DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2011/115

Offshore heavy mineral deposits Southwestern Sri Lanka

Christian Knudsen

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF CLIMATE AND ENERGY

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GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
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Summary

Off the coast of south-western Sri Lanka heavy mineral rich sediments are located and sampled. The Geological Survey of Canada conducted a geophysical survey in 1997, and mapped a number of potential offshore heavy mineral sand deposits/bodies ranging in size from 2 to 120 mill m^3.

The main part of the sandy deposits are pre-Holocene events where sand has been deposited during the fluctuating sea-level with both coastal sand and channel fill sediments deposited during a lowstand event. These sands are overlain by Holocene post transgression sediments.

11 samples collected by the Geological Survey of Canada during this survey have been analyzed by GEUS using CCSEM. These samples were collected using a van Veen grab sampler and are only represent the surficial deposits.

In the channels close to the shore, the sediments mainly consist of very fine-grained sand with heavy minerals in the fine sand to coarse silt fraction. In the offshore basins, the grain-size is coarser with heavy minerals in the fine- to medium-grained sand fraction.

The heavy mineral assemblage in all the analyzed samples is mature and the assemblage as well as the garnet types, resemble what is found onshore in the Kalu River and the beach where the river meet the ocean.

The titanium minerals in the offshore samples have slightly lower Ti contents as compared to the onshore equivalents, with an average of 56,7 % TiO_2 in combined ilmenite + leucoxene + rutile whereas the onshore (beach) samples in the same area has 58,8 % TiO_2.

If the samples collected are representative of the total resource in place, the grain-size of the near shore deposit Chanel 1 would be too fine (d_{50} is ca 50 µ). Unfortunate because this is the place where the content of valuable heavy minerals is high (avg. 3.8 %). The concentration of valuable heavy minerals ranges from 0.3 % to 11.6 %. A weighted average of the sands gives 1.9 % excluding offshore basin 3 and Chanel 4.

To get a better and more realistic impression of the heavy mineral resource in these offshore channels and basins, it would be necessary to collect drill core e.g. using gravity core equipment.

Introduction

Objectives

Offshore heavy mineral deposits of Sri Lanka are described in the literature, but no information concerning the mineralogy, mineral chemistry and grain-size of the deposits is available. Samples were obtained from the Geological Survey of Canada, and the aim of this report is to summarize the results of CCESM analysis of 11 samples representing the different offshore environments.

Background

Heavy mineral placer deposits have been exploited from beaches along the northeast and southwest coasts of Sri Lanka since the early 1900's, and a review of the quality of the onshore heavy mineral deposits incl. the recent work by GEUS for DuPont is given in Keulen and McLimans (2010).

The heavy minerals are not only located onshore but can also be found offshore as can be seen on Figure 1.

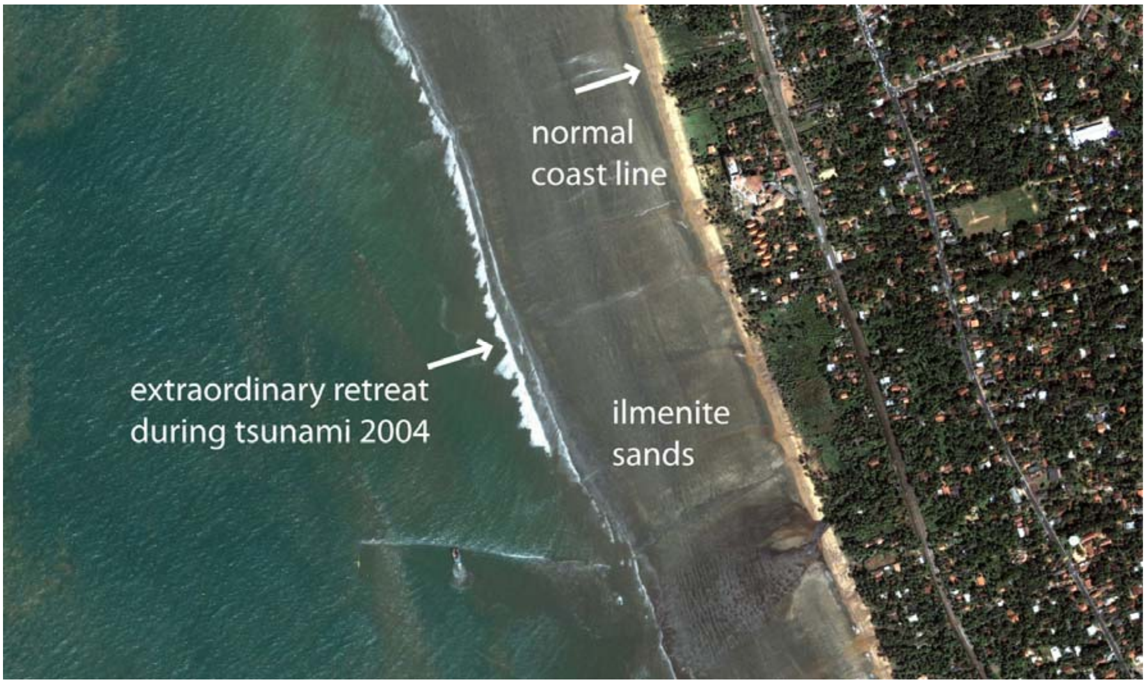


Figure 1 Kalutara beach at 26 December 2004. The heavy mineral rich sands on the shoreface are seen below the ordinary tide level revealed by the extraordinary retreat of the sea during the tsunami.

The processes that form the heavy mineral beach placers on the Sri Lankan coast are not completely understood. Coates (1935) and Searle (1962) suggested that heavy minerals were derived from the erosion of gneissic crystalline rocks of the hinterland and subsequently sorted and concentrated on the beach by waves and others (cited in Sonnichsen et al. 2000) argue that the continental shelf contains a reservoir of heavy minerals, which, during monsoon periods, is transported onto the shore.

Previous work

Meyer (1983) looked for offshore deposits of heavy minerals around Pulmoddai and found accumulations in a narrow strip of several hundred m width down to 10 m water depth.

A reconnaissance grab sampling program indicated the presence of shallow marine placer deposits just off Beruwala South-western Sri Lanka (Wickremeratne, 1986). The analysed samples contained 4 to 13 % heavy minerals in the offshore sands. The 29 samples tabulated in the report yield an average of 8.6 % heavy minerals and 5,8 % ilmenite, 0,3 % rutile and 0,6 % zircon in the raw sand. The grain-size in the offshore sediments was finer compared to the onshore placers and monazite was found to be enriched in fine sand and coarse silt.

Geological Survey of Canada 1997 campaign

In 1997 a marine geophysical survey was conducted in the same area of the south-western continental shelf off Sri Lanka (Sonnichsen et al. 2000) aiming at determining if sufficient volumes of recoverable heavy minerals rich sediment existed in water depths less than approximately 50 m.

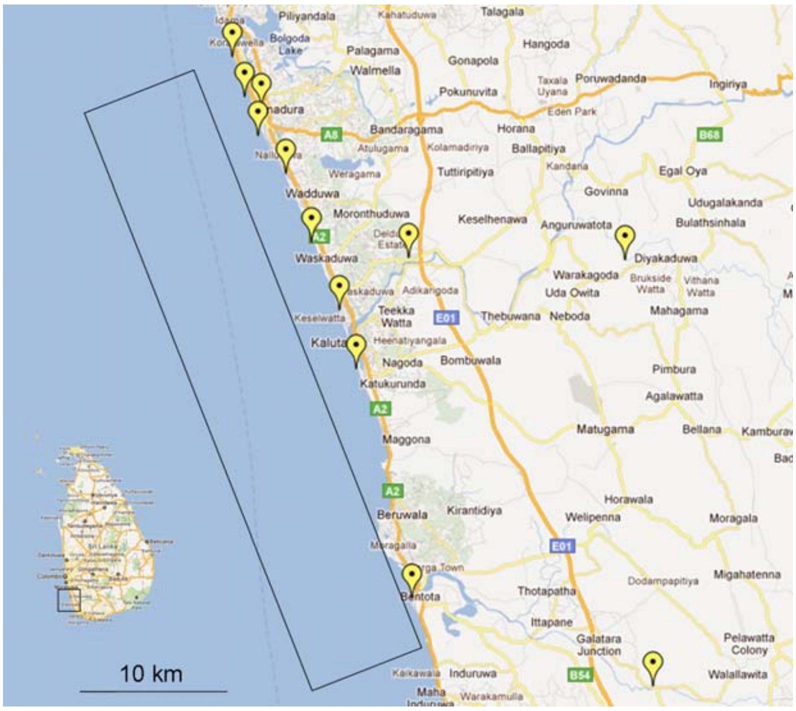


Figure 2

Location of the geophysical survey area of Sonnichsen et al. (2000) and samples analysed by GEUS previously (Keulen & McLimans, 2010).

They did not analyse the content, mineralogy nor the mineral chemistry of heavy minerals which accordingly is the purpose of this work.

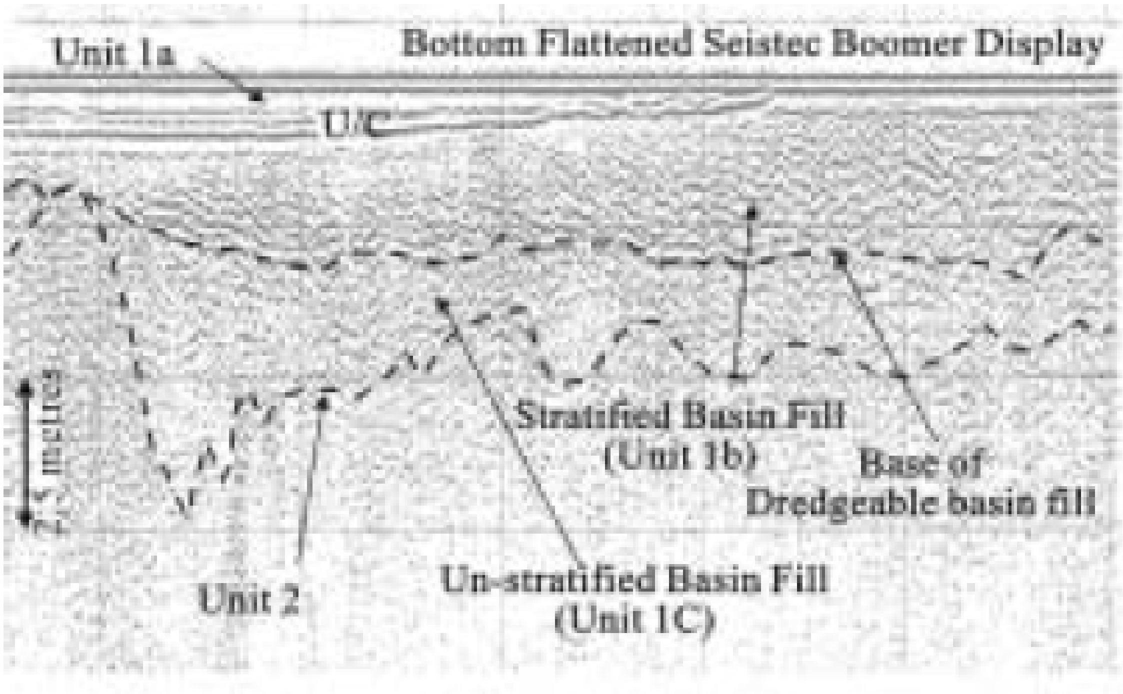


Figure 3 Seismic profile from Sonnicsen et al (2000). A thin Holocene unit (1a) consisting of marine silt and clay overlies stratified (Unit 1b, 7 to 8 m thick here) and less stratified reworked Pre-Holocene low-stand sediments (Unit 1c). These units rest on bedrock (Unit 2). Vertical bar to the left is 5 metres.

Seismic Unit 1a is 0 to 2 m thick, weakly stratified to unstratified unit with smooth surface relief (Figure 3). Unit 1a is the most widespread and uppermost seismic unit and probably represents Holocene post transgression sediments and the unit typically un-conformably overlies Seismic Units 1b and 1c.

Seismic Unit 1b has complex stratified channel-fill sediment reflectors up to 7 or 8 m thick (Figure 3) and is confined to basal portions of channels incised into the bedrock. It is interpreted to be a product of numerous cut and fill episodes.

Seismic Unit 1c is a generally massive unit, highly variable in character from region to region overlying highly irregular bedrock topography.

Seismic Units 1b and 1c are typically confined to basal portions of the identified basins and within the many paleo-channels throughout the survey region. They likely are pre-Holocene sediments deposited and modified under the effects of a fluctuating sea level. The stratified channel infill (Seismic Unit 1b) is most likely associated with layered fluvial sediments deposited at a lower stand of sea level in the Pleistocene. Seismic Unit 1 a, b and c are considered potential resources recoverable using dredge whereas Seismic Unit 2 represents indurated bedrock.

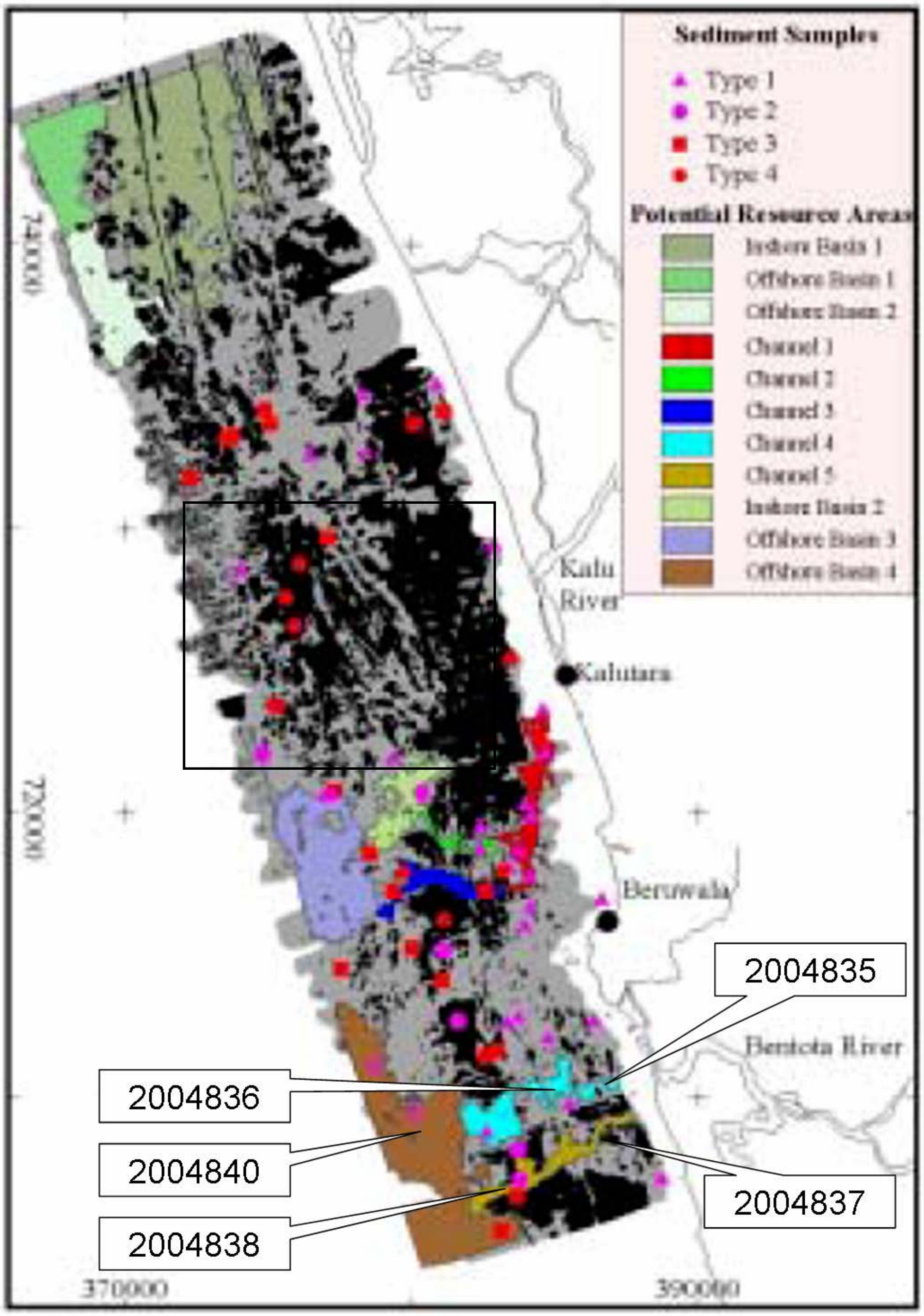


Figure 4

Surficial map of the survey area (from Sonnichsen et al. 2000).

Location of Figure 5 is indicated by square.

The grey areas consists of unconsolidated sediments whereas the black areas are indurated. The potential ressource areas are indicated with colours. The N-S trending lines are likely to be coast parallel dykes intruded into the Pre-Holocene unconsolidated sediments. The numbers are CCSEM analytical data in this report.

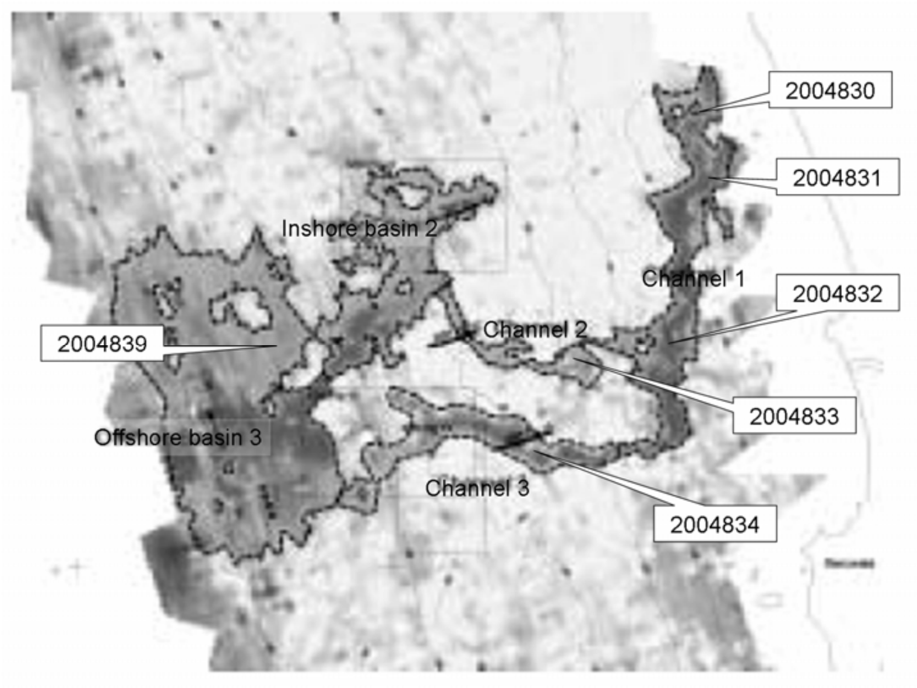


Figure 5

Grey-scale representation of the sediment isopach (Sonnichsen et al. 2000). The Channels are interpreted as submerged extensions of the Kalu River system with up to ca 10 m thick finely bedded

Table 1 Ressource volumes

	Km2	Mill m3	Mill Ton
Chanel 1	3,6	18,5	37,1
Chanel 2	0,7	1,6	3,2
Chanel 3	2,1	7,3	14,5
Chanel 4	3,9	18,1	36,1
Chanel 5	2,9	9,3	18,7
Inshore basin 1	27,4	117,6	235,2
Inshore basin 2	3,3	11,8	23,5
Offshore basin 1	7,0	53,3	106,7
Offshore basin 2	6,4	35,9	71,8
Offshore basin 3	11,1	49,9	99,8
Offshore basin 4	18,5	125,9	251,8
Total		449,2	898,4

Sediment volumes estimated by GSC (Sonnichsen et al. 2000). The tonnages are derived assuming sediment density of 2 ton per m^3.

The different ressource areas are shown on Figure 4 and 5.

On shore mineralogy and mineral chemistry

Keulen & McLimans (2010) state that the mineralogy of heavy minerals located on the beaches reflect the geology in the hinterland. So far a similar link between the composition of the onshore and off-shore heavy mineral assemblages has not been established.

The beach onshore equivalent to the investigated offshore area is marked as blue coast on Figure 6 & 7. This area is characterised by a mature heavy mineral paragenesis with a high proportion of stabile heavy minerals such as sillimanite/kyanite (Figure 6). The area is further characterised by variable TiO_2 in ilmenite and leucoxene (Figure 7), where it can be seen that areas with a very high proportion of very stabile heavy minerals such as ilmenite, leucoxene and zircon (marked by dashed lines on Figures 6) also have high TiO_2 in ilmenite and leucoxene (Figures 7). This relationship is probably caused by these samples being more altered. A similar relationship between very high content of the most stabile heavy minerals and high TiO_2 in ilmenite and leucoxene is also seen in the North-eastern part of Sri Lanka.

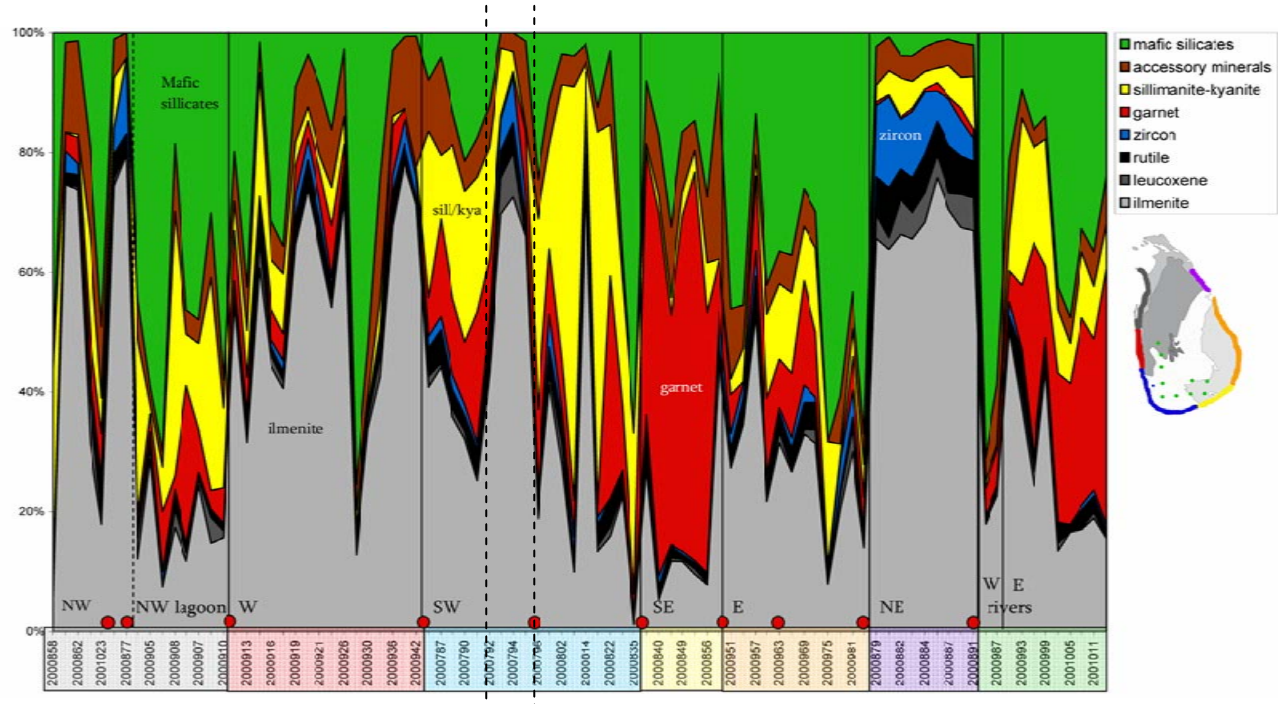


Figure 6: Mineral composition beach samples. From Keulen & McLimans (2010)

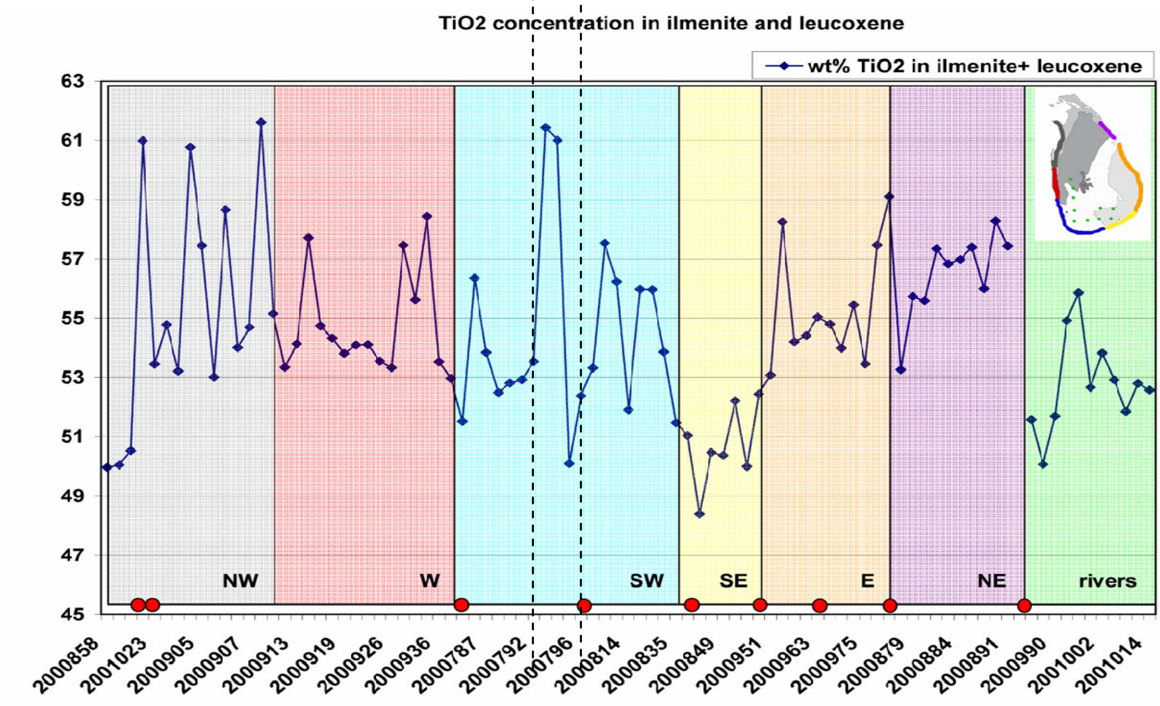


Figure 7 TiO_2 in ilmenite and leucoxene. From Keulen & McLimans (2010)

Analysis of the 1997 GSC samples

The samples analysed are surface sediments taken with Van Veen grab sampler. Accordingly, the samples do not represent the total volume of sand mapped out in the 1997 survey but only the surface sediments.

Table 2 **Heavy mineral content, grain-size and ilmenite composition in offshore sediment samples (CCSEM)**

CCSEM No	Location	Orig. No	% HM in raw sand	Ilmenite d50 (µ)	Ilm + Leuc. % TiO2	Ilm + Leuc+ Rutile % TiO2	Ilm + Leuc. % P2O5	% VHM of HM
2004830	Chanel 1	52-1	7,13	44	54,0	57,9	0,012	50,6
2004831	Chanel 1	55-1	3,91	45	52,8	56,1	0,020	52,5
2004832	Chanel 1	63B-1	11,61	46	54,0	58,4	0,020	49,0
2004833	Chanel 2	60-1	2,58	68	52,0	56,9	0,011	56,5
2004834	Chanel 3	D60-1	2,33	120	51,6	54,7	0,013	62,0
2004835	Chanel 4	1	1,61	44	55,3	64,6	0,013	52,1
2004836	Chanel 4	2	0,7	49	56,4	59,4	0,010	24,0
2004837	Chanel 5	79-1	1,66	54	54,6	56,7	0,012	31,8
2004838	Chanel 5	79-3	6,2	135	49,9	52,6	0,012	57,0
2004839	Offshore Basin 3	53-2	3,37	170	50,0	52,7	0,029	47,6
2004840	Offshore Basin 4	72-4	2,26	115	52,4	54,0	0,005	39,8
2004841	Offshore Basin 4	76-4	0,66	90	53,6	56,7	0,007	53,9
Mean offshore	11 samples		3,7	78	53,1	56,7	0,014	48,1
Mean onshore	9 samples				55,9	58,8	0,061	

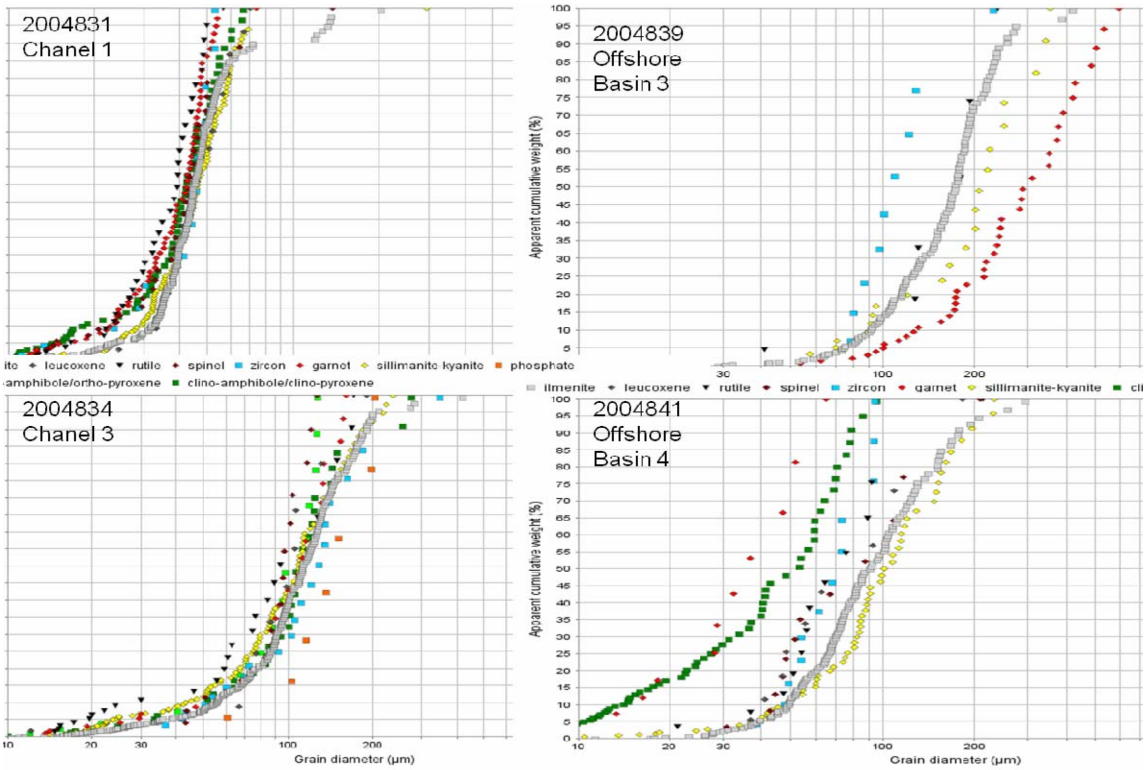
Grain-size

The samples vary considerably in grain-size, with the sand in the Chanel 1 area being the finest grained. The ilmenite in this area is coarse silt with a d50 (median grain-size) of ca. 45 µ. (Table 2). The grain-size distribution curves are steep in the Chanel 1 area and the grain-size distribution curves are close together and parallel (Figure 8). The heaviest heavy minerals (HM) such as rutile has the finest grain-sizes, which is to be expected from their hydrodynamic properties.

In Chanel 3 the grain-size is coarser and less steep (less well sorted). The rutile is finer grained than ilmenite, but the zircon is slightly coarser which not the usual pattern where zircon normally is finer grained than ilmenite. The kyanite/sillimanite curve is slightly more flat and hence not parallel to ilmenite, and the kyanite/sillimanite is finer grained than the ilmenite which is surprising as the grain density is considerably lower (3.6 – 3.6 g/cm^3) than ilmenite (ca. 4.7 g/cm^3).

In the Offshore basin 3, the relationship between the grain-size distribution curves are “normal” in the sense that zircon (blue) is finer than ilmenite (grey) in the middle and Ky/Sill (yellow) the coarser. The grain-size is generally large in this sample and the grain-size distribution patterns are very far apart in contrast to Chanel 1 area (Figure 8).

In Offshore Basin 4 the grain-size distribution curves are less steep as compared to both Chanel 3 and Offshore basin 3 (Figure 8) and the light heavy minerals such as garnet and amphiboles are surprisingly fine-grained. The latter is probably because these minerals are being broken down by physical and chemical processes.



Figur 8 Grain-size distributions in offshore sediments.

Titanium minerals composition

<u>Table 3</u> Ilmenite compositions

CCSEM	SiO2	Al2O3	TiO2	Fe2O3	Cr2O3	MnO	MgO	CaO	Na2O	K2O	ZrO2	Nb2O5	Y2O3	Ce2O3	Partic.
2004830	1,8	1,3	52,3	41,8	0,09	0,5	1,2	0,11	0,01	0,05	0,06	0,25	0,01	0,07	212
2004831	1,2	1,0	51,2	44,0	0,08	0,5	1,1	0,17	0,02	0,04	0,05	0,22	0,01	0,04	245
2004832	1,9	1,4	51,5	41,7	0,11	0,5	1,2	0,28	0,07	0,04	0,12	0,3	0,01	0,08	155
2004833	1,3	1,1	50,7	44,3	0,09	0,5	1,0	0,11	0,01	0,05	0,05	0,23	0,01	0,05	290
2004834	0,9	0,8	50,4	45,5	0,08	0,5	0,8	0,12	0,02	0,04	0,05	0,22	0,01	0,04	284
2004835	1,6	1,1	52,6	41,6	0,09	0,6	1,2	0,38	0,01	0,05	0,07	0,21	0,00	0,04	150
2004836	2,2	1,3	52,2	40,6	0,12	0,5	1,3	0,78	0,09	0,05	0,07	0,26	0,01	0,06	83
2004837	1,9	1,3	52,2	41,3	0,12	0,5	1,2	0,41	0,03	0,05	0,24	0,27	0,01	0,04	118
2004838	1,5	1,2	50,2	44,3	0,08	0,4	0,7	0,46	0,05	0,06	0,09	0,28	0,01	0,05	149
2004839	1,3	1,1	49,2	45,7	0,09	0,4	0,9	0,23	0	0,06	0,07	0,26	0,00	0,06	125
2004840	2,6	1,7	51,0	41,2	0,1	0,5	1,1	0,44	0,09	0,06	0,07	0,32	0,01	0,12	114
2004841	2,6	1,4	51,1	42,0	0,08	0,4	1,1	0,43	0,03	0,06	0,05	0,21	0,01	0,03	144
Mean	1,7	1,2	51,2	42,8	0,09	0,5	1,1	0,33	0,04	0,05	0,08	0,25	0,01	0,06	172

The compositions above are averages of the number of particles in each sample.

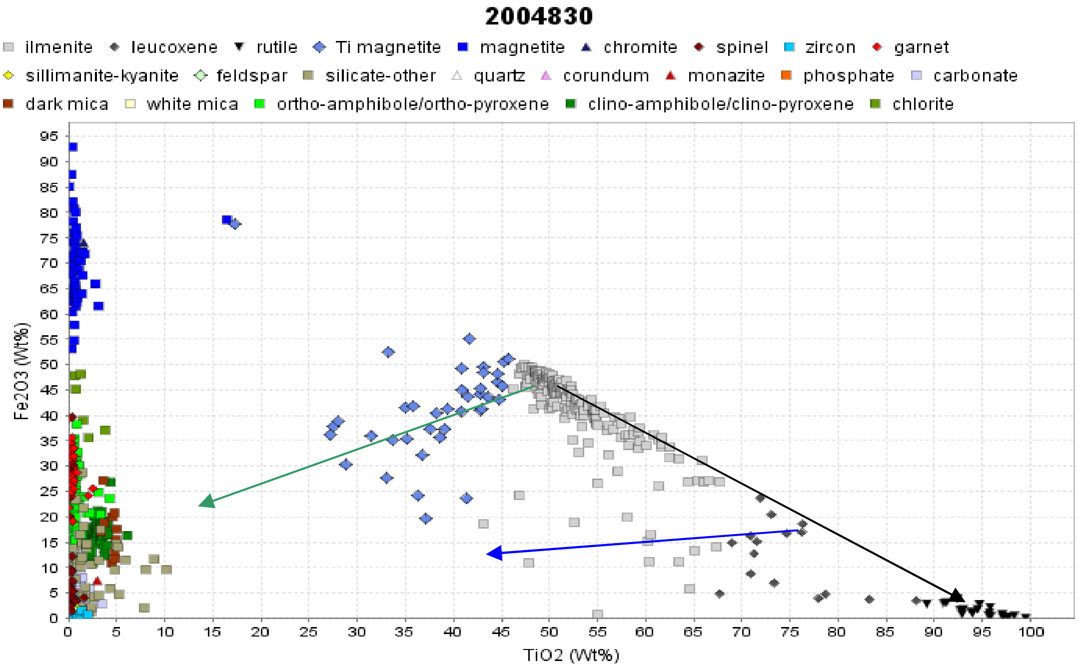


Figure 9 Fe_2O_3 versus TiO_2 in minerals grains from a sample in Chanel 1. CCSEM.

The black arrow show the trend induced by leaching of ilmenite. The green arrow shows mixing line between unaltered ilmenite and amphiboles etc. In the legend these grains are classified as Ti-magnetite but are likely to be non-liberated ilmenite grains. The blue arrow show mixing between leucoxene and clay

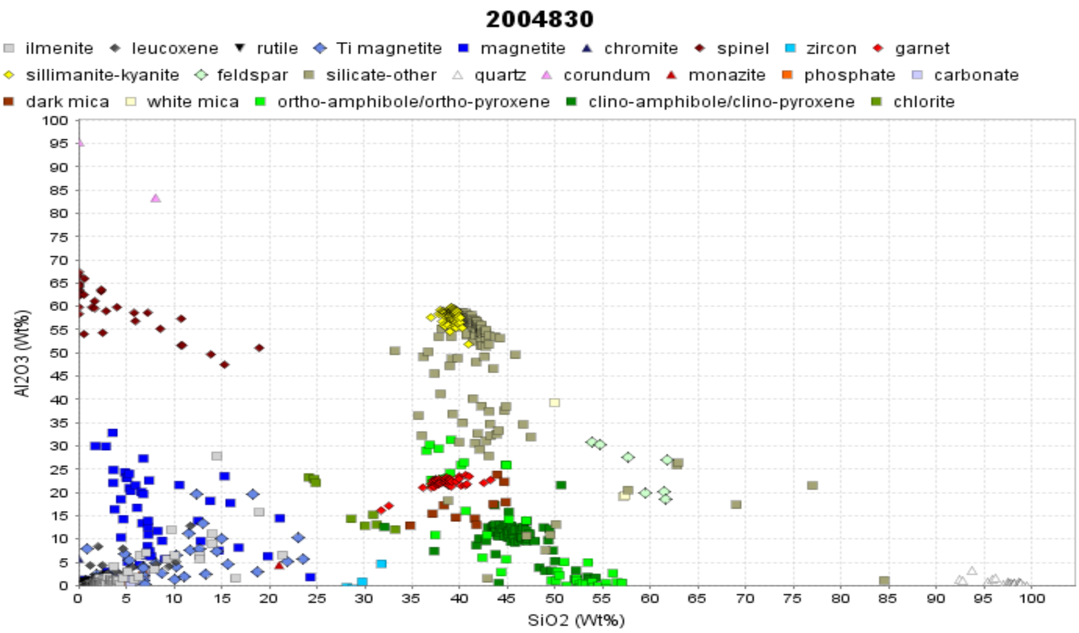


Figure 10 Al_2O_3 versus SiO_2 in minerals grains from a sample in Chanel 1. CCSEM.

Figure 10 shows that many of the "silicate other" group grains are close to the Ky/Sill group and the rest plot close to a tourmaline composition. Spinel is common and corundum is present which is characteristic for Sri Lanka.

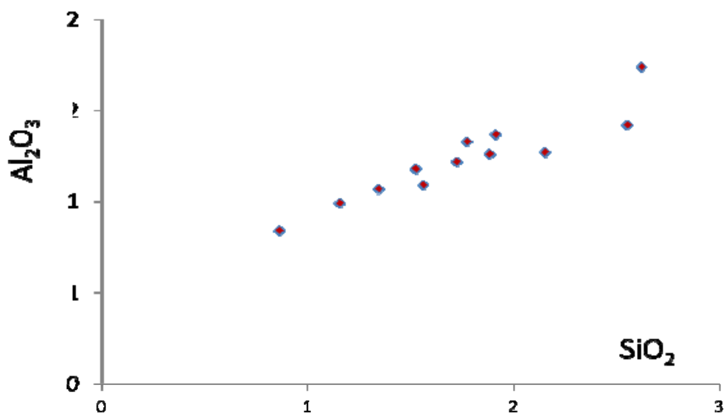


Figure 11

Al_2O_3 versus SiO_2 in ilmenite.

Each point represents average ilmenite composition (from Table 2).

Al_2O_3 and SiO_2 are related with a ratio similar to kaolinite.

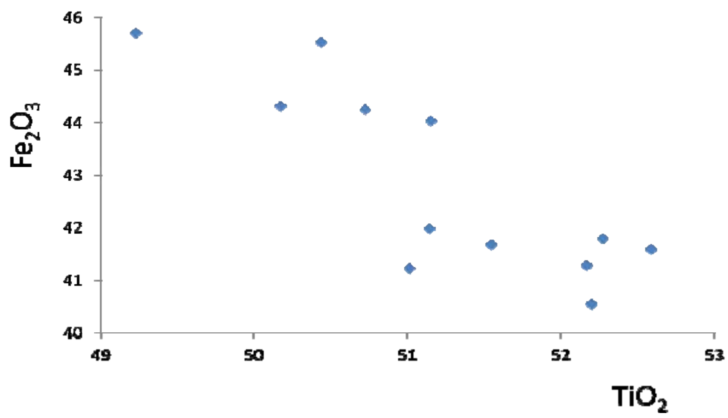


Figure 12

Fe_2O_3 versus TiO_2 in ilmenite.

These averages show ilmenite leaching trend (as seen on Figure 9) indicating that the samples in the different off-shore areas are leached to different degree.

Modal mineralogy

Table 4 **Modal mineralogy (CCSEM of the heavy minerals)**

2004-	830	831	832	833	834	835	836	837	838	839	840	841	Mean
Ilmenite	28	29,7	26,7	31,3	40,5	20,8	12	19	45,6	30	21,8	32	28,1
leucoxene	1,9	2,9	2,9	1,6	1,6	2,6	2,1	3,3	0,3	0,4	1,2	2	1,9
rutile	3,1	2,8	3,5	4	3	6,8	1,2	1,2	2,8	1,8	0,8	2,8	2,8
silicate-other	10	3,1	8,7	6,5	8,2	5,4	5,3	3,8	3,8	1,8	6,9	13,2	6,4
Ti magnetite	2,8	2,2	5,7	6,4	5,9	3,7	8,4	3,6	12,7	10	13,6	5,5	6,7
unclassified	6,3	10,8	7	3,1	11,1	4,9	29,9	28,6	10,8	8,6	17,8	11,2	12,5
zircon	1,7	1,2	2,6	2,2	4,8	6,2	0,5	2,1	1,3	1,4	1,5	1,6	2,3
garnet	5,4	5	4,5	6,8	3,3	4,5	2,8	4,8	1,2	29,4	0,2	0,4	5,7
sillimanite-kyanite	11,6	12,2	10,6	15,3	10,5	13,3	6,1	2,7	0,6	6,2	14,5	12,8	9,7
staurolite	0	0,3	0	0	0	0,6	0	0	4,7	0,8	1,4	0,3	0,7
magnetite	8,8	6,9	4,8	6	3,9	12,9	9,8	3,6	0,9	1,8	8,7	2,9	5,9
chromite	0,2	0	0	0	0	0,5	0,5	0	0,8	0	0	0	0,2
quartz	2,5	3	4	0,8	0,6	1	0,6	1,8	4,8	0,1	1,5	2,3	1,9
corundum	0,3	0,4	0,4	0	0,2	0,2	0	0	0,2	0	0	0,1	0,2
spinel-hercynite	3,8	3	2,3	2,1	1,4	1,1	1,6	3,5	0,7	7	7,1	2,3	3,0
feldspar	0,7	0,9	1,2	0,3	0,6	0,4	0,2	1,4	0,2	0	0	0,2	0,5
carbonate	12,8	15	14,9	13,2	3	15,1	19,1	20,5	7,3	0,5	2,1	10,4	11,2
phosphate	0,3	0,1	0,1	0,4	1,5	0,3	0	0,1	1,3	0,2	0,9	0	0,4

It is very surprising that we did not find high contents of monazite/phosphate in the samples. The modal mineralogy in the offshore samples is shown graphically on Figure 13 and compared to the onshore data.

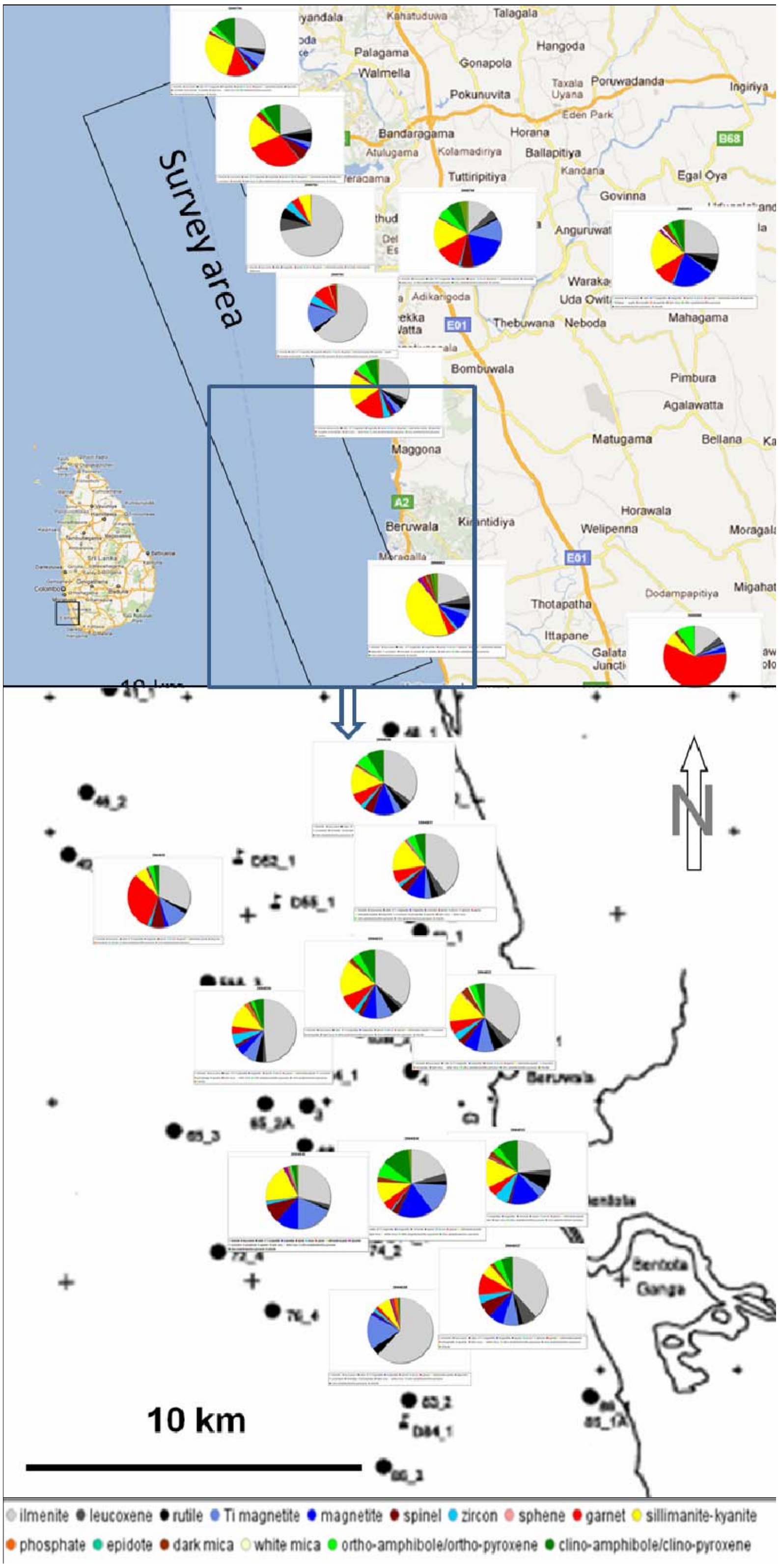


Figure 13

Modal mineralogy on- and offshore SW Sri Lanka.

The modal mineralogy varies considerably onshore in this area as is also seen on Figure 7.

The heavy mineral assemblage is characterised by being dominated by ilmenite and Ky/sill in this part of Sri Lanka with minor garnet and fairly little mafic silicates, in other words a mature assemblage.

The HM assemblage is rather monotonous off-shore indicating that it could originate from a common source. This source could be the Kalu River where the mineralogy is very similar.

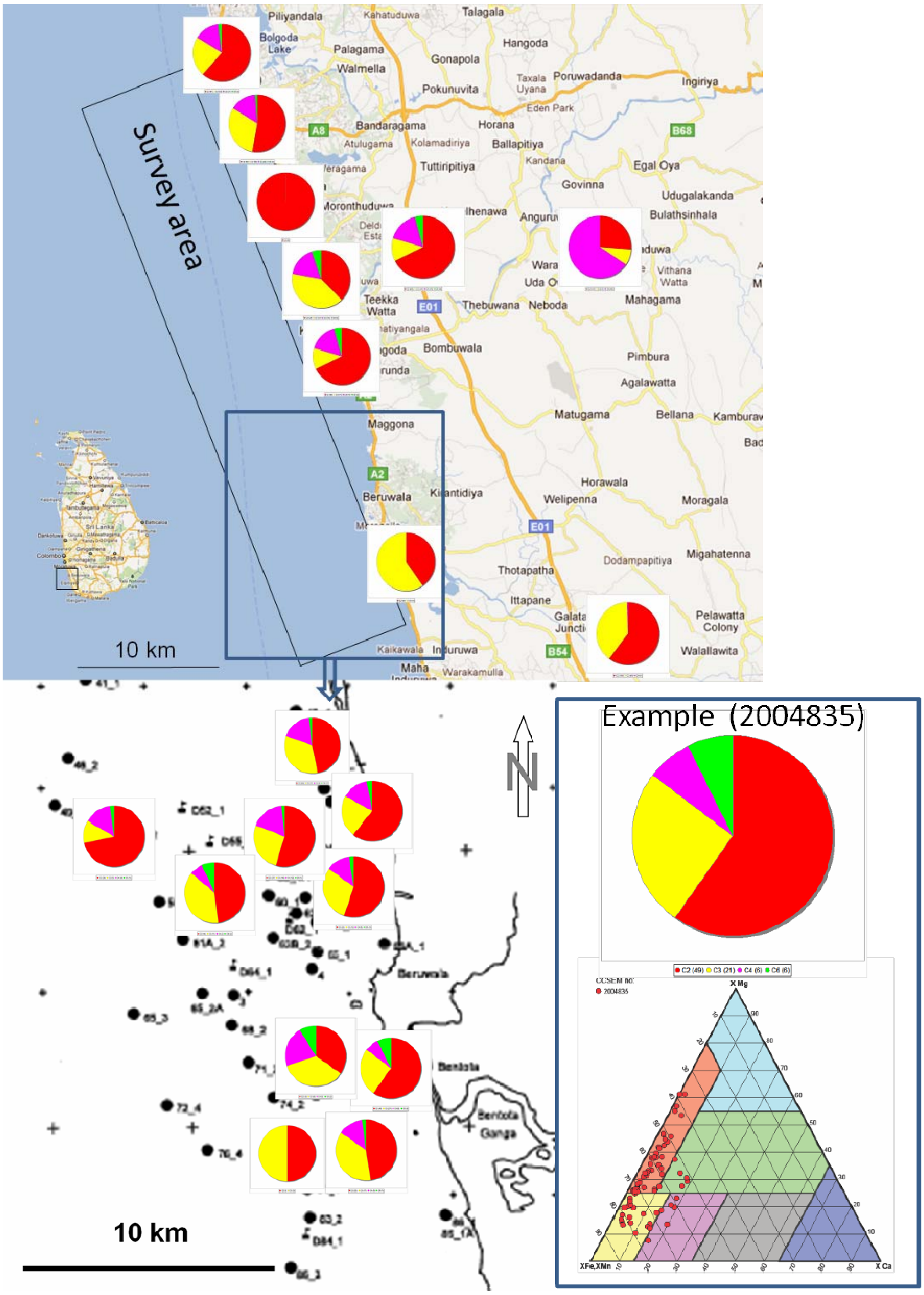


Figure 14 Garnet compositions on- and offshore. The yellow field represent low grade garnets from metasediments, the red high grade metasediments, the pink garnets from low grade amphibolites and green from high grade amphibolites.

As is the case with the modal mineralogy, the garnet composition patterns are rather similar in the offshore samples (Figure 14). Further, the offshore patterns more closely approximate the compositions from the Kalu River more than the Bentola River further south.

Spinel and Hercynite

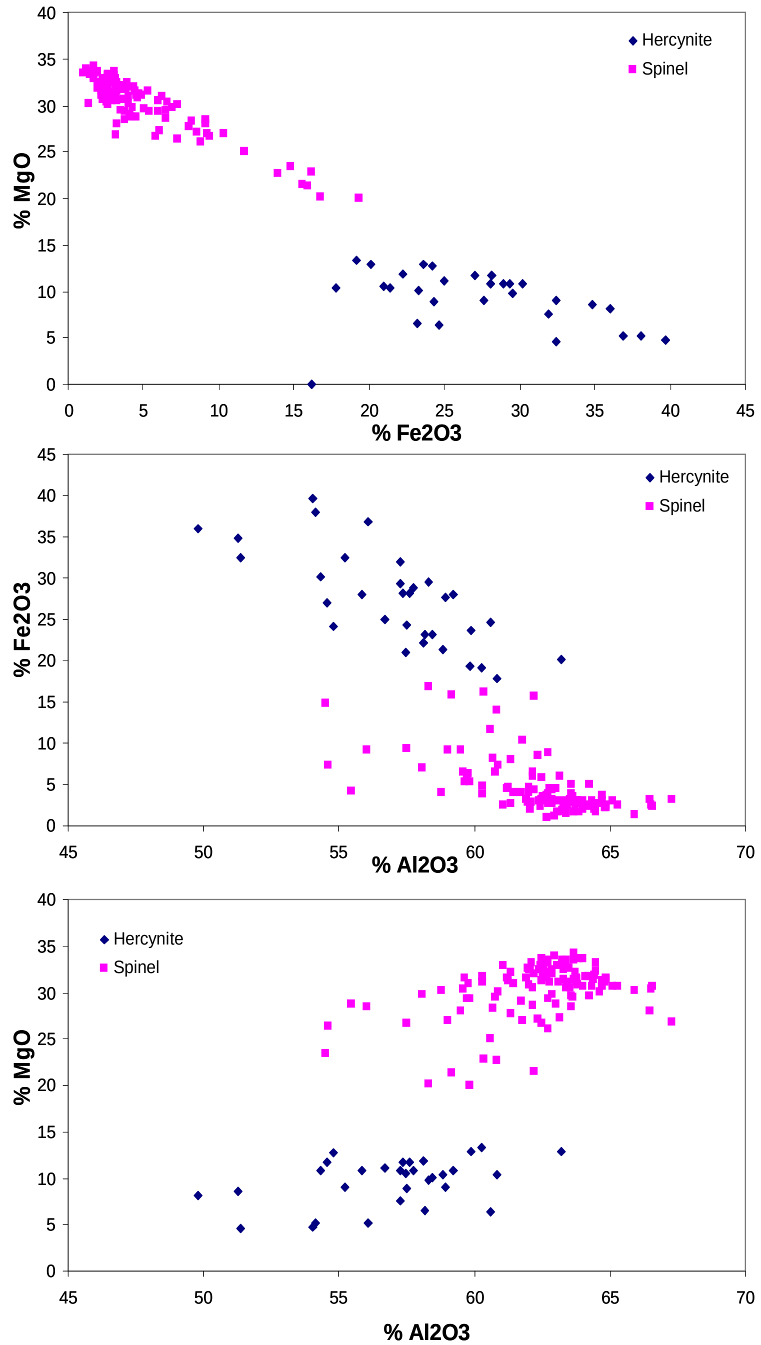


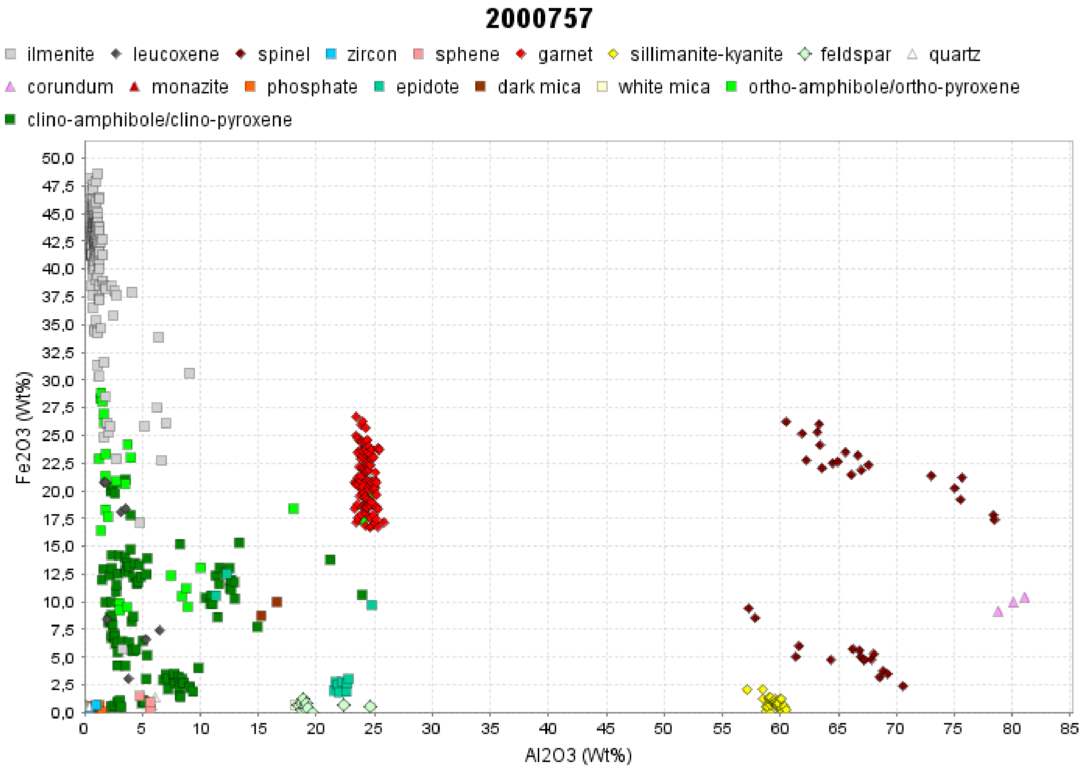
Figure 15

Composition of Spinel and Hercynite in the offshore sands (all samples).

As seen in Figure 10, there is a considerable content of spinel in the sands. This is not something that is commonly seen in heavy mineral concentrates. However it is not surprising as spinel in gemstone quality has long been found in gravel in Sri Lanka. As can be seen on Figure 15, these minerals fall in two groups – Spinel and Hercynite.

Spinel is a common high temperature mineral in metamorphic rocks that are relatively deficient in alkalis relative to aluminium. Aluminium oxide may form as the mineral corundum or may combine with either magnesia to form Spinel or iron to form Hercynite.

Gem quality spinel is also known from Mahenge and Matombo (Tanzania), Tsavo (Kenya) and in the gravels of Tunduru (Tanzania) and Ilakaka (Madagascar) localities that may also be part of the same high grade metamorphism during the Pan Aftrican orogeny as Sri Lanka. Accordingly, Spinel/Hercynite may be regarded as pathfinder minerals for this type of metamorphism – that also yield ilmenite that is susceptible to alteration. Bernstein et al. 2008 note the association between khondalites and high TiO_2 in ilmenite, which we also found on Madagascar. There is also a lot of spinel on the south-eastern tip of Madagascar (Figure 16) as well as spinel is common in Kerala, India.



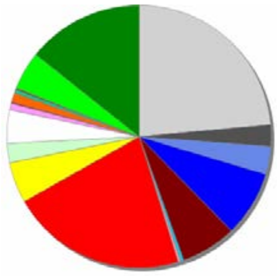


Figure 16

Fe_2O_3 versus Al_2O_3 in a sample from south-eastern Madagascar.

Spinel and hercynite (brown dots and pie) is one of the most common minerals in this sample from SE Madagascar.

Possible resources

The samples collected by Geological Survey of Canada (GSC) during the 1997 campaign only represent the uppermost part of the deposits that they mapped out during their geophysical fieldwork. Accordingly, the analytical results do not fully describe the resource but only the top of the deposit. However, it is the only information we have at hand at the moment. According to Table 5, the content of valuable heavy minerals (ilmenite, leucoxene, rutile, zircon, kyanite/sillimanite, staurolite, corundum & spinel) is only high in Chanel 1, whereas it is intermediate to low in the other areas.

Table 5 **Avg. Heavy minerals in raw sand (CCSEM)**

% in raw sand	**Ilmenite**	**leucoxene**	**rutile**	**zircon**	**sillimanite-kyanite**	**spinel, corund, staurolite**	**Valuable Heavy Min.**
Chanel 1	2,10	0,20	0,20	0,20	0,80	0,26	3,8
Chanel 2	0,81	0,04	0,10	0,06	0,39	0,05	1,5
Chanel 3	0,94	0,04	0,07	0,11	0,24	0,03	1,4
Chanel 4	0,21	0,03	0,06	0,05	0,13	0,03	0,5
Chanel 5	1,58	0,04	0,10	0,10	0,10	0,23	2,1
Offshore basin 3	0,20	0	0,01	0,01	0,04	0,06	0,3
Offshore basin 4	0,73	0,04	0,03	0,05	0,49	0,29	1,6

If we assume that the samples are representative for the whole volume mapped out by GSC and multiply the content of heavy minerals with the volumes found, we get the figures in Table 6. As the samples do not represent the deeper levels in the deposits, this will not be true, but give an order of magnitude.

Table 6 **Volumes (assuming that samples are representative)**

	Raw sand (Mill ton)	**Ilmenite (Mill ton)**	**Leucoxene (Mill ton)**	**Rutile (Mill ton)**	**Zircon (Mill ton)**	**Sill/ kyanite**	**Spinel, corundd, staurolite**	**Total (Mill ton)**
Chanel 1	37	0,78	0,07	0,07	0,07	0,30	0,10	1,4
Chanel 2	3	0,03	0,00	0,00	0,00	0,01	0,00	0,0
Chanel 3	15	0,14	0,01	0,01	0,02	0,03	0,00	0,2
Chanel 4	36	0,08	0,01	0,02	0,02	0,05	0,01	0,2
Chanel 5	19	0,29	0,01	0,02	0,02	0,02	0,04	0,4
Inshore basin 1	235	0,47	0,00	0,02	0,02	0,09	0,14	0,8
Inshore basin 2	24	0,17	0,01	0,01	0,01	0,12	0,07	0,4
Offshore basin 1	107							
Offshore basin 2	72							
Offshore basin 3	100	0,20	0,00	0,01	0,01	0,04	0,06	0,3
Offshore basin 4	252	1,84	0,10	0,08	0,13	1,23	0,73	4,1
Total	900	4	0,2	0,2	0,3	1,9	1,2	7,8

To make a realistic estimate of the heavy mineral resources in this offshore area it would be necessary to conduct drilling and sampling of the deeper parts of unit 1a, 1b and 1c. However, the underlying sediments would have to contain both high concentrations of heavy minerals as seen in Channel 1 and a grain-size as seen in e.g. Channel 3. The combination of sufficient grade of valuable heavy minerals in the ground (> 2 %) and high enough grain-size (> 100 µ) have not been found in the area, and if further exploration for titanium raw materials were to be conducted in Sri Lanka, this would not be the area.

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