Palaeohydrology of Late Pleistocene Lake, Alexandersfontein, Kimberley, South Africa

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The closed Alexandersfontein depression, now only an evaporation pan, harboured a +19 m lake with a surface area of 44 km² and Middle Stone Age occupance, a little before 16,000 BP. Assuming a temperature depression of 6° C, calculations show that rainfall was about twice that of today.

CONTROVERSY prevails as to the nature of Pleistocene climates in the interior of southern Africa[1–4]. For example, it is uncertain whether geomorphological[5] and palynological[6,7] indicators of relatively moist late Pleistocene climatic episodes reflect lower temperatures, higher rainfall, or both. In order to reduce some of the multiple, interacting factors that generally impede interpretation, a closed depression east of Kimberley was studied in 1971. Here a 328 km² basin drains ephemerally into the Alexandersfontein Pan, which lies athwart the Cape Province-Orange Free State border at approximately 28° 50′ S and 24° 48′ E. The floor of the pan receives a little spring influx but now only holds water sporadically after heavy rains; however, the depression once enclosed a number of substantial Pleistocene lakes.

The Alexandersfontein basin is formed on subhorizontal Dwyka shales extensively intruded by Karroo "dolerite" (diabase) sills, dykes and plugs that provide koppies of relief 30 to 100 m. Total elevation ranges from 1,119 m on the pan floor to 1,270 m along the irregular rim of the watershed. Whatever factors may have initiated the depression, one of countless such features in erosional topography around Kimberley[8–10], Pleistocene and later excavation must be attributed to periodic deflation, with crucial chemical weathering of the shales to which deepening is confined. The oldest surficial deposits are fragmentarily preserved, with little or no primary relief, along the eastern, southern and western margins of the depression (see Fig. 1). These consist of lacustrine and aeolian beds, often reworked, and reaching 55 to 60 m above the modern pan floor, although the present threshold of the basin is clearly defined at 1,151 m (+32 m), forming a conspicuous former overflow outlet to the Modder River drainage.

The younger lake beds under consideration here are shown in Fig. 1. They are better preserved and extensively exposed under a veneer of wash and drifting sand, and they seem to be confined by the 1,142 m (3,800 foot) contour of the 1:50,000 topographic maps (Nos. 2824 DB/DC/DD). Beach ridges of these younger lakes are well developed south of the modern pan (Fig. 1), with shoreline cliffs locally cut into shale along the northern peripheries. Specific stages are recorded at +17 to 19 m, +12 m and +6 m (see Fig. 2*a* and *b*).

Along section A (Fig. 2*a*), the highest lake beds reach +19 m and consist of a white, friable, "chalk": 81.5% $CaCO_3$, 3.5% opaline silica, and a further residue of silty clay. A sample of inorganic carbonate from a depth of 1 m gave a date of 16,010±185 BP, with $^{13}C=-0.77‰$ (SI-1115). As there is no carbonate bedrock in the basin, except for localized surface calcretes, this age must be considered a minimum, although the silica structure, which does not break down in HCl, has presumably restricted recycling of the carbonates. The +12 m beds form more conspicuous ridges here, locally with a 2 m nip. One section (A, Fig. 2*a*) begins with a prismatic, brownish-grey, sandy silt (14.5% $CaCO_3$), which followed by a columnar, pale-brown silty sand (27% $CaCO_3$), by weakly stratified, yellowish-brown sandy clay (6% $CaCO_3$), and ultimately a coarse, reddish wash. Whereas the sands of the three lower beds are derived from breakdown of local shales and diabase, the final wash includes subrounded, exotic quartz of aeolian type. Forms and deposits show that peripheral fluvial activity accompanied the +12 m lake stand, with the basal lacustrine beds succeeded by a lake-margin alluvium, and finally a fill, now exposed as a dissected fan.

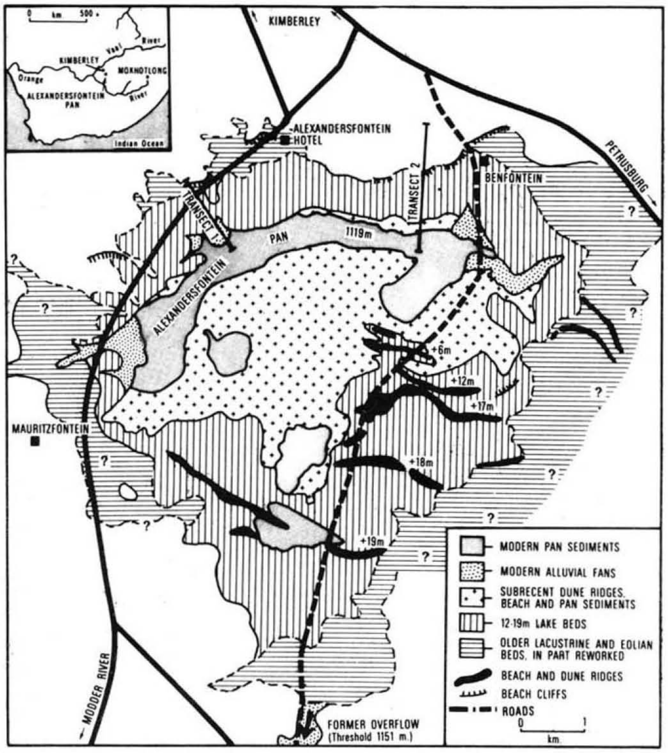

Fig. 1 Surficial deposits of the Alexandersfontein Pan.

Along section B (Fig. 2*b*) the +19 m lake is recorded by the upper half of a sequence that begins with a wash of silty sand ($CaCO_3$ sharply increasing from 7 to 27% at the top). Then follows a prismatic, light-grey marl (79% $CaCO_3$, 6% amorphous silica) with a silty clay residue. The abundant small gastropods *Pupilla* (*Gibbulinopsis*) *fontana* (Küster), *Pupilla* (*Afripupilla*) *tetrodus* (O. Boettger), *Vertigo antivertigo* (Draparnaud) and *Succinea striata* (Krauss) are terrestrial, but the last two are hygrophile, and we infer that these snails were reworked by rainwash or after a seasonal rise of lake level. A bulk sample of essentially inorganic carbonate gave a date of 11,025±110 BP (SI-1116), with $^{13}C = -0.44\%$. This is also a minimum date, but the secondary calcification and the presence of illuvial soil wash in small veins and hollows suggests a considerably greater degree of contamination by younger carbonates than in the case of SI-1115. These quiet-water, shoreline deposits are followed by a prismatic, light-grey clayey sand (9% $CaCO_3$ and 16% amorphous silica), and finally a similar silty sand (17% $CaCO_3$, 20% opaline silica). Along an alternate section (see Fig. 2*b*), the final bed is overlain by 2 m of well-stratified, gritty alluvium that was truncated before a prismatic, dark-grey clay was laid down. These additional details suggest a temporary regression, accelerated runoff and alluvial influx, culminating in a transgression that cliffed the deposit, with the dark cracking clays probably laid down on the lake margin a little later. The sands are again local except for some rounded, exotic quartz in the penultimate bed, preceding the temporary regression.

Altogether the +17 to 19 m lake (with beach ridges or cliff bases at those levels, but undifferentiated deposits to +23 m or higher) represents a long interval with appreciable oscillations of the shoreline, paralleled by persistent peripheral runoff and changes in the level of aeolian activity. The differential degree of "silicification" suggests a moderate to long time span before development of the +12 m shoreline, under similar conditions, with a last halt in regression at +6 m. Extensive deflation then attacked the centre of the basin, creating four separate pans of which the Alexandersfontein is by far the largest. Recent sedimentation involves a cracking, greyish-brown clayey silt, with 17 to 25% $CaCO_3$, a trace of amorphous silica, and sands entirely of local origin (shale residues, feldspar, trace quartz); depending on the local importance of sodium salts, *p*H varies from 7.9 to 9.0. Other recent or sub-recent deposits (Fig. 1) include extensive, stepped aeolian beach ridges or lunettes, with traces of higher lake "muds" to +3 m (see Fig. 2*b*).

As two ^{14}C dates of a little over 17,000 yr were obtained from large aquatic snails in terminal high-floodplain deposits of the Vaal River northeast of Kimberley[11], we feel that the +17 to 19 m lake very probably has a date of about 16,000 BP or a few millenia before. It is beyond question contemporary with the maximum glacial advance in higher latitudes, in what has been designated the Würm Upper Pleniglacial[12], and *Vertigo* is a Palaearctic form. No materials suitable for dating have yet been recovered from the +12 m lake beds, but a Late Glacial age may apply here.

This is the type area where J. H. Powers collected the "Alexandersfontein variant" of the Middle Stone Age (MSA)[13], and we found similar artefacts resting in profusion on the dark clays along transect *b* (Fig. 2), while Powers's collections came from wash on denuded surfaces of the +19 m lake beds or shorelines northeast of transect *a* (Fig. 2). A single, convergently-patterned, large Levallois flake on lydianite was found *in situ* well within a calcrete mantling the +12 m lake beds along transect *a*. Local MSA settlement was almost certainly coeval with the last stages of the +17 to 19 m lake, and may possibly have extended until (or resumed with) the +12 m lake. Corroboratively, D. M. Helgren and Leon Jacobson (personal communication) have recently discovered an MSA site with mammalian fauna *in situ* and at least partly in primary context in the 18 to 19 m shoreline south of the lake.

The palaeoclimatic implications of high, non-outlet lakes in the Alexandersfontein depression are considerable. The +17 to 19 m lake had an area of 44 km^2 and an average depth of almost 8 m, whereas the +12 m lake had an area of 24 km^2 and an average depth of 4 to 5 m. Evaporation over open water (by a Symons pan) now averages 2,120 mm yr^{-1} in Kimberley[14], whereas precipitation (averaged for nine stations in the quadrant 28° 50′–29° 00′ S, 24° 45′–25° 00′ E) is only 397 mm (ref. 15) with a calculated potential evapotranspiration of 932 mm, precluding all but incidental runoff from the drainage basin. In the upper Vaal drainage with almost double the rainfall and temperatures 2 to 3° C lower, the runoff quotient is only 9.3% or about 59 mm (ref. 16), implying that the calculated evapotranspiration by the Thornthwaite method here is 17.7% too high[17]. In the case of the +12 m lake, 1 mm of runoff across the entire basin would provide an influx equivalent to 11.7 mm of water over the 24 km^2 of lake surface, and in the case of the +19 m lake, 6.4 mm over a 44 km^2 lake. Consequently, assuming constant evaporation factors and no external groundwater losses or gains, and a reduction of potential evapotranspiration by 17.7%, the +12 m lake level could be maintained only with a precipitation of 1,046 mm and a runoff ratio of 0.9%.

It would be more realistic to assume a temperature depression of 6° C, a conservative estimate for the Würm Pleniglacial on the basis of periglacial and other cold-climate phenomena in South Africa[18–20]. Recalculating the potential evapotranspiration, this gives 695 mm for Kimberley, which is identical to that in the upper Vaal drainage today[17], so that the 9.3% runoff quotient can be safely used. Actual evaporation from open water exposed to a reduction in temperature of 6° C would be

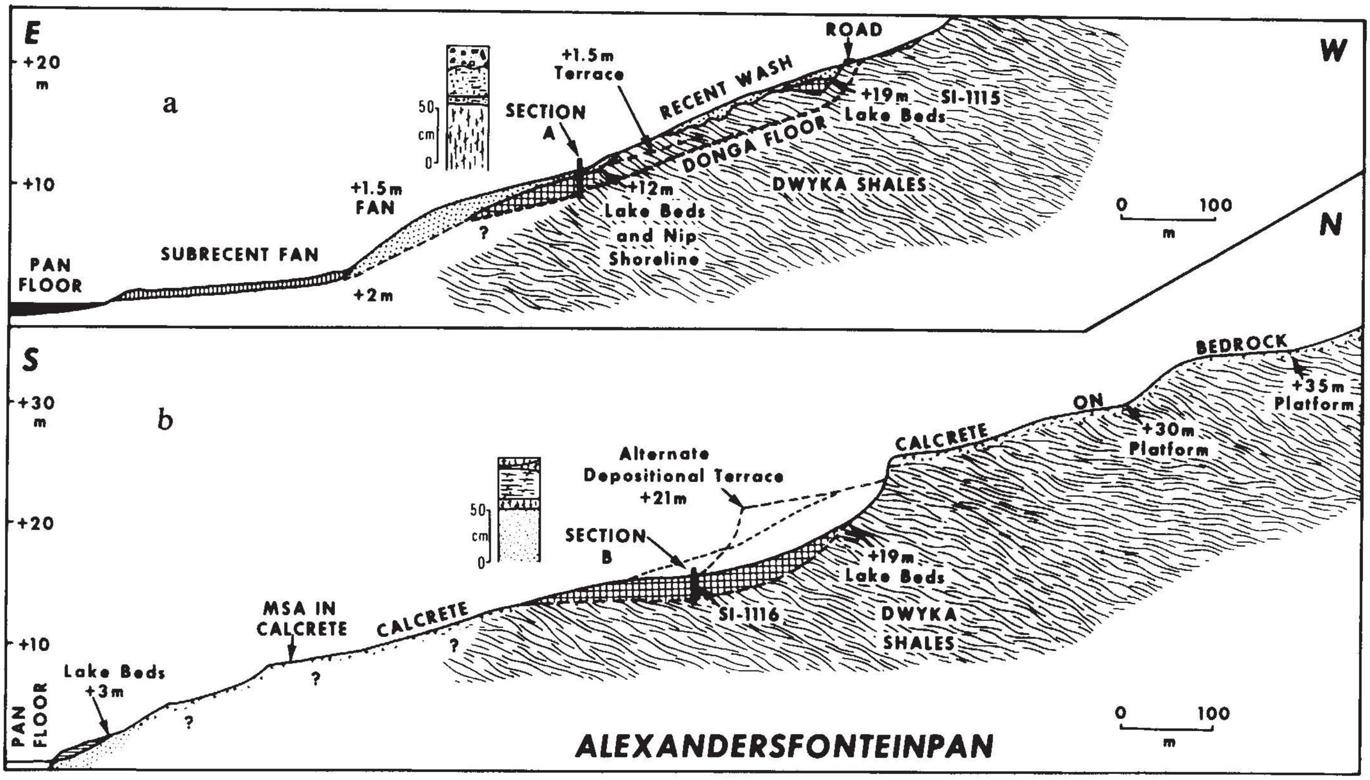

Fig. 2 *a* and *b*, Scale transects north of the Alexandersfontein Pan.

approximately 1,400 mm by analogy from the modern station Mokhotlong, Lesotho (12° C mean annual temperature compared with 18° C for modern Kimberley)[21]. In this case the hydrological budget would require 878 mm to balance with a +19 m lake and 671 mm in the case of the +12 m lake. By implication, with a 6° C drop of temperature, rainfall would theoretically need to be increased by 123% to maintain Pleniglacial Palaeolake Alexandersfontein at +19 m. The assumptions necessary to derive this figure caution against its use in more than a semi-quantitative manner. Even if temperatures and radiation received were substantially lower, however, rainfall would necessarily have been almost twice that of today.

Applying these data to a monthly lake budget, assuming a seasonal precipitation and evaporation regime analogous to that of today, and determining relative monthly distribution of runoff by a calibrated version of the Thornthwaite-Mather hydrological budget[22], a seasonal fluctuation of 4.1 cm could be inferred for the +19 m lake, with a maximum level in May and a minimum in December. Such computations are, however, unrealistic, for it is necessary to assume seasonal changes of rainfall and radiation.

Nonetheless, the Pleniglacial climate of the Kimberley district was necessarily both substantially cooler and wetter than today—in a relative as well as absolute sense—so corroborating van Zinderen Bakker's interpretation of the Florisbad pollen profile[6] and Coetzee's of that at Aliwal North[7]. This demonstrated wet period in the Interior Plateau of South Africa coincides with high lake levels in the middle latitudes but contrasts with a marked Pleniglacial dry phase in many parts of tropical Africa[23]. Two meteorological interpretations are possible. Equatorial displacement of the zonal boundary between the southern circumpolar westerlies and tropical easterlies during a Pleniglacial circulation[24] would significantly increase winter precipitation, decrease summer rainfall. On the other hand, the northern hemisphere circulation may have been appreciably strengthened during the Pleniglacial, displacing the tropical circulations of Africa southwards and thereby bringing the Kimberley region well within the summer rainfall belt (J. Bjerknes, personal communication).

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