact, and furthermore, as indicated in section 7.2.4 above, surface water seepage along the shale bedding planes is known to be a major factor in inducing slope instability in the Silverton formation, and must be considered during the design of the proposed cutting. The assessed impact is presented in table 1.

TABLE 1. Impact assessment
Alternative Route 1

Section	Significance	Spatial Scale	Temporal Scale	Probability	Rating
A 2.8km long cutting	HIGH	*Study Area*	Permanent	*Very likely*	4.5
	4	2	5	4	
B bridge at km 7	MODERATE	*Study Area*	Long term	*Very likely*	3.8
	3	2	4	4	
C 1.6km long fill.	MODERATE	*Study Area*	Medium term	*Very likely*	3.5
	3	2	3	4	
D 2km long cutting	HIGH	*Study Area*	Permanent	*Very likely*	4.5
		2	5	4	

8.2 *Alternative Route 2*

Six areas of potential environmental impact have been identified along the length of this route, which is the longest of the three alternatives. Each area has been labelled A to F in figure 3, (Appendix 1) and are discussed separately below :

8.2.1 *Section A*

At approximate chainage 6.4km, the proposed route crosses a small un-named tributary to the Klipfonteinspruit. At this position a small wetland has formed, and it is apparent that area is underlain by transported alluvial soils and deeply weathered residual soils derived from shale of the Silverton formation. To a limited extent this portion of the alignment is also underlain by intruded diabase sill. As mentioned in section 7.2 of this report these lithologies will decompose to form potentially highly expansive clay which are also likely to be compressible. The presence of these adverse geotechnical conditions will have to be overcome to accommodate the proposed railway line. These solutions may include the excavation and removal of some of the poor soils that may be replaced with more competent soil and rock. A pioneered fill, using rocks and boulders may also be considered. Both of these solutions will have an impact on the environment, which have been assessed and is shown in table 2 below.

8.2.2 *Section B*

The proposed alignment entails crossing the Klipfonteinspruit at two positions, of which this is the first, at approximately chainage 7.5km. The stream is a perennial river that flows across shale and diamictite of the Dwyka formation. The stream channel and adjacent floodplain will be underlain by transported alluvial soils and sedimentary rocks that are expected to be weathered to a significant depth. The river will have to be traversed by means of a small bridge or possibly culverts that will have to be suitably founded on bedrock. Furthermore the abutments on either side of the feature will also require appropriate foundations, and approach fills must be constructed, which will have an impact that has been assessed and presented in table 2 below.

8.2.3 *Section C*

This position represents the second crossing of the Klipfonteinspruit at approximately chainage 12km. The anticipated geotechnical conditions at this position are similar to those presented in 8.2.2 above.

8.2.4 *Section D*

At approximately chainage 13km, the proposed alignment crosses a small un-named tributary to the Wilgerivier. The underlying rock formations belong to the Dwyka formation, and the anticipated geotechnical conditions will be similar to those indicated for the stream crossings at B and C above.

8.2.5 *Section E*

In order to accommodate that maximum permitted gradient of 1% on the railway line, a section from approximately chainage 13.2km to chainage 15km (total length 1.6km) will be placed in a fill situation, which at its highest will be approximately 13m. The deemed environmental impact of the construction of the fill is shown in table 2.

It has been assumed that the material required to construct the fill will be obtained by balancing the earthworks requirements, i.e. the volume of material obtained from the cuttings will be sufficient to fulfil the fill requirements, and no borrow pits will be used. Should this assumption not be accurate, the spatial impact of haul roads and borrow pits as will be the temporal scale will be increased be one order.

8.2.6 *Section F*

From approximately chainage 15km to 17km the proposed alignment will be constructed in a cutting that will be up to 13m deep and approximately 2km long.

The entire length of the cutting will be within the shale of the Silverton formation. As discussed previously in this report (see section 7.2.4) the shales are susceptible to slope failure due to the very smooth bedding planes. The rock on the site dip at an angle of some 20º to 30º towards the southwest, which implies that the rock will dip into the propose cutting which may induce potential slope failure in the eastern face. Significant precautionary measures will be required to stabilise the cuttings.

A further complicating factor is the crossing of the proposed cutting with a small un-named stream at approximately chainage 16.2 km. It will be required that the stream is canalised around the cutting or directed into an aqueduct over the railway cutting. Both options will have a significant impact, and furthermore, as indicated in section 7.2.4 above, surface water seepage along the shale bedding planes is known to be a major factor in inducing slope instability in the Silverton formation, and must be considered during the design of the proposed cutting. The assessed impact is presented in table 2.

TABLE 2. Impact assessment
Alternative Route 2

Section	Significance	Spatial Scale	Temporal Scale	Probability	Rating
A wetland crossing	MODERATE	*Study Area*	Medium term	*Could happen*	3.3
	3	2	3	3	
B 1st Klipfonteinspruit crossing	HIGH	*Study Area*	Medium term	*Could happen*	3.6
	4	2	3	3	
C 2nd Klipfonteinspruit crossing	HIGH	*Study Area*	Medium term	*Could happen*	3.6
	4	2	3	3	

D stream crossing	HIGH	*Study Area*	Medium term	*Could happen*	3.6
	4	2	3	3	
E 1.6km long fill.	MODERATE	*Study Area*	Medium term	*Very likely*	3.5
	3	2	3	4	
F 2km long cutting	HIGH	*Study Area*	Long term	*Very likely*	4.5
		2	5	4	

8.3 ***Alternative Route 3***

Two areas of potential environmental impact have been identified along the length of this route, both of which are identified in the previously considered alternative routes, namely a deep cutting of approximately 2km long and a 700m long bridge. The affected sections have been labeled A and B in figure 4 (Appendix 1), and are discussed separately below :

8.3.1 *Section A*

The proposed alignment crossed an un-named tributary to the Klipfonteinspruit at approximately chainage 7 km. The stream is situated in a deep, narrow valley and in order to accommodate the technical requirements of the proposed railway line, this crossing must be supported on a bridge or a high fill. The maximum height of the crossing will be 30m, and it is therefore considered that an earth embankment will not be a viable solution, and this assessment is based on the assumption that a bridge will be constructed. The determined impact assessment is shown in table 3 below.

8.3.2 *Section B*

From approximately chainage 9.4km to 11.4km the proposed alignment will be constructed in a cutting that will be up to 13m deep and approximately 2km long.

The entire length of the cutting will be within the shale of the Silverton formation. As discussed previously in this report (see section 7.2.4) the shales are susceptible to slope failure due to the very smooth bedding planes. The rock on the site dip at an angle of some 20º to 30º towards the southwest, which implies that the rock will dip into the propose cutting which may induce potential slope failure in the eastern face. Significant precautionary measures will be required to stabilise the cuttings.

A further complicating factor is the crossing of the proposed cutting with a small un-named stream at approximately chainage 10.2 km. It will be required that the stream is canalised around the cutting or directed into an aqueduct over the railway cutting. Both options will have a significant impact, and furthermore, as indicated in section 7.2.4 above, surface water seepage along the shale bedding planes is known to be a major factor in inducing slope instability in the Silverton formation, and must be considered during the design of the proposed cutting. The assessed impact is presented in table 3.

TABLE 3. Impact assessment Alternative Route 3					
Section	**Significance**	**Spatial Scale**	**Temporal Scale**	**Probability**	**Rating**
A bridge at km 7	MODERATE	*Study Area*	Long term	*Very likely*	3.8
	3	2	4	4	
B 2km long cutting	HIGH	*Study Area*	Long term	*Very likely*	4.5
		2	5	4	

9. Conclusions

This evaluation has been based primarily on a desktop study that was complimented by a site visit to confirm certain geological and geotechnical features identified. The technical information used was obtained from the sources listed in section 2 of this report.

On the basis of the information available a geotechnical appraisal of each of the three alternative routes was completed. Each route is not unique and some sections are common to each, and therefore the environmental impacts over those sections will be identical. Portions of each of the alternative options for the proposed railway lines will be affected by geotechnical conditions that will have an environmental impact. **Alternative No 1 is affected at four areas of geotechnical concern along the proposed route, while six areas of concern are identified along Alternative No. 2 and two areas of concern are noted along Alternative 3.**

The proposed cutting beneath the crossing of the N4 freeway and the R 104 provincial road, which is approximately 2000m long and up to 13m deep is the geotechnical consideration that has the greatest impact. This is common to all three alternatives. Consideration should be given to placing the alignment closer to the eastern side of the Wilgerivier river, where the natural gradients are reduced and the length and depth of the proposed cuttings could be kept to a minimum.

On the basis of this geological and geotechnical evaluation, **the preferred option is Alternative 3, with Alternative 2 being the least favourable.**

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