LONG-TERM CLIMATIC STABILITY AND THE INTEGRITY OF A SOUTH AFRICAN NUCLEAR WASTE SITE

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ABSTRACT

The length of time that radioisotopes buried in a radioactive waste repository could remain potentially hazardous necessitates performance assessments which take long-term environmental change into consideration. The variability of climate is a key factor in the determination of possible environments and so future scenario predictions must revolve around probabilities of climatic change. A conceptual model of present wet- and dry-spell analogues over southern Africa is extrapolated into the future, based on the knowledge of climatic fluctuations in the past. Three likely future climatic scenarios are formulated and their possible consequences on the shallow-land trench repository in Bushmanland in the north western part of South Africa are discussed. The possible removal of the trench cap by erosive processes is addressed in detail. The arid and semi-arid environment that has characterized the past, is expected to continue for the next 100 000 years. Under these conditions, the removal of the trench cap by erosive processes within the next 300 years is unlikely.

INTRODUCTION

Radioisotopes buried in a radioactive waste repository could remain potentially hazardous for time periods that necessitate performance assessments which take long-term environmental change into account. Climatic variability is a key factor which needs to be considered in the prediction of future environments. In this regard, it is feasible to develop possible future climatic scenarios from an understanding of the variability of present, historical and palaeoclimates. These predictions can be used to assess the integrity of nuclear waste repositories under a variety of environmental conditions.

South Africa operates a nuclear waste disposal facility on the Bushmanland plateau in the north-western Cape Province on the farm Vaalputs (Fig.1). At present the site is used for the shallow-land disposal of low and intermediate level radioactive waste (1). The level of radioactivity in this waste remains hazardous for at least 300 years, after which it is assumed that the level approaches that of some natural ore bodies (2). It is, therefore, necessary to consider possible environmental changes within this timespan in the assessment of the integrity of a site for these types of waste.

Possible future climatic scenarios for the Bushmanland area have been developed from a palaeoclimatic reconstruction for southern Africa (3). The aim in this paper is to assess the consequences of these predicted future climates for the integrity of the nuclear waste repository in Bushmanland. The interaction between erosion and climatic processes forms the framework of this assessment.

GEOMORPHOLOGICAL HISTORY

The geomorphological history of the western Bushmanland plateau, where the waste disposal facility is situated, was reconstructed in order to establish the long-term stability of the sediments in which the radioactive waste was to be buried (4). Seventy to sixty million years ago (late Cretaceous to early Palaeogene) the Bushmanland plateau was an extensive, undulating plain of morphodynamic stability (Fig.2a). During the Oligocene (38 - 23 Ma ago) uplift occurred in conjunction with a possible increase in precipitation. Erosion of the western highlands resulted,

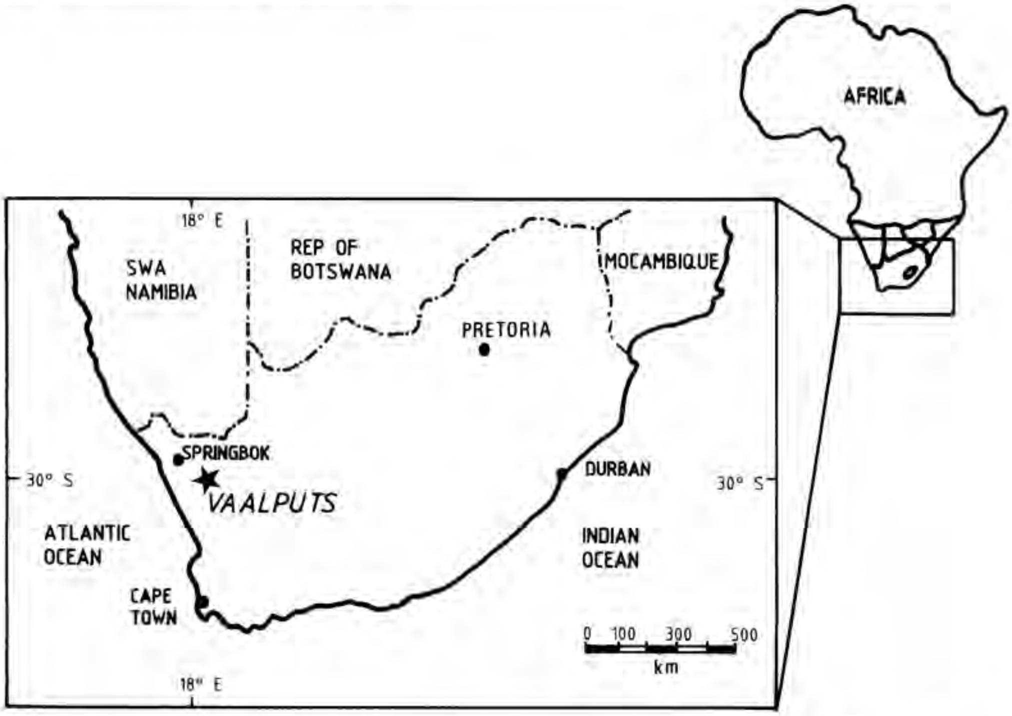

Fig. 1. Location of Vaalputs National Radioactive Waste Disposal Facility on the Bushmanland Plateau in the Republic of South Africa (3).

contributing to the formation of an extensive alluvial fan over the Bushmanland plateau (Fig.2b). From 23 to 5 Ma ago the fan was incised and regraded, probably accompanied by uplift. The Koa River to the east cut into the surface (Fig.2c). About 10 my ago the climate became drier with the upwelling of cold water along the west coast. Sand from the western highlands moved eastwards in the form of dunes and the Koa River became clogged and ceased to flow (Fig.2d). It is suggested that major calcrete formation occurred in western Bushmanland at this time (4). The dunes are now relict permanent features, known as palaeodunes. They are well vegetated and their shape is protected by discontinuous calcrete layers. During the Quaternary, stronger air turbulence than at present caused the dunes to degrade and this process still occurs today (Fig.2e). Generally, therefore, geomorphological evidence has shown the climate of the western Bushmanland plateau to be dry for at least the last 10 million years. The morphodynamic stability over this period has resulted in geomorphic processes such as fan development and transportation by wind sculpturing the landscape.

THE PRESENT CLIMATE OF BUSHMANLAND

South African climates are strongly influenced by the position of the subcontinent in relation to the subtropical high pressure belt. Rainfall is highly seasonal and is erratic both spatially and temporally. Isohyets show a general decreasing trend from east to west across the subcontinent. Bushmanland is situated in the arid western part of the country where rainfall exhibits a weak semi-annual cycle with approximately equinoctial peaks.

The Bushmanland region falls in the area that is transitional between the summer and winter rainfall regions. Whereas the south-western Cape constitutes the winter rainfall region of South Africa, rainfall is a summer phenomenon over the northern and eastern parts of the country. According to Schulze's (5) classification of climatic zones in South Africa, Bushmanland is situated in a region which is described as desert or poor steppe, where mean annual rainfall is characteristically less than 100 mm. Although the presence of the escarpment to the west and south-west creates a rain-shadow effect, some precipitation from the westerly frontal systems (which travel from the south west) does penetrate over this area.

Rainfall in the Bushmanland region is unreliable and extreme events do occur. An episodic event over four days in December 1985 resulted in 128 mm of rain; this can be classified as a 1:100 year rainfall event (6). The rainwater at no stage reached the water table, which is situated 50 m below the surface. Hence, the ground water regime was not affected (7). According to Schulze (8) it is unusual to record even one four-day rainy spell in a year over western regions of South Africa.

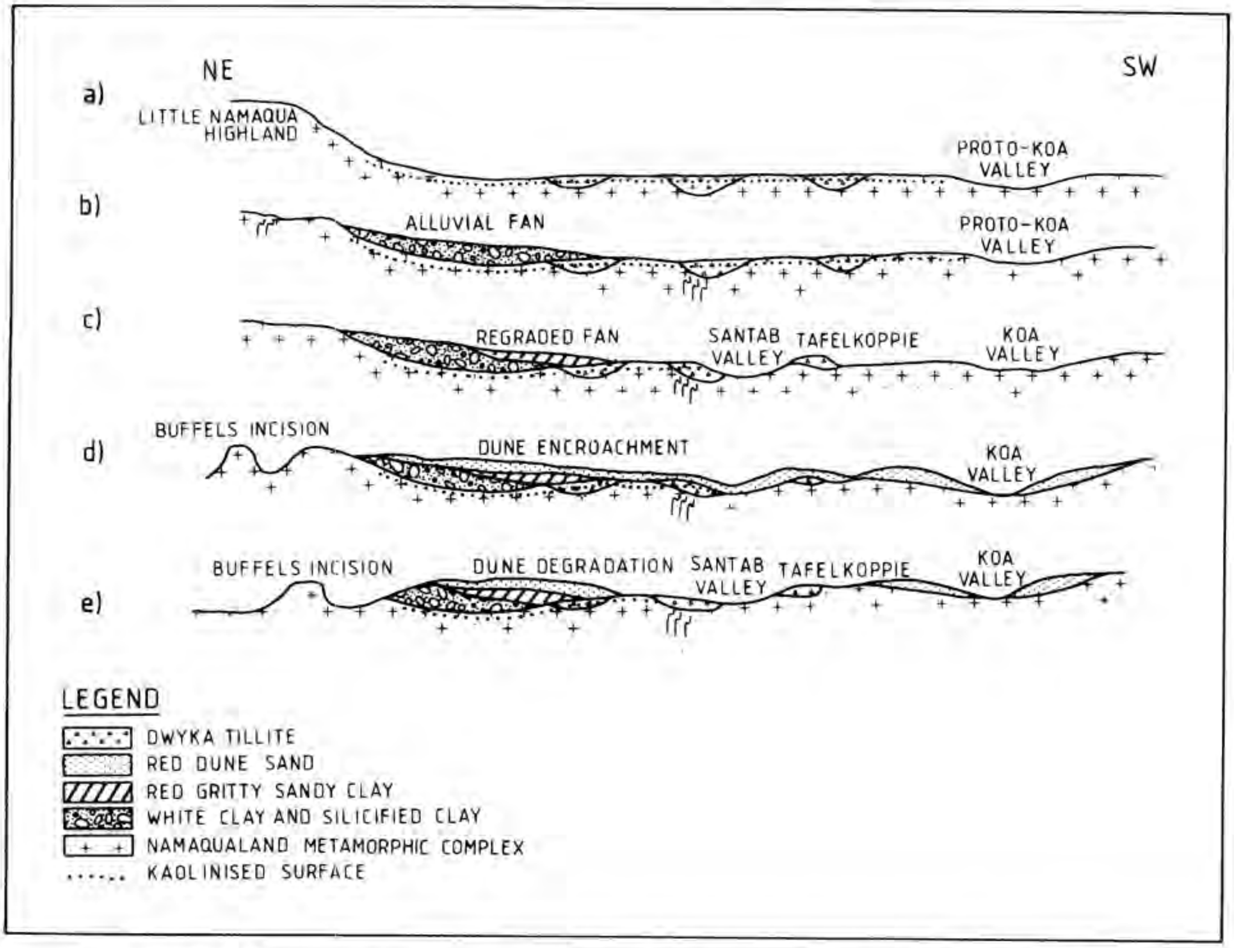

Fig. 2. A Geomorphological Reconstruction of the Western Bushmanland Plateau (4).

A PRESENT DAY MODEL OF SOUTH AFRICAN RAINFALL VARIABILITY

Rainfall variations over South Africa have formed the focus of much research. Alternating spells of above-and below-normal rainfall over the summer rainfall region, which show a quasi-periodicity of eighteen years, have been documented (9,10). A model has been proposed by Tyson (9) to explain the occurrence of these spells, which will be outlined briefly (Fig.3).

The wet-spell analogue is associated with above-normal rainfall over the *summer* rainfall region. This is the result of circulation patterns which enhance rainfall-producing conditions. Such conditions are associated with ridging of the South Atlantic Anticyclone around the coast of South Africa, thereby advecting moisture over the country. Another important atmospheric controlling mechanism is the Southern Oscillation, which when it is in high phase is associated with the occurrence of major rainfall-producing systems over South Africa (11,12). Consequently, cloud bands that link tropical and temperate disturbances become located along a north-west to south-east axis across the subcontinent (13). With the enhanced exchange of energy between tropical and temperate regions the tropical-temperate temperature gradient is reduced and mid-latitude cyclone tracks shift poleward, such that below-normal rainfall occurs over the winter rainfall region (9).

The reverse situation applies to the dry-spell analogue. The maximum zone for tropical heat release moves eastward as does the zone for preferred occurrence of major rain-producing circulation systems (11). Westerly storm-tracks shift equatorward because meridional energy fluxes diminish which results in a strengthening of the temperate-tropical temperature gradient. Whereas the winter rainfall region becomes wetter, below-normal rainfall occurs in the summer rainfall region (9). It has further been hypothesized that under extreme conditions such as those that would persist during a glacial the westerly circulation shifts equatorward such that the extent of the winter rainfall region extends to a latitude of 25°S (9,14,15).

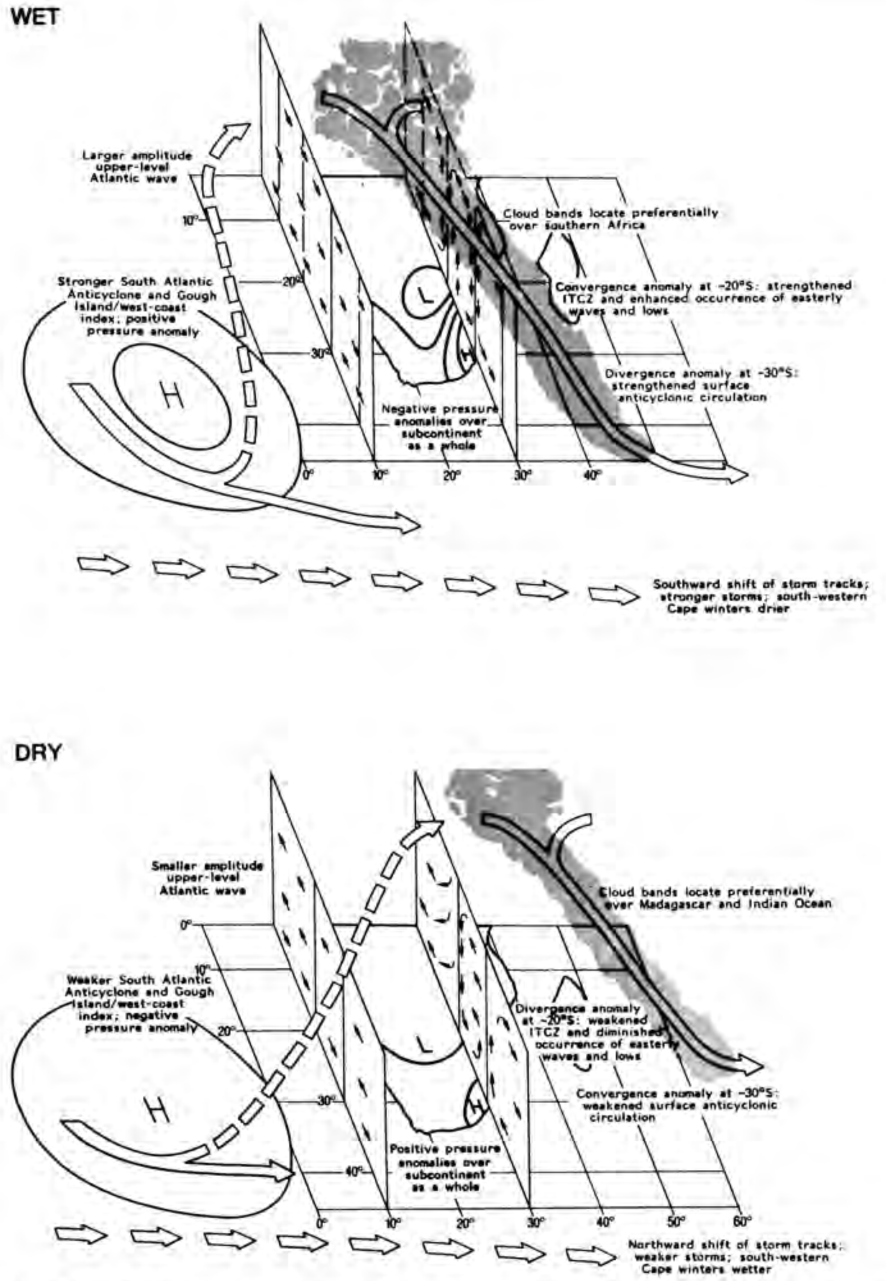

Fig. 3. A Conceptual Model of the Predominant Circulation Features Over Southern Africa During Spells of Predominantly Wet or Dry Conditions (9).

PALAEOCLIMATES OF THE LATE QUATERNARY

The past climates for the Bushmanland region have been interpolated from a palaeoclimatic reconstruction that has been developed for southern Africa and interpreted in terms of Tyson's model (9,14). Climatic periods that have been identified are:

25 000 - 15 000 BP	Generally moister and cooler, but arid phase around 18 000 BP. No glaciation. Westerlies strengthened. Extreme wet spell situation with an expanded winter rainfall region.
12 000 - 10 000 BP	Marked period of desiccation. Dry-spell situation with low

	rainfall over the summer rainfall region.
9 000 - 4 000 BP	Generally moister and warming trend. Present-day wet spell situation.
3 000 - present	Little change, but probably drying from about 1 000 BP.

These patterns have been explained in terms of shifts in the extent of the summer and winter rainfall regions, respectively (Fig.4). Since Bushmanland is situated in an area which is transitional between the summer and winter rainfall regions past climates can be expected to reflect these changes. Although palaeoclimatic evidence from the Bushmanland area is scarce, the patterns of climatic change described above are reflected in evidence from central interior regions of South Africa. Cooler and moist conditions prevailed over the interior from about 32 000 BP until 12 000 BP (16,17,18,19). A short period of desiccation is indicated at the Last Glacial Maximum (18 000 BP). From evidence relating to lake levels and pan levels, Deacon and Lancaster (20) conclude that Bushmanland climates were moister than at present from 30 000 until 13 000 BP. They state that it is not clear whether this was due to an increase in summer or winter precipitation.

Marked desiccation appears to have occurred over the subcontinent between 12 000 BP and 10 000 BP (14,16,17). A reversion to moister conditions is indicated around 9 000 BP, whereby western areas became moister whilst eastern and southern regions remained dry (14). Palaeosols in the Kalahari indicate warm and humid conditions, but further east, south of the Orange and Vaal rivers, warm and dry conditions prevailed (19,21) because summer rains did not penetrate this far (21). There is evidence of moister conditions from the southern Kalahari based on geological and biological criteria from about 8 000 BP (18,22). Climates over southern Africa appear to have been uniformly wetter than present during the period 8 000 BP to 4 000 BP as a result of enhanced summer rainfall. Climates between 3 000 and the present show very little change from the period 8 000 - 4 000 BP. It was predominantly moist and initially warm, becoming cooler (3,9).

FUTURE ENVIRONMENTAL SCENARIOS

The climate system is complex and has not as yet been adequately modelled (23,24,25). Global climate models do, however, give broad results which can be interpreted with local knowledge to get a regional explanation of future conditions. Another approach is to use analogue models to predict future environments. Despite the uncertainty of future climatic events, it is considered feasible to develop scenarios of future climates from palaeoclimatic interpretations (26). Similar reasoning has been used for modelling environmental change in the Northern Hemisphere (2,27) based on a simplified, pseudo-cyclic climatic variation. The

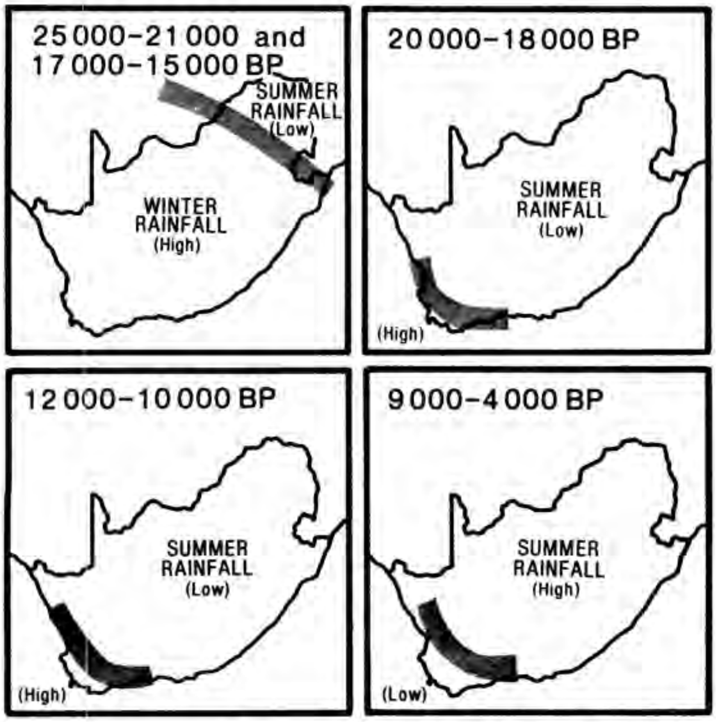

Fig. 4. Changes in the Boundary Zone Between the Summer and Winter Rainfall Regions of Southern Africa During the Late Quaternary (13).

three future scenarios which have been proposed for Bushmanland are:

- The present-day wet and dry spell
- Continued CO_2 warming until 2050 AD
- A glacial period.

These scenarios are based on three assumptions. Firstly, that Tyson's analogues of wet and dry spells could be used to explain palaeoclimates as well as future climates; secondly, that the present position of the poles does not change substantially, and thirdly that the present man-induced increase in CO_2 will lead to an increase in temperature.

The Present Day Wet and Dry Spell Conditions

Should the present-day oscillations in rainfall continue over the next few centuries the climate of Bushmanland can be expected to alternate between periods of above-normal rainfall and extreme aridity. Wetter conditions would result from summer rainfall systems. Such conditions would be associated with the high phase of the Southern Oscillation and enhancement of rainfall-producing systems in the easterly circulation. Nonetheless, the climate of Bushmanland would be expected to become no more than semi-arid as it is situated far from the moisture source. Even if it is assumed that the precipitation increased to that of the wetter region to the east of Bushmanland today (600 mm p. a.), it would remain a semi-arid area. Large diurnal and seasonal variations in temperature could be expected and windspeeds may decrease. These conditions could be compared to the wetter phase of the mid-Holocene (9 000 - 6 000 BP). Under the present-day extended dry spell situation, it would be hyperarid in Bushmanland, because of a lack of both winter and summer rainfall. Such conditions are analogous to those that prevailed between 12 000 and 10 000 BP (3,14).

Continued CO_2 Warming

According to Tyson (23) warming of the atmosphere as a result of the build up of 'greenhouse' gases could cause a decrease in rainfall over the summer rainfall region of South Africa. Hence, conditions equivalent to those associated with the occurrence of an extended dry spell will prevail over much of the country. Consequently, the Bushmanland region will remain arid because of a lack of both summer and winter rainfall.

A Glacial Period

Should a glacial period occur within the next 300 years, the extreme of the dry-spell situation would result; the equatorward movement of the westerly circulation would be more marked than it is in the present-day situation because of an extreme tropical-temperate temperature gradient. North of the expanded winter rainfall region, conditions which cause below-normal rainfall in the summer rainfall region will prevail. This situation may be compared to the Late Pleistocene period (25 000 - 15 000 BP), during which moister conditions prevailed because of an increase in the extent of the winter rainfall region. The increase in the winter rainfall as a result of the penetration of rain-bearing westerly wave disturbances during this phase would have little effect on precipitation in Bushmanland due to rain-shadow effects, as is evidenced at the present time. Increased windspeed during the Last Glacial Maximum has been documented. Hence, accelerated erosion could be expected during glacial periods in Bushmanland.

Geomorphological Processes

Due to its tectonic stability, mainly exogenic geomorphological processes operate in Bushmanland. Only those associated with wind and water are considered, as glaciation is not expected to occur due to Bushmanland's proximity to the equatorial regions. Wind has been instrumental in the degradation of surface sediments in western Bushmanland in the past. Increased windspeeds could accelerate this denudation process but this would essentially result in a redistribution of material from the eastern and western margins which has occurred periodically in the past (4). Within the repository area the material composing the fan has been depleted of finer material, leaving coarse particles which are not easily transported by wind. This process is, therefore, not considered in the scenarios.

Water erosion is more important than wind erosion. Fluvial processes are virtually absent in Bushmanland where stream channels have been choked with sand and drainage occurs within enclosed basins. An increase in precipitation may encourage channelling, although this would probably not be extensive as even the higher rainfall area to the east does not have a well-developed river system. The inactive Koa River valley is located 60 km to the east of the repository where knickpoint migration towards the site may occur. Even if the estimated rate of migration of 1 km every 1 million years for the Drakensberg Escarpment in the wetter part of South Africa (with a precipitation of 1200 mm p.a.) (29) were taken, this would not affect the trenches for 60 million years. Similarly, the eastward migration of rivers from the western escarpment 10 km away would take 10 million years. The low relief and low rainfall of Bushmanland make this rate unlikely and so fluvial processes have not been taken into consideration.

Slope processes that have been considered are soil creep, surface wash and slope retreat. As little information is available from the South African region, general rates of these processes have been used (26,30). Soil creep occurs continuously due to moisture changes and collapse of animal burrows, root holes and other voids. Rates vary from 0.4 - 2.2 mm p.a. to a maximum of 15 mm p.a. (30). The rate increases with increased slope angle and moisture content. Since the trench has gentle slopes, of less than 11 degrees, only changes in moisture are significant.

Surface wash may be one of the most likely causes of denudation in Bushmanland. This movement of soil downslope can occur through rainsplash erosion and by sheet erosion. These rates vary with slope angle, vegetation cover and weathering processes. Increased precipitation, however, encourages vegetation growth which would make this process less effective. Extreme rates of 2 - 200 mm per 1 000 years are given (30). These rates are accelerated by at least one order of magnitude due to vegetation destruction (26). Slope retreat occurs due to various physical weathering processes and results in landslides and rockfalls. This process is, however, unlikely to be significant in Bushmanland as the topography is too flat.

Future Environmental Scenarios

A major concern for shallow-land burial is the exposure of the waste by the removal of the top of the waste trench. The geomorphological processes that could effect this are addressed in each scenario.For simplicity it is assumed that each of the scenarios would persist from the present to 300 years hence and due to the unknown periodicity of the conditions the many possible combinations of the scenarios has not been attempted. The area is to be isolated, therefore an alteration of the state of the local environment by man is not considered.

In the present-day dry spell the gentle topography of Bushmanland may only result in a maximum rate of 2.2 mm p.a., equivalent to a denudation of 0.6 m in 300 years. In the case of surface wash an average rate of 100 mm per 1 000 years is assumed. This results in only 30 mm being eroded after 300 years. During the wet-spell analogue increased precipitation and intensity of storms could increase these rates. If, in the worst case, ground lowering by soil creep reaches a rate of 10 mm p.a., 3 m of soil cover would be eroded in 300 years, which would remove the trench cap. However, surface wash with a maximum rate of 200 mm per 1 000 years would only result in 60 mm of erosion. Increased vegetation cover would reduce these rates. Even in an extended wet spell the response of the hydrological environment would be slow. Eventually the level of ground water would rise. This effect was modelled by Levin (7) and found to be insignificant on the ground water flow in the area. If, under extended wet-spell conditions, water movement beneath the soil surface results in slope retreat, an average rate of 5 000 mm per 1 000 years (24,26) can be taken resulting in erosion of 1.5 m in 300 years. Resistant surface conditions make this highly unlikely, however.

CO_2 warming by the year 2050 AD is assumed to result in an atmospheric warming of 1 to 2°C. According to Tyson (23), an extended dry spell could be expected. The rates of the processes of soil creep and surface wash could be expected to be similar to a dry-spell analogue but would be more persistent so that denudation of 300 mm and 16 mm respectively may be reasonably assumed. Sea level changes would have little effect on this inland area, as the base-level of erosion is determined by the level of internal drainage basins.

Although it has been suggested that the next glacial period will occur in the next 50 000 years (31), it could be argued that the move to the initiation of ice age has been accelerated by man's activities and could occur within 50 to 100 years. If this were the case, an increase in the winter rainfall area would be expected with the extension of the westerly wind belts to the north. This would be a dry-spell analogue similar to the Last Glacial Maximum. Although western Bushmanland does experience some winter rainfall the rainshadow effect of the western highlands would result in little increase under these conditions. No increases in rates for soil creep and surface wash have therefore been assumed.

CONCLUSION

It has been suggested that past climates can be extrapolated into the future and interpreted within the framework of a conceptual model which explains extended wet and dry spells. It is therefore reasonable to assume that the arid and semi-arid environment that has prevailed in western Bushmanland in the past could continue for the next 100 000 years and that the region, due to its position, will be ice-free. Wetter periods with periodic incidences of high rainfall will occur but these will never result in a climate that is more than semi-arid.

The effects of the geomorphological processes discussed in this paper have been conservatively estimated. Even so, the possibility of the trench cap being removed is unlikely. The shallow-land trenches of the South African radioactive repository are situated in an area where wetter and drier phases have been experienced since the formation of the dunefield which is in existence today. Discontinuous calcrete layers just below the surface as well as vegetation have preserved these dunes by making them resistant to erosion. The trenches are situated on a topographical high in an area of low relief which should result in rates of geomorphological processes that are lower than those estimated here. Increased rainfall during wetter years will contribute to a greater vegetation cover, reducing erosive effects.

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REFERENCES

1. B.B. HAMBLETON-JONES, N.J.B. ANDERSEN, M. LEVIN, H.J. BRYNARD, F.A.G.M. CAMISANI-CALZOLARI, J.N. FAURIE, N. NIEMAND, E. RAUBENHEIMER, M.A.G. ANDREOLI, and S.J. POSNIK, "A Summary of the Geotechnical and Environmental Investigations Pertaining to the Vaalputs National Radioactive Waste Disposal Facility", PER-143, AEC, Pelindaba, South Africa (1986).
2. P.S. RINGROSE, A.F. CHADWICK, F.A.T. KLEISSEN, J.P.A. LARKIN, D.T. POLLOCK and R.D. WILMOT, "Probabilistic Simulation of the Long-term Evolution of Radioactive Waste Disposal Sites", Int.Symp.Safety Assessment of Radioactive Waste Repositories, Paris, France, October 9 -13, 1989, IAEA (1989).
3. M.J. MULLER, S.J. POSNIK and M. LEVIN, "Long-term Climatic Effects on the National Radioactive Waste Disposal Facility: A Reconstruction of the Palaeoenvironments of Bushmanland, South Africa", Palaeoecol. of Africa (1990, in press).
4. T.S. MCCARTHY, B.P. MOON and M. LEVIN, "Geomorphology of the Western Bushmanland Plateau, Namaqualand, South Africa", S. Afr. Geogr. J., 67,2, p.160-178 (1985).
5. B.R. SCHULZE, "Climate of South Africa. Part 8: General Survey", WB28, S.A. Weather Bureau, Pretoria, South Africa (1980).
6. R.E. SCHULZE, Unpublished Report on Northern Cape Rainfall, Dept. of Agric. Eng., Natal Univ., Pietermaritzburg, South Africa (March 1984).
7. M. LEVIN, "A Geohydrological Appraisal of Vaalputs Radioactive Waste Disposal Facility in Namaqualand, South Africa", Unpub. PhD Thesis, Univ. of the Orange Free State, South Africa (1988).
8. B.R. SCHULZE, "South Africa" in J.F. GRIFFITHS (ed), "Climates of Africa", World Survey of Climatology, Vol 10, Elsevier, Amsterdam, p.501-586 (1972).
9. P.D. TYSON, "Climatic Change and Variability in Southern Africa", Oxford University Press, Cape Town, South Africa (1986).
10. P.D. TYSON, "The Atmospheric Modulation of Extended Wet and Dry Spells over Southern Africa, 1985-1987", J. Clim., 4, p.621-635 (1984).
11. J.A. LINDESAY, M.S.J. HARRISON and M. HAFFNER, "The Southern Oscillation and South African Rainfall", S. Afr. J. Sci., 82, p.196-198 (1986).
12. J.A. LINDESAY, "South African Rainfall, the Southern Oscillation and a Southern Hemisphere Semi-annual Cycle", J. Clim., 8, p.17-30 (1988).
13. M.S.J. HARRISON, "A Generalised Classification of South African Summer Rain-bearing Synoptic Systems", J. Clim., 4, p.547-560 (1984).
14. M.J. COCKCROFT, M.J. WILKINSON, and P.D. TYSON, "The Application of a Present-day Climatic Model to the Late Quaternary in Southern Africa", Climatic Change, 10, p.161-181 (1987).
15. M.J. MULLER and P.D. TYSON, "Winter Rainfall over the Interior of South Africa during Extreme Dry Years", S. Afr. Geogr. J., 70, p.20-30 (1988).
16. K.W. BUTZER, "Late Quarternary Environments in South Africa", IN J.C. VOGEL, "Late Cainozoic Palaeoclimates of the Southern Hemisphere", A.A. Balkema, Rotterdam, p.235-264 (1984).
17. K.W. BUTZER, R. STUCKENRATH, A. BRUZEWICZ, and D.M. HELGREN, "Late Cenozoic Palaeoclimates of the Ghaap Escarpment, Kalahari Margin, South Africa", Quat. Res., 10, p.310-339 (1978).
18. L.E. KENT and K-H. GRIBNITZ, "Freshwater Shell Deposits in the Northwestern Cape Province: Further Evidence for a Widespread Wet Phase During the Late Pleistocene in Southern Africa", S. Afr. J. Sci., 81, p.361 - 370 (1985).
19. K. HEINE, "The Main Stages of the Late Quaternary Evolution of the Kalahari Region, Southern Africa", Palaeoecol. of Africa, 15, p.53-76 (1982).
20. J. DEACON and N. LANCASTER, "The Late Quarternary of Southern Africa", Oxford University Press, U.K. (1988).
21. J.A. COETZEE, "Pollen Analytical Studies in East and Southern Africa", Palaeoecol. of Africa, 3, p.1-146 (1967).
22. E.M. VAN ZINDEREN BAKKER, "Pollen Analytical Studies of the Wonderwerk Cave, South Africa", Pollen et Spores, 24, p.235-250 (1982).
23. P.D. TYSON, "Modelling Climatic Change in Southern Africa : A Review of Available Methods", S. Afr. J. Sci. (1990 in press).
24. A.B. PITTOCK and M.J. SALINGER, "Southern Hemisphere Climate Scenarios", Climatic Change (1990 in press).
25. M.J. SALINGER and A.B. PITTOCK, "Climate Scenarios for 2010 and 2050 A.D. : Australia and New Zealand", Climatic Change (1990 in press).

26. M.B. SEDDON and P. WORSLEY, "Long-term Effects on Potential Repository Sites : Climate and Geomorphological Changes", FLPU85-11, Fluid Processes Research Group, British Geological Survey, Keyworth, England (May 1985).

27. G.S. BOULTON, "Time Dependent Modelling of Environmental Change : The Effect of Quaternary Glaciations", Int.Symp. Safety Assessment of Radioactive Waste Repositories, Paris, France, October, 9-13, 1989, IAEA (1989).

28. R.H. COOKE and A. WARREN, "Geomorphology in Deserts", B.T. Batsford Ltd., London (1973).

29. L.C. KING, "Canons of Landscape Evolution", Bull. Geol. Soc. Am., 64, p.721-751 (1953).

30. B.P. MOON, "Hillslope Form and Development" in B.P. MOON and G.F.DARDIS (ed), "The Geomorphology of Southern Africa", p.57-77, Southern Book Publishers (Pty) Ltd., South Africa (1988).

31. J. IMBRIE and J.Z. IMBRIE, "Modelling the Climatic Response to Orbital Variation", Science, p.207, p. 943-953 (1980).