An overview of the heavy mineral potential of Liberia

by P.J. Hancox and D. Brandt*

Synopsis

Heavy mineral deposits have been known from Liberia since the 1950s from both river and beach placers. The heavy mineral content of beach sands ranges between 28–62% and the suite includes ilmenite, rutile, zircon and magnetite. These occur together with kyanite, sillimanite, staurolite and garnet. The average ilmenite content is 82% with minor zircon (11%), rutile (6%) and monazite (1%). The ilmenite is, however, of poor quality with haematite intergrowths and a titanium content ranging from 10–42.4% (average ±25% TiO_2). The amounts of rutile and zircon, while of suitable quality, have also previously been deemed too low for economic exploitation.

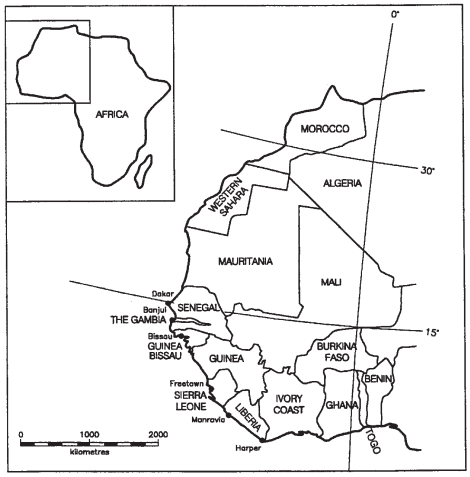

Figure 1—Map of northwest Africa showing Liberia's geographical position in relation to the area studied by Barclay[3]

Introduction

Liberia has recently emerged from a seven-year civil war that has left the country bereft of infrastructure and struggling to re-ignite its economy, partly by means of its mineral wealth. During 1997 the Wits Geology Department staff therefore undertook a review of the literature of the geology of Liberia, including a vast bibliography covering most aspects of the basement and economic geology of Liberia, Sierra Leone and the adjacent Archaean terrains of Guinea and the Ivory Coast[1]. Various members of staff then compiled reports on individual aspects and further studies were undertaken in the country in late 1997. Due to economic constraints, the heavy mineral (HM) sands were not studied in detail, and no review was undertaken of their potential.

Although the Indian Ocean Region dominates world supply of heavy minerals[2], heavy mineral deposits, particularly rutile, are known from West African countries such as Sierra Leone, Senegal and the Gambia[3]. As Liberia lies to the southeast of Sierra Leone (Figure 1), this paper forms a natural continuation of the deposits described by Barclay[3]. Unlike Sierra Leone, Senegal and the Gambia, only exploration/evaluation phase projects have been undertaken in Liberia, with no working mines to date. The past exploration activity for HM sands in Liberia is also poorly documented and a large amount of the information is contained in obscure in-house reports. During the war, much of the documentation of the Ministry of Lands and Mines and Geological Survey was lost or destroyed by looters; however, a number of these reports have been procured by the authors, who also have first-hand experience of the coastal sands of Liberia. For this reason a review of the known occurrences of heavy minerals are presented here.

History

Most of the early reports on heavy minerals in Liberia deal with minor fluvial deposits, often associated with gold[4]. During 1949 and 1950 occurrences of HM sands in western Liberia

* *Geology Department, University of the Witwatersrand, South Africa.*

were documented under the supervision of G. Lill of the National Ocean Survey[4]. These investigations concentrated on inland occurrences, as well as beach sands on Bushrod Island, which lies to the northwest of the capital Monrovia. Ilmenite, rutile, zircon, garnet and kyanite were shown to be present as inland occurrences, but at low concentrations (<2%). Modern to recent beach sands along Liberia's 560 km coastline proved more viable with HM contents of between 1–6%, with local concentrations of up to 20%. This work[4] showed ilmenite to form between 5.5–88.9% of the HM fraction, with zircon between 0.1–26.5% and rutile between 0.1–20.1%[4].

Although heavy minerals were therefore known throughout Liberia as river and beach placers since the 1950s, not much attention was paid to them until the early 1970s. This came about due to the compilation of the radioactivity map of Liberia, which followed the 1968 airborne radiometric survey[5,6]. This map showed a number of pronounced radiometric anomalies along the Atlantic coast, believed to be due to the slight uranium content of zircon, and the thorium in the monazite of the HM accumulations. Due to these findings the UNMS studied areas at Bomi, Kingsville and Robertsport during 1970 and 1971. This was followed up by studies centred on a 45 km stretch of coastline from Monrovia to Marshall[7] (Figure 2.) with special attention paid to raised fossil beaches. This site was based on the delineation of heavy-mineral accumulations by airborne (visual) reconnaissance and was in turn followed up by banka drilling and the digging of test pits and trenches. Geophysical methods were unsatisfactory due to the low magnetite value, weak magnetism of the ilmenite and the thick sand cover, which prevented radioactive delineation below 0.5 m. Pits were restricted to 2.0 m due to the high water table levels and therefore banka drilling to 12 m was undertaken on every third hole. Due to the lack of laboratory facilities in Liberia, most of the assays in respect to heavy mineral content were carried out by UN staff only with the aid of a binocular microscope.

Additional studies were undertaken from January to August 1973[8], during which time a 103 km stretch between Monrovia and the border with Sierra Leone was thoroughly investigated. Contrary to the area studied in 1972[7], no heavy mineral concentrations were discovered in the raised beaches, and in general the HM content was poorer than between Marshall and Buchanan. An additional 40 km was investigated between Marshall and Buchanan, however, due to the onset of the rainy season this fieldwork was of a limited nature. These two studies combined, therefore cover a 188 km stretch of coastline (± 33.5% of the coastline). In 1974 the coastal stretch between the Cestos River mouth and the border with the Ivory Coast was under private concession (W.H. Muller Co.). Early exploration activities were undertaken by the Muller Co.[9,10] and a twenty-ton bulk sample was collected for pilot testing in Australia, from which encouraging results were obtained for commercial amounts of rutile, zircon, ilmenite and monazite. The concession was, however, later taken over by LIBSEC and a number of sites between Harper and the Cestos River mouth were evaluated. LIBSEC reported to the Ministry of Lands and Mines for the period 1974–1980 on areas east and west of Greenville (Sino County) and east and west of Harper (Maryland County). The deposit was, however, considered to be low grade with ±5% HMC and reserves estimated at several hundred million tons. In 1979 LIBSEC cancelled their concession. Most recently samples have been taken by the authors and colleagues for ICP-AES, XRF and SEM studies, although these results are not yet available. To date the only stretch of coastline not investigated is a 65 km reach between Buchanan and the Cestos River mouth (Figure 2).

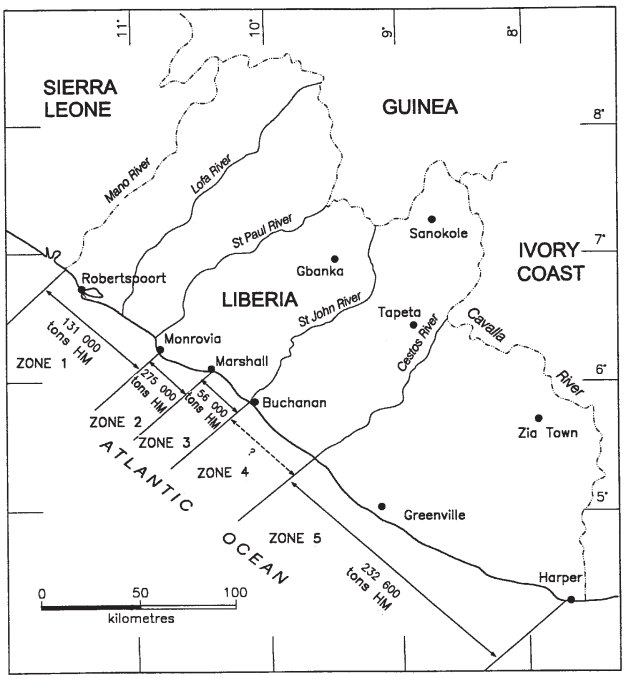

Figure 2—Map of Liberia showing the five major zones of known HM accumulations, as well as the main towns and rivers mentioned in the text

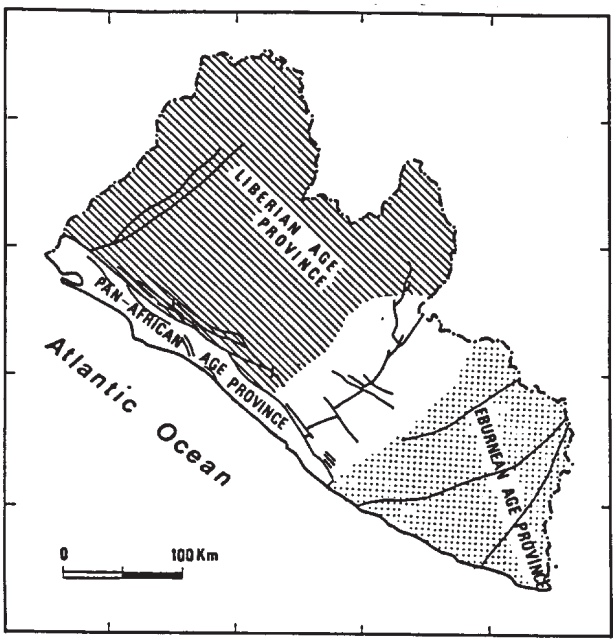

Figure 3—Age province map of Liberia (after the Geologic Map of Liberia, 1983)

General geological setting and provenance

Liberia forms part of the Guinean shield and over 90% of the country is underlain by a basement of Pre-Cambrian rocks of Liberian (2700–3200 Ma) and Eburnean age (2500 Ma) provinces[11–14] (Figure 4). These are predominantly igneous and metamorphic rocks, which are conformably overlain by metavolcano-sedimentary formations of quartzite, banded ironstone, amphibolites and ultramafics. The latter form prominent linear features across the country. These Pre-Cambrian strata are overlain by Palaeozoic sandstones which are intruded by Mid-Jurassic (172–192 Ma)[15] diabase (dolerite) dikes. These strata are overlain by Cretaceous, Tertiary and Quaternary aged formations[16], with the last-named being host to the HM occurrences. The age of the younger HM deposits may be constrained by the occurrence of plant remains at 4.4 m above ASL which have been dated as 6160 ± 600 BP. Those seaward of these are younger and probably all pre-date 6000 BP.

Although no direct studies linking the HM to source rocks have been undertaken, the igneous and metamorphic rocks of granitic, schistose and gneissic character are ideal sources for heavy minerals such as ilmenite and rutile, as well as magnetite and red garnets. Magnetite and ilmenite may also be liberated from the breakdown of the Jurassic diabases (dolerites). Nair[17] associated the monazite in beach occurrences of heavy minerals with granites, granite-pegmatites, La-rich monazite pegmatite and calcite-bastnaesite vein rock units. One site of particular interest occurs at Robertsport, about 25 km southeast of the Sierra Leone border. Here a roundish norite promontory about 10 km in diameter outcrops. Beach exposures (Figure 4) show this to be a small layered igneous complex, and its presence as a headland may account for the relatively high percentage of HM in the modern beach sands.

Structurally the metamorphic rocks of the Liberian and Eburnean age provinces trend mainly northeast-southwest, whereas the Pan African province trends a coast-parallel northwest-southeast. Jurassic diabase (dolerite) dikes also trend northwest-southeast and form a linear pattern across Liberia. These structural features and lineaments impart a strong control on the course of the country's drainage (Figure 2).

Geomorphology

The source rocks are drained by a series of six large, sub-parallel to parallel rivers (Figure 2), flowing roughly southwest at approximately right angles to the coastline. These rivers supply HM-bearing sediment to the coastline, which is reworked to the north by longshore drift currents (1.5–2 knots[4]) and concentrated by wave action. The present beaches therefore, consist partly of sand discharged from the rivers and partly of sand supplied via wave action on headlands such as Cape Mesurado and Robertsport. The coastal area in general consists of a narrow sandy beach, behind which coastal plain bush, swamps or lagoons occur. The width of the beach strip (Figure 5) varies from between several km near the border with Sierra Leone, to less than a km in the southeast of the country.

Occurrences

The first three main occurrences of HM were documented by the UNMS at Bomi, Kingsville and Robertsport during 1970 and 1971. Drilling in the Bomi area revealed irregular concentrations of HM both at the surface and at depth. The HM-bearing layers averaged only 20 cm thick with a HM content of less than 10%. At Kingsville HM concentrations occur some 200 m inland from the shoreline as a surficial concentration 15 cm thick and some 300 m long. These surficial accumulations reached up to 40% HM content. At Robertsport, HM accumulations occur on the present beach and reach a maximum of 75% HM content. As previously mentioned this local concentration is due mainly to the presence on the beach of outcrops of a mafic layered complex (Figure 4).

Apart from these three early studied sites, HM-bearing sands occur along the entire coast of Liberia, generally as mineralized layers up to 15 m wide and 1 m thick, and as part of small ridges or raised beaches. The total heavy mineral concentration (HMC) of the sands ranges from 28–62% and is dominated by ilmenite, rutile, zircon and monazite minerals, with accessory garnet, staurolite, tourmaline, magnetite and epidote. HM grain size ranges between 0.84 and 0.25 mm with more than 90% being less than 0.5 mm. These occurrences have been studied as five separate zones[7–10] (Figure 2) and are, here, briefly reviewed from northwest to southeast.

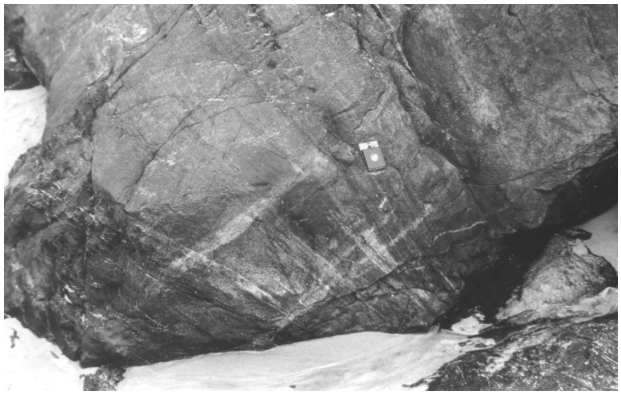

Figure 4—Beach outcrop exposures of the layered mafic complex and Robertsport

Figure 5—Beach strip with modern-recent HM accumulations on the step, which separates the foreshore from the backshore and lagoonal environments

Mano River to Monrovia (zone 1)

Between Monrovia and the Mano River the HM-bearing sand occurrences in the area investigated by the UNDP[8] form intermittent, narrow and thin strips with low HM contents. These occur on top of the sea-facing sand bar (berm), in front of a low escarpment separating the sandy beach from the grass covered coastal plain.

Monrovia to Marshall (zone 2)

Four types of heavy mineral occurrences were delineated by the UNDP[7] team in the 45 km stretch between Monrovia and Marshall. Three of these are near surface concentrations on raised beaches whereas the fourth is deeper, being situated between 6–9 m below sea-level. HM concentrations tend to occur as highly concentrated, well defined horizontal to sub-horizontal laminae (Figure 6).

The town of Marshall is situated some 50 km east-southeast of Monrovia at the joint outflow of the Junk (Du) and Farmington Rivers. Here the heavy mineral concentration occurs at the inland edge of a ± 50–100 m wide heath separating the backswamp from the current beach (Figure 7). The deposit is of the shoestring type, with a total length of 1980 m, varying in width between 20–60 m (average 38 m). The average thickness (above the water table) is given as 2 m and the average HM content as 42%. It is believed that the concentration of the heavy minerals took place with a sea-level some 2–6 m below the present7. Modern beach sands may contain up to 2–3% HM, believed to be reworked from older accumulations (Figure 8).

Marshall to Buchanan (zone 3)

The 40 km stretch between Marshall and Buchanan forms the southeastern limit of the 1973 UNDP survey and is generally poor in HM[8]. Like other parts of the coast the HM are concentrated on top of the sand bar and in front of the step. HM concentrations of up to 28% are also known inland of the present beach in raised fossil beach deposits. Due to adverse groundwater conditions, these were not, however, fully investigated by the UNDP team[8].

Buchanan to Cestos River (zone 4)

This area has not been investigated by the present authors and could not be evaluated from the current literature. At present this is the only zone that is totally unexplored.

Cestos River to Harper (Zone 5)

The area between the Cestos River and Harper forms the southeastern limit of HM occurrences in Liberia and has been evaluated mainly by the W.H. Muller Co.[9,10], LIBSEC and LISMORE[18]. Like elsewhere along the coast, HM concentrations occur as recent to present beach sands and as shallowly buried HM concentrations in front of the landward step.

In general therefore, HM concentrations in Liberia occur in up to five different settings:

- modern surface deposits
- recent-present beach sands with between 1–3% HM, periodically replenished by wave action (Figure 8)
- shallowly buried HM concentrations in front of the landward step with HM concentrations of between 40–80% (Figure 9)
- deep seated (6–12 m) HM concentrations close to the present shoreline, but below both present sea and groundwater levels
- possible inland deposits to the west of Buchanan.

Estimated reserves

Total reserves for the areas previously investigated are given in Table I. Total reserves amount to 744 700 tons of HM of

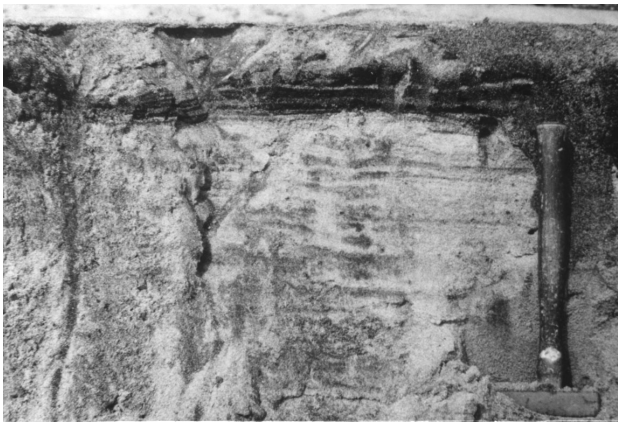

Figure 6—Beach cut showing the sub-horizontal laminae of HM and the nature of the near surface accumulations

Figure 7—Beach sand HM occurrences southeast of Monrovia. Note modern surface accumulations as well as those on top of the berm

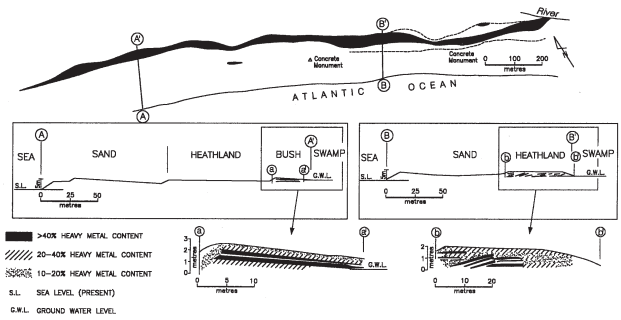

Figure 8—Beach sand HM occurrences at Marshall (After UNDP 1972[7])

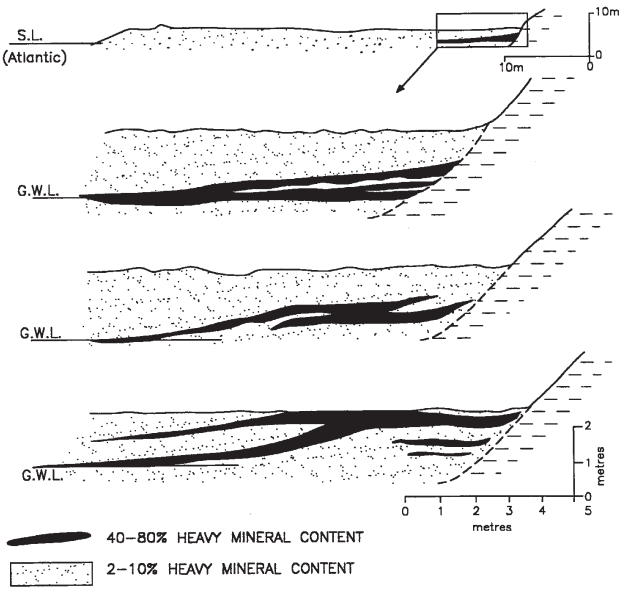

Figure 9—Representative sections of beach sand HM occurrences along the coast of Liberia (after UNDP 1972/1974[7,8])

Table I

Estimated reserves of Heavy Minerals in the studied sections of Liberia

Area	HM tonnage	Ilmenite	Zircon	Rutile	Monazite
Monrovia–Mano	181 000	150 380	16 170	11 630	2 820
Marshall–Buchanan	56 100	49 740	3 510	1 940	910
Monrovia–Marshall	275 000*	192 200	31 600	11 600	3 600
Harper–Cestos	232 600	113 500	48 100	58 900	12 100
Total	744 700	505 820	99 380	84 070	19 430

** 36 000 tons are magnetite between Monrovia and Marshall*

which 505 820 tons are ilmenite, 99 380 tons are zircon, 84 070 tons are rutile, 19 430 tons are monazite. Some 36 000 tons of magnetite and 68 310 tons of heavy silicates also occur.

Other possible accumulations of HM not taken into account in Table I are:

- The inland area to the west of Buchanan and the coastal strip between Buchanan and the Cestos River mouth
- Small isolated occurrences not included in the estimated tonnage
- Sand with HM concentrations below 10%, above, below, and outside of the investigated areas
- Recent beach sands considered barren by the UNDP programme but containing 1–3% HM
- Deep seated (6–12 m) rich HM occurrences documented by the UNDP programme of 1972
- Shallow coastal shelf deposits.

Chemical and mineralogical compositions

Ilmenite

Entirely unaltered ilmenite is rare, and most of the ilmenite has been altered to various degrees, mainly by the removal of iron[7]. This is shown by haematite-ilmenite inter-growths which sometimes have rutile lamellae in the haematite-ilmenite inter-growth. The ilmenite has a low TiO_2 content which usually ranges between 10–42.5% for the area from Buchanan to the Mano River. Most values lie between 23–33% and the average is 28.2%. For the Greenville area the W.H. Muller Co.[9,10,19] reported values between 51.5–53.4%. The chromium content is high[20], being between 0.09–0.4% (average 0.23 (0.33% Cr_2O_3). Vanadium averages 0.41% and manganese 0.48%.

Rutile and zircon

No chemical or analytical data exists as to the make-up of the rutile and zircon in Liberia. Mineralogically zircon occurs as colourless to pink, purple, brown and grey crystals, and as opaque malacons. The rutile is light red to black in colour.

Monazite

Little attention has been paid to the chemical composition of the monazite,[21,22] however, the UNDP team[7,8] provide figures of total rare earth element (REE) plus thorium of 68.65% (27.9% P_2O_5). Rosenblum[21] presented REE and partial oxide data for four monazites from western Liberia, as well as for eleven monazites from the Buchanan and Robertsport beaches[22]. Nair[17] reports on the rare-earth element (REE) distributions of eleven monazite concentrations from the coast and hinterland and states that Liberian monazites have higher REE (ThO_2 = 3%) than monazites from the USA, Brazil, India, Madagascar and South Africa.

Infrastructure, social and environmental considerations

For the most part the coastal belt is void of habitation and cultivation and has only a low population density. At present Liberia has no coherent environmental policy although this is set to change soon. The existing road system is poor and has not been upgraded since the end of the civil war. Secondary roads on lateritic surfaces become almost impassable during the wet season and are generally in very poor condition. For the most part (80% of the coast is inaccessible from inland by road), access to the beach is only by foot-path from fishing huts or villages, or from the ocean. The port at Monrovia is, however, functional.

Conclusions

Although there are large areas of suitable provenance rocks inland of the coastal plain, Liberia lacks geologically young sand dunes in the coastal plain. All the present-day beach sands and most of the younger Holocene deposits are clean and free-running, whereas some of the older deposits that lie directly on weathered bedrock are locally weakly cemented by clay or iron oxides. All of the heavy minerals and 99% of the

sand is also smaller than 1 mm and from an exploitation point of view the sand would therefore require little or no sieving prior to heavy mineral extraction. The oversize and slimes contents are not known.

The most promising area for economic occurrences of HM, particularly rutile, in Liberia was believed to be the 188 km stretch of coastline from the border with Sierra Leone to Buchanan. This area has however, proved to have HM tonnages too low for large-scale mining, containing proposed reserves of only 512 100 tons HM, with the assemblage dominated by ilmenite (82%) with lesser zircon (11%), rutile (6%) and monazite (1%). As for the rest of the coastline, the ilmenite is intrinsically of low quality and most has been altered to various degrees. It also has a low TiO_2 content (around 28%) and rather high chromium content, making it unsuitable for the production of titaniferous slag for use in the pigment or other industries. Hockin[1957] believed that due to the fact that both normal and altered ilmenite occurred together in various samples, and that the relative percentage of normal ilmenite increased as the haematite-ilmenite decreased, that it may be possible to find areas where normal ilmenite is present in quantity, and free from contamination. At present however such areas are unknown. Fossil beach terraces or older buried strandlines may prove to contain better quality ilmenite with higher TiO_2 and lower contamination levels than the younger nearshore deposits. Ramsay[23] has also shown that relict beach systems may be stranded on the shelf as a consequence of sea-level fluctuations during the Quaternary. The outlook for older marine shoreline, dunal or shelf deposits is however not highly promising.

Due to the low quality of the ilmenite, the economic value of Liberia's heavy mineral sands is therefore confined predominantly to the rutile and zircon. Current reserves of these two minerals are only 99 380 tons of zircon and 84 070 tons rutile. Although the rutile and zircon is of suitable quality, these amounts have previously been deemed too low for economic exploitation. The lack of infrastructure, and extended length and small cross-section of the deposits would also prove difficult for mining, thereby further hampering the viability of any mining venture. Based on the current state of knowledge therefore, the HM deposits of Liberia seem to be generally of poor quality and low tonnage. It should however be noted that exploration has not been exhaustive and that few modern techniques have been used.

Abbreviations used in the text

LIBSEC = Liberia Beach Sands Exploration Company
UN = United Nations
UNDP = United Nations Development Programme
UNMS = United Nations Mineral Survey
USGS = United States Geological Survey

References

1. MASTER, S. Report on the compilation of the Bibliography of the Geology and Mineral Resources of Liberia and Sierra Leone, and the adjacent Archaean terrains of Guinea and Ivory Coast, West Africa. Economic Geology Research Unit, *University of the Witwatersrand*, South Africa. 1997. 33 pp.
2. TAYLOR, R.K.A. and MOORE, D.E. The dominant role of the Indian Ocean Region in the supply of titaniferous feedstocks. *Heavy Minerals 1997*. South African Institute of Mining and Metallurgy, Johannesburg, 1997. pp. 7–16.
3. BARCLAY, J. A historical overview of heavy mineral deposits of Senegal, The Gambia and Sierra Leone. *Heavy Minerals 1997*. Johannesburg, South African Institute of Mining and Metallurgy, 1997. pp. 23–32.
4. THAYER, T.P., LILL, G.G., and COONRAD, W.L. Mineral Exploration in Western Liberia 1949–1950. Geological Survey Special Paper No. 4. Republic of Liberia Ministry of Lands and Mines. 1974. 51 pp.
5. BEHRENDT, J.C. and WOTORSON. C.S. Aeromagnetic and gravity investigations of the coastal area and continental shelf of Liberia, West Africa, and their relation to continental drift. *Geological Society of Americ*a Bulletin 81, 1970. pp. 3563–3574.
6. BEHRENDT, J.C. and WOTORSON. C.S. An aeromagnetic and aeroradioactivity survey of Liberia (West Africa). *Geophysics* 36(3), 1971. pp. 590–604.
7. United Nations Development Programme. Beach-sand Heavy-Mineral Occurrences between Monrovia and Marshall. *Technical Report 5.* 1972.
8. United Nations Development Programme. A description of heavy-mineral bearing beach sand occurrences between Monrovia and the Sierra Leone border and between Marshall and Buchanan. *Technical Report* DP/UN/LIR-72–010/1, 1974. 33 pp.
9. W.H. Muller and Company Exploration Liberia, July 1967–July 1971. Final Report for Ministry of Lands and Mines, Liberia. 1971.
10. VAN GRIETHUYSEN, H.V. Mineral exploration of Wm. H. Muller and Company in East Liberia. *Geological Mining and Metallurgical Society of Liberia*. Bulletin 4, 1971. pp. 86–95.
11. HURLEY, P.M., LEO, G.W., WHITE. R.W., and FAIRBURN, H.W. Liberian age providence (about 2,700 m.y.) and adjacent provinces in Liberia and Sierra Leone. *Geological Society of America.* Bulletin 82, 1971. pp. 3483–3490.
12. HURLEY, P.M., LEO, G.W., and WHITE. R.W. Approximate location of the boundary between the Eburnean and Liberian Orogenic province in eastern Liberia. In: Hurley, P.M. (Ed). Variations in isotopic abundances of strontium, calcium and argon and related topics. *Massachusetts Institute of Technology. Seventeenth Annual Progress Report*, Cambridge, Massachusetts, 1969. pp. 131–132.
13. WHITE, R.W. and LEO, G.W. Geological summary of the age provinces in Liberia. *Geological Mining and Metallurgical Society of Liberia.* Bulletin 4, 1971. pp. 96–106.
14. HEDGE, C.E., MARVIN, R.F., and NAESER, C.W. Age provinces in the basement rocks of Liberia. *J. Res. U.S. Geol. Surv*., 3(4), 1975. pp. 425–429.
15. WHITE, R.W. and LEO, G.W. Geological reconnaissance in western Liberia. *Liberian Geological Survey.* Special Paper No. 1, 1969. 18 pp.
16. WHITE, R.W. Stratigraphy of the sedimentary basins on the coast of Liberia. *Liberian Geological Survey* Special Paper 3, 1972. 14 pp.
17. NAIR, A.M. Rare Earth Element distribution in the Monazites of Liberia. *Liberian Geological Survey Report*, Monrovia, Liberia, 1985. 9 pp.
18. Lismore Pty Ltd. Mineral Sand Exploration, Eastern Liberia. Unpubl. internal Lismore report. 1974.
19. HOCKIN, H.W. Mineral composition of Prospecting Samples from Liberia. Research report BR-9055, Columbia-Southern Chemical Corporation. 1957.
20. LEO, G.W. and HOLMES, A.J. Evaluation of chromite content of some heavy-mineral concentrates, Liberia. Memorandum Report No. 22, *Liberian Geol. Surv*., Monrovia. 1969.
21. ROSENBLUM, S. Preliminary spectrographic analyses of Monazite from Western Liberia. *Liberian Geological Survey Report* MR-48. 1969.
22. ROSENBLUM, S. Analyses and economic potential of Monazite in Liberia. *Liberian Geological Survey Report* LI-79. 1973.
23. RAMSEY, P.J. Offshore Heavy Mineral placer deposits of the southeast African shelf. This Volume. 1999. ◆