PAPERS PRESENTED

AN OVERVIEW OF WORLD THORIUM RESOURCES, INCENTIVES FOR FURTHER EXPLORATION AND FORECAST FOR THORIUM REQUIREMENTS IN THE NEAR FUTURE

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Abstract

Thorium occurs in asociation with uranium and rare earth elements in diverse rock types. It occurs as veins of thorite, uranothorite and monazite in granites, syenites and pegmatites. Monazite also occurs in quartz-pebble conglomerates, sandstones and fluviatile and beach placers. Thorium occurs along with REE in bastnaesite, in the carbonatites.

Present knowledge of the thorium resources in the world is poor because of inadequate exploration efforts arising out of insignificant demand. But, with the increased interest shown by several countries in the development of Fast Breeder Reactors using thorium, it is expected that the demand will increase considerably by the turn of the century.

The total known world reserves of Th in RAR category are estimated at about 1.16 million tonnes. About 31% of this (0.36 mt) is known to be available in the beach and inland placers of India. The possibility of finding primary occurrences in the alkaline and other acidic rocks is good, in India. The other countries having sizeable reserves are Brazil, Canada, China, Norway, U.S.S.R., U.S.A., Burma, Indonesia, Malaysia, Thailand, Turkey and Sri Lanka.

Considering that the demand for thorium is likely to increase by the turn of this century, it is necessary that data collected so far, globally, is pooled and analysed to identify areas that hold good promise.

Introduction:

Thorium in association with uranium and Rare Earth Elements (REE) occurs in diverse rock types; as veins of thorite, thorianite, uranothorite and as monazite in granites, syenites, pegmatites and other acidic intrusions. It also occurs as an associated element with REE bearing bastnaesite in carbonatites. Monazite also occurs in quartz-pebble conglomerates, sandstones and in fluviatile and beach placers.

Prior to the second world war thorium was used widely in the manufacture of gas mantles, welding rods, refractories and in magnesium based alloys. Its use as fuel in nuclear energy, in spite of its limited demand as of now and low forecast, is gaining importance because of its transmutation to ^{233}U. Several countries like India, Russia, France and U.K. have shown considerable interest in the development of fast breeder reactors (FBR) and it is expected that by the turn of this century some of the countries would have started commissioning large capacity units.

2. World deposits:

Present knowledge of the Thorium resources is poor because of the relatively low-key exploration efforts arising out of insignificant demand. For the same reason the possibility of discovering new finds in addition to increasing the known resources contained in the deposits already known is good.

The largest known reserves of thorium are contained in the beach and inland placer deposits of monazite, which is exploited so far for its REE content (55-60% REO).

Monazite placers are reported from Australia, Egypt, India, Liberia, Brazil, Malgachi and the United States of America (Florida). In Brazil, monazite occurs associated with ilmenite and zircon along the eastern and southeastern Atlantic coast [1]. It also occurs at Araxa in association with carbonatites. In Burma, placer deposits derived from the weathering of biotite granites occur in the southern Shan states. Considerable quantities of cassiterite and wolframite occurring in these placers are derived by the weathering of quartz veins and pegmatite dykes injected into the granites.

Malaysian deposits occur on the coast of Kedan and Perlis at Pulan Lankawi and Seremban. Monazite associated with columbite and xenotime occurs in Ulusempam area near Pahang. Cassiterite placers at Trengganu contain as much as 58% monazite. The occurrences of monazite in Thailand and Indonesia are similar to the occurrences in Burma [2; 3].

In Sri Lanka rich deposits derived by the weathering of schists, granulites and gneisses occur along the N and NW coast. Alluvial deposits also occur in the lower valley of Kaleganga in Ratnapura district. The largest placer deposit (12,000 t) near Pulmoddai extending over a distance of 3 km. and a width of 50 m. contains 3 million t of sand at 0.4% monazite, 18% rutile and 62% ilmenite [3].

In Bangladesh monazite is also reported to occur in the beach placers (derived from granites) near Chittagong. Similar deposits are also reported to occur in Southern China, between Chianhua Hsien in South Western Hunan province to Kung Chen Hsien in northeastern Kwangsi province. Extensive deposits are also reported from Kwangtung province.

In Canada, large Thorium reserves associated with Uranium (with Th:U ranging from 3.5 to 1 to 0.5:1) occur in Elliot Lake area and other Huronian complexes. Thorium is also reported from the granitic and syenitic rocks in the Bancroft area of Ontario. Many occurrences of this type are reported from the Grenville geological province, the Charlebois Lake and the La Ronge areas in Saskatchawan. It also occurs at Oka in association with uranium and niobium in the carbonatites in Qubec [4]. In Turkey, the Eskisehir-Sivrihisar area is estimated to contain 880 thousand t of Thorium.

In USA about 80% of the known Th reserves occur in vein type thorite deposits in the Lemhi Pass area of Idaho and Montana and in the Western mountains of Central Colarado. Large reserves of Th are also known to occur associated with bastnaesite in the massive carbonatite deposits of California [4]. The Florida beach placers wherefrom monazite could be recovered along with ilmenite are estimated to contain 0.3% to 1% monazite [4].

The details of world reserves and production are given in Table I and Figure 1.

TABLE I

WORLD THORIUM RESERVES AND PRODUCTION
(Based on USBM Mineral Industry Survey, May 16, 1985)

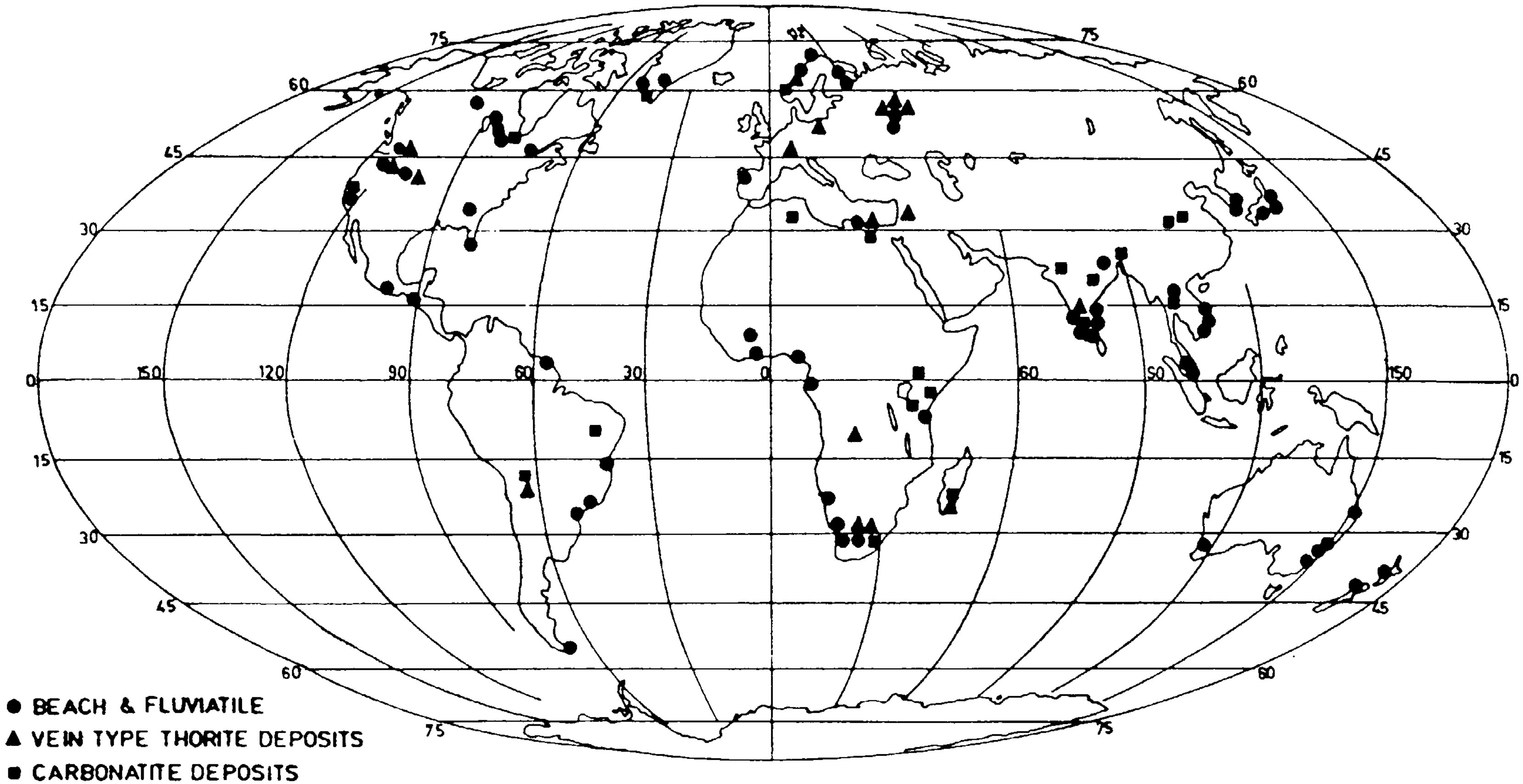
In thousands of tonnes

	Name of the country	Reserve Base RAR	Production
1.	United States of America	200 + 520*	17.03
2.	Australia	40	8.0
3.	Brazil	70	1.1
4.	Canada	240	--
5.	India	360	4.0
6.	Malaysia	10	0.2
7.	Norway	150	--
8.	OMEC	55	0.2
9.	OPEC	35	1.5
10.	China	@380*	6
11.	U.S.S.R.	@120	n.a.
	Total	1,160	37.5

* Bastnaesite

n.a. - not available

@ excluded.



THORIUM DEPOSITS IN THE WORLD

FIG. 1.

3. Thorium occurrences in India:

Although many occurrences of uranothorite, thorite, thorianite and monazite are reported from in several intrusive pegmatites and younger granites of all ages, monazite occurring in the beach and inland placers remains the main thorium and REE bearing mineral source assessed by AMD (Fig. 2).

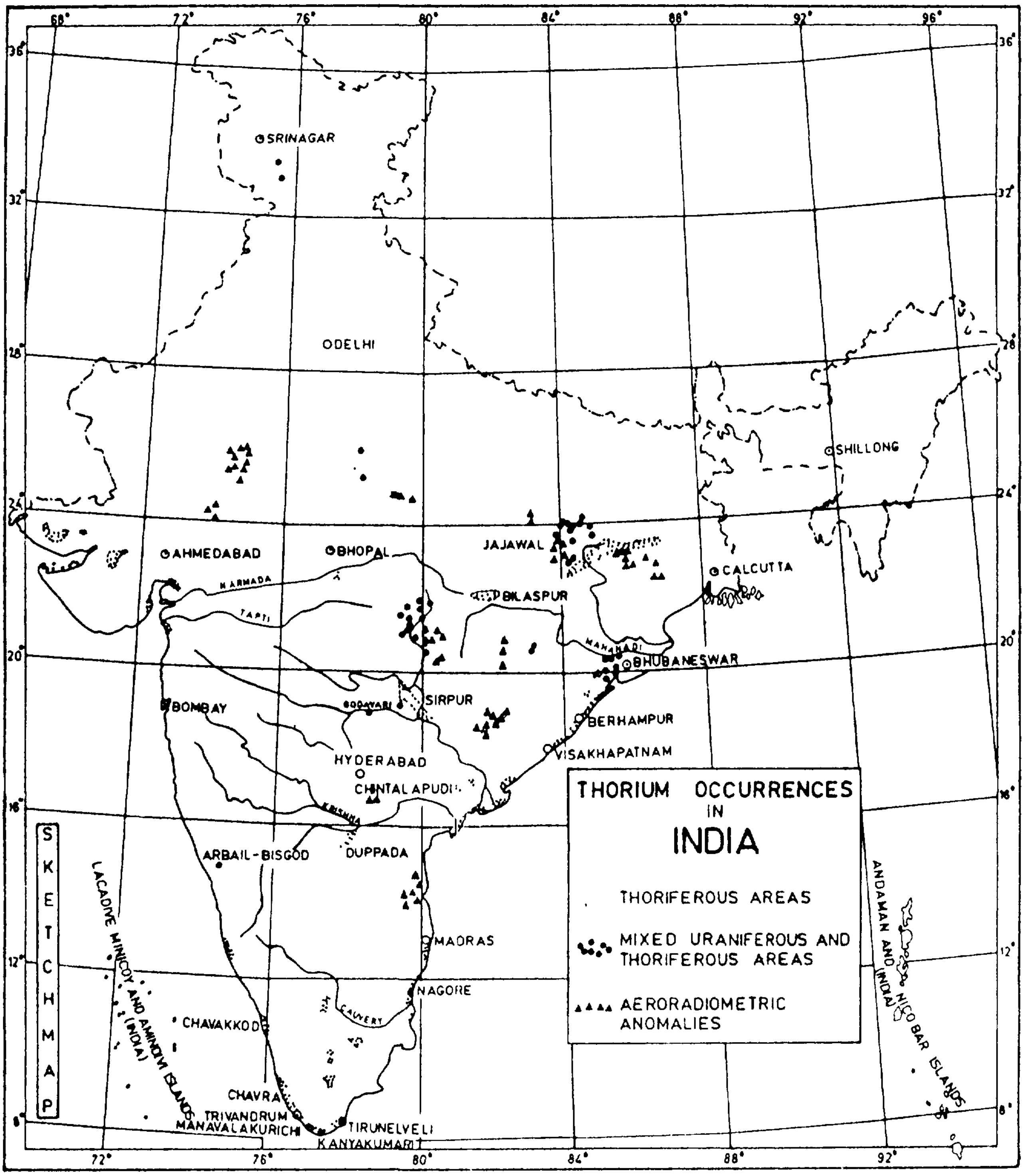


FIG. 2.

The occurrence of monazite in the placers (assessed so far at 4.5×10^6 t) may be divided into 4 types: (i) the Beach and Dune sands on the West and East coasts (42%); (ii) the Teris (16%); (iii) the sea bed (10.0%) and (iv) inland placers (32%).

3.1 Beach sands:

Although monazite occurs associated with ilmenite and other hm in the beach sands, skirting the entire Peninsular India, its economic concentration is confined to only some areas where suitable plhysiographic conditions exist. The west coast placers are essentially beach or barrier deposits with development of dunes where aeolin action is prominent in dry months. On the other hand, the east coast deposits consist of extensive dunes fringing the coast.

3.1.1. West coast

Of the several west coast deposits assessed so far the deposits at Chavara and Manvalkurchi in Kerala and Tamil Nadu respectively, are rich in hm content [5]. The other deposits occurring north of Chavara, stretching over a distance of 50 km. upto Ratnagiri are leaner with a hm content of $\approx$ 20% of which monazite forms 0.06% [6].

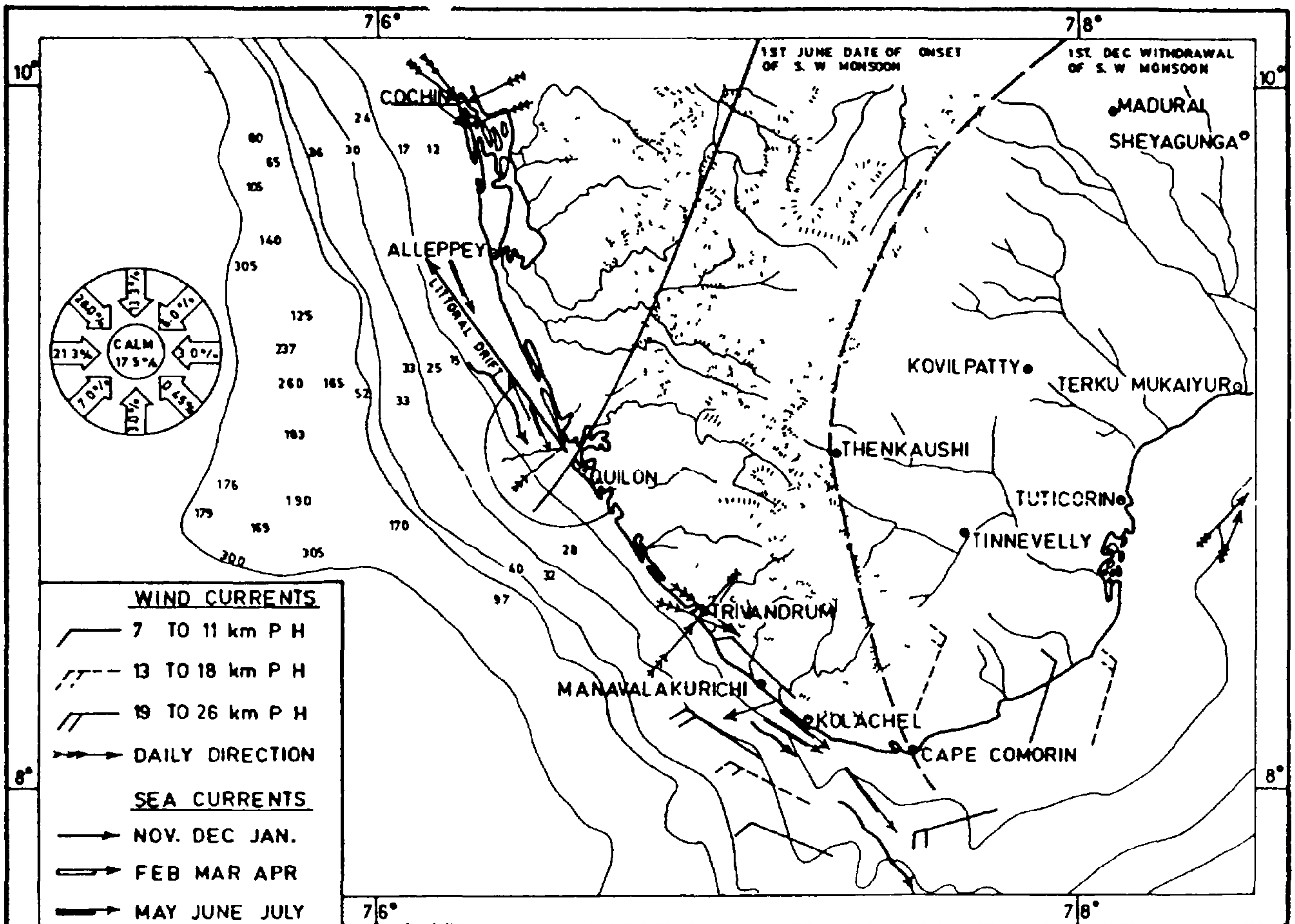
3.1.2 Origin of West Coast deposits:

Physiographically the peninsular India on the west coast may be divided into three divisions: (i) the 25-40 km. wide western ghats which rise steeply to an average height of 1200 m. above m.s.l. along a conspicuously straight fault (ii) the 20-30 km. wide narrow coastal strip (30 m. high) to the west, drained by 41 fast west flowing rivers and (iii) the narrow (45 km. wide) continental shelf with an average depth of 29 fathoms.

The western ghats receive about 3000 mm. of rainfall annually. All west flowing rivers are small and descend into the narrow coastal belt to finally empty into irregular, labile net work of estuaries and lagoons. The beaches along the coast are about 3 to 4 m. high.

Geologically, the western uplands consist of ortho and para gneisses of Precambrian age, charnockites of felsic to ultramafic composition and leptynites, intruded by swarms of pegmatites. Overlying these Precambrian rocks are the Tertiary Quilon-Warkala beds consisting of laterites, semi-consolidated sandstones and clays with lenses of lignite. They vary in thickness and dip 3° seaward. Overlying these beds asre the recent unconsolidated alluvial clays and estuarine sands.

A series of uplifts of western ghats shifted the strand line seaward resulting in the formation of bars, spits and lagoons [7]. The hm deposits are formed in four successive stages: (i) lateritisation of gneissic complexes, (ii) successive mountain uplift and simultaneous seaward shift of strand line., (iii) reworking of the beach sands by sea waves, which rise often to a height of 3 m. in 12 s. period and (iv) littoral drift caused by the breaking of the waves far away from the shore and consequent northerly movement of lighter minerals along the reflected waves. The

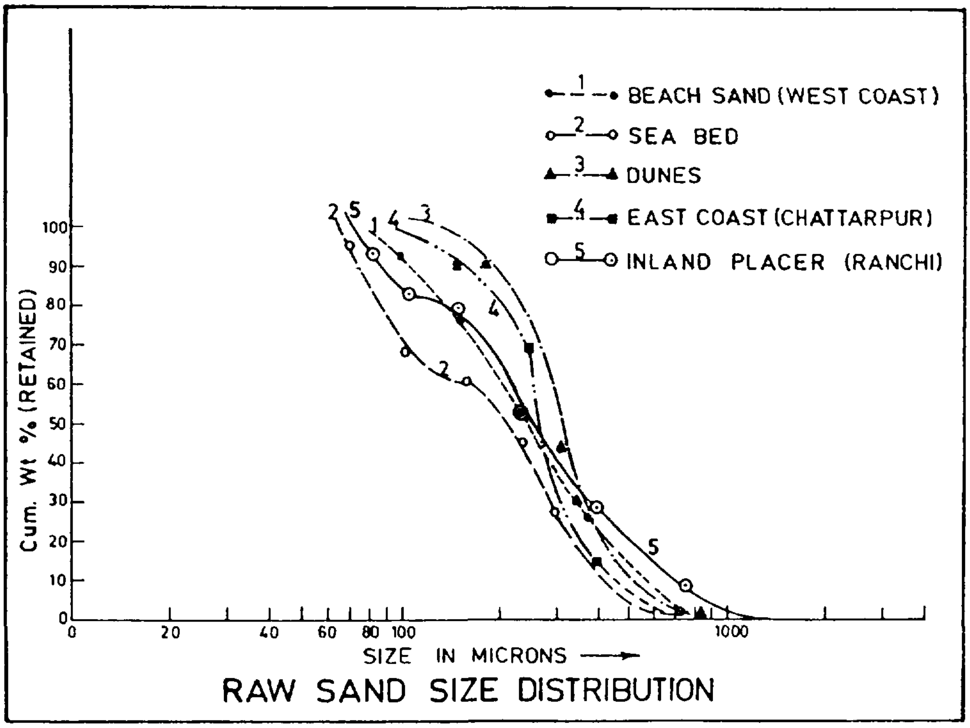


BATHY-METRIC CHART OF WEST COAST

FIG. 3.

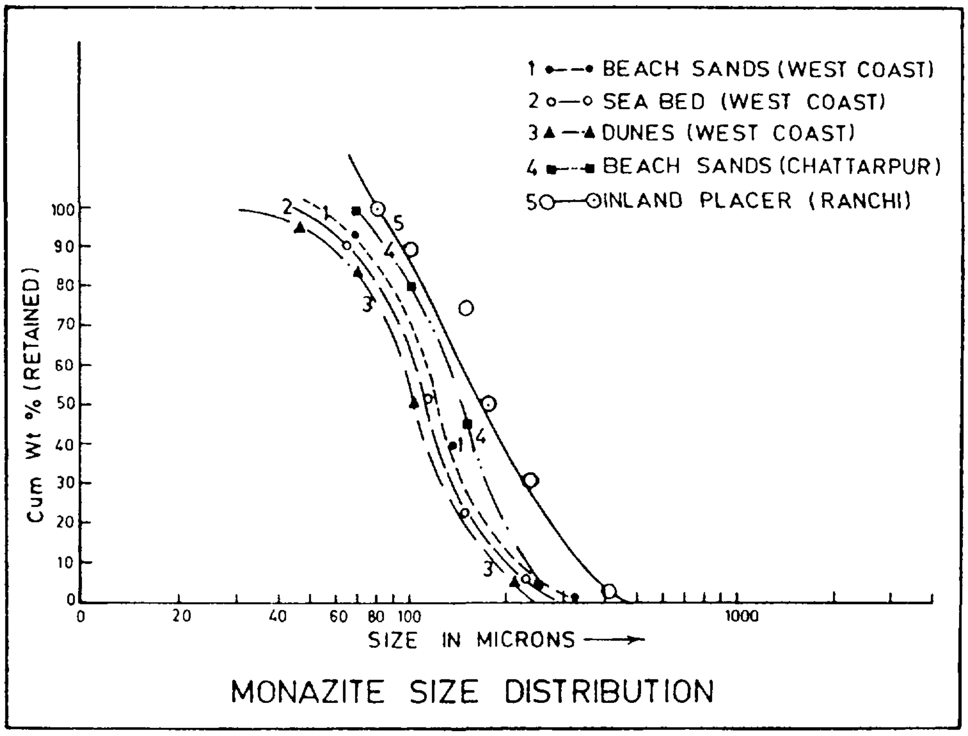
wind and wave action causes erosion of Warkala beds during high wave period and suppliments the littoral drift (Fig.3) [8]. The barrier formed works like a riffle on the wilfley table and deposits the hm on the beach. The light minerals are carried forward [9]. The similarity in the size (Fig.4 and 5) and sphericity (($\psi \sim 0\ 8$) of the hm from the beach and sea bed ($\bar{D}_{80} = 100\mu$) indicates that there is very little fresh accretion to the sea bed. There is only an annual making and remaking of the coast line when the hm are enriched on the seaward side of the bar by a factor of > 9 [10]. The beach sands of Chavara bar (Kerala) contain (73% hm), 60-70% ilmenite (61% TiO_2). 4-7% garnet, 0.5% to 1% monazite (9.0% ThO_2), 5-8% zircon and 1.15% sillimanite.

In Manavalakurchi, Tamil Nadu, the deposit is formed by the "southerly tilt of the tip of the peninsula [9] aided by seasonal variation of sea currents, both in direction and magnitude [10]. It contains 64% hm with 45-50% ilmenite (with 54% TiO_2), 2-3% rutile, 3-4% monazite (9-10% ThO_2), 4-6% zircon and 56% garnet [12]. The higher percentage of monazite and garnet in this area is attributable to the high density of intrusion of the pegmatites and leptynites in the hinterland and its location on the sea side of the embayment of eroded laterite [13].



1 BEACH SAND (WEST COAST)
2 SEA BED
3 DUNES
4 EAST COAST (CHATTARPUR)
5 INLAND PLACER (RANCHI)
Cum. Wt % (RETAINED)
SIZE IN MICRONS
RAW SAND SIZE DISTRIBUTION

FIG. 4.



1 BEACH SANDS (WEST COAST)
2 SEA BED (WEST COAST)
3 DUNES (WEST COAST)
4 BEACH SANDS (CHATTARPUR)
5 INLAND PLACER (RANCHI)
Cum Wt % (RETAINED)
SIZE IN MICRONS
MONAZITE SIZE DISTRIBUTION

FIG. 5.

3.1.3 Dunes:

The dunes near Manavalakurchi situated at the mouth of Valliyar river are formed by aeolin action on the beaches during the dry season. They contain 50% hm of which 35% is ilmenite (55% TiO_2), 1.35% rutile, and 3.3% monazite (9-10% ThO_2) [14].

3.1.4 Sea bed off the Neendakarai-Kayankulam bar:

Investigations conducted about 600 m. off the Neendakarai-Kayankulam bar over a length of 22 km shows that the sea bed contain 5% hm of which 0.05% is monazite (9.5% ThO_2) [15].

3.1.5 The Teris:

The 'teris' are dunes formed by aeolin action in the arid, rain shadow plains east of western ghats. Typically, these dunes analyse upto 10% hm of which 3-4% is ilmenite and 0.06% to 0.35% is monazite [15].

3.1.6 The East Coast deposits:

The east coast beach placers and dunes are low grade with 8-20% hm. Their formation is influenced by the northerly long shore currents and the consequent annual littoral drift of about 2 million t of sand containing 4-5% hm. The sediments from eastern ghats, which consist of charnockites, khondalites and alkali rocks, are carried by east flowing rivers and deposited to form deltas and shallow beaches. During the low tide the beaches from the surf zone are exposed to strong, incessant wind action during summer months and cause accretion and landward migration. Of the several occurrence studied the Chatrapur deposit (Orissa) with about 20% hm and 0.5% monazite is important

The origin of these dunes may be traced to the initial building up of off-shore bars/spits resulting in the formation of frontal dunes and lagoons. Subsequently, the lagoons are filled by the deposition of fresh burden from local streams and spill over sand from frontal dunes and also the littoral drift. This results in the formation of low undulating inter dunes sandy area and finally the rear landward dunes wherever land barriers exist [17].

In addition to the Chatrapur occurrences several exploitable deposits (25-30% hm; 0.2% monazite) occur along the east coast, in Andhra Pradesh and Tamil Nadu.

4. Inland placers:

Significant occurrences of monazite-bearing inland placer deposits are located in the Ranchi plateau. The bed rocks in the region comprise of Archean metasediments profusely injected by aplo-pegmatites and finally by a porphyritic granite (18). The bed rock is covered by a 11/2 m thick mantle of coarse, yellow alluvium with thin discontinuous dark bands which contain 2-10% hm of which 0.45% to 1.0% is monazite.

5. Primary sources:

In addition to the placer deposits described above several primary occurrences of Th are noted at many places.

Of these, possible economic concentrations that might merit economic consideration in future are: (i) Proterozoic quartz-pebble conglomerates overlying the Archean basements., (ii) Jurassic sandstones of Kutch in Gujrat and the Gondwana sandstones in M.P., (iii) The igneous rocks of Dhabi, Jajawal (M.P.), Palamau (Bihar) along a 150 km long shear zone, (iv) The pegmatites of Salem District (Tamil Nadu) intruding biotite schists and (v) The alkali syenites and carbonatites of Sevattur, Pakkanadu (Tamil Nadu), Sung Valley (Meghalaya), Khammam & Visakhapatnam (A.P.), Kishengarh (Rajasthan) and several other occurrences.

6. Reserves:

The current knowledge of thorium reserves in the world is small. In Brazil, several monazite placers occur on the Atlantic coast. In addition large reserves (87%) are associated with bastnaesite in Araxa carbonatites. In Canada 240 x 10^3 t of thorium resources are identified so far, bulk of which are associated with uranium (Th:U 3.5:1/0.5:1) in the quartz-pebble conglomerates of Elliot lake. In South Africa, of 12500 t of Th identified, about 77.5% is estimated to occur in the carbonatites, 11.2% in the sandstones of Karoo supergroup, and only 5% in the quartz-pebble conglomerates and the rest as veins in Archean complex.

China and USA have a large reserve base because of the association of Th (0.5% to 1% ThO_2) with REO in its bastnaesite deposits associated with carbonatites. The Chinese reserve associated with the bastnaesite in the carbonatites of Inner Mangolia are estimated at 380,000 t of Th [19].

According to USBM Industrial survey (1985), [20] the US reserves of thorium are estimated at about 200,000 t of which, about 70% occurs in vein type thorite deposits. The reminder are in the carbonatite deposits in California. Small amount of monazite (0.35%) are also recovered alongwith ilmenite, from the beaches of Florida.

The reserve base of other countries like Sri Lanka, Malaysia, Norway etc. are small and forms only 20% of the world total.

In India thorium reserves are estimated at 0.36 x 10^5 t of Th forming $\approx$ 30% of the known world resources [21]. The details of Indian reserves are given in Table-II.

7. Process flowsheet:

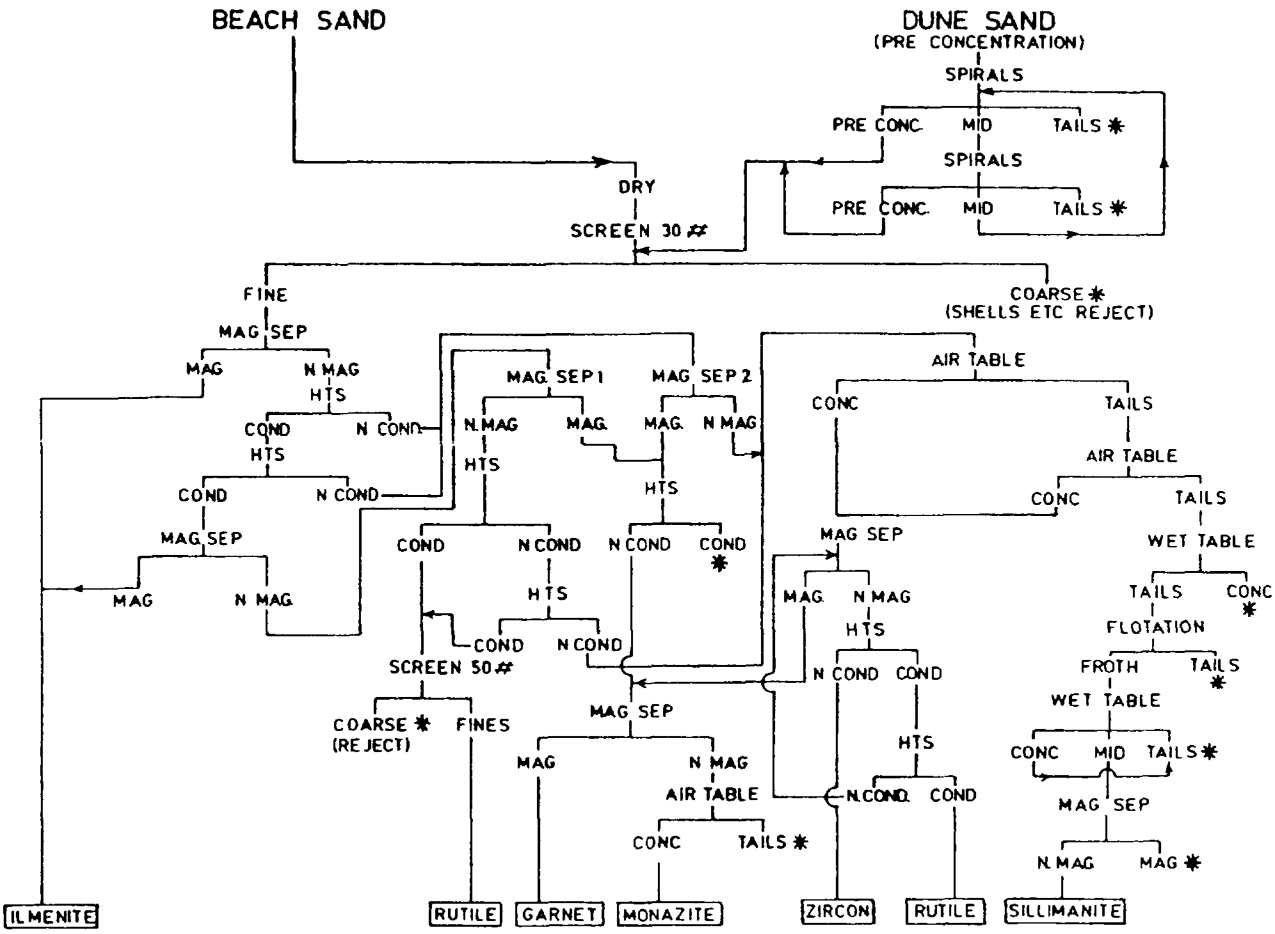
A generalised industrial process flowsheet for the separation of individual minerals is given in Figure 6. It comprises of five unit operations: (i) sizing, (ii) magnetic separation of varying intensity, (iii) high tension separation (HT), (iv) air/wet tabling and (v) flotation.

TABLE II

RESERVES OF MONAZITE

In million tonnes

	Nature	RAR		EAR I	
		Monazite	ThO_2	Monazite	ThO_2
1.	Beach sands and dunes	1.60	0.144	0.29	0.026
2.	Teris	0.73	0.066	--	--
3.	Sea bed off coast	--	--	0.43	0.038
4.	Inland placers	--	--	1.44	0.130
	Total	2.33	0.210	2.16	0.194



GENERALISED FLOW SHEET WEST COAST BEACH SAND

FIG. 6.

The raw sand is trucked to the plant where it is dried and sized using 35 mesh screen. The oversize is rejected and the undersize is treated in HT separators. The conducting minerals are subjected to magnetic separation (light intensity) to yield a crop of ilmenite in the magnetics and rutile in the non-magnetics. The non-conducting minerals are subjected to a successive stages of light and high intensity magnetic separation to yield monazite in the magnetics which is cleansed by using air/wet tabling and/or flotation to the required grade. The non-magnetics of high intensity magnetic separation are cleaned on an air table to yield a concentrate of zircon and lights (tails) of silliminite. Silliminite is further cleaned using fatty acid flotation to obtain a marketable grade crop. Though ideally ilmenite and rutile must report as conducting magnetics and non-magnetics, several minerals, particularly garnet reports in these concentrates. Therefore, several steps of cleaning and scavenging are undertaken to yield and required grade of monomineralic concentrates and increase the recovery of individual minerals.

In case of low grade Dunes and east coast placer deposits, tests using several alternative equipment such as Tables, Trays, Cones and Spirals indicated that spirals are most satisfactory since they offer flexibility and also yield a rejectable tailing analysing 2.9% hm and a concentrate (75% hm at 90% recovery), which could be fed to the dry mill.

8. Discussion:

The reasonably assured resources of thorium in India, form about 31% of the world's estimated deposits. The reserves could have been several times more if systematic surveys are carried out for thorium in the geologically promising terrains such as we have in the acid intrusive belt of Salem in Tamil Nadu, the hinterland of Kerala and the alkali syenitic and carbonatite rocks of Tamil Nadu, Andhra Pradesh, Rajasthan, Madhya Pradesh, Bihar and Meghalaya.

Taking an overview, while intensive and extensive exploration identified 2×10^6 t of U in RAR category, the known thorium reserves, assessed so far in the same category indicate 1.2×10^6 t even when the inputs for locating thorium reserves are incidental to prospecting for hm like ilmenite and/or uranium. Therefore, globally speaking the possibility of increasing the Th reserves is high.

Long term projections of IAEA for the nuclear power growth for the period 2025 indicates an inadequate supply [22] of uranium even when a lower growth rate for nuclear energy (using LMFBR) and the planned growth of uranium production are considered. The gap will increase considerably, if the demand for nuclear energy increases and more reactors are commissioned.

While it is true that large stocks of available depleted U can be utilised, countries that have limited identified resources of U, may have to use Th to ensure continuous growth rate in their quest for power.

Thus, in the long term, it is necessary that the data collected globally is pooled, and prospective areas are identified for funding of surveys that might be considered rewarding.

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