

ECONOMIC GEOLOGY OF THE HEAVY  
MINERAL PLACER DEPOSITS IN  
NORTHEASTERN FLORIDA

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DEPARTMENT OF ENVIRONMENTAL PROTECTION  
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DIVISION OF ADMINISTRATIVE & TECHNICAL SERVICES  
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FLORIDA GEOLOGICAL SURVEY  
Walter Schmidt, *State Geologist and Chief*

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ECONOMIC GEOLOGY OF THE HEAVY MINERAL PLACER DEPOSITS  
IN NORTHEASTERN FLORIDA

by

Harald Elsner

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It is, however, being made available, because it is a valuable contribution to the study and understanding of Florida's Heavy Mineral deposits.

Sincerely,

Walter Schmidt, Ph.D.  
State Geologist and Chief  
Florida Geological Survey

**Printed by the  
Florida Geological Survey  
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Florida Department of Environmental Protection**

**Tallahassee  
1997**

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## Abstract

Heavy mineral placers have been mined in northeastern Florida for several decades. Although decreasing in importance, Florida still has a considerable share in the world production of ilmenite, rutile, zircon, and monazite.

To obtain information about the geology of these heavy mineral placers more than 230 laminar sand samples were taken from cores and in the field.

Granulometric analyses included dry-sieving in a nest of sieves and calculation of moment measures of weighed sand fractions. Suite statistics were successfully used to determine depositional environments of the various placers and underlying formations.

Smaller samples of the same stratigraphic horizons were checked for their heavy mineral composition and their total heavy mineral content in weight-percentages. Several hundred grains each of the magnetic and non-magnetic fractions were determined under the microscope. Heavy minerals of northeastern Florida in order of abundance are: ilmenite, leucoxene, zircon, staurolite, sillimanite, epidote, rutile, tourmaline, kyanite, hornblende, garnet, topaz, corundum, andalusite, monazite, anatase, sphene, xenotime, spinel (gahnite), chloritoid, brookite, and beryl. Cassiterite was found only in certain heavy mineral concentrates. Titanomagnetite, pyrite, and hemoilmenite were determined under the ore-microscope.

While in the Early Tertiary Florida was characterized by the deposition of limestones on a shallow carbonate platform, in the Miocene influence of clastic material from the Appalachian mountains increased. Deposition of the well-known Hawthorn Group had already been influenced by glaciations of the Antarctic.

In Early Pliocene time a transgression led to sedimentation of shelly and carbonaceous sands in northeastern Florida. Initiated by a glacial episode 3.1 to 2.9 Ma B. P., braided rivers deposited huge amounts of coarse sand on the Atlantic and Gulf coastal plains. During a short transgression between 2.8 and 2.6 Ma B. P. these fluvial sediments of the Citronelle-Cypresshead Formation were partly reworked in Florida and the Central Ridges of the Peninsular of Florida were formed.

Information about the Late Pliocene/Quaternary history of Florida is very limited and a model had to be developed to allow correlation of the various known fossil shoreline complexes (Wicomico = + 30.5 m, Penholoway = + 21.3 m, Talbot = + 12.8 m, Pamlico = + 7.6 m, Princess Anne = + 4.0 m, Silver Bluff = + 1.4 m) with dated global events:

The Pamlico shoreline complex was definitely formed during the last interglacial which had its climatic optimum 125 ka B. P. Maximum mean sea level of this interglacial was not higher than + 6 m. Assuming a constant rate of uplift (1.28 cm/1,000 yrs.) and reasonable former mean sea level elevations, ages of all the other shoreline complexes can be calculated.

Comparison of these hypothetical shoreline ages with well-established global climatic variations revealed the following stratigraphic history, which is in excellent agreement with biostratigraphic results from other parts of the Atlantic coastal plain and the Gulf of Mexico.

Following a series of glacial episodes between 2.4 and 2.0 Ma B. P., the Wicomico transgression can be dated  $1.9 \pm 0.1$  Ma B. P. Another series of climatic deteriorations between 1.8 and 1.5 Ma B. P. separates it from the Penholoway transgression  $1.3 \pm 0.1$  Ma B. P. Sediments of the Talbot shoreline complex (ca. 550 ka B. P.) are not defined in the area of investigation. The age of the Pamlico transgression has already been mentioned. It was followed within a very few thousand years by the Princess Anne transgression. The Silver Bluff complex was formed during the Holocene climatic optimum about 6,000 years ago.

With original reserves of more than 1.3 billion metric tonnes of ore sand or nearly 52 million metric tonnes (Mt.) of available heavy minerals, Trail Ridge is one of the largest heavy mineral placer deposits in the world. The southern areas of this pronounced feature of 230 km length have been mined since 1946. Underlying the mineralized eolian sands in the southernmost part are peats of a former cypress swamp which was buried by migrating dunes. These dunes received their material from beach sands of the former Atlantic coast to the east. Waves at that time ( $1.9 \pm 0.1$  Ma B. P.), on the other hand, were mostly reworking relatively coarse fluvial sands of the Citronelle-Cypresshead Formation. Mineralogical and granulometric characteristics of this partly eroded Formation are still preserved in the dune sands of Trail Ridge. To the west of the southern part of Trail Ridge, the former Gulf of Mexico acted as a barrier to the migrating dunes. Farther to the north, Trail Ridge did not exist as a single ridge from the beginning, but large islands were separated by tidal inlets, deltas and even marine straits. Prolonged dune migration led to the formation of the present-day ridge which was partly eroded and partly covered by barren eolian sands during later Pleistocene climatic oscillations.

The Folkston deposit in southeastern Georgia was mined between 1965 and 1974. Nearly 29 Mt. of ore sand and 0.6 Mt. of heavy mineral concentrates were recovered from mostly eolian placers of the Penholoway shoreline complex. Only small, hardly economic extensions of the main deposit remained unmined.

The very small Boulogne deposit contained original reserves of 26 Mt. of ore sand or 0.9 Mt. of available heavy minerals. Due to very low grades in the southern part only the northern area was mined between 1974 and 1979 yielding 0.25 Mt. of heavy mineral concentrates. Sedimentologic analyses revealed the following stratigraphy in the area of mineralization: Overlying Miocene, Early Pliocene and various Late Pliocene sediments are epidote-rich coastal dune sands of Early Penholoway age. With transgressing seas they partly remained as obstacles on the shallow sea floor, so that heavy minerals were deposited in the vicinity of these nearshore bars. Sedimentologic parameters are distinctive but cannot be confused with those of beach-storm or eolian placers.

The Green Cove Springs deposit has been mined since 1972. Original reserves of the entire district may have been around 15 Mt. of available heavy minerals. Granulometric analyses of the main ore body revealed exactly the same stratigraphy as in the northern Boulogne deposit of the same age. While heavy minerals in this main ore body were also deposited in the nearshore zone in front of drowned coastal dune ridges, the western ore body seems to be of eolian origin. Differences between both ore bodies are pronounced.

West of the City of Jacksonville only small parts of a huge eolian placer deposit were mined between 1942 and 1964. Comparable in size to the Recent Amelia Island, this former "Jacksonville Island" was formed during the Pamlico transgression. Original reserves may be calculated as 242 Mt. of ore sand containing 13.3 Mt. of available heavy minerals.

North and northeast of the small town of Yulee, four well-defined ridges contain an estimated 143 Mt. of ore sand with only 4.5 Mt. of available heavy minerals. In this area beach-storm placers are overlain by low-grade eolian sands which contain the bulk of the heavy minerals. The western ridges were formed during the Pamlico transgression whereas the easternmost ridge must be correlated with the Princess Anne shoreline complex. Due to the low grades of the entire deposit and competitive land use, the Yulee heavy mineral placers will never be mined.

Evergreen Hill, west of the Yulee ridges, was sampled for scientific reasons only; it does not constitute a heavy mineral deposit.

At the end of the 1950s it was planned to mine a small eolian placer deposit of only 0.9 Mt. of available heavy minerals on Amelia Island. By 1970, however, it was decided to develop the area of mineralization into a luxury resort, which became known under the name Amelia Island Plantation.

Little Talbot Island, another barrier island of the so-called Sea Island chain, is a protected Florida State Park. Relatively high-grade eolian and beach-storm placers make up theoretical reserves of 2.3 Mt. of available heavy minerals. Epidote and hornblende dominate the heavy mineral suite; the percentage of the heavier and economic heavy minerals, however, is rather small.

High-grade beach-storm placers and adjacent eolian placers of the Recent Atlantic coast near Ponte Vedra Beach were the first to be mined in northeastern Florida, from 1916 to 1929. Mining of mineralized sands was by hand and recovery of heavy minerals rather poor. The change of the heavy mineral composition with increasing total heavy mineral content is well documented along Recent coastlines.

Chances of the discovery of economic heavy mineral placer deposits on the shelf off northeastern Florida are rather slim. Reasons are manifold; further exploration should be undertaken closer to the coast.

The heavy mineral industry of northeastern Florida has always been strongly influenced by economic needs. Within the last 80 years mining has shifted from coastal to less populated central areas of Florida. Recovery of heavy minerals from low-grade deposits was made possible by discoveries by Florida-based industries. While exploration headquarters are still located in Florida, exploration has shifted into other states. In the area of investigation, however, a few economic heavy mineral deposits may still remain undiscovered.

## Introduction

Florida, the southernmost state of the USA, is known to the public for only one of its resources. This, of course, is the sand, which together with the sunshine makes Florida so attractive to tourists not only from America and, therefore, makes up the main revenue of the state.

For geologists, however, other natural resources are of much more interest. Phosphorite, for example, can be found in such a thickness and distribution, that it makes Florida to the largest phosphate producing nation in the world. One should not forget another resource, i. e. water, which is of even greater importance to the local population. Also of great economic importance are building materials, i. e. sand, gravel, chalk, and limestone of every classification which are mined above all along the central axis of the Florida peninsula.

Easily neglected is another resource group, which has a long mining history in Florida: Starting in 1916 heavy minerals (h. m.) were mined in northeastern Florida along the beaches of the Atlantic coast (see chapter on Ponte Vedra Beach) and products made up from these minerals used during World War I. While the coastal reserves were depleted very soon and similar deposits nowadays cannot be mined due to the almighty tourism industry (see chapters on Amelia and Little Talbot Islands), exploration and, therefore, also mining has shifted into the less densely populated interior of Florida (see fig. 1).

Since the beginning of the '80s the golden times of h. m. mining in the southeastern US have gone and exploration has shifted into other areas. But still Florida remains one of the more important h. m. producers in the world, as shall be shown in the following table:

|                         | Ilmenite    | Rutile       | Zircon      | Monazite     |
|-------------------------|-------------|--------------|-------------|--------------|
| Australia               | 48 %        | 52 %         | 55 %        | 29 %         |
| Malaysia                | 13 %        | --           | P           | 12 %         |
| USA                     | 13 %        | 5 %          | 10 %        | 1 %          |
| <i>of which Florida</i> | <i>95 %</i> | <i>100 %</i> | <i>90 %</i> | <i>100 %</i> |
| CIS                     | 11 %        | 2 %          | 10 %        | --           |
| South Africa            | --          | 13 %         | 16 %        | --           |
| Sierra Leone            | --          | 25 %         | P           | --           |
| Brazil                  | P           | P            | P           | 8 %          |
| Sri Lanka               | P           | P            | P           | --           |
| China                   | P           | --           | P           | 39 %         |
| India                   | --          | P            | P           | 8 %          |
|                         | (1989)      | (1989)       | (1989)      | (1986)       |

Tab. 1: Relative share of the most important nations in the production of some h. m. after various authors

P = important producer, -- = no or minor producer

Ilmenite and rutile, recalculated after Lynd (1990 b)

Zircon, recalculated after Garnar (1990)

Monazite, recalculated after O'Driscoll (1988)

In 1987, a general inquiry of my major professor in Germany, Prof. Dr. D. Henningsen, of the University of Hannover was answered kindly by Dr. W. F. Tanner, Regents Professor at the Florida State University in Tallahassee, who was looking for a student to assess information explaining Trail Ridge (and its h. m. deposits) as a beach ridge. Beach ridges in northeastern Florida, however, normally do not reach elevations and widths of more than one meter and lengths of more than one kilometer. The Trail Ridge feature, on the other hand, is more than 25 m high, several kilometers wide, and more than 200 km long.

After a short study it got clear that this ridge had to be seen in close context with the other, smaller h. m. deposits in northeastern Florida. Astonishingly enough, however, hardly any literature about these deposits was available, so that a completely new and above all independent report became necessary.

The collection of new data of many deposits was eased considerably by the free admission to the core library of the Florida Geological Survey (F.G.S.) in Tallahassee. While the branch of the U.S. Geological Survey in Florida is working on hydrogeological problems only, the F.G.S. is in charge of gathering and evaluating all available information on the geology of Florida. It is so strongly understaffed, however, that e. g. a stratigraphic correlation of Plio-Pleistocene sediments, which was decisive for understanding the depositional history of the various h. m. deposits, was not available in the beginning and had to be worked out for the first time.

In total contrast to this situation the mining companies in Florida have collected a huge set of data for having been engaged in exploration programs for several decades. These data, however, are not available to the public and are even seldomly used by the exploration geologists for doing work on a scientific level. While only short glimpses into these data sets were possible when working together with E. I. Du Pont de Nemours & Co., Inc. (Du Pont) and Associated Minerals (USA), Inc. (AMU), in 1992 renamed to Renison Goldfields Consolidated (RGC) (USA) Mineral Sands Inc., most of the files of the former Humphreys Mining Company (HMC) were at the author's disposal. These files, however, only made up a fraction of the former archives of HMC which consisted of analyses and extensive reports on most h. m. deposits not only in the southeastern USA.

Economic considerations have affected the mining of h. m. in northeastern Florida for nearly 80 years and have also influenced this work: During a worldwide price high for h. m. in 1989/90, support by exploration geologists of Du Pont and above all RGC was limited and missing information had to be collected during discussions with other employees of these mining companies.

While the original Ph. D. dissertation (in German) included

- a complete description of all analytical techniques used,
- the Cenozoic stratigraphy of northeastern Florida, and
- the theories of placer formation in various environments,

this report had to be restricted to the economic information now available on the various placer deposits of northeastern Florida. To allow readers to see these economic data in a wider context, however, a much more general abstract, taken from the original thesis, was given in the beginning.



| DIVIDE                                 | BY         | TO OBTAIN<br>UNITED STATES UNITS |
|----------------------------------------|------------|----------------------------------|
| centimeters (cm)                       | 2.54       | inches                           |
| cubic meters (m <sup>3</sup> )         | 0.764551   | cubic yards                      |
| kilograms (kg)                         | 0.4535924  | pounds                           |
| kilometers (km)                        | 1.609341   | miles (statute)                  |
| meters (m)                             | 0.914398   | yards                            |
| meters (m)                             | 0.30479947 | feet                             |
| micrometers (μm)                       | 0.00000254 | inches                           |
| millimeters (mm)                       | 0.00254    | inches                           |
| square meters (m <sup>2</sup> )        | 0.092903   | square feet                      |
| square meters (m <sup>2</sup> )        | 0.836124   | square yards                     |
| square meters (m <sup>2</sup> )        | 4046.84016 | acres                            |
| tonnes (t)                             | 0.907185   | tons (short, 2000 lbs.)          |
| tonnes/cubic meter (t/m <sup>3</sup> ) | 1.18655917 | tons (short)/cubic yards         |

Tab. 2: United States system of measurement conversion factors

# **Economic geology of the heavy mineral placer deposits in northeastern Florida**

## **Trail Ridge**

Trail Ridge is the name of a geomorphologic ridge extending from Blue Pond Lakes in Clay Co., Florida for about 209 km to north of Jesup, Wayne Co., Georgia. Its elevation declines steadily from 77.7 m above mean sea-level (msl) southeast of Kingsley Lakes to 60.4 m above msl near Highland to 51 m above msl east of Macclenny, where it is breached by the St. Marys River. Farther north it reaches 46 m above msl west of Folkston and 42 m above msl east of Hoboken, Georgia. Not clearly delineated at its northern end it, nevertheless, can be followed via Screven to northwest of Jesup, where it finally reaches an elevation of 47 m above msl.

While before and during World War II Trail Ridge was only of interest to geomorphologists, only months later it became known as one of the biggest h. m. deposits in the USA. The history of its discovery is known in detail and was described by Mining World (1948, 1955 a, b, c), Spencer (1948), Thoenen & Spencer (1948), Thoenen & Warne (1949), Thoenen (1950), Lenhart (1951), Carpenter et al. (1953), Roberts (1955), Calver (1957), Grogan et al. (1964), Giese et al. (1964), Peterson (1966), Garnar (1971, 1980, 1983), Pirkle & Yoho (1970), Pirkle (1972), Pirkle et al. (1974, 1989), and Pirkle & Pirkle (1984). More recent information can be found in Industrial Minerals (1990) and Pirkle et al. (1991).

The origin of Trail Ridge and its h. m. deposits had been discussed for decades, when starting in 1985 (Rich b, Force & Garnar) all available and above all new data were discussed on a scientific basis. More recent publications (Force & Rich, 1989; Force, 1991) only used the result of this discussion explaining Trail Ridge as an eolian feature.

Granulometric and h. m. analyses by Elsner (1992 a) (see figs. 2 - 7) validated this theory and even brought forth more details, so now it can be stated that:

- the northern parts of Trail Ridge started as barrier islands, merging together with falling sea-level by migrating coastal dunes.
- the whole southern part of Trail Ridge was formed as an inland dune with winds blowing from the Atlantic coast in the northeast to the Gulf of Mexico in the southwest.
- overlying coarse sands of the late Pliocene Citronelle-Cypresshead Fm. (3.0 Ma B. P.), marine sands of the late Pliocene Nashua Fm. (2.8 - 2.6 Ma B. P.), and peat of a local cypress swamp (2.4 - 2.0 Ma B. P.), the eolian sands in the south can be correlated with a world-wide eustatic sea-level high ( $1.9 \pm 0.1$  Ma B. P. = late Pliocene).
- h. m. now found in Trail Ridge were originally winnowed from sediments of the younger parts of the Citronelle-Cypresshead Fm. which are now completely eroded.

Mining at the southern end of Trail Ridge by Humphreys Gold Corporation (HGC) for E. I. Du Pont de Nemours & Co., Inc. (Du Pont) started in April 1949 (Trail Ridge plant) with the separation of ilmenite and residue (a mixture of rutile, ilmenite and leucoxene). Zircon was sold starting in 1950 (Garnar, 1983), and staurolite in June 1952 (Evans, 1955, Fulton, 1975, 1983). About 16 km north a second plant (Highland) was opened in April 1955, and in January 1958 the whole operation was taken over by Du Pont itself (see fig. 8). In mid 1993 Du Pont commenced operations at Maxville, partially closing down its Highland facilities (Industrial Minerals, 1993)

In place of all other heavy mineral placer deposits currently being mined or already mined out in northeastern Florida, mining and concentration of h. m. from the Trail Ridge deposit shall be explained in more detail.

Very detailed technical descriptions of the mining/separation processes (most of them with photos and flow-diagrams) have been given by Lenhart (1951), Engineering and Mining Journal (1952), Carpenter et al. (1953), Evans (1955), Roberts (1955), Mining World (1955 c), Calver (1957), Giese et al. (1964), Grogan et al. (1964), Peterson (1966), Mertie (1975), and Thompson & Whittle (1990). More recent information can be found in Garnar (1971), and Stouffer (1988). As a standard paper on h. m. separation processes, Garnar (1973) can be cited, who also prepared the flow-diagram (fig. 9) of the Du Pont h. m. separation process at Trail Ridge.

About one or two years before the start of actual mining all trees are cut and scrub is cleared to give way for bulldozers removing the upper 15 cm of top soil for later reclamation. Mining of the ore sand from depths of more than 20 m is by a cutterhead suction dredge floating in a shifting pond. Every hour more than 1,000 tonnes of sand from an area of 30,000 - 40,000 m<sup>2</sup>/month are being mined. The cut-off grade at Trail Ridge is 3 wt.-% h. m., with a cut-off grade of 2 wt.-% h. m. in nearly all other h. m. placer deposits in Florida.

With the ground-water level only 1 - 2 m below surface, a sand-water-mixture is sucked in which is pumped by pipelines to a floating wet mill. There more than 1,000 Humphreys spirals are used to concentrate the h. m. by gravimetric processes only. First rougher spirals manage a concentration of 4 wt.-% h. m. in the ore sand to 10 - 15 wt.-%, intermediate cleaner spirals enrich to 40 - 50 wt.-%, while finally finisher spirals produce a wet mill concentrate with an average grade of 80 - 85 wt.-% h. m. Scavenger spirals are also inserted for the separation of h. m. from middlings and tailings. A sample of the wet mill concentrate randomly taken at the Highland plant even contained 91.29 wt.-% h. m. (Elsner, 1992 a). The average wet mill recovery factor is 80 % h. m., with most light h. m. being returned to the end of the dredge pond.

Before entering the dry mill process the wet mill concentrate is treated with sodium hydroxide, which is used to remove all organic coatings which otherwise would make separation more difficult. After drying, the hot wet mill concentrate is placed in the stationary dry mill. Here at the beginning electrically conducting minerals are separated from non-conducting ones in several steps by ionizing the minerals at 35,000 V in rougher, scavenger, and cleaner high-tension separators. High-intensity magnets are later used to separate the magnetic minerals of the conducting fraction, i. e. mainly ilmenite. The non-magnetic minerals of the conducting fraction are treated as outlined in fig. 9 and finally separated in a coarse staurolite and a high-TiO<sub>2</sub> residue concentrate. From the non-conducting fraction another magnetic staurolite concentrate (Biasill) and more important various zircon concentrates in a zircon-mill using gravimetric processes again are being produced. The average dry mill recovery factor is much higher than 90 % h. m.

In the early '90s at Highland only ilmenite, residue, and staurolite concentrates were being produced, while the zircon-quartz rest was moved to the Trail Ridge plant for separation of zircon concentrates.

In northeastern Florida in 1992 Du Pont produced ten different h. m. concentrates, namely:

- titanium-mineral concentrates: Ilmenite, and Residue
- staurolite concentrates: Biasill, Coarse Staurolite, and Starblast
- zircon concentrates: Standard Zircon, Premium Zircon, Zircon T, Zirclean, and Zircore.

Data regarding the characteristics of those h. m. concentrates, i. e. their mineralogical, chemical, and granulometric composition can be found in appendix II.

After mining of the h. m. enriched sand the former mining areas are leveled and planted with fast-growing plants against wind erosion. The loosening of the soil equals the volume reduction by extracting the h. m. and even increases the value of the land (T. E. Garnar, pers. comm. 1990).

Sewages are cleaned in settling basins by adding lime to settle out suspended particles and afterwards are released into local creeks.

In 1988 about 260 people were working for Du Pont in Florida (Pirkle & Reynolds, 1988) only a small increase compared to 1952 with a staff of 225 (Engineering and Mining Journal, 1952).

As for this work detailed economic data from only one h. m. deposit of northeastern Florida were available (Yulee deposit) none of the well-known methods for calculating the content of ore deposits were applicable. Instead a simplified formula was used, which, however, has often yielded more than just satisfactory results (Dr. P. Simon, pers. comm. 1990).

This formula is:  $HM = Q \times P$   
while:  $Q = V \times W$ , and  
while:  $V = A \times T$ .

In this formula A is the area of the ore deposit in  $m^2$  and T the average ore thickness in m. Using these two figures V, the volume of the ore deposit in  $m^3$  can be calculated. By multiplying with the weight factor W, here the weight of the ore sand in tonnes per  $m^3$  ( $t/m^3$ ), hence follows the content of the ore deposit in tonnes. Another multiplication with the h. m. concentration P in weight percentages gives the amount of all available h. m. in tonnes. This figure can easily be splitted into the various economic minerals if the h. m. composition is known.

Most problematic beside the knowledge of the key factors A, T, and P, is the weight factor W. Although figures (Baxter, 1977, p. 116) and formulas (Macdonald, 1983, p. 61) for its calculation can be found in the literature, comparisons with data from h. m. deposits of northeastern Florida mined out are not in line except from the Trail Ridge deposit ! After Lynd & Lefond (1983, p. 1341) weight factors of h. m. deposits in the southeastern USA vary between 1.44 and 1.60  $t/m^3$ .

Especially the calculation of the content of the Trail Ridge deposit proves to be very difficult. Nearly all literature data on its available h. m. reserves date back nearly 30 years and were given by Meyer (1960), Giese et al. (1964), and Peterson (1966). According to these publications the whole Trail Ridge deposit was said to contain about 500 mill. metric tonnes (Mt.) of ore sand, of which by assuming a h. m. concentration grade of 3.9 wt.-% on the average an amount of 19.4 Mt. available h. m. can be derived. In 1988 Fantel et al. supposed both the Green Cove Springs and the Trail Ridge deposits still to contain reserves of more than 1 billion metric tonnes of ore sand. Carpenter & Carpenter (1991), on the other hand, stated the original h. m. content of both the Trail Ridge and Highland sections of the Trail Ridge deposit to have been 42.6 Mt.

For this work a complete recalculation of the geological h. m. content of the deposit seemed advisable. For this task the following data were at hand:

The area of the whole Trail Ridge ore deposit is not known in detail. In fig. 8 only the eastern outline of the Highland deposit is based on drilling results (T. E. Garnar, pers. comm., 1991). The western limit approximately equals the Clay-Bradford County border line, where the ore thickness is close to 3.7 m (12 feet) (N. W. Stouffer, pers. comm., 1990). Technically mining of heavy mineral rich sands with a thickness of less than 6 m is not possible (or rather not economic) (N. W. Stouffer, pers. comm., 1990), so that the exact western limit of the Trail Ridge ore body was never determined and Du Pont does not even possess any mining rights in that area (T. E. Garnar, pers. comm., 1991). The extent of the Maxville ore body to the north was taken from the sketchy map by Pirkle et al. (1977). The outline of the southern Trail Ridge deposit was taken from topographic maps, a draft by Pirkle et al. (1970), and a sketch map by N. W. Stouffer (written comm., 1990).

These outlines cited above were kindly planimetrically measured by Dr. E. Hofmeister of the Geological Survey of Lower Saxony at a scale of 1:24,000, resulting in 30.0 km<sup>2</sup> for the Trail Ridge deposit (south of Rd. 225), 21.9 km<sup>2</sup> for the Highland deposit (between US 301 and Rd. 225), and 25.7 km<sup>2</sup> for the Maxville deposit (north of US 301). These figures add up to 77.6 km<sup>2</sup> for the whole southern Trail Ridge ore body, of which 9.9 km<sup>2</sup> could not or will not be mined for rights of possession (N. W. Stouffer, written comm., 1990).

The average thickness of the ore body was given by Carpenter et al. (1953), Evans (1955), Calver (1957), E. V. Whittle (1957, and pers. comm., 1990), Mertie (1958, 1975), Pirkle & Yoho (1970), Pirkle et al. (1971), Lynd & Lefond (1975, 1983), and Mallard (1986) to be 10.7 m (35 feet). The maximum ore thickness is 21.4 m (70 feet) (Garnar, 1972, 1978 b; Force & Garnar, 1985; Fantel et al., 1986; N. W. Stouffer, pers. comm., 1990).

The weight factor is known quite well after Humphreys Gold Corporation to be 1.60 t/m<sup>3</sup>.

The average h. m. concentration of the ore deposit is 4 wt.-% after Thoenen (1950), Lenhart (1951), Carpenter et al. (1953), Evans (1955), Calver (1957), E. V. Whittle (1957, and pers. comm., 1990), Meyer (1960), Pirkle & Yoho (1970), Pirkle et al. (1971), Mallard (1986), and Force (1991). Force & Garnar (1985) cited a concentration of 3.5 wt.-%, while Mining World (1948), Spencer (1948), and Mertie (1958, 1975) published an average value of 3.9 wt.-%. R. M. Carver (pers. comm., 1990) mentioned 2.4 to 3.5 wt.-% for the Maxville deposit with an average grade of 3.1 wt.-%. A calculation of average data of ore sands from cores stored at the Florida Geological Survey core library (Elsner, 1992 a, see fig. 7) gave an average concentration of 3.93 wt.-% h. m..

Using  $A = 77.6 \text{ km}^2$ ,  $T = 10.7 \text{ m}$ ,  $W = 1.60 \text{ t/m}^3$  and  $P = 3.9 \text{ wt.-%}$ ,  $V$  can be calculated with 830.32 mill. m<sup>3</sup> of ore sand with a weight of 1,328.51 Mt. By this the original content of the ore deposit can be calculated with 51.8 Mt. of available h. m. (original reserve base, after U.S. Bureau of Mines/U.S. Geological Survey, 1980), which were made up by about 27.4 Mt. of titanium minerals, 7.8 Mt. of zircon, 8.9 Mt. of staurolite, but only 15,500 tonnes of monazite (see tab. 3).

Based on these data it becomes clear that before the start of mining in 1949 the Trail Ridge ore body was not only the biggest h. m. deposit of the Atlantic coastal plain (Mertie, 1958; Pirkle et al., 1984; 1989; Force & Garnar, 1985; Force & Rich, 1989), but one of the five biggest h. m. placer deposits in the world (see tables 22 and 23).

|                       | Mining World (1948)<br>Spencer (1948)<br>Peterson (1966) | Mallard (1986) | Meyer (1980) | Overstreet (1967)<br>Whittle (1957)<br>Calver (1957) | Forbes (1991) | Pirkle et al. (1991)<br>(TRAIL RIDGE) | Pirkle et al. (1991)<br>(HIGHLAND) | Elsner (1992 a) |
|-----------------------|----------------------------------------------------------|----------------|--------------|------------------------------------------------------|---------------|---------------------------------------|------------------------------------|-----------------|
| Ilmenite              |                                                          | 42.6 %         |              |                                                      |               | 34.7 %                                | 32.8 %                             | 36.8 %          |
| Leucoxene             | 54 %                                                     | 5.1 %          | 46 %         | 45 %                                                 | 50 %          | 7.9 %                                 | 10.1 %                             | 14.3 %          |
| Rutile                |                                                          | 1.5 %          |              |                                                      | 2 - 3 %       | 3.4 %                                 | 1.8 %                              | 1.7 %           |
| Zircon                | 15 %                                                     | 16.3 %         | 14 %         | 15 %                                                 | 15 %          | 20.6 %                                | 16.2 %                             | 15.0 %          |
| Staurolite            | 14 %                                                     | 23.2 %         | 26 - 28 %    | 20 %                                                 | 15 %          | 11.0 %                                | 19.5 %                             | 17.2 %          |
| Tourmaline            | 5 %                                                      |                |              | 5 %                                                  | 5 %           | 4.2 %                                 | 6.7 %                              | 4.3 %           |
| Sillimanite           | 6 %                                                      | 11.3 %         | 4 - 5 %      | 5 %                                                  | 5 - 6 %       | 17.5 %                                | 12.3 %                             | 6.0 %           |
| Kyanite               | 3 %                                                      |                | 2 - 5 %      | 4 %                                                  | 3 %           |                                       |                                    | 3.3 %           |
| Spinel                | +                                                        |                | +            |                                                      | +             | 0.0 %                                 | 0.1 %                              | 0.1 %           |
| Andalusite            |                                                          |                |              | 6 % (+ Pyroxene)                                     |               |                                       |                                    | 0.3 %           |
| Corundum              | +                                                        |                | +            |                                                      | +             | 0.6 %                                 | 0.4 %                              | 0.4 %           |
| Topaz                 |                                                          |                |              |                                                      |               |                                       |                                    | 0.4 %           |
| Monazite/Xenotime (B) | +                                                        |                | +            | +                                                    | +             | 0.1 %                                 | 0.1 %                              | <0.1 %          |
| Garnet (C)            | +                                                        | 0.0 %          |              |                                                      |               | 0.0 %                                 | 0.0 %                              | <0.1 %          |
| Epidote (D)           |                                                          | 0.0 %          |              |                                                      |               | 0.0 %                                 | 0.0 %                              | <0.1 %          |
| Hornblende (E)        |                                                          | 0.0 %          |              |                                                      |               | 0.0 %                                 | 0.0 %                              | 0.0 %           |
| Brookite              |                                                          |                |              |                                                      |               |                                       |                                    | <0.1 %          |
| Anatase               |                                                          |                |              |                                                      |               |                                       |                                    | <0.1 %          |
| Sphene                |                                                          |                |              |                                                      |               |                                       |                                    | <0.1 %          |
| total                 | 97 % +                                                   | 100.0 %        | 92 - 97 %    | 98 % +                                               | 95 - 97 %     | 100.0 %                               | 100.0 %                            | 99.8 % +<br>(A) |

Tab. 3: Average composition of h. m. concentrates of the Trail Ridge placer deposit after various authors

Not being mined can or could be about 2.5 Mt. of h. m. ( $A = 9.9 \text{ km}^2$ ,  $T = 8 \text{ m}$ ,  $W = 1.60 \text{ t/m}^3$ ,  $P = 2 \text{ wt.-%}$ ) due to missing rights of possession, and another 0.16 Mt. ( $A = 77.6 - 9.9 = 67.7 \text{ km}^2$ ,  $T = 0.15 \text{ m}$ ,  $W = 1.60 \text{ t/m}^3$ ,  $P = 1 \text{ wt.-%}$ ) from the upper 15 cm of top soil.

Combining all these new data it can now be stated that Du Pont originally had reserves of 49.1 Mt. of h. m. at its disposal, of which, at a rough estimate, about 65 % have been mined up to date.



## Folkston

The Folkston ore deposit is situated about 4 km north of the St. Marys River in Charlton Co., Georgia, but must be dealt with when describing the h. m. deposits in northeastern Florida. About 8 km north of the Trail Ridge feature the Folkston deposit lies between 24 m to 30 m above msl, only 3 km west of the St. Marys Meander Plain, which reaches elevations of only 4 m to 6 m above msl. The main area of the Folkston deposit encompasses the central part of a very weakly delineated north-south trending ridge with a width of 2 km and a length of 11 km. The only sharp limit of this ridge is marked by Baileys Branch, a local creek flowing into the Satilla River. Further to the west and northwest three more, very small h. m. deposits are known (see fig. 10), which can be correlated with even smaller ridges.

The Folkston h. m. deposit was discovered in 1952 by Du Pont in the course of an extensive exploration program on h. m. At the end of the '50s Humphreys Gold Corporation was commissioned to go into planning for the mining of this deposit, which finally took place between August 1965 to July 1974 after leaving the Jacksonville deposit. Only the main deposit was mined, starting in the south and moving northward with an approximate rate of 431 tonnes ore sand every hour or 6,000 m<sup>2</sup>/month (Humphreys Mining Company, 1974). Worth mentioning is the crossing of Georgia Highway 252, which took place within one month, leaving a strip of 32 m (105 ft.) unmined to both sides of this road. Also for the first time in Florida h. m. mining history reclamation took place at the end of mining, which left behind "eye-pleasing green pastures enhanced by two lakes for recreation and water storage" (Mining Engineering, 1936, p. 36) and gained Humphreys Mining Company an award by the state of Georgia for "outstanding reclamation of surface mined land" (Garnar, 1978 b).

The geology and age of the Folkston h. m. deposit has never been looked at in great detail. By comparison with granulometric, mineralogical, and geomorphologic data from other deposits (especially Jacksonville) it can be supposed, however, that the main deposit formed as a part of a barrier island. Its age can be correlated with one of the maxima of the Penholoway transgression, about  $1.3 \pm 0.1$  Ma B.P.. The Folkston north and west extensions are presumed to have formed as nearshore bars during the same transgression.

The composition of the h. m. suite of the Folkston placer deposit (main area) is known from

- a.) one report (Humphreys Gold Corporation, 1959),
- b.) one sample of original ore sand (see fig. 11) placed at the author's disposal by John Gully, former employee of Humphreys, and
- c.) one random sample taken in the field near the surface, 600 m northwest of the former mining site south of Baileys Branch

|               | a) pilot study<br>HGC (1959) | b) Folkston - ore sand | c) sample,<br>south of Baileys Branch |
|---------------|------------------------------|------------------------|---------------------------------------|
| h. m. content | 3.81 %                       | 4.22 %                 | 0.68 %                                |
| ilmenite      | 59.6 %                       | 31 %                   | 28 %                                  |
| leucoxene     | in ilmenite                  | 27 %                   | 23 %                                  |
| rutile        | in ilmenite                  | 7 %                    | 7 %                                   |
| zircon        | 16.5 %                       | 9 %                    | 11 %                                  |
| kyanite       | 7.9 %                        | 2 %                    | 2 %                                   |
| sillimanite   | in kyanite                   | 5 %                    | 13 %                                  |
| andalusite    | in kyanite                   | +                      | 1 %                                   |
| staurolite    | 11.5 %                       | 9 %                    | 7 %                                   |
| tourmaline    | in staurolite                | 3 %                    | 2 %                                   |
| epidote       | 3.7 %                        | 3 %                    | +                                     |
| garnet        | in epidote                   | 1 %                    | 0 %                                   |
| hornblende    | 0.0 %                        | +                      | 1 %                                   |
| monazite      | 0.8 %                        | 1 %                    | 1 %                                   |
| xenotime      | in monazite                  | +                      | +                                     |
| topaz         | 0.0 %                        | 1 %                    | 2 %                                   |
| corundum      | 0.0 %                        | 0 %                    | 1 %                                   |
| spinel        | 0.0 %                        | 0 %                    | +                                     |
| anatase       | 0.0 %                        | +                      | 1 %                                   |
| sphene        | 0.0 %                        | +                      | 0 %                                   |
| chloritoid    | 0.0 %                        | +                      | 0 %                                   |

Tab. 4: H. m. composition of ore sands of the Folkston placer deposit (main area) (compare fig. 14). Notice good correlation between samples a) and b) (except titanium minerals and zircon contents). After Lynd & Lefond (1975, 1983), the titanium mineral content of the ore sand of the main area was 56 %.  
All data in wt.-%. (+ = less than 0.5 wt.%)

Similar to the Trail Ridge deposit the Folkston placer deposit was mined by a cutter-head suction dredge with a pre-concentration of h. m. in a wet mill by Humphreys spirals. In the stationary dry mill a mixed concentrate of titanium minerals (ilmenite, leucoxene, and rutile), called titanium product, was produced. In the zircon (wet and dry) mill zircon was the end-product, while an important by-product used to be a monazite concentrate. About its production (see fig. 11) former chief engineer E. V. Whittle wrote in a private letter to A. E. Humphreys in Denver in 1966: " In the operation of the crossbelt the feed is introduced on an endless belt which in turn passes under seven magnetic belts each of increasing magnetic intensity and operating at right angles to the feed belt. As the feed passes under each of the seven crossbelts, the magnetic material is lifted and moved to one side until it is removed from the magnetic field and drops into a pocket for removal. Belt #1 is the least magnetic and, therefore, removes only the most magnetic material such as rust, iron fillings, etc. Each succeeding belt is in turn more magnetic and removes a correspondingly less magnetic material from the feed belt. Belt #2 removes primarily garnet, #3, garnet-staurolite, #4, staurolite-monazite and #5, 6, 7 remove monazite. Some material remains on the feed belt and is returned to the zircon mill. This material is mostly zircon and is referred to as 'tail belt product'."

This means that only three different h. m. concentrates were produced at Folkston:

- a titanium product containing ilmenite, leucoxene, and rutile, and
- a zircon concentrate, which both were sold to Du Pont, as well as
- a monazite concentrate, which was bought by the chemical company W. R. Grace & Co.

To increase the amount of rare earths (RE) in the monazite concentrate (and thereby selling it at a higher price), xenotime was separated from "belt #2" and mixed with the monazite. By this procedure it was possible to increase the rare earths oxide (REO) content from about 56 - 57 % to more than 60 %, which also had its effect on the relative content of some of the heavier rare earths (see chemical analyses in appendix II).

Xenotime as a separate product, however, was never sold at any time (E. V. Whittle, pers. comm., 1990; Thompson & Whittle, 1990).

In 1971 (unpublished) J. Gully had a closer look at the zircon wet mill tailings (see fig. 11), finding :

64.3 wt.-% quartz,  
27.2 wt.-% staurolite, garnet, and epidote,  
6.4 wt.-% kyanite, and sillimanite,  
2.1 wt.-% zircon, and  
traces of ilmenite, leucoxene, and rutile.

76.0 wt.-% of the h. m. fraction of 35.7 wt.-% were magnetic, consisting above all of staurolite, as well as minor amounts of garnet, epidote, ilmenite, and leucoxene.

The non-magnetic part of 24.0 wt.-% was made up of about 80 - 85 % kyanite/sillimanite (see appendix II: II-F.-Kyasill), 15 - 20 % zircon, and traces of rutile and leucoxene.

In 1973 T. E. Garnar analyzed a similar sample from Folkston getting these unpublished results:

|             |        |
|-------------|--------|
| ilmenite    | 2.4 %  |
| leucoxene   | 6.9 %  |
| rutile      | 0.2 %  |
| garnet      | 2.0 %  |
| epidote     | 14.3 % |
| staurolite  | 31.2 % |
| tourmaline  | 6.9 %  |
| kyanite     | 9.3 %  |
| sillimanite | 21.6 % |
| zircon      | 5.2 %  |

As the Folkston placer deposit, or rather its main area, was mined completely, comparisons between the estimated (Humphreys Gold Corporation, 1959) and the final (Humphreys Mining Company, 1974) mining data are possible. Also a recalculation of the original h. m. content can be made (see tab. 5).

|                                              | re-calculation<br>Elsner (1992 a) | pilot study<br>after HGC (1959) | mined 1965 - 1974<br>(after HMC (1974)) |
|----------------------------------------------|-----------------------------------|---------------------------------|-----------------------------------------|
| A (km <sup>2</sup> )                         | 7.097                             | 7.097                           | ca. 6.5                                 |
| T (m)                                        | 2.5                               | 2.5                             | 2.5                                     |
| V (mill. m <sup>3</sup> )                    | 17.741                            | 17.741 (?)                      | 15.860 (?)                              |
| W (t/m <sup>3</sup> )                        | 1.78                              | 1.73 (?)                        | 1.78 (?)                                |
| Q (Mt.)                                      | 31.580                            | 30.638 (?)                      | 28.946472                               |
| P (%)                                        | 4.25                              | 4.27                            | 4.25                                    |
| HM (Mt.)                                     | 1.342                             | 1.308                           | 1.230                                   |
|                                              | available                         | available/mineable              | produced                                |
| Titanium Product (t)                         | ca. 800,000 (60 %)                | 779,719/545,805                 | 462,001                                 |
| Zircon (t)                                   | ca. 121,000 (9 %)                 | 215,862                         | 128,863                                 |
| Monazite (t)                                 | ca. 13,400 (1 %)                  | 10,466                          | 11,415                                  |
| mining operating time                        |                                   |                                 | 3,170 d/67,210.2 h                      |
| average                                      |                                   |                                 | 21.20 h/d                               |
| mining recovery (HM)                         |                                   | 92 %                            | 94 %                                    |
| wet mill operating time                      |                                   |                                 | 3,170 d/70,173.6 h                      |
| average                                      |                                   |                                 | 22.14 h/d                               |
| wet mill concentrate (t)                     |                                   |                                 | 823,547                                 |
| wet mill recovery (zircon)                   |                                   | 85 %                            |                                         |
| wet mill recovery (monazite)                 |                                   | 85 %                            |                                         |
| wet mill recovery (TiO <sub>2</sub> )        |                                   | 80 %                            | 82.4 %                                  |
| wet mill recovery (unecon. HM)               |                                   | 70 %                            |                                         |
| wet mill recovery (total HM)                 |                                   |                                 | 70.0 %                                  |
| dry mill operating time                      |                                   |                                 | 3075 d/70,745.7 h                       |
| average                                      |                                   |                                 | 23.01 h/d                               |
| dry mill concentrate (t)                     |                                   |                                 | 602,279                                 |
| dry mill recovery (TiO <sub>2</sub> )        |                                   | 95 %                            | 94.3 %                                  |
| dry mill recovery (HM)                       |                                   |                                 | 73.1 %                                  |
| zircon wet mill recovery (ZrO <sub>2</sub> ) |                                   | 70 %                            |                                         |
| zircon dry mill recovery (ZrO <sub>2</sub> ) |                                   | 80 %                            |                                         |

Tab. 5: Planned and achieved production, and recalculation of original reserve base of the Folkston placer deposit (main area) (all data in metric tonnes = t)

|                              | "western extensions" | "northern extensions" | total    |
|------------------------------|----------------------|-----------------------|----------|
| TiO <sub>2</sub> in ore sand | 1.48 %               | 1.83 %                | 1.80 %   |
| A (km <sup>2</sup> )         | 0.904                | 1.217                 | 9.218    |
| T (m)                        | 1.6 (?)              | 2.0 (?)               | 2.3      |
| V (mill. m <sup>3</sup> )    | 1.447                | 2.435                 | 21.6     |
| W (t/m <sup>3</sup> )        | 1.78 (?)             | 1.78 (?)              | 1.78 (?) |
| Q (Mt.)                      | 2.576                | 4.334                 | 38.5     |
| P (%)                        | ca. 3 (?)            | ca. 4 (?)             | ca. 4    |
| HM (Mt.)                     | 0.077                | 0.173                 | ca. 1.6  |

**Tab 6: Economic geology of the "west" and "north extensions" of the Folkston placer deposit and assumed original reserve base of the Folkston placer district  
(TiO<sub>2</sub>-content after Humphreys Gold Corporation, 1959, "main area": 1.84 %)**

All three individual placers of the Folkston placer district contained about 1.6 Mt. of available h. m., of which most (ca. 80 %) were mined between 1965 and 1974. The Folkston placer district, therefore, can be considered depleted by both economic and geologic aspects.

## Boulogne

The Boulogne h. m. deposit was named after a small village with the same name, located at the St. Marys River close to the Georgia State border. Following Florida State Road 121 from Boulogne to the south one reaches the northern boundary of the placer deposit after 2.5 km.

As near Folkston, before mining the area was covered with trees and characterized by numerous small ponds and swamps. The deposit itself encompassed the central part of a ridge trending nearly north-south, and reaching a width of 1.9 km and a length of more than 5.3 km. With an average altitude of the surroundings of 23 to 27 m above msl, the highest point of the ridge, i. e. the deposit was 32.6 m above msl.

Of utmost importance for the explanation of its origin is another ridge, 3.5 km north-east, reaching a width of 2.8 km and a length of 5.6 km. This "Pigeon Creek Church Ridge" is separated from the Boulogne ridge by the Pigeon Creek, draining into the St. Marys River via Hampton Lake (see fig. 12).

Nothing has ever been published about the discovery of the Boulogne deposit. Most probably it was found in the wake of the exploration program for the Folkston placer district in the '50s. (compare fig. 13). Without mining the Folkston placer deposit first, production at Boulogne would have never been feasible. With Folkston, however, the necessary personnel and infrastructure was at hand and in July 1974 the complete wet mill and dredge from Folkston were dismantled, cleaned and rebuilt at Boulogne within only four months. On Nov. 20, 1974 mining and separation at Boulogne started, although the wet-mill concentrate had to be hauled to Folkston by truck for further processing in the dry mill. (Garnar, 1978 b, E. V. Whittle, pers. comm., 1990). As in all the years before a "Titanium Product" and the zircon were sold to Du Pont while the monazite was shipped to W. R. Grace & Co. (Thompson & Whittle, 1990) (compare fig. 14).

Starting from the north and soon crossing Florida State Road 121, mining moved to the south, with ore grades steadily decreasing. South of a minor road further mining would not have been feasible anymore (E. V. Whittle, pers. comm., 1990), so on Oct. 14, 1979 the dredge and wet mill at Boulogne closed down, followed 40 days later by the dry mill in Folkston.

After reclamation of the Boulogne deposit in 1980 (Garnar, 1983) it was planned to start mining the Altama h. m. placer deposit near Brunswick, GA, which was described by Pirkle et al. in 1989. As world market prices for h. m. were very low, however, mining this deposit would not have been feasible anymore, so that in 1980 Humphreys Gold Corporation/Humphreys Mining Company, after more than 90 years of activity, had to go out of business.

Continuing some of Humphreys former activities is Carpc, Inc. in Jacksonville, a consultant, which once arose from Humphreys Gold Corporation itself.

It was possible to outline the complete geology of the Boulogne deposit by re-analyzing the core "Boulogne 1", which after 25 years still is stored in the F.G.S. core library (see fig 15). The findings of these analyses have been explained in detail by Elsner (1992 a, b). There it was stated that the placer itself was formed in a nearshore bar environment at the maximum of the Penholoway transgression, some 1.3 Ma. B.P. Most probably during the following regression barrier islands formed a little bit farther east, allowing h. m. to be concentrated in dunal systems, leading to placer deposits like Folkston "main area" and presumably "Pigeon Creek Church Ridge".

Mining, processing, and separation of h. m. from the Boulogne deposit was exactly the same as near Folkston (see fig. 11). Naturally production data were quite different, however, and can be quoted after Humphreys Mining Company (1980) as follows:

|                                  |                                                                                |
|----------------------------------|--------------------------------------------------------------------------------|
| • wet mill feed                  | 3.75 % h. m. @ 1.32 % $\text{TiO}_2$                                           |
| • wet mill tailings              | 1.09 % h. m. @ 0.28 % $\text{TiO}_2$                                           |
| • wet mill concentrate           | 68.2 % h. m. @ 29.9 % $\text{TiO}_2$ , 6.8 % $\text{ZrO}_2$                    |
| • organic index before scrubbing | 196                                                                            |
| • organic index after scrubbing  | 44                                                                             |
| • dry mill non-conductors        | 43.4 % h. m. @ 2.43 % $\text{TiO}_2$ , 11.9 % $\text{ZrO}_2$                   |
| • zircon wet mill tailings       | 27.1 % h. m. @ 1.35 % $\text{TiO}_2$ , 0.82 % $\text{ZrO}_2$                   |
| • Titanium Product               | 71.7 % $\text{TiO}_2$ , 0.67 % $\text{ZrO}_2$                                  |
| • zircon concentrate             | 65.8 % $\text{ZrO}_2$ , 0.13 % $\text{TiO}_2$ , 0.58 % $\text{Al}_2\text{O}_3$ |
| • monazite concentrate           | 63.3 % T.O., 0.56 % $\text{TiO}_2$ , 2.91 % $\text{ZrO}_2$ , 7.9 % insol.      |

After an unpublished map at a scale of 1:4,800 (E. V. Whittle, unpublished) the area A of the northern part of the Boulogne placer deposit, which was mined out, is known quite precisely to be 2.571300  $\text{km}^2$ . After Pirkle et al. (1971, p. 18, 1974, p. 1131, and 1977, p. 50) the total area of the Boulogne placer deposit was about 4.149  $\text{km}^2$ , of which 3.259  $\text{km}^2$  belonged to the northern, and 0.890  $\text{km}^2$  to the southern part.

After Pirkle et al. (1971, 1974), Lynd & Lefond (1975, 1983), Garnar (1978 b, 1980, 1985), and US Bureau of Mines (1987), the average thickness of the ore sand in the area mined out was varied between 5 and 25 ft. (1.5 to 7.6 m). After Thompson & Whittle (1990) as well as E. V. Whittle (pers. comm., 1990) the mean ore thickness was 15 ft. (4.6 m). Comparing all these information with data from Humphreys Mining Company (1980), who summarized all available production data, the following table can be presented:



|                                       | northern<br>part | southern | total   | mined<br>1974 - 1979 |
|---------------------------------------|------------------|----------|---------|----------------------|
| A (km <sup>2</sup> )                  | 3.259            | 0.890    | 4.149   | 2.517300             |
| T (m)                                 | 4.6              | 4.0      | 4.5     | 4.6                  |
| V (mill. m <sup>3</sup> )             | 14.991           | 3.560    | 18.671  | 11.572               |
| W (t/m <sup>3</sup> )                 | 1.41             | 1.41     | 1.41    | 1.41                 |
| Q (Mt.)                               | 21.138           | 5.020    | 26.325  | 16.316745            |
| P (%)                                 | 3.75             | 2.0      | 3.4     | 3.75                 |
| HM (Mt.)                              | 0.793            | 0.100    | 0.895   | 0.612                |
|                                       |                  |          |         |                      |
| Titanium Product (t)                  | 490,000          | 60,000   | 555,000 | 193,137              |
| Zircon (t)                            | 100,000          | 13,000   | 115,000 | 50,046               |
| Monazite (t)                          | 4,000            | 500      | 4,500   | 2,834                |
|                                       |                  |          |         |                      |
| mining operating time                 |                  |          |         | 1,707 d/35,579.4 h   |
| average                               |                  |          |         | 20.84 h/d            |
| mining recovery (HM)                  |                  |          |         | 95.2 %               |
|                                       |                  |          |         |                      |
| wet mill operating time               |                  |          |         | 1,701 d/35,579.4 h   |
| average                               |                  |          |         | 20.84 h/d            |
| wet mill concentrate (t)              |                  |          |         | 545,623              |
| wet mill recovery (TiO <sub>2</sub> ) |                  |          |         | 79.5 %               |
| wet mill recovery (HM)                |                  |          |         | 63.9 %               |
|                                       |                  |          |         |                      |
| dry mill operating time               |                  |          |         | 1,717 d/37,965.8 h   |
| average                               |                  |          |         | 22.11 h/d            |
| dry mill concentrate (t)              |                  |          |         | 246,017              |
| dry mill recovery (TiO <sub>2</sub> ) |                  |          |         | 97.1 %               |
| dry mill recovery (HM)                |                  |          |         | 72.8 %               |

Tab. 7: Original reserve base of the Boulogne placer deposit and production data of the area mined between 1974 to 1979 (after Humphreys Mining Company, 1980)

In 1987 the original reserves of the Boulogne placer deposit were stated by the U.S. Bureau of Mines to have been some 20 mill. short tons (= 18.14 Mt.) of ore sand. This is only about 70 % of the recalculated figure of 26.325 Mt. given above.



## Green Cove Springs

The Green Cove Springs h. m. placer deposit (Clay Co., FL.) was named after a small village with the same name, located at the western shore of the broad St. Johns River. The main ore body stretches from a few kilometers southeast of the village for about 19 km to the south near Bostwick. The average width of this deposit is 1.4 km (maximum: 2.4 km). It forms the eastern and central part of an only weakly delineated ridge, which is reaching an elevation of about 40 m above msl. west of the deposit.

Approximately 2.4 km farther west lies the small ore body, reaching a width of only a few hundred meters and a length of some 7 km.

This small ore body, on the other hand, is separated by a zone some 100 - 200 m wide and without any h. m. enrichments from the western ore body, which also is about 7 km long and about 1.3 km wide. In sharp contrast to the main ore body this western ore body encompasses an obvious ridge, which overtops the surrounding swamps by ca. 8 m (maximum elevation: 39.3 m above msl.). Similar to Boulogne the area is tree-covered and dotted with numerous shallow swamps. Forestry is by the Union Camp Corporation (see fig. 16).

The main ore body of the Green Cove Springs placer deposit was found in 1966 by an exploration geologist, who was working for Union Camp Corporation and in charge of investigating all company-owned forest areas in the southeastern US. Apart from finding the Green Cove Springs placer deposit he was lucky enough to discover the Altama h. m. placer deposit near Brunswick, Georgia (Pirkle et al., 1989) as well, which has already been mentioned one chapter before (E. V. Whittle, pers. comm., 1990).

For the mining of the Green Cove Springs deposit a company named Titanium Enterprises was founded by both Union Camp Corporation as the land-owner (50 %) and American Cynamid as the mineral purchaser (50 %) (Pirkle et al., 1971, 1974, Garnar, 1972, 1978 a, b, 1980, Lynd & Lefond, 1975, 1983, Industrial Minerals, 1978, Harvey & Brown, 1986, Pirkle & Reynolds, 1988).

Mining started in 1972 from the north proceeding southward. Of these first years not much is known, besides that titanium minerals, zircon, and monazite were separated. Thoughts about also producing garnet (I.-G.C.S.-garnet, see appendix II) and staurolite (I.-G.C.S.-staurolite) concentrates in the mid of the '70s did not advance (C. Webb, pers. comm., 1991). According to Industrial Minerals (1979 b) the average mining rate was about 1,000 tonnes/hour; after in 1976 production of monazite was increased. In 1971 Pirkle et al. assessed that there were enough mineral reserves for a mining period of 25 to 28 years.

On July 1, 1978 (Industrial Minerals, 1978 a), however, Titanium Minerals stopped production, mainly for the dramatic decrease of zircon prices on the world market (Industrial Minerals, 1980 a). To keep losses at a minimum tailings were processed for staurolite, zircon, and monazite during the following sale negotiations (Industrial Minerals, 1978, 1979 a, b, Garnar, 1980 a, Harvey & Brown, 1986).

Humphreys Mining Corporation was one of the first companies being informed about the planned sale of the Green Cove Springs deposit. Because of having economic problems itself, it was not able, however, to shift production from Folkston to Green Cove Springs (E. V. Whittle, pers. comm., 1990). In late April 1980, after working out a feasibility study, the whole operations and mining permits of the Green Cove Springs deposit were bought by Associated Minerals Consolidated Ltd. (AMC), a subsidiary of Consolidated Gold Fields Australia (now: Renison Goldfields Consolidated Ltd. = RGC) for 11.7 mill. US-\$. Investments of another 6 mill. US-\$ were planned for the coming years, as reserves should be high enough to allow a yearly production of 25,000 tonnes of rutile, 25,000 tonnes of zircon, 50,000 tonnes of

ilmenite, and minor amounts of leucoxene, monazite, and staurolite for the next 16 years (Industrial Minerals, 1980 b).

After the taking over of the deposit by AMC and the founding of the subsidiary Associated Minerals (USA) Inc. (AMU) staurolite was being produced for the first time from Green Cove Springs. In 1985, however, production of this mineral already ceased (Garnar, 1987). By applying Australian knowledge and being the only US-producer of a rutile concentrate (capacity: 32,000 tonnes/yr., after Lynd, 1987; production: 27,000 tonnes/yr., after Lynd, 1990) first profits could be realized as early as 1983 (Harvey & Brown, 1986).

In the progress of an exploration campaign near the main ore body in the early '80s as another success the western and small ore bodies were discovered. After Harvey & Brown (1986) by finding these deposits the reserves of AMU (in 1992 renamed to RGC (USA) Mineral Sands Inc.) were doubled.

The geologic history of the Green Cove Springs deposit is very similar to that of the Folkston and Boulogne ore bodies and has been described in detail by Elsner (1992 b). According to his evaluation which is based on the results of h. m. and grain size analyses of several cores drilled in the h. m. deposits of northeastern Florida and information by the mining companies, the main ore body was formed in a nearshore bar environment during the Penholoway transgression, some  $1.3 \pm 0.1$  Ma. ago. While nothing certain is known about the origin of the small ore body, the western ore body must have been formed as a coastal dune containing a totally different h. m. suite with less economic minerals than in the main deposit (see figs. 17 and 18 and tab. 8).

|                            | Boulogne                | Green Cove Springs  |                           |                           |                         |
|----------------------------|-------------------------|---------------------|---------------------------|---------------------------|-------------------------|
|                            | Boulogne 1<br>(W 10482) | Union Camp 3<br>--- | Union Camp 1<br>(W 10481) | Union Camp 2<br>(W 12112) | western ore body<br>--- |
| Surface elevation          | 30.8 m                  | 36.0 m              | 34.1 m                    | 25.9 m                    | ---                     |
| Ore thickness              | 7 m                     | 6 m                 | 5 m                       | 3 m                       | 10 m                    |
| Average grade              |                         |                     |                           |                           |                         |
| Elsner (1992 a)            | 2.71 %                  | ---                 | 8.36 %                    | 7.92 %                    | 3.25 %                  |
| Pirkle et al. (1971, 1991) | 3.12 %                  | 3.67 %              | 4.83 %                    | 3.67 %                    | ---                     |
| Economic minerals          |                         |                     |                           |                           |                         |
| Ilmenite                   | 35.2 %                  | ---                 | 33.9 %                    | 33.6 %                    | 26 %                    |
| Leucoxene                  | 19.8 %                  | ---                 | 20.3 %                    | 19.1 %                    | 17 %                    |
| Rutile                     | 6.8 %                   | ---                 | 8.1 %                     | 9.4 %                     | 7 %                     |
| Zircon                     | 13.0 %                  | ---                 | 16.9 %                    | 13.4 %                    | 7 %                     |
| Monazite/Xenotime          | 0.5 %                   | ---                 | 1.0 %                     | 0.3 %                     | 0 %                     |
| Sum                        | 75.3 %                  | ---                 | 80.2 %                    | 75.8 %                    | 57 %                    |
| Non-economic minerals      |                         |                     |                           |                           |                         |
| Garnet                     | 0.4 %                   | ---                 | 0.7 %                     | 0.0 %                     | 2 %                     |
| Epidote                    | 2.4 %                   | ---                 | 0.2 %                     | <0.1 %                    | 13 %                    |
| Hornblende                 | 0.6 %                   | ---                 | 0.8 %                     | 0.3 %                     | 2 %                     |
| Sillimanite                | 6.5 %                   | ---                 | 4.5 %                     | 5.9 %                     | 4 %                     |
| Andalusite                 | 0.3 %                   | ---                 | 0.3 %                     | 0.2 %                     | 1 %                     |
| Kyanite                    | 1.6 %                   | ---                 | 1.2 %                     | 1.1 %                     | +                       |
| Staurolite                 | 8.9 %                   | ---                 | 8.5 %                     | 12.1 %                    | 15 %                    |
| Tourmaline                 | 1.9 %                   | ---                 | 2.0 %                     | 3.4 %                     | 4 %                     |
| Spinel                     | 0.1 %                   | ---                 | <0.1 %                    | 0.0 %                     | +                       |
| Corundum                   | 0.6 %                   | ---                 | 0.2 %                     | 0.3 %                     | +                       |
| Topaz                      | 1.2 %                   | ---                 | 0.6 %                     | 0.8 %                     | 1 %                     |
| Anatase                    | 0.1 %                   | ---                 | 0.5 %                     | 0.0 %                     | 0 %                     |
| Brookite                   | 0.0 %                   | ---                 | <0.1 %                    | 0.0 %                     | 0 %                     |
| Sphene                     | 0.1 %                   | ---                 | 0.2 %                     | 0.1 %                     | 0 %                     |
| Chloritoid                 | <0.1 %                  | ---                 | 0.0 %                     | 0.0 %                     | 0 %                     |
| Sum                        | 24.7 %                  | ---                 | 19.8 %                    | 24.2 %                    | 43 %                    |
| Total                      | 100.0 %                 | ---                 | 100.0 %                   | 100.0 %                   | 100 %                   |

Tab. 8: Average h. m. grade and composition of the Boulogne and Green Cove Springs placer deposits (after Elsner 1992 b)

A comparison of available data on the average h. m. composition of the Green Cove Springs main ore body is given below (see also fig. 19).

|                   | Pirkle et al. (1991) | Elsner (1992 a) |
|-------------------|----------------------|-----------------|
| ilmenite          | 47.0 %               | 33.8 %          |
| leucoxene         | 6.4 %                | 19.7 %          |
| rutile            | 4.6 %                | 8.8 %           |
| zircon            | 15.1 %               | 15.1 %          |
| kyanite           | 6.7 %                | 1.1 %           |
| sillimanite       | in kyanite           | 5.2 %           |
| staurolite        | 9.4 %                | 10.3 %          |
| spinel            | 0.1 %                | < 0.1 %         |
| corundum          | 0.3 %                | 0.3 %           |
| tourmaline        | 6.2 %                | 2.7 %           |
| monazite/xenotime | 0.7 %                | 0.7 %           |
| garnet            | 0.5 %                | 0.3 %           |
| epidote           | 3.1 %                | 0.1 %           |
| hornblende        | 0.1 %                | 0.5 %           |
| topaz             |                      | 0.7 %           |
| anatase           |                      | 0.4 %           |
| andalusite        |                      | 0.2 %           |
| sphene            |                      | 0.1 %           |

Tab. 9: Average h. m. composition of the Green Cove Springs main ore body (all data in wt.-%).

By mining its deposit with a bucketwheel suction dredge and the increased use of shaking tables for the separation of the various h. m. AMU (RGC) differs from the other former and current h. m. producers in northeastern Florida. Publications showing flow-diagrams of the Green Cove Springs plant are not known and, consequently, could also not be made available by AMU.

Of utter importance to AMU (RGC), which currently employs about 125 people in Florida (J. Elder, pers. comm., 1990) is an ecologically based reclamation of its mining site.

Well known are details on the h. m. concentrates produced by AMU (RGC). After ceasing further production of staurolite in 1985, now ilmenite, leucoxene, rutile, zircon, and monazite concentrates are being sold.

Production of ilmenite (min. 63 %  $\text{TiO}_2$ ) was 63,000 tonnes/yr. in 1986, and that of leucoxene (65 %  $\text{TiO}_2$ ) 12,000 tonnes/yr. (Clarke, 1986). Further on with a capacity of 35,000 tonnes/yr. 25,000 tonnes/yr. of zircon (min. 66.5 %  $\text{ZrO}_2$ ) were produced in 1982 (Coppe, 1983), rising with an increased capacity to 35,000 tonnes/yr. in 1986 (Harvey & Brown). Production figures of rutile were already given (27,000 tonnes/yr.), those of monazite (min. 57 % REO, max 7 %  $\text{ThO}_2$ ) are said to have been 700 tonnes/yr. in 1984 (Griffiths), and the capacity in 1988 (O'Driscoll) to have been 700 - 800 tonnes/yr.

Taking into account a ratio of monazite to xenotime in parts of the main ore body of three to one (after Elsner, 1992 a), after the planned increase of the wet mill capacity to 1,800 tonnes/h about 150 - 300 tonnes/yr. of xenotime could be produced.

Monazite is being sold to Rhone Poulenc, France. Rutile is sent to a TiO<sub>2</sub>-pigment plant of Kemira Oy Inc. in Savannah, GA, while ilmenite is bought by Du Pont for its TiO<sub>2</sub>-pigment plants in Tennessee and Delaware. Leucoxene is being used by Kerr Mc Gee in Mobile, AL to produce synthetic rutile. Zircon is crushed in South Carolina and New York to zircon flour (see Garnar, 1980), which is being used above all in the ceramics and refractory industries.

The volume of the deposit is difficult to calculate, especially the tonnages of available h. m. The area of the various deposits is well known due to a map kindly supplied by AMU (RGC) in a scale of 1:24,000 and can be given with 23.218 km<sup>2</sup> (main ore body), 6.022 km<sup>2</sup> (western ore body), and 1.811 km<sup>2</sup> (small ore body) respectively.

The average thickness of the h. m. enriched zone in the main ore body was stated by Pirkle et al. (1971, 1974), Lynd & Lefond (1975, 1983), Garnar (1978 b, 1980), Wynn et al. (1985), Fantel et al. (1986), and U.S. Bureau of Mines (1987) to be 6 m (20 ft.), and after Pirkle (1972) to be a little bit more than 4.5 m (15 ft.). In the cores „Union Camp 1“ it was 5 m, in „Union Camp 2“ 3 m, and in „Union Camp 3“ 6 m (see figs. 17 and 18). An average thickness of 5 m, therefore was assumed by Elsner (1992 a). The depth of actual mining differs between 4.6 and 10 m (S. K. Gilman, pers. comm., 1991), while latter value also is the average thickness of the western ore body.

The volume factor W is not known, but at least in the main ore body it should be similar to the Boulogne placer deposit, i. e. about 1.41 t/m<sup>3</sup>. As the western ore body is an eolian placer a different factor of e.g. 1.60 t/m<sup>3</sup> (see Jacksonville deposit) must be used for any calculation.

The average h. m. content of the main ore body is in dispute, as can be shown by tab. 10.

| Pirkle et al. (1991) |                     | Elsner (1992 a)                |                     |
|----------------------|---------------------|--------------------------------|---------------------|
| depth                | h. m.-concentration | depth                          | h. m.-concentration |
| Union Camp 1         |                     | Union Camp 1                   |                     |
| 0.0 - 0.9 m          | 1.12 wt.-%          | 0.5 m                          | 1.74 wt.-%          |
| 0.9 - 1.5 m          | 1.17 wt.-%          | 1.5 m                          | 1.78 wt.-%          |
| 1.5 - 3.0 m          | 3.49 wt.-%          | 2.5 m                          | 6.86 wt.-%          |
| 3.0 - 4.7 m          | 9.39 wt.-%          | 3.5 m                          | 26.15 wt.-%         |
|                      |                     | 4.5 m                          | 5.28 wt.-%          |
| 4.7 - 5.3 m          | 1.63 wt.-%          | 5.5 m                          | 1.10 wt.-%          |
| ore deposit (avg.):  | 4.83 wt.-%          | ore deposit (avg.):            | 8.36 wt.-%          |
| Union Camp 2         |                     | Union Camp 2                   |                     |
| 0.0 - 0.3 m          | 1.54 wt.-%          | 0.5 m                          | 2.56 wt.-%          |
| 0.3 - 1.5 m          | 2.18 wt.-%          | 1.5 m                          | 7.85 wt.-%          |
| 1.5 - 3.0 m          | 5.29 wt.-%          | 2.5 m                          | 13.36 wt.-%         |
| 3.0 - 4.6 m          | 1.28 wt.-%          | 3.5 m                          | 0.31 wt.-%          |
| ore deposit (avg.):  | 3.67 wt.-%          | ore deposit (avg.):            | 7.92 wt.-%          |
| Union Camp 3         |                     | missing in core library of FGS |                     |
| 0.0 - 1.5 m          | 1.30 wt.-%          |                                |                     |
| 1.5 - 3.0 m          | 5.16 wt.-%          |                                |                     |
| 3.0 - 4.6 m          | 4.84 wt.-%          |                                |                     |
| 4.6 - 6.1 m          | 3.36 wt.-%          |                                |                     |
| 6.1 - 7.6 m          | 1.53 wt.-%          |                                |                     |
| ore deposit (avg.):  | 3.67 wt.-%          |                                |                     |



Tab. 10: H. m. concentration of sands in cores Union Camp 1, Union Camp 2, and Union Camp 3 (Green Cove Springs main ore body) after Pirkle et al. (1991) and Elsner (1992 a)

Although laminar samples should not be used for economic evaluations, differences in tab. 10 between counts of Elsner and Pirkle are so strong, that a simple explanation, like incidentally (always) h. m.-enriched laminae were sampled by Elsner, is not maintainable.

Comparisons with literature data are of any help neither. The average  $\text{TiO}_2$ -content of 1.3 % of the ore sand of the Green Cove Springs placer deposit given by the U.S. Bureau of Mines (1987) can at least be doubted (see Wynn et al., 1985) (Boulogne: 3.75 wt.-% h. m. @ 1.32 %  $\text{TiO}_2$  in ore sand; Folkston: 4.25 wt.-% h. m. @ 1.63 %  $\text{TiO}_2$  in ore sand). According to Wynn et al. (1985) the Green Cove Springs deposit is volumetrically smaller than the Trail Ridge deposit but richer in h. m. (Trail Ridge: 3.9 - 4.0 wt.-%). The maximum ilmenite content is said to be 10 wt.-%, corresponding to a h. m. content of about 20 - 30 wt.-%.

For the following calculation an average h. m. concentration of 7 wt.-% for the main ore body shall be assumed, while the h. m. concentration of the western ore body is known to be 3.25 wt.-% (S. K. Gilman, pers. comm., 1990).

|                          | main ore body | western ore body | small ore body | total    |
|--------------------------|---------------|------------------|----------------|----------|
| A ( $\text{km}^2$ )      | 23.218        | 6.022            | 1.891          | 31.131   |
| T (m)                    | 5.0           | 10.0             | 4.5            | 5.9      |
| V ( $\text{mill. m}^3$ ) | 116.090       | 60.220           | 8.509          | 184.819  |
| W ( $\text{t/m}^3$ )     | 1.41          | 1.60             | 1.60 (?)       | 1.46 (?) |
| Q (Mt.)                  | 163.687       | 96.352           | 13.615         | 273.654  |
| P (wt.-%)                | 7.0           | 3.25             | 3.25 (?)       | 6.05     |
| HM (Mt.)                 | 11.458        | 3.131            | 0.442          | 15.031   |

Tab 11: Economic geology of the Green Cove Springs placer deposit

The reliability of the h. m. reserves of the Green Cove Springs placer deposit calculated above is hard to judge. Only some economic data are known very well, while others are not known at all.

After T. E. Garnar (pers. comm., 1990) the remaining reserves at the end of the '80s were said to be about 8 Mt. quoting an unknown Australian source. Roughly assuming that at that time about one third of the main ore body and half of the western ore body had been mined, this figure is in good agreement.

## Jacksonville

The city of Jacksonville is situated in the centre of the northeastern Florida h. m. placer district. Lying 6 km east of the city, now covered and surrounded by sprawling suburban houses, another large placer deposit can be found, stretching north-south for about 17 km. Several important highways cut through this deposit.

Before the start of mining at the beginning of the '40s, the area consisted of an arrangement of sand hills side by side out of the surrounding wide marsh areas. Oak trees, pines and palmettos thrived in the middle of a dense brushwood. The basis of the area's surface lay relatively constant at  $9.3 \pm 0.2$  m a.s.l. (Wood, 1944). But already at that time the suburban settlement Southside Estates was developed, below which particularly high-grade h. m. enrichments could be drilled (but not mined).

The northern part of the Jacksonville deposit of (see fig. 20) was discovered by the Titanium Alloy Manufacturing Company (TAMCO), a subsidiary of the National Lead Company (now National Lead Industries Inc.) in the course of the exploration within the scope of the mining of the Mineral City deposit (see below) (J. Gully, pers. comm., 1991, compare with Gillson, 1959).

In December 1942 the Rutile Mining Company of Florida (RMCof) was founded by TAMCO to extract the titanium minerals (Calver, 1957; Overstreet, 1967). In August 1943 mining began, but after a short time of production, however, problems appeared. The RMCof used a bucket wheel dredge for mining the ore sand. For h. m. concentration selectively eight shaking tables (recovery factor: 85 - 92 % h. m.) or six flotation cells (recovery factor: max. 80 % h. m.) were used. The resulting h. m. concentrate then was dried in a coal-fired oven, whereby, however, only a humidity reduction from 16 % to 6 % could be achieved.

In the dry mill the non-conducting zircon and the aluminum-silicates were separated by electrostatic processes and then stockpiled. Electric magnets were used for the final separation of the electrically conducting minerals ilmenite and rutile (Humphreys & Hubbard, 1945 and unpublished notes of HGC, 1944). The rutile was used by TAMCO, whereas National Lead was interested in the ilmenite.

Because of the described separation process only very impure rutile rich in quartz (average 89.7 %  $\text{TiO}_2$ ) and ilmenite (average 58.7 %  $\text{TiO}_2$ ) concentrates could be produced. Since there was a high demand for these strategic minerals for war reasons, already at the beginning of December 1943 TAMCO approached to HGC in order to increase its production capacity by installation of some Humphreys spirals in their wet mill.

From May to December 1943 Humphreys spirals had been used in the mining of chromite beach placers in Coos Bay, OR, and HGC was very interested in a subsequent assignment (Humphrey & Hubbard, 1945; Thompson & Whittle, 1990). Therefore, it was agreed upon with TAMCO to not only install some spirals but to take over the complete mining and the extraction of h. m. out of the Jacksonville deposit. For that purpose the complete plant in Oregon was dismantled, transported over 5,863 km to Florida (Humphreys & Hubbard, 1945) and assembled there again (compare Gillson, 1959).

Effective from April 1, 1944 HGC took over the exclusive responsibility in Jacksonville, whereby the bucket wheel dredge first was replaced by a cutterhead suction dredge and a little later the shaking tables and flotation cells by some 252 Humphreys spirals. The planned capacity of this new plant was at 360 tonnes of ore sand per hour at 20 hours of mining per day (Humphreys & Hubbard, 1945; Hubbard, 1948; Spencer, 1948; Thoenen & Warne, 1949; Detweiler, 1952; Calver, 1957; Overstreet, 1967; Thompson & Whittle, 1990).

Also the separation of the h. m. in the dry mill could be arranged in a considerably more effective way (Lenhart, 1949). Whereas the RMCoF could ship 26 railway carriages within the eight months of their activity, HGC succeeded in extracting about the same quantity (24 wagons with 1,023,655 tonnes of rutile) within only five months. At the same time the quality of the products could be increased: from 58.7 % to 59.9 %  $\text{TiO}_2$  in the ilmenite and from 89.7 % to 92.4 %  $\text{TiO}_2$  in the rutile.

Of his first year of operation it is also known that the average h. m. content of the ore sand was 6.64 wt.-%. In the wet mill concentrate this value could be increased to 90.9 wt.-%. In the h. m. fraction of this wet mill concentrate the rutile made up 7.4 wt.-% on the average, and the ilmenite 44.1 wt.-%. According to Thompson & Whittle (1990) the appropriate zircon, or rather monazite contents were 11, or rather 0.5 wt.-%. In the h. m. fraction of the wet mill-tailings only 1.06 wt.-% of rutile and 2.43 wt.-% of ilmenite were contained (unpublished notes, HGC).

According to Rove (1946) from April 1, 1944 to Dec. 1, 1945 8,832 tonnes of rutile and 55,955 tonnes of ilmenite were extracted by HGC. After the installation of a zircon mill (Hubbard, 1948) in August 1945 zircon was also extracted on own account, that was until Dec. 1, 1945 1,731 tonnes, first from tailings, later also out of the ore sand. At this point of time the average h. m. content of the ore sand was only 4 wt.-% with a cut-off grade of 3 wt.-% of h. m. On the average the h. m. fraction contained 51.4 wt.-% of ilmenite, 8.1 wt.-% of rutile, and 12 - 14 wt.-% of zircon. The average mining thickness came to 3.8 m (12.5 feet) without overburden.

Until the beginning of October 1944 some 0.726 Mt. of ore sand were mined by HGC (Humphreys & Hubbard, 1945), according to Humphreys Investment Company (1946) until the end of 1945 already 2.804 Mt. Until October 1948 this quantity was increased to about 8.2 Mt. (Hubbard, 1948) and until 1962 to about 55 Mt. (Cook, 1962).

In 1949 for the first time small quantities of monazite were separated (Calver, 1957), whereby the content of monazite in the h. m. fraction was said to be 0.7 wt.-% (Mertie, 1975). According to Meyer (1960) the production capacity in 1959 scarcely amounted to 44,000 tonnes of ilmenite and 14,000 tonnes of zircon per year. According to E. V. Whittle (pers. comm., 1990) about 300 - 500 tonnes of monazite were extracted per year. Partially even garnet was sold to interested customers.

While the mining by the RMCoF had been concentrated in particularly high-grade areas in the north of the Jacksonville deposit, because of the technical modifications undertaken by HGC, also low-grade areas could be mined (see Mertie, 1975). In the years from 1944 (1943) to 1953 large parts of the deposit north of the Atlantic Boulevard (Highway 10) were mined. Complete production installations came into existence along Mill Creek Road (see fig. 20). There the h. m. were pre-concentrated in the wet mill and thereafter separated in the neighboring dry mill. The extracted monazite was packed in sacks, while the ilmenite, rutile and zircon concentrates, were taken by trucks as bulk goods to the nearest railway station, some 8 km



away (Detweiler, 1952). Later on mining moved to the so-called Ingram-Merrill tract (see below).

With the recalling of the Trail Ridge mining contract by Du Pont in 1958 the independent sale of zircon was stopped and all zircon taken from Du Pont (E. V. Whittle, pers. comm., 1990).

It was planned to mine the Skinner Tract from the end of 1959 to the spring of 1966, this tract being situated farther in the south where the h. m. deposit was covered, different from the other tracts, by barren sands (see fig. 21). As early as on Sept. 15, 1958, however, in this area the removal of the overburden had begun, on Oct. 2, 1958 the first ore sand was mined, and on Nov. 24, 1958 the first h. m. concentrate out of this deposit was produced (unpublished notes, HGC). As a consequence of the increasing distance to the main plant on the Mill Creek Road it was decided to move the stationary wet mill into the center of the new deposit and from then on to transport the produced h. m. pre-concentrate by truck to the dry mill being situated 8.6 km to the north.

After the exhaustion of all accessible areas of the deposit the contract with TAMCO was cancelled on Dec. 31, 1964 and all plants moved to Folkston in 1965, where mining started by order of Du Pont (Garnar, 1972; Thompson & Whittle, 1990) in August 1965.

It has particularly to be mentioned that in 1966/1967 the Carpco Engineering Company returned to the tailings areas to produce and sell a monazite, and until then unique for Florida, even a xenotime concentrate (J. Gully, pers. comm., 1991).

The h. m. composition of the Jacksonville ore sands was published only once (Detweiler, 1952, repeated by Calver, 1957, and U.S. Bureau of Mines, 1987). Further information could be taken from reports by RMCof (1944) and Wood (1944) While having a closer look at a wet mill h. m. concentrate from the Jacksonville plant, Miller (1945) erroneously took the mineral enstatite, not occurring in Florida sands, for sillimanite.

|             | Detweiler (1952)<br>ore sand | RMCof (1944)<br>ore sand | Wood (1944)<br>ore sand | Miller (1945)<br>wet mill conc. |
|-------------|------------------------------|--------------------------|-------------------------|---------------------------------|
| ilmenite    | 40 %                         | 38 %                     | 39.2 %                  | 26 %                            |
| leucoxene   | 4 %                          |                          |                         |                                 |
| rutile      | 7 %                          | 12 %                     | 10.5 %                  | 5 %                             |
| zircon      | 11 %                         | 15 %                     | 15 %                    | 3 %                             |
| kyanite     | present                      | 10 %                     | 10 %                    | 3 %                             |
| staurolite  | present                      | 6 %                      | present                 | 21 %                            |
| sillimanite | present                      |                          |                         |                                 |
| (enstatite) |                              |                          |                         | 24 %                            |
| garnet      | present                      | 1 %                      | present                 | 1 %                             |
| monazite    | < 0.5 %                      | 0.5 %                    | 0.5 %                   | +                               |
| tourmaline  | present                      | present                  | present                 | 6 %                             |
| magnetite   |                              | 4 %                      | present                 | +                               |
| epidote     |                              | present                  | present                 | 11 %                            |
| hornblende  |                              | present                  | present                 | 1 %                             |
| sphene      |                              |                          |                         | 1 %                             |

Tab. 12: H. m. composition of ore sands and of a wet mill concentrate of the Jacksonville placer deposit after various authors.

All data in wt.-%. (+ = traces, less than 0.5 wt.-%)

After Mertie (1975) in the northern part of the deposit the ratio of ilmenite to rutile to zircon was 4:1:1.5. Other minerals in the ore sands are said to have been staurolite, kyanite, sillimanite, monazite (0.7 wt.-%), tourmaline, garnet, epidote, and xenotime.

Overstreet (1967) mentioned a monazite content of 0.5 wt.-% in the h. m. fraction. After Cannon (1950) epidote and hornblende seemed to have been important.

In the zircon mill tailings besides 46.6 % quartz and 1.6 % not determined opaque minerals Browning et al. (1956) discovered 4.7 % kyanite, 8.5 % sillimanite, 4.2 % zircon, 20.2 % staurolite, 4.2 % tourmaline, 5.8 % epidote, 1.8 % garnet, and 0.6 % rutile.

After Elsner (1992 a) in the tailings of the Jacksonville deposit also andalusite, topaz, spinel, corundum, anatase, and chloritoid (!) can be found.

Using all available data the average h. m. composition of the Jacksonville deposit can be assumed to have been as follows (tab. 13):

|                   |                 |            |               |
|-------------------|-----------------|------------|---------------|
| ilmenite          | 38 - 40 wt.-%   | leucoxene  | 4 - 10 wt.-%  |
| rutile            | 7 - 10 wt.-%    | zircon     | 10 - 15 wt.-% |
| monazite/xenotime | 0.5 - 0.7 wt.-% | staurolite | 6 - 10 wt.-%  |
| sillimanite       | 10 - 15 wt.-%   | epidote    | 10 - 15 wt.-% |
| tourmaline        | 3 - 6 wt.-%     | hornblende | 1 - 5 wt.-%   |
| topaz             | 1 - 2 wt.-%     | kyanite    | 3 wt.-%       |
| garnet            | 1 wt.-%         | corundum   | < 1 wt.-%     |
| andalusite        | < 1 wt.-%       | anatase    | < 1 wt.-%     |
| spinel            | 0.1 wt.-%       | sphene     | 0.1 wt.-%     |
| chloritoid        | 0.1 wt.-%       |            |               |

Tab. 13: Average h. m. composition of the Jacksonville placer deposit

The origin and age of the Jacksonville h. m. deposit is clear and can be given as follows:

During the climatic optimum of the last interglacial (Sangamon) along the total Atlantic coastal plain the Pamlico-sediment complex was formed (fossil average sea level height including uplift: + 7.6 m). In this time a barrier island formed in the area just east of the city of Jacksonville, having about the same dimensions as the Recent Amelia Island to the northeast. West of this former „Jacksonville Island“ there was an extensive salt marsh. On „Jacksonville Island“ big dune ridges came into existence in which the h. m. were concentrated in the shape of (coastal) dune placers, after having been pre-concentrated on the beach.

In the two northern mining areas the basis of the ore body lay at about 7.6 m (25 feet) above msl. whereby a position of these ore sands in the Pamlico complex seems to be assured. The maximum dune thickness was about 9 m. Compared to the relatively low-grade dune placers, high-grade beach placers make up only a very small part of the present Jacksonville deposit.

The beginning deterioration of the climate in the transition to the Wisconsin glacial initiated a slow regression of the sea level. The former salt marsh west of the „Jacksonville Island“ fell dry, later being used as a bed by the developing Johns River. The sea level only sinking very slowly was favorable to the formation of an extensive beach ridge plain, now

clearly visible to the east on air photos and satellite images. The beach ridges in the south that are concavely bending to the west thereby copy the shape of the former drumstick-shaped „Jacksonville Island“.

During a later point of time (pleniglacial?) relatively h. m.-poor sands were blown in, today covering older, mineralized dune sands with a thickness of more than 9 m in the southern part (Skinner Tract) of the former „Jacksonville Island“.

Simplified flow diagrams of the dressing procedure for the separation of the h. m. out of the Jacksonville deposit applied by HGC were published by Humphreys & Hubbard (1945) as well as by Thompson & Brown (1950). Very good presentations considerably more comprehensive can be found in Carpenter & Griffith (1960) and Giese et al. (1964) which is referred to here. A detailed description of the applied procedure was given by Detweiler (1952).

During the mining of the Jacksonville deposit some 115 to 150 persons were employed by HGC (J. Gully, pers. comm., 1991). Each an ilmenite, a rutile, a zircon and a monazite concentrate were being produced. Small quantities of garnet were sold to individual customers. Xenotime was separated from the tailings by Carpco Engineering after the end of mining.

Some, until now unpublished information regarding the h. m. content of the Jacksonville deposit, are known from various company's internal reports. The northern part, i. e. the one above all mined in the 1940s, also called "northern deposit", was at that time arranged into different tracts (see fig. 20).

By using data of various internal reports of HGC and RMCoF (i. e. Wood, 1944) an average h. m. content of 4.7 wt.-% for the northern area of the Jacksonville deposit can be calculated. Although the average ore sand thickness is said to have been some 6 m (20 feet) according to Detweiler (1952), Mertie (1958, 1975) and the U.S. Bureau Of Mines (1987), a figure of only 5 m (also see Pirkle, 1972) seems to be more probable. The mined area amounted to about 988 acres (3.998 km<sup>2</sup>), about 40 acres of which were used by the RMCoF.

Tract #4 (Ingram-Merrill = 400 acres) together with another small tract (Anders = 16 acres) being situated in the middle of the Jacksonville deposit was called Ingram-Merrill Tract (416 acres = 1.683 km<sup>2</sup>). According to an unpublished calculation by Humphreys dated May 27, 1946 its reserves (average h. m. content of 5.1 wt.-%) amounted to 95,000 tonnes of ilmenite, 19,100 tonnes of rutile, and 23,000 tonnes of zircon. (Original data converted in metric tonnes and assuming a mining recovery factor of 75 %.). Arnold (1957) carried out radiometric and magnetic measurements in the Ingram-Merrill and Skinner Tracts. According to these an average ore thickness of 4.1 m with an average h. m. content of 4.8 wt.-%. can be calculated for the Ingram-Merrill Tract.

Mining data of the southernmost Skinner Tracts (A. C. Skinner = 426 acres, R. G. Skinner = 24 acres, Anders = 94 acres) are very well known from Lewis (1954) and are included in tab. 14

|                           | northern deposit | Ingram-Merrill | Skinner | mined  | total   |
|---------------------------|------------------|----------------|---------|--------|---------|
| A (km <sup>2</sup> )      | 3.998            | 1.683          | 2.201   | 7.628  | 36.848  |
| T (m)                     | 5.0              | 4.1            | 2.99    | 4.1    | 4.1     |
| V (mill. m <sup>3</sup> ) | 19.990           | 6.900          | 6.581   | 31.275 | 151.077 |
| W (t/m <sup>3</sup> )     | 1.60             | 1.60           | 1.60    | 1.60   | 1.60    |
| Q (Mt.)                   | 31.984           | 11.040         | 10.530  | 50.040 | 241.723 |
| P (wt.-%)                 | 4.7              | 5.1            | 7.44    | 5.55   | 5.5     |
| HM (Mt.)                  | 1.503            | 0.563          | 0.783   | 2.752  | 13.295  |

Tab. 14: Economic geology of the Jacksonville placer deposit (further explanation see text)

The probable size of the complete Jacksonville placer deposit („Jacksonville Island“) indicated in tab. 14 was derived from maps and is a rather conservative assumption. According to Lewis (1954) and Wood (1944) the weight factor W concordantly amounted to 1.60 t/m<sup>3</sup>, only Rove (1946) supposed a factor of 1.47 t/m<sup>3</sup>.

According to Cook (1962) approximately 1600 acres were mined by HGC until mid-1962; there were added nearly 95 acres in the year 1964 (Whittle, 1965). With assumed 150 acres in the period from the middle of 1962 to the end of 1963, they amount to approx. 1,845 acres, to be added further the area of 40 acres mined by RMCoF, consequently 1,885 acres (7.628 km<sup>2</sup>). This corresponds approximately to the theoretically possible mining area of 1,948 acres (northern deposit = 988 acres, Ingram-Merrill = 416 acres, Skinner = 544 acres). The difference of more than 60 acres is probably due to existing roads at that time, which had to be excepted from mining.

On the whole it can be stated that only a very small part (25 %) of the whole Jacksonville deposit has been mined. The chances for a continuation of the mining in the central part of the deposit can be said to be very small because of the permanently increasing coverage with buildings. However, the possibility has to be pointed out, that there exists another big deposit only a short distance from the former mining areas (see chapter on history and future of h. m. mining in northeastern Florida).

## Yulee

Yulee is the name of a small but rapidly growing village in the northeast of Nassau County, Florida, some 30 km to the north of the city of Jacksonville.

Between the village of Yulee and the St. Marys River respectively its affluent Bells River in the north and northeast lie several ridges irregularly shaped. These ridges predominantly overgrown with turkey oaks, live oaks, pines and palmettos are separated from each other by numerous flat swamps and small creeks. The sand ridges belong to the Atlantic Ridges and are situated in the eastern region of the St. Marys Meander Plain (see fig. 20).

A detailed work concerning the hydrogeological conditions prevailing in this area were presented by Spangler et al. (1989).

- The Crandall Ridge forms the northwesternmost of the so-called Yulee Ridges with elevations of more than 13 m above msl. It becomes four meters higher directly on the bank of the St. Marys River where a steep bluff, the so-called Reids Bluff, was formed by erosion. The Crandall Ridge reaches a maximum width of 2.2 km, and a length of 4.2 km (area of the h. m. deposit: 4.634 km<sup>2</sup>).
- Two kilometers farther to the east follows another ridge, called Bells Ridge, with elevations of more than 15 m above msl. To the north it borders on the meandering Bells River where also a steep bluff, the so-called Bells Bluff can be found. Another bluff, the Roses Bluff, is situated approximately 1 km northwest of the Bells Bluff. The Bells Ridge is divided into several hills being separated by swampy areas. On the highest of them in the south a trailer park has been established. In this area the Bells Ridge is bordered in the west by the McQueen Creek, the Lofton Creek in the south and the Blounts Branch in the east. The area of the h. m. deposit comprises 8.984 km<sup>2</sup>.
- Some 100 m farther to the east follows an extended sand ridge, reaching elevations of 12 m. This ridge shall be called Haven Road Ridge. The area of the ore deposit formed in it was determined with 2.377 km<sup>2</sup>.
- In the south of the settlement Chester at the Bells River the biggest of the four ridges containing h. m. can be found. Along its total length of 12 km runs the Chester Road so that the name Chester Road Ridge was chosen for it. This Chester Road Ridge forking in the north is remarkable lower than the other three ridges and reaches elevations of only 9.5 m above msl. It is crossed by several roads of various sizes and is characterized by numerous swampy areas (ore deposit: 13.733 km<sup>2</sup>).

Most of the area is owned by ITT Rayonier, Inc. and is used for forestry. In other parts more and more holiday houses, small settlements, churches and cemeteries come into existence. It is striking that many properties, also outside the forestry areas, are not accessible for the public.

According to Pirkle et al. (1984) the Yulee h. m. deposit was discovered by the already mentioned Chief Geologist of Du Pont, Dr. J. L. Gillson, at the beginning of the 1950s. For the first time the location of the new discovery was published in 1959 by Gillson in a map of all known h. m. deposits of the southeastern USA.

Lynd & Lefond (1975, 1983) indicated that the h. m. deposit was explored by different companies, among them only "lately" by the Pennsylvania Glass Sand Corporation, a subsidiary



of ITT Rayonier, who owns most of the area. Exploration data of these companies also built the basis of the monography on the Yulee deposit by Pirkle et al. (1984).

One of the other companies drilling in the Yulee Ridges was HMC. 266 holes were drilled in this area from Nov. 30, 1970 to March 12, 1971, partly up to 9 m (30 feet) deep. From each drill hole mixed samples were taken in 2-feet-intervals (surface: 4 feet) and checked for total h. m. and the  $\text{TiO}_2$  contents.

The complete documents of this exploration campaign were gratefully put at the author's disposal by E. V. Whittle in 1991. Nearly all economic-geological information of this chapter (see below) originate in the evaluation of the 257 (of formerly 266) drill holes, of which the exact location could still be determined precisely after more than 20 years.

According to the mutual opinion of all exploration geologists working in northeastern Florida the Yulee deposit will never be mined. The reason for this is less the volume of the deposit than rather the competitive use of the area by the rapidly growing population around the village of Yulee (Dr. E. C. Pirkle, Dr. F. L. Pirkle, J. C. Reynolds, E. V. Whittle, T. E. Garnar, J. M. Elder, pers. comm., 1990).

The age and origin of the Yulee Ridges can be summarized as follows:

During the last interglacial (Sangamon) on the whole Atlantic coastal plain a transgression took place, the so-called Pamlico transgression. At that time a barrier island was formed in the northeast of present-day Yulee on the southern bank of the former mouth of the St. Marys River. Today this barrier island is still preserved in form of the Bells Ridges (compare Huddestun, 1988). By the formation history of this former Bells Island the sediments being made accessible today in the Bells Bluff are typical of a regression (prograding barrier island sequence). To the west of the former Bells Island a salt marsh was formed (base of Reids Bluff), to the north there was the tidal inlet (base of Roses Bluff) of the St. Marys River.

With the beginning regression first the salt marsh and a little later also the tidal inlet fell dry. At the climax of the second short-time transgression at the end of the Sangamon interglacial (Princess Anne transgression) another barrier island was formed. Also on this barrier island h. m. were concentrated in dunes. In the inland area of this Chester Road Island the dune complex of the Crandall Ridge, in which the h. m. are also present as eolian placers, came into being.

According to Mallard (1986) the Yulee Ridges formed as mesotidal, drum-stick shaped barrier islands dominated by tides similar to present-day Amelia Island. Also Pirkle et al. (1984) compared the former Yulee barrier islands with the Recent Amelia Island (see fig. 23). There would, however, be more justified a comparison of the fossil Yulee Ridges, consisting of „Bells Island“ (Pamlico) and „Chester Road Island“ (Princess Anne) with Big Talbot Island (Silver Bluff) and Little Talbot Island (Recent) that one time in the future could build a kind of Talbot Ridges. Amelia Island (Silver Bluff core) on the contrary shows strong similarities with the former „Jacksonville Island“ (see above) (Pamlico and Princess Anne?).

|             | Pirkle et al. (1991 b) | Grosz et al. (1989) | Elsner (1992a) |
|-------------|------------------------|---------------------|----------------|
| ilmenite    | 52.7 %                 | 31.2 %              | 28.7 %         |
| leucoxene   | 2.2 %                  | 4.6 %               | 8.7 %          |
| rutile      | 7.4 %                  | 10.2 %              | 2.7 %          |
| zircon      | 16.0 %                 | 8.3 %               | 5.5 %          |
| epidote     | 6.6 %                  | 7.5 %               | 26.2 %         |
| sillimanite | 5.4 %                  | 10.3 %              | 10.7 %         |
| kyanite     | 1.3 %                  |                     | 2.5 %          |
| staurolite  | 5.2 %                  | 12.2 %              | 7.2 %          |
| tourmaline  | 2.3 %                  | 5.7 %               | 2.5 %          |
| hornblende  | 0.8 %                  | 0.4 %               | 3.0 %          |
| garnet      | 0.4 %                  |                     | 1.0 %          |
| others      | 0.3 %                  |                     |                |
| monazite    |                        | 2.0 %               | < 0.1 %        |
| xenotime    |                        |                     | < 0.1 %        |
| andalusite  |                        |                     | 0.2 %          |
| topaz       |                        |                     | 0.5 %          |
| corundum    |                        |                     | 0.2 %          |
| sphene      |                        |                     | 0.1 %          |
| chloritoid  |                        |                     | < 0.1 %        |
| anatase     |                        |                     | 0.2 %          |

Tab. 15: Average h. m. composition of the Yulee placer deposit after various authors (all data in wt.-%).

Whereas the calculations of T. E. Garnar (cited in Pirkle et al., 1991 b) correspond to the average values of all ore sands (dune and beach placers), the data (3 samples) given by Grosz et al. (1989) as well as by Elsner (1992 a) (4 samples) reflect the h. m. composition of the less mineralized dune sands close to the surface (leucoxene and epidote contents!).

Because of the data of the exploration campaign of HMC at the beginning of the 1970s put at the author's disposal by E. V. Whittle, it was possible to calculate the ore volume of the individual mineralized Yulee Ridges quite precisely (see tab. 16).

|                           | Crandall R. | Bells R. | Haven Road R. | Chester Road R. | total   |
|---------------------------|-------------|----------|---------------|-----------------|---------|
| A (km <sup>2</sup> )      | 4.634       | 8.984    | 2.377         | 13.733          | 29.729  |
| T (m)                     | 3.55        | 2.97     | 2.44          | 2.94            | 3.00    |
| V (mill. m <sup>3</sup> ) | 16.452      | 26.683   | 5.800         | 40.375          | 89.311  |
| W (t/m <sup>3</sup> )     | 1.60        | 1.60     | 1.60          | 1.60            | 1.60    |
| Q (Mt.)                   | 26.324      | 42.693   | 9.281         | 64.600          | 142.898 |
| P (wt.-%)                 | 3.34        | 3.37     | 2.96          | 2.92            | 3.12    |
| HM (Mt.)                  | 0.879       | 1.439    | 0.275         | 1.886           | 4.479   |

Tab. 16: Economic geology of the Yulee placer deposit



The only other values comparable to the ones calculated above were presented by Pirkle et al. (1984) who indicated an ore volume of approx. 1.2 mill. short tons (1.089 Mt.)  $\text{TiO}_2$ , an ore deposit size (A) of approx. 5,000 acres (20.234  $\text{km}^2$ ) and an ore sand thickness (T) of approx. 9 feet (2.75 m). Applying a  $\text{TiO}_2$  content of 1.13 % in the ore sand (calculated by data from the HMC exploration campaign) an ore volume (Q) of approx. 96.3 Mt. of ore sand with approx. 3 Mt. of available h. m. can be calculated.

T. E. Garnar (pers. comm., 1990) on the contrary assumed the h. m. content of the Yulee placer deposit to be approx. 5 mill. (short?) t. of h. m.

## Amelia Island

Amelia Island, located at the southern end of the Sea Island Chain, is the biggest of the two barrier islands of northeastern Florida. With a length of more than 21 km and a width of up to 4 km its highest elevation is more than 10 m above msl. The core of the island, at the same time the geologically oldest part of the island, is situated in the west and borders on the wide salt marsh of the Amelia and South Amelia Rivers. In its northern part the small town of Fernandina Beach founded in 1567 extends with its historical city center (see fig. 23).

The beach but also dune placers of Amelia Island have been known for many years (Overstreet, 1967) and were explored by the U.S. Bureau of Mines (Marshall, 1954; Peyton, 1955) and numerous private companies (Mertie, 1958, 1975). In the south of Amelia Island a large property belonging to Union Carbide was drilled in the mid-50s by HGC. The h. m. ore body found was to be mined as early as 1957 by the Union Carbide & Carbon Corporation (Giese et al., 1964; Mining World, 1955 b). For this purpose an old dredge dismantled in parts as well as a Cannon circulator concentrator for the dry mill already waited in Fernandina Beach for their recall (E. V. Whittle, pers. comm., 1990). In August 1957, however, world market prices for titanium minerals began dropping drastically (Mertie, 1958, 1975; Garnar, 1980), so that mining was postponed for an undefined time.

At the end of 1969 Union Carbide contacted Du Pont in order to negotiate about the production of h. m. concentrates (ilmenite, rutile, zircon, monazite, according to Overstreet, 1967) that still remained unmined. Investigations by Du Pont, however, proved the non-feasibility of the planned enterprise so in mid 1970 it was decided to drop all further mining plans.

Since Union Carbide then was no more interested in its property on Amelia Island, the whole area with a size of 3,300 acres (13,355 km<sup>2</sup>) was sold to the Sea Pines Company of Hilton Head Island, SC (T. E. Garnar, written comm., 1991). During the following years the above-mentioned company turned its new property into a luxury resort with tennis-courts and golf courses, apartment buildings as well as shopping centers (Garnar, 1972, 1978a, b, 1980). The value of this meanwhile well-known property named Amelia Island Plantation, exceeds the value of the h. m. being latent under it by all means.

Nothing is known about the granulometry or the depositional origin of the former ore sands, but according to descriptions by Mertie (1975), above all, it must have been dune placers. Referring to his descriptions the ore sands reached an elevation of up to 7.6 m (25 feet) in the center of the deposit, dipping to the east and to the west down to the present msl. The average h. m. content of the ore deposit is said to have been 3 wt.-% (Mertie, 1975). Other figures were given by Pirkle et al. (1984) and T. E. Garnar (written comm., 1991) with approx. 4 wt.-%, or even 11 wt.-% (Mallard, 1986).

The average h. m. composition of the former ore deposit is known by T. E. Garnar (written comm., 1991) and can be compared with data given by Eichenholtz (1986) respectively Eichenholtz et al. (1989) of the beach ridge plain north of Fernandina Beach (74 samples of 30 drill holes) and by Peyton (1955) of 32 drill holes along highway A1A.

|                   | Garnar (1991) | Peyton (1955) | Eichenholtz (1986) |
|-------------------|---------------|---------------|--------------------|
| h. m. grade       |               | 2.00 %        | 1.01 %             |
| ilmenite          | 37.0 %        | 49.2 %        | 50.28 %            |
| leucoxene         | 9.7 %         |               | 1.91 %             |
| rutile            | 4.6 %         | 5.3 %         | 2.63 %             |
| zircon            | 11.2 %        | 10.7 %        | 6.61 %             |
| monazite/xenotime | 0.2 %         | 0.7 %         |                    |
| staurolite        | 6.9 %         | 5.5 %         | 3.18 %             |
| tourmaline        |               | 2.7 %         | 1.45 %             |
| kyanite           | 6.4 %         | 1.7 %         | 6.02 %             |
| sillimanite       |               | 3.8 %         |                    |
| garnet            | 0.6 %         | 2.2 %         | 1.48 %             |
| epidote           | 20.3 %        | 16.4 %        | 22.31 %            |
| hornblende        |               | 0.3 %         | 4.13 %             |
| mica              | 1.8 %         |               |                    |
| collophane        |               | 1.5 %         |                    |
| others            | 1.3 %         |               |                    |

Tab. 17: Average h. m. composition and grade of sands of different areas of Amelia Island after various authors (all data in wt.-%).

Only little is known about the size of the ore body, which was planned to be mined by Union Carbide on Amelia Island. According to E. V. Whittle (pers. comm., 1990) the ore deposit stretched from close to the airport near Amelia City over American Beach, in its center, south to Franklinton.

After Mallard (1986) the original area of the ore deposit measured approximately 10 km x 1.5 up to 2.5 km, with an average thickness of 1.8 m (6 feet). An area of close to 8 km<sup>2</sup>, however, according to indications given below seems to be more probable.

According to Peyton (1955) dredging down to an average depth of 3.1 m would have been possible.

According to Pirkle et al. (1984) the volume of the deposit amounted to 320,000 short tons of TiO<sub>2</sub>. T. E. Garnar (written comm., 1991) gave the same figure (cut-off grade: 3 wt.-% h. m.) also mentioning an average h. m. content of 4 wt.-% and an average TiO<sub>2</sub> content of 62.5 % in the titanium minerals, which, on the other hand, made up 51.3 wt.-% of the h. m. fraction. From these data a volume of the original deposit of some 0.9 Mt. of h. m., respectively 23 Mt. of ore sand may easily be calculated.

Union Carbide planned to produce 30,000 tons of ilmenite and 5,000 tons of rutile per year.

According to Peyton (1955) the average TiO<sub>2</sub> content of the Amelia Island ilmenite was 58.4 %. The monazite of Amelia Island was said to contain 4.83 % ThO<sub>2</sub> and 0.58 % of U<sub>3</sub>O<sub>8</sub>.

According to T. E. Garnar (written comm., 1991) the chemical composition of the ilmenite (81 % of the titanium minerals) was analyzed to be 58 % TiO<sub>2</sub>, 15.2 % FeO and 21.4 % Fe<sub>2</sub>O<sub>3</sub>. Leucoxene (13 % of the titanium minerals) contained 74 % TiO<sub>2</sub>, rutile (6 % of the titanium minerals) consisted of 98 % TiO<sub>2</sub>.

## Little Talbot Island

Little Talbot Island is the southernmost island of the Sea Island Chain south of Amelia Island. The island being 7.2 km long and just more than 1 km wide comprises an area of approx. 6.9 km<sup>2</sup>. It is built up by elongated N-S-trending beach ridges which are covered by dunes, reaching elevations of more than 6 m above msl. (see fig. 24).

The whole island belongs to the state park system of Florida (Little Talbot Island State Park) where any commercial use is strictly prohibited. The Atlantic beach of the island is known as one of the most beautiful beaches of the USA.

Because of the restriction to a few touristic activities Little Talbot Island practically is an untouched barrier island where natural enrichments of h. m. can excellently be observed in nature.

Already when reaching Little Talbot Island on highway A1A black veils of h. m. on the dunes bordering the highway strike the eye. For this reason it did not remain a secret to the companies exploring in Florida that the whole island was rich in h. m. (Mertie, 1975), and already in 1946 Rove (p. 2.) reported: "Du Pont has apparently spent from \$ 75,000 to \$ 100,000 this year (1945) in a non-productive search. They claim that Little Talbot Island is one of the best looking shore prospects they have seen."

In the 1950s also exploration teams of the U.S. Bureau of Mines were making their way onto the island. At least some data are known of their reports (Marshall, 1954; Peyton, 1955). A short time later the island was declared a State Park and thereby forever withdrawn from the grip of the mining companies.

|                   | Peyton (1955)<br>Big Talbot Island | Peyton (1955)<br>Little Talbot Island | Eichenholtz (1989)<br>Little Talbot Island |
|-------------------|------------------------------------|---------------------------------------|--------------------------------------------|
| number of samples | n = 4                              | n = 11                                | n = 74                                     |
| h. m. grade       | 1.05 %                             | 1.92 %                                | 7.00 %                                     |
| ilmenite          | 48.7 %                             | 42.2 %                                | 53.20 %                                    |
| leucoxene         |                                    |                                       | 1.37 %                                     |
| rutile            | 4.1 %                              | 3.4 %                                 | 4.92 %                                     |
| zircon            | 10.0 %                             | 6.6 %                                 | 14.68 %                                    |
| monazite          | 0.5 %                              | 0.5 %                                 |                                            |
| staurolite        | 6.7 %                              | 4.7 %                                 | 4.13 %                                     |
| sillimanite       | 5.0 %                              | 4.0 %                                 | 5.66 %                                     |
| kyanite           | 2.7 %                              | 1.9 %                                 |                                            |
| epidote           | 17.3 %                             | 22.6 %                                | 12.32 %                                    |
| hornblende        | 0.3 %                              | 1.7 %                                 | 1.29 %                                     |
| tourmaline        | 2.2 %                              | 3.0 %                                 | 0.52 %                                     |
| garnet            | 2.4 %                              | 1.4 %                                 | 1.70 %                                     |
| collophanes       | 0.1 %                              | 8.0 %                                 |                                            |

Tab. 18: Average h. m. composition and grade of sands of Little and Big Talbot Islands after Peyton (1955), and Eichenholtz (1989) (all data in wt.-%).

Only a few years ago the h. m. composition of the sands of Little Talbot Island were the object of scientific investigations again (Eichenholtz, 1986; Eichenholtz et al., 1989). Because of the insufficient analytical methods used it seemed to be advisable, however, to take at

least some new samples which were analyzed according to procedures described in detail by Elsner (1992 a).

One of the granulometrical findings was that the average grain size of the beach sands of Little Talbot Island decreases from north to south, whereas the sorting gets better.

Mineralogical findings are even more interesting, as the blackish veils of h. m. seem to be more greenish-blackish, the color coming not from high monazite, but rather hornblende and above all epidote contents. Samples taken from deeper holes confirmed the possibility of a continuous mineralization of the island with a considerable amount of the h. m. always being epidote (see fig. 25).

Concentrations of nearly only the heavier, i.e. the more economic h. m. are to be found in the upper backshore area. These storm-built concentrations reach thicknesses of only 1 to 2 decimeters. A continuous seam can best be observed in the north of Little Talbot Island, whereas to the south a splitting into several a little bit thinner layers takes place.

Although a mining of the h. m. was for all times prevented after the integration of Little Talbot Island into the Florida State Park System, the „theoretical“ h. m. content of the island can be calculated.

As already amplified, obviously the whole island (6.9 km<sup>2</sup>) is mineralized, whereby an average dune sand thickness of approx. 3 m is reached. On Little Talbot Island are hence found 20.7 mill. m<sup>3</sup> of ore sand corresponding to 33.1 Mt. of ore sand at a (dune sand) weight factor of 1.60 t/m<sup>3</sup>.

According to Eichenholtz (1986) the average h. m. content of the dune sands can be calculated with 7.00 wt.-%, according to Elsner (1992 a) it can be given as even 8.27 wt.-%. The absolute h. m. content of the beach sands (not regarding the storm-built placers) probably is still lower than the average value of 4.98 wt.-% calculated by Elsner (1992 a). On the other hand an average h. m. content of 1.92 wt.-% as indicated by Peyton (1955) definitely seems to be too low.

Using the data given by Eichenholtz (1986), based on the counting of 74 samples, an ore content of 2.3 Mt. h. m. (on a conservative basis) can be calculated, of which only a bit more than 1 Mt. should consist of economically interesting minerals.

## **Ponte Vedra Beach (Mineral City)**

North of the St. Johns River far into the Carolinas barrier islands of the Sea Island Chain form the Atlantic Coast of the southeastern USA. South to Miami Beach elongated beach and dune ridges can be found, being separated from the mainland by lagoons or the Florida Intracoastal Waterway. The structure of the above mentioned beach and dune ridges is very similar along the whole Atlantic coast: an approx. 200 m wide and up to 10 m high dunal belt is joined on its seaward side by a gently descending beach, in case of low tide, 150 m wide on the average. On its landward side the coastal highway A1A can be traveled to enjoy the coastal scenery.

The beaches that have been investigated more closely by Elsner (1992 a) belong to two sections, the southern one comprising all of 23 km long Anastasia Island. The northern part of the northern section (55 km), stretching from Mayport at the St. Johns River mouth south for 15 km along the coastal towns of Atlantic Beach, Neptune Beach and Jacksonville Beach is characterized by artificial beaches (Dr. W. F. Tanner, pers. comm., 1990) and, therefore, was not studied in detail. South to this section relatively pristine beaches can still be found, which have been known for their h. m. enrichments for quite a long time.

According to Liddell (1917) Henry H. Buckman and George A. Pritchard were the first to carry out an investigation of the industrial minerals of Florida at the beginning of World War I. Investigating one of their sand samples they found a striking concentration of ilmenite which startled them quite a bit. In order not to enter an unlimited market, they had a closer look at all the beaches between Savannah, SC and the southern tip including the Gulf beaches of Florida without, however, discovering any other deposits of this mineral. The highest concentration of h. m. was detected between the St. Johns River in the north and St. Augustine in the south with its center near the present-day Ponte Vedra Beach.

Together they founded a mining company, named it Buckman and Pritchard Inc., and bought a property on which plants and administration buildings were erected. This settlement soon got known by the name of Mineral City.

Near Mineral City the beach was approx. 160 m wide at low tide, giving way to 4 m high and up to 60 m wide dune ridges to the west (Liddell, 1917). Those parts of the dunes containing the most h. m., and all the storm-placers in the foredune area having an average concentration of 20 wt.-% h. m. were being mined.

Mining started in 1916 first on sands with an even considerably higher h. m. concentration. These were the sands of the so-called "friendship vein", reaching a maximum width of 21 m (70 feet) and an average thickness of 2.7 m (9 feet). According to Liddell (1917) this „friendship vein“ was even underlain by another 2.4 m (8 feet) of only little lower-graded placers. Martens (1928), however, after visiting the plant site by himself, considered these data as completely exaggerated and reported a thickness of only 60 to 75 cm, a width of 7.6 to 10.7 m and a h. m. concentration in the darkest storm-placer layers of up to more than 60 wt.-%. Everyone visiting the beaches near the former Mineral City site nowadays will clearly see that the data, given by Martens (1928) are much more probable than those by Liddell (1917).

At the beginning of mining only ilmenite was of interest, being processed to titanium tetrachloride, which was used for tracer bullets, spotting shells, and smoke screens (Martens, 1928; Calver, 1957; Peterson, 1966; Garnar, 1972, 1978 a, b; U. S. Bureau of Mines, 1987).

During those early years also very small quantities of monazite and zircon were said to have been extracted (Liddell, 1917, p. 155). According to Overstreet (1967), however, the maximum production of monazite was reached in 1925 with only approx. 900 kg.

After the end of World War I production declined considerably. In 1922 Buckman & Pritchard, Inc. were bought by the National Lead Company, from then on considered a subsidiary of the last mentioned company which is much larger. With the take-over in 1922 also for the first time in Florida the large scale separation of zircon began. All the zircon concentrates produced were used in the refractory industry, for which National Lead held a US patent. In 1925 rutile followed as another mineral being separated for the first time (Martens, 1928; Gillson, 1949; Calver, 1957; Meyer, 1960; Overstreet, 1967; Garnar, 1980, 1985).

Although the different h. m. first were only extracted from the ore sands alone, with time the old tailings grew in importance (Thoenen & Warne, 1949, details in Martens, 1928). In this way a second climax of production at the end of World War I was reached in 1927 (Calver, 1957; Garnar, 1980).

Only a short time later, however, in 1929, the mining of h. m. out of the beach sands near Mineral City was completely stopped. According to Calver (1957) this was caused both by the exhaustion of the h. m.-rich parts and the hard competition by Indian and Australian producers. Neither should the beginning of the Great Depression in that year be neglected.

During the 13 years of production between 1916 and 1929 the mining near Mineral City had proceeded north for approx. 5 km. The h. m. rich layers extended still farther, but mining was not possible due to the bathing activities in that area. Into the other direction mining had extended to the south for even 13 km, and a continuation was planned in spite of much lower grades (Martens, 1928; Overstreet, 1967).

After closure of the production plants Buckman & Pritchard, Inc., still in possession of National Lead Company, was renamed into Ponte Vedra Company. This company recultivated the former mining site, using the old tailings and mining ponds for the design of a large golf course. In 1942 the whole property was sold and the present-day luxury settlement of Ponte Vedra Beach was developed (Calver, 1957; Garnar, 1972, 1978 a, b, 1980). Today's center of Ponte Vedra Beach, the Ponte Vedra Country Club and Golf Course, is situated exactly in the center of the former mining site.

70 years ago the separation of h. m. from the Mineral City deposit was quite different from operations today. A floating dredge operating in the dunes had only a very low capacity. The majority of the h. m. in the beach sands, therefore, was loaded on trucks with a shovel and hauled to the wet mill in Mineral City (Spencer, 1948). For a short time also a narrow-gauge railway as a means of transport was in action (Liddell, 1917; Martens, 1928).

In the wet mill the natural h. m. concentrate containing 20 wt.-% of h. m. on the average, according to Spencer (1948) 28 wt.-% of h. m., was mixed with water and handled over 18 shaking tables. The wet mill concentrate produced with a recovery factor of 75 % on the average is said to have contained on the average 55 % of ilmenite, 20 % of zircon, 6 % of rutile, 2 % of monazite, 14 % of other h. m. as well as only 3 % of light minerals (quartz, feldspar, shell fragments). A single sample of this concentrate checked by Martens (1928) even contained 98.5 % of h. m.. After the determination of 3174 (!) grains he was able to give the following list:



46.5 % of ilmenite,  
 0.5 % of leucoxene,  
 9.9 % of rutile,  
 3.6 % of monazite,  
 2.2 % of staurolite,  
 2.8 % of epidote,  
 0.9 % of garnet,  
 0.2 % of sillimanite,  
 0.1 % of tourmaline,  
 0.2 % of hornblende,  
 0.1 % of sphene,  
 0.1 % of spinel,  
 0.2 % of collophanes  
 as well as traces of corundum and anatase.

Afterwards this wet mill concentrate was dried and by magnetic and electrostatic separation an ilmenite concentrate was being produced. The non-magnetic part was then handled over further wet shaking tables. By this new concentration on the shaking tables most of the remaining light minerals as well as the Al-silicates could be separated. Remaining rutile was separated electrostatically from the zircon and each a rutile and a zircon concentrate produced by the use of even more shaking tables and magnetic separators. Ilmenite and zircon were sold as bulk goods as well as rutile in sacks to the Titanium Pigment Company, Inc. of St. Louis, Missouri that took over also the processing of the zircon.

A calculation of the probable original volume of the deposit is only possible in a general way. As key parameters a total length of the h. m. placers of 40 km from Jacksonville Beach in the north to Vilano Beach in the south can be assumed. Theoretically the maximum widths of the beach placers could have been approx. 10 m (on the average 20 wt.-% of h. m.) and approx. 200 m (on the average 2.42 wt.-% of h. m., according to Peyton, 1955) of the dune placers. According to Martens (1928) the beach sands were mineralized down only to the elevation of the sea level (= thickness of 2 m), whereas according to Peyton (1955) the average dune thickness was 4 m. Finally calculating the weight factor (W) according to Macdonald (1983: p. 61) the following values result:

|                           | beach | dunes  | total  |
|---------------------------|-------|--------|--------|
| A (km <sup>2</sup> )      | 0.400 | 8.000  | 8.400  |
| T (m)                     | 2.0   | 4.0    | 3.9    |
| V (mill. m <sup>3</sup> ) | 0.800 | 32.000 | 32.800 |
| W (t/m <sup>3</sup> )     | 1.82  | 1.62   | 1.60   |
| Q (Mt.)                   | 1.456 | 51.840 | 53.296 |
| P (wt.-%)                 | 20.0  | 2.42   | 2.85   |
| HM (Mt.)                  | 0.291 | 1.255  | 1.546  |

Tab. 19: Economic geology of coastal placer deposits along the Recent Atlantic coast between Jacksonville Beach and Vilano Beach

In contrast to the values given above there are the calculations by Liddell (1917) with 30 to 39 Mt. of ore sand of a considerably shorter beach section. Based on Liddell's data Overstreet (1967) stated an original monazite content of the Mineral City placer deposit of 4500 tonnes.

## Offshore

The offshore area stretching out in front of the Atlantic coastal plain has been the subject of intensive geoscientific research for nearly 25 years. For this work, however, neither the stratigraphy in several hundred meters depth nor the partially complicated structure of the continental shelf off Florida is of any meaning.

Turning to the sedimentological conditions off the coast of northeast Florida the following picture can be described:

Within a few meters of water depth the relatively steeply sloping shoreface zone turns into the nearshore area being characterized by numerous shoals respectively bars. According to detailed investigations by Meisburger & Field (1975) this nearshore zone is built up by fine to very fine badly sorted silty quartz sands with a thickness up to 2.5 m („shoreface facies“ according to Meisburger & Field, 1975). The mica content partially is very high, also mollusk fragments can make up for 20 % of the sediment. Feldspar, h. m. and phosphorite nodules can be found only subordinately. Down to water depths of 5 - 10 m the bottom of the shelf is strongly mottled due to bioturbation (Howard & Scott, 1983). The already mentioned shoals reach a height of up to 6 m and principally are build up by sand (Nocita et al., 1990).

In water depths between 14 to 17 m a sedimentological change takes place to fine to coarse, well to badly sorted light gray sands. These quartz sands contain up to 15 % of carbonate in form of mollusk fragments. The feldspar content was found to be between 0.5 and 4 % with an average of 1.5 %. The number of phosphorite nodules increases, while the mica content decreases considerably. Heavy minerals again can be found only in traces. The thickness of these sands of the „inner shelf facies“ (Meisburger & Field, 1975) varies between 30 and 90 cm, only sporadically a thickness of 2.5 m is reached.

Below the sands of the „shoreface“ and the „inner shelf facies“, respectively, brown, dolomitic-silty or white, foraminiferous quartz sands can be drilled. These sands both belong to the „residual facies“ (Meisburger & Field, 1975) that also makes up for the bottom of the sea floor farther offshore, with water depths 24 m and deeper.

The flat offshore area off northeastern Florida represents a continuation of the Atlantic coastal plain that is itself only a shelf fallen dry (Grosz et al., 1986). Having been known for a long time this fact has, of course, provoked speculations regarding the h. m. content of the Recent shelf since the beginning of h. m. mining in Florida. Above all in submarine elongated sand ridges, i. e. inundated glacial sediment complexes it was expected to find h. m. placers. Also shoals of all kinds and inundated glacial river beds were said to contain h. m. deposits (Zellars-Williams Company, 1988). As especially interesting some considered those regions where also onshore h. m. deposits had been found (Emery & Noakes, 1968; Kudrass, 1987).

Already in 1954 (Rock Products) an exploration permit for h. m. off the coast of northeastern Florida was granted without, however, any find later being reported. In the 1960s and 1970s in the frame of general investigations of the sea bottom floor the absolute h. m. content of the shelf sediments was analyzed in more detail. Both Pilkey (1963) and Henry & Hoyt (1968) reported average h. m. contents of less than 0.5 wt.-%.

Without allowing to be influenced by such reports the U.S. Geological Survey carried out further investigations in the past years off the whole Atlantic coast, thereby also testing new geophysical exploration methods (Grosz & Escowitz, 1983; Wynn & Grosz, 1986; Grosz

et al., 1986; Grosz, 1987; Nocita et al., 1990). With only few exceptions, however, no h. m. enrichments being worth mining could be found.

Of course, the mining companies exploring in the southeastern USA were not inactive and also carried out independent offshore exploration programs, their specific results being treated as confidential without any exception. It is, however, generally known, that nowhere off the Atlantic coast sediments enriched in h. m. were discovered which by any economic constellation would justify considerations regarding possible mining (W. L. Evans, pers. comm., 1990, in contrast to that: Grosz et al., 1986 and Grosz, 1987).

As already mentioned until today no h. m. placers at all have been found off the coast of north-eastern Florida. The highest h. m. content ever published is 2.40 wt.-% (Grosz et al., 1986; Grosz, 1987). Also in the future discoveries of h. m. deposits worth mining are not to be expected. For this opinion a number of reasons can be given:

- 1) Most of the world-wide known coastal placers formed by the reworking of fluvial and littoral sands that were deposited during the glacials on the Recent shelves. Thereto Riggs & Belknap (1988: p. 57) wrote: "Thus, regressions create temporary storage of new sediment on the shelf, while transgressions extensively rework these sediments, carrying some shoreward with the coastal system and losing some seaward to the slope." As nearly no material for reworking was available during the glacials in times of lower sea level, the coastal sediment complexes formed during that time might have been fundamentally thinner and correspondingly might have contained far less h. m.
- 2) On one hand by the reworking of glacial littoral sediments the early Holocene transgression has created the basis for Recent coastal placers, on the other hand by this reworking it has considerably reduced the probability of the conservation of former beach placers on the shelf floor.
- 3) Climate in the glacials neither favored an extensive alteration of ilmenite into leucoxene nor the weathering of the „disturbing“ minerals hornblende, epidote, pyroxene and magnetite. Possible placer deposits hence might contain high fractions of economically non-interesting h. m. components.
- 4) To discover already quite large deposits like Green Cove Springs on the shelf can be compared with the search for a needle in a haystack. Besides, drill campaigns have to be limited to a coarse pattern with distances of at least several kilometers between the drill holes because of the immense areas to be covered.
- 5) Geophysical exploration methods of the shelf are still at their beginnings (Wynn & Grosz, 1986) and have until now not fulfilled any of the optimistic hopes for a cheaper, faster and at the same time more reliable exploration activity (W. L. Evans, pers. comm., 1990).
- 6) Barrier islands of early Holocene age being possibly rich in h. m. were only be detected solitarily in form of erosional remains off the coast of northeastern Florida.
- 7) Off the northeastern Florida coast covering economically completely uninteresting Tertiary sediments lie only very thin sand layers whereby the discovery of thick h. m. deposits is excluded from the beginning.

8) Until today governed by natural and legal restrictions exploration activities have been carried out nearly only on the outer shelf outside the three-miles-zone. Only within a few kilometers or rather hundred meters off the coast, however, those physical processes occur on the sea floor which might eventually lead to a settlement of larger amounts of h. m. (Dr. P. Lee, pers. comm., 1991).

Should the search for h. m. on the shelf be continued in spite of all these restrictions, it is recommended to yield to areas much closer to the coast. Good exploration objectives might thereby offer the island bases, the possibly larger nearshore bar systems off those islands as well as, above all, the shoals in front of the river mouths. Especially the latter might perhaps at least fulfill some of the ambitious hopes that are often connected with the search for h. m. in the offshore zone.

Although, as already pointed out for several times, no submarine h. m. deposits worth mining off the Atlantic Coastal Plain have been discovered until today, techniques for possible mining in the offshore zone are already known. Detailed, but of course completely theoretical essays about this subject are to be found in Harvey & Brown (1986), U. S. Bureau of Mines (1987) and Zellars-Williams Company (1988).

## History and future of heavy mineral mining in northeastern Florida

The first h. m. placers of the USA were mined in Cleveland Co., North Carolina, starting in 1895. Their monazite was used for the production of thorium, which was needed for the manufacture of incandescent gas lights. By the spread of electric lights these first h. m. mining operations in the USA came to a sudden stop in 1916 (Garnar, 1980).

The need of another mineral, on the other hand, initiated the beginning of h. m. mining in Florida. This mineral was ilmenite, which titanium, converted to titanium tetrachloride, found several "applications" during World War I (see chapter on Ponte Vedra Beach). This potential demand was answered by Henry H. Buckman and George A. Pritchard by the opening of their operations south of Jacksonville Beach, which soon got known under the name Mineral City. There, typical high-grade beach placers and adjacent strongly mineralized dunes were mined mostly by hand.

At the end of World War I the market for ilmenite collapsed and in 1922 the former independent company Buckman & Pritchard Inc. was bought by the former National Lead Company and its operations continued as a subsidiary. After this change of ownership for the first time ever zircon was commercially produced in Florida, which was exclusively sold to customers in the refractory industry. Rutile, for the first time separated in 1925, was converted by National Lead into titanium dioxide and used as a raw material for the rapidly growing pigment industry. Also in 1925 monazite was first commercially produced in Florida.

Although the market for h. m. steadily increased during the following years the mining operations in Florida were stopped in 1929. This stop was caused by the depletion of the h. m. rich beach placers and the strong competition of Indian producers. In the '30s mining of h. m. started on the Australian east coast, increasing the supply even further. Not till 1939, with the beginning of World War II, the demand for h. m. increased again.

The first who answered to these changing market conditions was again George A. Pritchard. This time he was mining h. m. placers for the Riz Mineral Company on both sides of the Indian River (Brevard and Indian River Co.) between 1939 and 1943 (Mertie, 1958, 1975). The minerals ilmenite, zircon, and monazite were separated in a mill near Palm Bay, 4 km south of Melbourne, Brevard Co. With the depletion of these beach placers at the Indian River, the operations changed to dune placers, which were mined starting in September 1943 south of Vero Beach, 5 km onshore.

Meanwhile the war had expanded and the supply routes from Australia and India to the USA were cut off. With the USA joining the war in 1941 the demand for raw materials multiplied without enough deposits, in this case for h.m., being mined.

For this reason in 1942, the Titanium Alloy Manufacturing Co., a subsidiary of National Lead, decided to start mining h. m. in Florida. It focused its attention on a deposit east of Jacksonville, discovered by National Lead in the '30s, which at that time had also taken over the Mineral City operations close nearby. National Lead and Titanium Alloy Manufacturing Co. together founded the Rutile Mining Company of Florida, which in fall 1943 started mining the dune placers near Jacksonville, producing ilmenite and rutile for war purposes. Within a short time, however, they encountered a number of serious difficulties in their process, caused by their operation techniques applied, which endangered further production on the whole.

Help arrived with Humphreys Gold Corporation, founded in 1934, but looking back to a much longer mining history (Thompson & Whittle, 1990). In 1943 this company had taken the assignment to concentrate chromite from beach placers in Oregon and for this purpose had developed and later run the so-called Humphreys Spirals (Thompson & Welker, 1990).

After executing this commission a subsequent contract was made with the Rutile Mining Company of Florida and in April 1944 responsibility for the h. m. mining operations near Jacksonville was taken over. By the installation of Humphreys Spirals and technical changes in the mining of the h. m. enriched sand, they succeeded in making the operations profitable again. After the end of World War II, in 1946 zircon, and in 1949 monazite was first produced from the Jacksonville deposits.

From a technical point of view the separation of h. m. was considerably eased by an invention of J. Hall Carpenter, who, first as an employee of National Lead, later of Humphreys, developed the "High-tension Separator" in 1946. In 1948 he founded Carpc, Inc., Jacksonville, which from that time on offered technical equipment to mining companies not only in Florida.

Also with the end of World War II, the chemical company E. I. Du Pont de Nemours & Company, Inc. started a large-scale exploration program on h. m. in Florida. In 1946, nearly at the same time with the U.S. Bureau of Mines, the Trail Ridge deposit was discovered, for which the necessary mining rights were acquired till the end of 1947. As the success of Humphreys Gold Corporation's mining operations at Jacksonville had spread, Du Pont commissioned this company with the mining of their h. m. from Trail Ridge too. After only starting with ilmenite and rutile, zircon was being separated from 1950 and staurolite from 1952 for the first time anywhere. In 1955 Humphreys opened the Highland plant north of the Trail Ridge site, which led to a doubling of the tonnages produced.

Meanwhile the situation also had changed in central Florida. In 1948 the Riz Mineral Company was sold and rearranged by its new owner, who changed its name to Florida Ore Processing Company, Inc., implemented technical changes in the Palm Bay plant and started production of a garnet concentrate. At the same time mining of dune placers south of Vero Beach was continued till 1954 (Calver, 1957).

In that year this deposit was depleted and mining shifted to west of Winter Beach. Here, south of Wabasso and northwest of Vero Beach, an extremely low-grade (1.5 - 2 wt.-% h. m.) dune placer had been discovered by the well-known George A. Pritchard before the end of World War II, but not paid attention to any further for its low h. m. content (Mertie, 1975).

By order of Hobart Brothers Welding Company, the Florida Ore Processing Company started mining this new deposit in 1954. In March 1955 the Florida Minerals Company, a direct subsidiary of Hobart Brothers Welding Company took over the mining, while the h. m. still were concentrated in the Palm Bay plant, till on Oct. 17, 1955 this plant caught fire. With the complete destruction of their plant all activities of the Florida Ore Processing Company ceased.

Hobart Brothers Company, however, decided not to stop mining at its just opened site, but to erect a new plant close to its Winter Beach deposit. Here, from February 1956 to the end of all h. m. mining in central Florida in 1963, small amounts of ilmenite, rutile, zircon, monazite, and garnet were produced (Calver, 1957; Garnar, 1980).



While in the early '50s the Florida Ore Processing Company and Humphreys Gold Corporation for National Lead on one side and Du Pont on the other were already mining h. m. placers in Florida, the search for similar deposits all over the southeastern United States continued.

Du Pont discovered the h. m. placers at Folkston and Yulee and did exploration work on the barrier islands of the Sea Island Chain (Gillson, 1959).

In 1955 National Lead acquired a large piece of land north of the Highland site of Trail Ridge.

Along the southern Atlantic coast, Atlantic Engineering Corporation, Palm Beach (Thoenen & Warne, 1949), was engaged in prospecting, while offshore northeastern Florida, Freeman, Inc., founded by C. E. Freeman, Jacksonville, was interested in h. m. placers (Rock Products, 1954).

Heavy Minerals Company, a subsidiary of Crane Company, discovered h. m. placers along the Recent Gulf coast west of Panama City Beach, Florida, but decided instead to start mining (1955 - 1959) fluvial monazite placers in Horse Creek, South Carolina (details in Mertie, 1975, p. 25).

Glidden Company in 1957 lost a lawsuit on mining h. m. placers on Cumberland Island (Fantel et al., 1986, E. V. Whittle, pers. comm., 1990) and, thereupon, preferred to mine titanium minerals from placers near Lakehurst, New Jersey (1964 - 1978).

Union Carbide and Carbon Corporation planned to mine h. m. on Amelia Island, while Nuclear Magnetic Mining Company, St. Augustine, together with Chesapeake and Colorado National Corporation had plans to mine h. m. from Anastasia State Park south of St. Augustine and from placers near Pensacola, Florida.

Humphreys Gold Corporation also played a major role in the exploration of several placer deposits. Its major competitor at that time was the Bear Creek Mining Company, a subsidiary of Kennecott Copper Corporation, which beginning in 1954, did systematical exploration work above all in all counties of northeastern Florida (Mertie, 1958, 1975). An unpublished report of the activities of this latter company in St. Johns County were found in the files of the Florida Geological Survey in Tallahassee. Conclusions, drawn by rechecking raw data from 225 holes drilled along public roads to depths of 10 meters in that county, were used in drawing fig. 27.

By the mid '50s numerous h. m. deposits had been discovered, of which a majority should be mined. In fall 1957, however, the U.S. military surprisingly decided to cut down aircraft construction in favor of rocket production (Garnar, 1980). As for military aircrafts a large part of the U.S. titanium production was used, a strong deterioration of ilmenite and rutile prices was the immediate result. This price decline in turn led to a stop of nearly all mining plans and to the withdrawal of the majority of companies prospecting in Florida.

An increase of zircon prices at nearly the same time, however, initiated Du Pont not to renew the agreement with Humphreys Gold Corporation on the mining of the Trail Ridge deposit, but to take over the production in 1958 itself.

In 1964 Humphreys Gold Corporation closed down its Jacksonville operations after more than 20 years and shifted mining to the Folkston site in southeast Georgia, where production was started in 1965 for Du Pont on a dune placer already discovered in 1952.

From 1966 to 1967 Carpco Engineering returned to the unreclaimed Jacksonville tailings and for the first time in Florida produced a xenotime concentrate.

In 1972 American Cynamid Company, interested in titanium minerals, and Union Camp Corporation, the property owner, founded a mining company called Titanium Enterprises with the aim to mine h. m. placers south of Green Cove Springs, which were discovered in 1966 by Union Camp Corporation. Till 1978 ilmenite, rutile, zircon, and monazite was produced from this second-largest placer deposit in Florida after Trail Ridge. In 1978, however, a decline of zircon prices led to a stop of all operations and the complete Green Cove Springs deposit including all equipment was offered for sale.

| <b>Deposit</b>                                                                                                                                             | <b>Mining</b>                                                    | <b>Operator</b>                                    | <b>Products offered</b>  |
|------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------|----------------------------------------------------|--------------------------|
| <i>Mineral City</i>                                                                                                                                        | 1916 - 1929                                                      | Buckman & Pritchard, Inc.                          | Il, Rt, Zr, Mo           |
| <i>Melbourne</i>                                                                                                                                           | 1939 - 1943                                                      | Riz Mineral Co.                                    | Il, Rt, Zr, Mo           |
| <i>Vero Beach</i>                                                                                                                                          | 9' 1943 - 1948                                                   | Riz Mineral Co.                                    | Il, Rt, Zr, Mo           |
|                                                                                                                                                            | 1948 - 1954                                                      | Florida Ore Processing Co.                         | Il, Rt, Zr, Mo, Gr       |
| <i>Winter Beach</i>                                                                                                                                        | 1954 - 3' 1955                                                   | Florida Ore Processing Co.                         | Il, Rt, Zr, Mo, Gr       |
|                                                                                                                                                            | 1955 - 1956                                                      | Florida Minerals Co.                               | Il, Rt, Zr, Mo, Gr       |
| <i>Jacksonville</i>                                                                                                                                        | 8' 1943 - 3' 1944                                                | Rutile Mining Co. of Florida                       | Il, Rt                   |
|                                                                                                                                                            | 4' 1944 - 12' 1964                                               | Humphrys Gold Corp.                                | Il, Rt, Zr, Mo, Gr       |
|                                                                                                                                                            | 1966 - 1967                                                      | Carpco Engineering (tailings)                      | Mo, Xe                   |
| <i>Folkston</i>                                                                                                                                            | 8' 1965 - 7' 1974                                                | Humphreys Gold Corp.                               | Ti-Pr, Zr, Mo            |
| <i>Boulogne</i>                                                                                                                                            | 11' 1974 - 11' 1979                                              | Humphreys Mining Co.                               | Ti-Pr, Zr, Mo            |
| <i>Trail Ridge</i>                                                                                                                                         | 4' 1949 - 1958                                                   | Humphreys Gold Corp.                               | Il, Res, St              |
|                                                                                                                                                            | 1958 - today                                                     | E. I. Du Pont de Nemours & Co., Inc.               | Il, Res, St              |
| <i>Highland</i>                                                                                                                                            | 4' 1955 - 1958                                                   | Humphreys Gold Corp.                               | Il, Res, Zr, St          |
|                                                                                                                                                            | 1958 - today                                                     | E. I. Du Pont de Nemours & Co., Inc.               | Il, Res, Zr, St          |
| <i>Maxville</i>                                                                                                                                            | 1993 - today                                                     | E. I. Du Pont de Nemours & Co., Inc.               | Il, Res, Zr, St          |
| <i>Green Cove Springs</i>                                                                                                                                  | 1972 - 6' 1978                                                   | Titanium Enterprises                               | Il, Rt, Zr, Mo           |
|                                                                                                                                                            | 7' 1978 - 4' 1980                                                | Titanium Enterprises (tailings)                    | Zr, Mo, St               |
|                                                                                                                                                            | 4' 1980 - 1991                                                   | Associated Minerals (USA) Inc.                     | Il, Rt, Lx, Zr, Mo, (St) |
|                                                                                                                                                            | 1992 - today                                                     | Renison Goldfields Cons. (USA) Mineral Sands, Inc. | Il, Rt, Lx, Zr, Mo       |
| <p>Il = Ilmenite, Rt = Rutile, Lx = Leucoxene, Res = Residue, Ti-Pr = Titanium Product<br/> Zr = Zircon, Mo = Monazite, Xe = Xenotime, St = Staurolite</p> |                                                                  |                                                    |                          |
| 1916                                                                                                                                                       | first commercial production of ilmenite concentrate in Florida   |                                                    |                          |
| 1922                                                                                                                                                       | first commercial production of zircon concentrate in Florida     |                                                    |                          |
| 1925                                                                                                                                                       | first commercial production of rutile concentrate in Florida     |                                                    |                          |
| 1925                                                                                                                                                       | first commercial production of monazite concentrate in Florida   |                                                    |                          |
| 1944                                                                                                                                                       | first use of Humphreys Spirals in Florida                        |                                                    |                          |
| 1946                                                                                                                                                       | first use of high tension separators in Florida                  |                                                    |                          |
| 1948                                                                                                                                                       | first commercial production of garnet concentrate in Florida     |                                                    |                          |
| 1952                                                                                                                                                       | first commercial production of staurolite concentrate in Florida |                                                    |                          |
| 1966                                                                                                                                                       | first commercial production of xenotime concentrate in Florida   |                                                    |                          |

Tab. 20: Important economic data of heavy mineral mining in Florida

One of the companies interested in taking over the operations was Humphreys Mining Company, successor of Humphreys Gold Corporation. In 1975 after depletion of the Folkston placer deposit this company had started mining the Boulogne placer nearby on its own account. For 1980 it was planned to shift operations again, this time to the Altama placers near Brunswick, Georgia.

These plans, however, could not be realized for economic calculations and in 1980, after closing down its Boulogne site, Humphreys had to go out of business. It was not before 1986 that Carpco, Inc. started production of Humphreys Spirals again, and in 1988 merged with Humphreys Process Equipment, to in this way continue at least a part of the tradition of the former many-membered and worldwide operating Humphreys companies.

For this reason a different owner for the Green Cove Springs operations had to be found. In 1980 the experienced Associated Minerals Consolidated, a subsidiary of the Australian mining company Consolidated Gold Fields Australia Ltd. (now Renison Goldfields Consolidated Ltd.) took over. After the recovery of h. m. prices and successful exploration of a new placer west of the main Green Cove Springs deposit, with the newly founded subsidiary Associated Minerals (USA) Inc., a new name was soon established on the Florida h. m. market.

Presently, in the mid '90s, only two companies are active in Florida (see fig. 26). On the one hand this is Du Pont, still mining the Trail Ridge deposit at its Trail Ridge and its new Maxville sites, and on the other it is Renison Goldfields Consolidated (USA) Mineral Sands Inc., renamed in 1992 from Associated Minerals (USA) Inc., mining its Green Cove Springs ore body. Both companies are working together in a friendly way, as long as no new exploration targets are concerned.

Partner in all questions of dressing techniques still is Carpco Inc. in Jacksonville which since 1986 is also producing the well-established Humphreys Spirals again. Renison Goldfields Consolidated (USA) has another supplier of technical equipment in its Australian mother company.

While in earlier years only few geologists were asked to state their opinions on questions on economic geology problems, now all mining companies have their own geological sections, which above all are engaged in exploration programs.

Plans of Du Pont to continue mining Trail Ridge even farther north at the Folkston West site (Pirkle et al., 1993) are proceeding, above all encountering problems due to increased environmental restrictions (Okefenokee Swamp National Park nearby). RGC (USA) on the other hand recently has decided to develop the Old Hickory placer deposit in Virginia (Carpenter & Carpenter, 1991).

Finally coming to the question whether any of the other h. m. placers in northeastern Florida could be mined there is no clear picture. General requirements for h. m. placer deposits in the southeastern United States, already published in 1950 by Cannon, who stated a minimum grade of 4 - 5 wt.-% h. m. and a reserve of at least one million short tons of h. m. are still valid. His relatively low minimum grade cited above is based on the use of Humphreys Spirals, which for the first time enabled the concentration of h. m. from those low-grade deposits. Nowadays even a cut-off grade of 2 wt.-% h. m. is acceptable, which allows the mining of large scale deposits (see: Mertie, 1958, p. 23 and Lynd, 1983, p. 1340).

A closer look at the placers already discovered in northeastern Florida, shows only minor chances for the start of mining of any of these deposits. The very small deposit on Amelia Island was covered by buildings and, therefore, will never be mined. A similar fate can be expected for the much larger Yulee deposit.

Subrecent h. m. placers situated along the beaches of Florida will never be mined again, as all barrier islands and beaches of the USA (outside Alaska) are either strongly covered with buildings (Hilton Head Island, Ossabaw Island etc.) or are protected by their conversion into recreation areas (Little Talbot Island, Cumberland Island).

In the placer district of Folkston-Boulogne several small placers are known, which, however, are not worth mining. Whether the Trail Ridge feature really contains feasible h. m. concentrations in its northern part is only known by Du Pont. The economic problems in starting the operations at their Maxville site, however, do not favor an opening of any other mining site (e. g. Fokston West) within this century.

The only remaining deposit is the Jacksonville one, of which only a minor part was mined between 1943 and 1964. Reserves of h. m. still in place can be calculated as about 10 million tons. As in this area the covering with buildings is also increasing rapidly, most of these reserves are not available any more. Totally unknown on the other hand is, whether this placer district extends to the east below the swampy beach ridge plain between Jacksonville and Jacksonville Beach.

Above all west of Pablo Creek an increased radiation could be observed by aeroradiometric surveys (Grosz et al., 1989), which at any rate could be a sign for h. m. placers (barrier island of Princess Anne ?) (see fig. 27).

In 1977, 25 km to the south, near the small town of Darien, St. Johns County, a well was drilled by the Florida Geological Survey (Scott # 2 = core no.: W 13751) at a surface elevation of 18.6 m above msl, with cores only taken at certain intervals (see fig. 27).

At this is the only one of thirteen wells, drilled outside of known placer deposits and containing sands with more than 2 wt.-% h. m., results of analyses of samples of this core (after Elsner, 1992 a) shall be cited below:

| depth       | h. m.  | econ. min. | Ep + Hb | mean         | std. dev. | skewness | kurtosis |
|-------------|--------|------------|---------|--------------|-----------|----------|----------|
| 0 - 5 ft.   | 0.57 % | 54 %       | 12 %    | 2.496        | 0.312     | + 0.635  | 11.788   |
| 10 - 15 ft. |        |            |         | not analyzed |           |          |          |
| 15 - 20 ft. | 2.40 % | 71 %       | 1 %     | 2.580        | 0.303     | + 0.028  | 7.849    |
| 20 - 25 ft. |        |            |         | not analyzed |           |          |          |
| 25 - 30 ft. | 2.33 % | 67 %       | 1 %     | 2.597        | 0.523     | + 2.286  | 12.522   |
| 30 - 35 ft. |        |            |         | not analyzed |           |          |          |
| 35 - 40 ft. |        |            |         | not analyzed |           |          |          |
| 40 - 45 ft. |        |            |         | not analyzed |           |          |          |
| 45 - 50 ft. |        |            |         | not analyzed |           |          |          |
| 50 - 55 ft. | 0.21 % | 35 %       | 30 %    | 2.624        | 0.445     | - 1.770  | 10.765   |

Tab. 21: Sediment parameters of sands of well Scott # 2. Surface: 18.6 m above msl  
(Ep = epidote, Hb = hornblende, all data in wt.-% or phi)

As only few samples of the core of well Scott # 2 were analyzed, neither the former depositional environment, nor the thickness of the h. m. enriched sand is known precisely. Comparisons with other placers of northeastern Florida, however, favor a deposition of the sands between 30 and 35 ft. in the nearshore zone. Sands between 15 and 20 ft. could have been deposited in an eolian environment. Situated directly south of the Jacksonville deposit these placers could be of Sangamon age too.

The h. m. content of other regions of St. Johns County were checked by the Bear Creek Mining Company back in the '50s (see above). Most of those samples gave h. m. percentages of less than 0.5 wt.-%, only sands of the Pamlico age beach ridge plain west of St. Augustine did contain h. m. with a maximum of 4.85 wt.-%.

If we summarize all the various statements given above, the whole area between Interstate 95 to the west and the Intracoastal Waterway to the east, and between St. Johns River to the north and St. Augustine to the south seems to be of great promise. An extensive exploration program including also the swampy areas of this region could most probably lead to the discovery of new feasible deposits (see fig. 27).

At Doctor's Inlet Grosz et al. (1989) were able to show a radioactive anomaly, of which no clear origin is known.

The extension of the Penholoway age shoreline north of Doctor's Inlet near Whitehouse was already discovered by Thoenen & Warne (1949). According to J. M. Elder (RGC, pers. comm., 1990) the placer deposits in this area, however, can not be mined due to a nearby air-base and the dense population west of Jacksonville.

The discovery of new h. m. placer deposits in the future could be eased by geophysical means, which have been developed a great deal further since the ages of McKelvey & Balsley (1948). While these authors were mapping h. m. concentrations in the beach zone by using a low-flying airplane, in other areas the application of (aero)radiometric surveys yielded much better results (Moxham, 1954; Arnold, 1957; Grosz et al., 1989).

Apart from its high precision there are, however, some disadvantages to this method, as only zircon and above all monazite by their radioactivity can be detected and as even a few decimeters of h. m. poor sands strongly hamper the discovery of placer deposits in sediments below (Wynn & Grosz, 1983). The effect of interfering radiations of phosphates, both from phosphorite deposits as well as from fertilizers, and from granite used in buildings, was discussed in detail by Grosz et al. (1989).

Tests of the U.S. Geological Survey to detect concentrations of ilmenite by induced polarization (IP) were described by Wynn & Grosz (1983) and Wynn et al. (1985). Tests of this method were also run in the offshore zone (Wynn & Grosz, 1986) although till now no final judgment about the practical uses of this method can be rendered.

After Force (1991, p. 80) all h. m. placer deposits in the southeastern United States, i. e. all deposits ever mined in Florida and the Folkston deposit in SE-Georgia have yielded 5 Mt. of  $\text{TiO}_2$  all together. 14 Mt. of  $\text{TiO}_2$  still remain in the ground, of which at least some may be worth producing in the future.

## Geologic summary and economic conclusion

In northeastern Florida nine different h. m. placer deposits are known. All are to be found parallel to the Recent or fossil shorelines, which means that their deposition was closely linked to former sea level changes. For the first time information about these local sea level changes could be correlated with global events which ages, in turn, can be given relatively precisely by reviewing the international literature. By combining all formerly available information and new findings the Cenozoic history of northeastern Florida can now be summarized as follows:

During the early and middle Tertiary Florida was a carbonate platform similar to the Recent Bahamas platform. In late Miocene time the first noteworthy amounts of clastic sediments from the Appalachian mountains reached the Florida platform and by the mid-Pliocene the deposition of carbonates was restricted to the southern tip of the Florida peninsula. In northern and central Florida, coarse, poorly sorted clastic sediments (Cypresshead-Citronelle Formation) were deposited by braided rivers. With rising sea level in middle late Pliocene time the sea inundated major parts of this former river plain with its waves breaking against the central parts of Florida, thereby finally forming the central Lakes Wales Ridge system.

Close to end of the Pliocene the sea level dropped again. Strong winds picked up the sandy sediments of the former sea floor and huge dunal systems were formed, the largest probably lying along the central axis of northern peninsular Florida. At the very end of the Pliocene the sea level (Wicomico sea level) rose again, destroying all but the largest dune system, the Trail Ridge feature, which now contains the largest h. m. placer deposit in the USA.

By the middle Pleistocene another glacial complex had initiated a new cycle of h. m. transport and deposition, when with rising sea level at the very end of this glacial complex dunes were formed along the advancing shoreline in northeastern Florida. Most of these coastal dunes were destroyed by a sea level still rising, but a few remained as obstacles on the shallow sea floor and by transverse bottom currents led to the deposition of h. m. in the nearshore zone. In this way the placer deposits of Boulogne and Green Cove Springs (main ore body) were formed. Coastal dunes of this Penholoway sea level make up the Folkston and Green Cove Springs western ore bodies.

During the last interglacial (Pamlico sea level) several more placer deposits in northeastern Florida were formed, most of their h. m. having been deposited in the eolian environment (Yulee and Jacksonville deposits).

Eolian and beach storm placer deposits of Holocene age can be found on Amelia and Little Talbot Islands, as well as along the beaches between Jacksonville Beach and St. Augustine.

To allow direct economic comparisons between these various known h. m. placer deposits of northeastern Florida, their most important economic parameters were summarized in tab. 22. There, the rank of size of the placer deposits is easily recognizable. With original reserves of nearly 52 million metric tonnes (Mt.) of available h. m. Trail Ridge is leading in front of the Green Cove Springs deposit with only a third of its size. Only these two deposits are currently being mined: Trail Ridge for nearly 50 years and Green Cove Springs for close to 25 years.

The original h. m. reserves of the Jacksonville deposit (mining between 1943 and 1964) have not been much smaller than those of the Green Cove Springs deposit. Theoretical reserves, still remaining in the Jacksonville area may be about 10 Mt. of h. m. This is more than



double the reserve of the Yulee deposit and more than eleven times the tonnage of h. m. in place before the start of production near Boulogne, which was the smallest placer deposit ever mined in Florida.

Also of great importance are the differences in the h. m. suite of the various deposits. Both the monazite and rutile contents of the Trail Ridge placer are rather low, as well as the monazite contents of the Yulee and Amelia Island deposits. The placer deposits on Little Talbot Island remain those with the lowest percentage of economic minerals.

Characteristics of some selected especially big h. m. placer deposits from other regions of the world are given in tab. 26. At first sight it is getting clear that the two largest h. m. deposits in the world, WIM 150 and Richards Bay, contain about three times as many h. m. as Trail Ridge. Besides, before being mined, Trail Ridge has been among the five biggest placer deposits in the world. The Green Cove Springs and Jacksonville deposits can both be ranked into the "upper middle class". All the other placers of northeastern Florida are only of local importance.

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"The half of knowledge is to know where to find knowledge"

Inscription Dodd Hall, Florida State University

|          |   |                                                                     |
|----------|---|---------------------------------------------------------------------|
| AAPG     | = | American Association of Petroleum Geologists                        |
| AIME     | = | American Institute of Mining, Metallurgical and Petroleum Engineers |
| GSA      | = | Geological Society of America                                       |
| SEPM     | = | Society of Economic Paleontologists and Mineralogists               |
| SME      | = | Society of Mining Engineers                                         |
| GCAGS    | = | Gulf Coast Association of Geological Societies                      |
|          |   |                                                                     |
| F.G.S.   | = | Florida Geological Survey                                           |
| G.G.S.   | = | Georgia Geological Survey                                           |
| U.S.B.M. | = | United States Bureau of Mines                                       |
| U.S.G.S. | = | United States Geological Survey                                     |
|          |   |                                                                     |
| JSP      | = | Journal of Sedimentary Petrology                                    |
| EMJ      | = | Engineering and Mining Journal                                      |
| PPP      | = | Paleogeography, Paleoclimatology and Paleoecology                   |

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... It is astonishing and incredible to us, but not to Nature; for she performs with utmost ease and simplicity things which are even infinitely puzzling to our minds, and what is very difficult for us to comprehend is quite easy for her to perform.

Galileo  
 Dialogue Concerning the Two World Systems (1630)

cited in: Komar (1976)

## Appendices

### Appendix I: Origin of analyzed samples

a.) samples from well cores (see fig. 27 and tab. 24) stored in the core library of the Florida Geological Survey, Tallahassee:

| well number | well name     | county    | surface | total depth | location       |
|-------------|---------------|-----------|---------|-------------|----------------|
| W 10488     | Trail Ridge 1 | Clay      | 72.8 m  | - 28.3 m    | T6S-R23E-31dbd |
| W 10489     | Trail Ridge 2 | Clay      | 62.8 m  | 18.4 m      | T5S-R23E-19baa |
| W 12360     | Highland 1    | Bradford  | 61.6 m  | - 88.7 m    | T4S-R22E-25cdb |
| W 12361     | Highland 2    | Baker     | 58.2 m  | 19.5 m      | T4S-R22E-12abd |
| W 10473     | Trail Ridge 3 | Baker     | 50.9 m  | - 36.9 m    | T2S-R22E-15ddd |
| W 10482     | Boulogne 1    | Nassau    | 30.8 m  | 2.6 m       | T4N-R23E-26dcb |
| W 10481     | Union Camp 1  | Clay      | 34.1 m  | 1.2 m       | T7S-R23E-21cac |
| W 12112     | Union Camp 2  | Putnam    | 25.9 m  | - 8.2 m     | T8S-R26E-10cdd |
| missing     | Union Camp 3  | Clay      | 36.0 m  | 4.0 m       | T7S-R26E-6cdd  |
| W 13815     | Cassidy 1     | Nassau    | 24.4 m  | - 125.0 m   | T3N-R24E-32aa  |
| W 13744     | Scott 1       | St. Johns | 8.5 m   | - 68.3 m    | T6S-R28E-8d    |
| W 13751     | Scott 2       | St. Johns | 18.6 m  | - 85.6 m    | T5S-R28E-11cb  |
| W 13765     | Scott 3       | St. Johns | 7.6 m   | - 66.1 m    | T6S-R28E-14bba |
| W 14619     | Carter 1      | Duval     | 3.7 m   | - 148.7 m   | T1S-R27E-42    |
| W 14219     | Jennings 1    | Clay      | 27.4 m  | - 122.5 m   | T4S-R24E-27ddd |
| W 14193     | Fox Meadows 1 | Clay      | 15.2 m  | - 93.6 m    | T4S-R25E-13bac |
| W 14179     | Long Branch 1 | Clay      | 26.2 m  | - 71.3 m    | T4S-R23E-16aad |
| W 13769     | Harris 1      | Clay      | 29.6 m  | - 67.7 m    | T6S-R25E-7cd   |
| W 14283     | Wainwright 1  | Bradford  | 55.2 m  | - 30.8 m    | T6S-R22E-24dc  |
| W 14255     | Mizelle 1     | Bradford  | 40.5 m  | - 2.1 m     | T7S-R19E-1da   |
| W 14280     | Varnes 1      | Bradford  | 42.7 m  | - 10.8 m    | T7S-R21E-4cb   |
| W 13814     | Raiford 1     | Bradford  | 39.0 m  | - 43.9 m    | T5S-R21E-26cba |

Tab. 24: Key parameters of well cores of northeastern Florida

b.) samples from h.m. mining operations and others:

|                   |                                                                       |
|-------------------|-----------------------------------------------------------------------|
| G.C.S.-W.O.B.     | Original raw sand sample from the Green Cove Springs western ore body |
| G.C.S.-W.M. Tail. | Tailings of the Green Cove Springs wet mill,                          |
| G.C.S.-W.M. Cc.   | Green Cove Springs wet mill concentrate,                              |
| Hi.-W.M.Cc.       | Highland wet mill concentrate                                         |
| F.                | Original raw sand sample from the Folkston ore body                   |
| F.-W.M.Tail.      | Folkston wet mill tailings,                                           |
| F.-W.M.Cc.        | Folkston wet mill concentrate,                                        |

## Appendix II: Characteristics of heavy mineral samples

|                |                 |                  |                  |
|----------------|-----------------|------------------|------------------|
| Il = ilmenite  | Ky = kyanite    | Sp = spinel      | Co = corundum    |
| Lx = leucoxene | St = staurolite | To = topaz       | Se = sphene      |
| Rt = rutile    | Gr = garnet     | Si = sillimanite | Br = brookite    |
| Zr = zircon    | Ep = epidote    | An = andalusite  | At = anatase     |
| Mo = monazite  | Hb = hornblende | Tm = tourmaline  | Cs = cassiterite |
| Xe = xenotime  | Be = beryl      | Cl = chloritoid  | + = < 0.5 wt.-%  |

|          |   |                                                                            |
|----------|---|----------------------------------------------------------------------------|
| HM       | = | heavy mineral content in weight-percent                                    |
| Lx/Il    | = | ratio of leucoxene to ilmenite                                             |
| mean     | = | arithmetic mean of the grain size distribution in phi                      |
| SD       | = | standard deviation of the grain size distribution (moment measures)        |
| Sk       | = | skewness of the grain size distribution (moment measures)                  |
| K        | = | kurtosis of the grain size distribution (moment measures)                  |
| T.F.     | = | fine tail of the grain size distribution ( $\geq 4$ phi) in weight-percent |
| all: pan | = | 5 phi                                                                      |

| phi    | mm    | ASTM mesh | Tyler mesh |
|--------|-------|-----------|------------|
| - 2.00 | 4.000 | 5         | 5          |
| - 1.75 | 3.364 | 6         | 6          |
| - 1.50 | 2.824 | 7         | 7          |
| - 1.25 | 2.378 | 8         | 8          |
| - 1.00 | 2.000 | 10        | 9          |
| - 0.75 | 1.682 | 12        | 10         |
| - 0.50 | 1.414 | 14        | 12         |
| - 0.25 | 1.189 | 16        | 14         |
| 0.00   | 1.000 | 18        | 16         |
| 0.25   | 0.841 | 20        | 20         |
| 0.50   | 0.707 | 25        | 24         |
| 0.75   | 0.595 | 30        | 28         |
| 1.00   | 0.500 | 35        | 32         |
| 1.25   | 0.420 | 40        | 35         |
| 1.50   | 0.354 | 45        | 42         |
| 1.75   | 0.297 | 50        | 48         |
| 2.00   | 0.250 | 60        | 60         |
| 2.25   | 0.210 | 70        | 65         |
| 2.50   | 0.177 | 80        | 80         |
| 2.75   | 0.149 | 100       | 100        |
| 3.00   | 0.125 | 120       | 115        |
| 3.25   | 0.105 | 140       | 150        |
| 3.50   | 0.088 | 170       | 170        |
| 3.75   | 0.074 | 200       | 200        |
| 4.00   | 0.063 | 230       | 250        |
| 4.25   | 0.053 | 270       | 270        |
| 4.50   | 0.044 | 325       | 325        |

Tab. 25: Conversion table of sieve sizes

$$\begin{aligned}
 (x) \text{ mm} &= \text{how many phi?} \rightarrow \log_2(x) = \ln(x)/\ln(2) \rightarrow \text{phi looked for} \\
 (x) \text{ phi} &= \text{how many mm?} \rightarrow e^{(-x)(\ln(2))} \rightarrow \text{mm looked for}
 \end{aligned}$$

## Ilmenite and leucoxene

In northeastern Florida ilmenite was or is being mined in the following sites: Ponte Vedra Beach, Jacksonville, Trail Ridge, and Green Cove Springs. Titanium minerals of the Folkston and Boulogne deposits were not separated, but sold as "Titanium Product" (a mixture of ilmenite, leucoxene, and rutile). RGC sells a low-grade leucoxene mixture from its Green Cove Springs deposits. By request of this company no results of any analyses of this product may be published. Du Pont is producing the so-called "Residue", a mixture of leucoxene and rutile, for its own pigment plants.

A number of analyses of these titanium mineral concentrates have been published in the literature. Most of them are not very detailed, but may easily be compared with findings of this work.

### Trail Ridge:

|                           | TiO <sub>2</sub> | Fe <sub>2</sub> O <sub>3</sub> | FeO    | Cr <sub>2</sub> O <sub>3</sub>                                                                                                                                                                          | V <sub>2</sub> O <sub>5</sub> | L.O.I. |
|---------------------------|------------------|--------------------------------|--------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------|--------|
| Gillson (1949)            | 64.0 %           | 26.0 %                         | 4.1 %  |                                                                                                                                                                                                         |                               |        |
| Carpenter et al. (1953)   | ca. 63 %         |                                |        |                                                                                                                                                                                                         |                               |        |
| Lynd et al. (1954)        | 64.1 %           | 25.6 %                         | 4.7 %  | 0.07 %                                                                                                                                                                                                  | 0.12 %                        | 1.0 %  |
| Calver (1957)             | ca. 63 %         |                                |        |                                                                                                                                                                                                         |                               |        |
| Lynd (1960a)              | 64.0 %           | 26.0 %                         | 4.8 %  |                                                                                                                                                                                                         |                               |        |
| Giese et al. (1964)       | 63.0 - 66.8 %    |                                |        |                                                                                                                                                                                                         |                               |        |
| Temple (1966)             | 69.2 %           | 26.0 %                         | 4.8 %  |                                                                                                                                                                                                         |                               |        |
| Teufer & Temple (1966)    | 64.2 %           | 25.2 %                         | 4.1 %  |                                                                                                                                                                                                         |                               |        |
| Peterson (1966)           | ca. 64 %         |                                |        |                                                                                                                                                                                                         |                               |        |
| Garnar (1971)             | 64.5 %           |                                |        |                                                                                                                                                                                                         |                               |        |
| Mackey (1972)             | 64.3 %           | 27.16 %                        |        |                                                                                                                                                                                                         |                               |        |
| Garnar (1973)             | ca. 64 %         |                                |        |                                                                                                                                                                                                         |                               |        |
| Mertie (1975)             | 61.5 %           | 26.40 %                        | 4.61 % |                                                                                                                                                                                                         |                               |        |
| Lynd & Lefond (1975)      | 64 %             | 28.48 %                        | 1.33 % | 0.007 % CaO, 0.20 % MgO,<br>0.12 % P <sub>2</sub> O <sub>5</sub> , 0.10 % Nb <sub>2</sub> O <sub>5</sub> ,<br>0.28 % SiO <sub>2</sub> , 1.23 % Al <sub>2</sub> O <sub>3</sub><br>(the same: Lynd, 1985) |                               |        |
| Lynd & Lefond (1975)      |                  |                                |        |                                                                                                                                                                                                         |                               |        |
| Pirkle et al. (1984)      | ca. 64 %         |                                |        |                                                                                                                                                                                                         |                               |        |
| Force & Garnar (1985)     | ca. 65 %         |                                |        |                                                                                                                                                                                                         |                               |        |
| USBM (1985)               | ca. 66 %         |                                |        |                                                                                                                                                                                                         |                               |        |
| Thompson & Whittle (1990) | ca. 63 %         |                                |        |                                                                                                                                                                                                         |                               |        |
| Lynd (1990)               | ca. 65 %         |                                |        |                                                                                                                                                                                                         |                               |        |

Tab. 26: Chemical composition of Trail Ridge ilmenite after various authors

|                         | TiO <sub>2</sub> | Fe <sub>2</sub> O <sub>3</sub>                                                 | FeO                      | L.O.I. |
|-------------------------|------------------|--------------------------------------------------------------------------------|--------------------------|--------|
| Gillson (1949)          | 82.1 %           | 9.0 %                                                                          | 1.6 % (also Lynd, 1960a) |        |
| Carpenter et al. (1953) | ca. 80 %         | (also Calver, 1957;<br>Giese et al., 1964;<br>Peterson, 1966;<br>Garnar, 1971) |                          |        |
| Temple (1966)           | 82.8 %           | 14.9 %                                                                         | 2.3 %                    | 1.4 %  |

Tab. 27: Chemical composition of Trail Ridge residue after various authors

Specific weights of Trail Ridge ilmenite and Trail Ridge residue were cited by Temple (1966) as 4.09 g/cm<sup>3</sup> and 3.77 g/cm<sup>3</sup>, respectively. Photos of various Trail Ridge ilmenite concentrates can be found in Temple (1966) and Garnar (1978 a, 1980).

Raw data of grain size analyses of Trail Ridge ilmenite concentrates were published by Garnar (1980). This author stated the mean grain size of the ilmenite concentrate as 161  $\mu$ m.

Mertie (1953), Lynd et al. (1954), and Temple (1966) pointed out that only a small part of the ilmenite separated from the Trail Ridge placer is "fresh" ilmenite, defined by its stoichiometric chemical composition (52.66 % TiO<sub>2</sub>, 47.34 % FeO, 0.00 % Fe<sub>2</sub>O<sub>3</sub>, after Mackey, 1966).

In the Trail Ridge ilmenite concentrate (I) Prof. Dr. J. F. W. Negendank (written comm.) discovered mostly leucoxene, followed only in second rank by fresh, brown ilmenite, which at its rim, however, was also already altered to leucoxene. In the Trail Ridge residue concentrate (I) minerals found in rank of their frequency were: rutile - ilmenite - leucoxene - hemoilmenite (rare) - pyrite flakes (rare) - titanomagnetite (very rare).

#### Folkston:

The chemical composition of the "Titanium Product", produced from the Folkston placer was given by the United States Bureau of Mines (1987) with ca. 71 % TiO<sub>2</sub>, by Lynd & Lefond (1975, 1983) and Thompson & Whittle (1990) with ca. 72 % TiO<sub>2</sub> and by Humphreys Gold Corporation (1959) with 72.4 - 77.5 % TiO<sub>2</sub>. Temple (1966) published results of one analysis with 76.1 % TiO<sub>2</sub>, 22.8 % Fe<sub>2</sub>O<sub>3</sub>, 1.0 % FeO, and 0.9 % L.O.I.. The specific weight was said to have been 3.81 g/cm<sup>3</sup>.

Pirkle et al. (1984) published a TiO<sub>2</sub>-content of pure ilmenite of the Folkston placer of ca. 62 %. For this work it was not possible to analyze any samples of the original "Titanium Product", but only of lab concentrates of ilmenite, leucoxene, and rutile. After Prof. Dr. J. F. W. Negendank (written comm.) in sample "I-F.-II." above all leucoxene and strongly weathered ilmenite were found.

Findings of two grain size analyses of the original "Titanium Product" were found in unpublished notes of HGC. The following mean grain sizes could be calculated (n = 2) (for a conversion table see tab. 25):

| mesh       | wt-%     |
|------------|----------|
| + 48.....  | 0.023 %  |
| 65.....    | 0.029 %  |
| 80.....    | 0.380 %  |
| 100.....   | 2.305 %  |
| 115.....   | 8.557 %  |
| 150.....   | 20.973 % |
| 170.....   | 32.689 % |
| 200.....   | 30.241 % |
| 250.....   | 2.678 %  |
| - 250..... | 2.468 %  |

Based on these data the mean grain size of the "Titanium Product" can be given as 3.399 phi (94.8  $\mu$ m). Garnar (1980) published a mean grain size of the Folkston ilmenite of 97  $\mu$ m.

### Green Cove Springs:

After Garnar (1973) the average  $\text{TiO}_2$ -content of the Green Cove Springs ilmenite was 63 %. In 1980 he published photos of an ilmenite concentrate produced by Titanium Enterprises. Pirkle et al. (1984) stated an average  $\text{TiO}_2$ -content of this ilmenite of 64 %.

Prof. Dr. J. F. W. Negendank (written comm.) analyzed the I - Green Cove Springs ilmenite concentrate, discovering in rank of frequency: leucoxene - fresh, brown ilmenite with leucoxene alteration rims - fresh ilmenite.

RGC kindly offered the analysis of a bulk sample of ilmenite sent to Du Pont in early 1990:

|                         |        |                        |        |
|-------------------------|--------|------------------------|--------|
| $\text{TiO}_2$          | 64.2 % | $\text{MnO}$           | 1.31 % |
| $\text{ZrO}_2$          | 0.03 % | $\text{CaO}$           | 0.11 % |
| $\text{SiO}_2$          | 0.32 % | $\text{MgO}$           | 0.19 % |
| $\text{Al}_2\text{O}_3$ | 0.69 % | $\text{V}_2\text{O}_5$ | 0.16 % |
| $\text{Cr}_2\text{O}_3$ | 0.11 % | $\text{P}_2\text{O}_5$ | 0.11 % |

### Boulogne:

Thompson & Whittle (1990) published a  $\text{TiO}_2$ -content of the "Titanium Product" produced from the Boulogne placer of 72 %. Based on unpublished analyses ( $n = 2$ ) of HMC the chemical composition of this concentrate was 72.4 %  $\text{TiO}_2$ , 20.25 %  $\text{Fe}_2\text{O}_3$ , and 2.04 %  $\text{FeO}$ .

The mean grain size after these analyses can be given with 3.320 phi (100.1  $\mu\text{m}$ ).

Garnar (1980) published photos of Boulogne ilmenite and cited a mean grain size, as in Folkston, of 97  $\mu\text{m}$ .

### Jacksonville:

|                                 | $\text{TiO}_2$ | $\text{Fe}_2\text{O}_3$ | $\text{FeO}$             | $\text{Cr}_2\text{O}_3$ | $\text{V}_2\text{O}_5$ | $\text{P}_2\text{O}_5$ | L.O.I. |
|---------------------------------|----------------|-------------------------|--------------------------|-------------------------|------------------------|------------------------|--------|
| Gillson (1949)                  | 60.3 %         | 26.3 %                  | 5.6 % (also Lynd, 1960a) |                         |                        |                        |        |
| Mertie (1953)                   | 61.5 %         | 26.5 %                  | 4.5 %                    |                         |                        |                        |        |
| HGC (unpublished, $n = 1$ )     | 59.3 %         | 24.46 %                 | 10.37 %                  |                         |                        |                        |        |
| HGC (unpublished, $n = 1$ )     | 61.0 %         | 25.9 %                  | 5.8 %                    |                         |                        |                        |        |
| Du Pont (unpublished, $n = 7$ ) | 60.1 %         | 22.3 %                  | 10.8 %                   | 0.07 %                  | 0.13 %                 | 0.33 %                 |        |
| Lynd (1960 a)                   | 60.3 %         | 26.3 %                  | 5.7 %                    | 0.22 %                  | 0.14 %                 |                        |        |
| Giese et al. (1964)             | 60.4 %         |                         |                          |                         |                        |                        |        |
| Temple (1966)                   | 66.3 %         | 24.2 %                  | 9.5 %                    |                         |                        |                        | 1.7 %  |
| Mackey (1972)                   | 60.4 %         | 28.52 %                 | 4.70 %                   |                         |                        |                        |        |
| Mertie (1975)                   | 64.0 %         | 25.0 %                  | 4.5 %                    |                         |                        |                        |        |

Tab. 28: Chemical composition of Jacksonville ilmenite after various authors

According to unpublished notes of HGC the mean grain size of the ilmenite in 1961 was 3.249 phi (105.2  $\mu\text{m}$ ), and in 1962 3.312 phi (100.7  $\mu\text{m}$ ). The ilmenite concentrate produced in Jacksonville was sent to a pigment plant of the National Lead Company in St. Louis and in this plant used for the manufacture of color pigments on a Ca-basis.



Another unpublished note is referring to an extensive chemical analysis of Jacksonville ilmenite in the first years of mining (January 13, 1945):

|                                |         |                   |         |
|--------------------------------|---------|-------------------|---------|
| TiO <sub>2</sub>               | 60.63 % | FeO               | 6.62 %  |
| SiO <sub>2</sub>               | 1.0 %   | CaO               | 0.50 %  |
| ZrO <sub>2</sub>               | 0.60 %  | MgO               | 1.2 %   |
| SnO <sub>2</sub>               | 0.001 % | MnO               | 1.4 %   |
| Fe <sub>2</sub> O <sub>3</sub> | 25.76 % | BaO               | 0.01 %  |
| Al <sub>2</sub> O <sub>3</sub> | 2.0 %   | CuO               | 0.001 % |
| Cr <sub>2</sub> O <sub>3</sub> | 0.25 %  | PbO               | traces  |
| Ni <sub>2</sub> O <sub>3</sub> | 0.05 %  | Na <sub>2</sub> O | 0.003 % |
| B <sub>2</sub> O <sub>3</sub>  | 0.05 %  |                   |         |
| V <sub>2</sub> O <sub>5</sub>  | 0.05 %  |                   |         |

For this work ten of the ilmenite, leucoxene, and residue concentrates produced in northeastern Florida could be analyzed. On the next pages the results of nine (without Green Cove Springs leucoxene) of these geochemical (tab. 29) and mineralogical/granulometric analyses (tab. 30) are compiled.

**Geochemistry:** All data were established by using X-ray fluorescence analysis at the German Geological Survey in Hannover with partial rechecking by several measurements. All data in weight-percent or parts per million (ppm), respectively. Percentages of SO<sub>3</sub> and As are minimum figures.

**Mineralogy:** All data in weight-percent. A list of mineral abbreviations used can be found at the beginning of this chapter.

**Granulometry:** All data in weight-percent. For comparison reasons the sieve sizes were given in ASTM-mesh. A conversion table in phi and mm is given in table 25.

|      |                          |        |                           |
|------|--------------------------|--------|---------------------------|
| I    | = sample taken in 1990   | II     | = sample taken in 1991    |
| 1    | = sample 1               | 2      | = sample 2                |
| A    | = variety A              | B      | = variety B               |
| T.R. | = Trail Ridge            | G.C.S. | = Green Cove Springs      |
| F.   | = Folkston               | J.     | = Jacksonville            |
| Il.  | = "Ilmenite"             | Lx.    | = "Leucoxene"             |
| Res. | = "Residue"              | Rt.    | = "Rutile"                |
| St.  | = "Staurolite"           | CSt.   | = "Coarse Staurolite"     |
| Bia. | = "Biasill"              | Stb.   | = "Starblast"             |
| Gr.  | = "Garnet"               | Kya.   | = "Kyasill"               |
| Zr.  | = "Zircon"               | SZr.   | = "Standard-grade Zircon" |
| PZr. | = "Premium-grade Zircon" | ZrT.   | = "Zircon T"              |
| Zrc. | = "Zirclean"             | Zro.   | = "Zircore"               |

|                                | I-T.R.<br>Il. | II-T.R.<br>Il. | I-G.C.S.<br>Il. | I-J-1<br>Il. | I-J-2<br>Il. | I-F.<br>Il. | II-F.<br>Lx. | I-T.R.<br>Res. | II-T.R.<br>Res. |
|--------------------------------|---------------|----------------|-----------------|--------------|--------------|-------------|--------------|----------------|-----------------|
| TiO <sub>2</sub>               | 64.89         | 64.30          | 63.67           | 62.70        | 62.95        | 59.78       | 81.23        | 80.89          | 79.37           |
| SiO <sub>2</sub>               | 0.05          | 0.40           | 0.19            | 0.06         | 0.10         | 0.84        | 1.00         | 0.31           | 1.18            |
| Zr/HfO <sub>2</sub>            | 0.04          | 0.25           | 0.05            | 0.14         | 0.13         | 0.21        | 1.33         | 0.87           | 1.11            |
| Al <sub>2</sub> O <sub>3</sub> | 1.48          | 1.81           | 1.43            | 1.36         | 1.32         | 1.82        | 2.42         | 1.51           | 1.65            |
| Fe <sub>2</sub> O <sub>3</sub> | 28.27         | 28.10          | 28.94           | 30.24        | 30.44        | 31.77       | 9.18         | 11.69          | 12.97           |
| MnO                            | 1.02          | 1.02           | 1.19            | 1.36         | 1.38         | 1.48        | 0.47         | 0.39           | 0.43            |
| MgO                            | 0.31          | 0.30           | 0.30            | 0.30         | 0.27         | 0.34        | 0.20         | 0.20           | 0.18            |
| CaO                            | 0.07          | 0.08           | 0.17            | 0.12         | 0.06         | 0.36        | 0.21         | 0.08           | 0.08            |
| Na <sub>2</sub> O              | 0.07          | 0.08           | <0.05           | <0.05        | <0.05        | <0.05       | 0.07         | 0.15           | 0.13            |
| K <sub>2</sub> O               | <0.01         | <0.01          | 0.01            | <0.01        | 0.01         | 0.01        | 0.01         | 0.01           | <0.01           |
| P <sub>2</sub> O <sub>5</sub>  | 0.17          | 0.14           | 0.19            | 0.18         | 0.16         | 0.34        | 1.12         | 0.20           | 0.22            |
| V <sub>2</sub> O <sub>5</sub>  | 0.14          | 0.15           | 0.14            | 0.14         | 0.14         | 0.13        | 0.18         | 0.19           | 0.20            |
| Cr <sub>2</sub> O <sub>3</sub> | 0.06          | 0.06           | 0.09            | 0.09         | 0.09         | 0.11        | 0.13         | 0.09           | 0.10            |
| (SO <sub>3</sub> )             | <0.05         | <0.05          | <0.05           | <0.05        | <0.05        | <0.05       | <0.05        | <0.05          | <0.05           |
| L.O.I.                         | 2.67          | 2.77           | 2.56            | 2.22         | 2.09         | 1.59        | 1.08         | 1.87           | 2.00            |
| (As)                           | 12            | <7             | 11              | 21           | 10           | 27          | 28           | 29             | 27              |
| Bi                             | <10           | <10            | <10             | <10          | <10          | <10         | <10          | <10            | <10             |
| Co                             | 44            | 32             | 47              | 70           | 54           | 61          | 10           | 30             | 13              |
| Cs                             | 94            | 97             | 85              | 100          | 94           | 91          | 142          | 124            | 111             |
| Cu                             | n.a.          | 157            | 123             | n.a.         | 111          | n.a.        | 158          | n.a.           | 122             |
| Ga                             | 114           | 78             | 139             | 81           | 82           | 62          | 88           | 105            | 80              |
| Hf                             | <18           | 57             | <18             | <18          | <18          | <18         | 217          | 193            | 217             |
| Mo                             | 4             | 16             | 18              | 5            | <4           | <4          | 30           | 47             | 51              |
| Nb                             | 684           | 674            | 688             | 748          | 740          | 769         | 1327         | 2303           | 1827            |
| Ni                             | 8             | <7             | <7              | <7           | <7           | <7          | 47           | <7             | <7              |
| Pb                             | 219           | 188            | 224             | 228          | 140          | 129         | 257          | 188            | 201             |
| Rb                             | 15            | 11             | 18              | 9            | 15           | 21          | 14           | 16             | 11              |
| Sc                             | 56            | 52             | 49              | 46           | 45           | 52          | 40           | 52             | 55              |
| Sn                             | 35            | 46             | 24              | 30           | 29           | 33          | 74           | 894            | 404             |
| Sr                             | 61            | 55             | 26              | 14           | 25           | 72          | 33           | 40             | 70              |
| Ta                             | 81            | 69             | 78              | 61           | 92           | 63          | 107          | 242            | 192             |
| Th                             | 53            | 17             | 114             | 102          | 71           | 215         | 1345         | 57             | 53              |
| U                              | <5            | 5              | <5              | <5           | <5           | 32          | 193          | 10             | 23              |
| W                              | <10           | 29             | <10             | <10          | 27           | 19          | 132          | 222            | 136             |
| Y                              | <5            | 17             | 22              | 11           | <5           | 78          | 1077         | 18             | 24              |
| Zn                             | 232           | 225            | 213             | 253          | 241          | 304         | 182          | 128            | 107             |
| Zr                             | 302           | 1809           | 380             | 1050         | 950          | 1505        | 9631         | 6303           | 8079            |

In some samples impurities of grains of monazite, zircon, garnet, or epidote (see Baker, 1962, p. 117), or cassiterite (see Grosz, 1987, p. 343), or staurolite, or other Al-silicates (see tab. 44) were found.

Tab. 29: Geochemical composition of ilmenite and leucoxene concentrates produced in north-eastern Florida.

|            | I-T.R.<br>Il. | II-T.R.<br>Il. | I-G.C.S.<br>Il. | I-J-1<br>Il. | I-J-2<br>Il. | I-F.<br>Il. | II-F.<br>Lx. | I-T.R.<br>Res. | II-T.R.<br>Res. |
|------------|---------------|----------------|-----------------|--------------|--------------|-------------|--------------|----------------|-----------------|
| Il         | 81.0          | 98.2           | 78.2            | 87.2         | 74.5         | 83.0        | 78.8         | 23.3           | 83.3            |
| Lx         | 18.8          | 0.3            | 21.3            | 9.3          | 23.3         | 13.4        | 2.2          | 24.4           | 2.8             |
| Rt         |               | 1.0            | 0.1             | 2.7          | 1.5          | 1.3         | 15.3         | 50.0           | 10.4            |
| Zr         |               | 0.2            |                 | 0.2          | 0.3          | 0.2         | 1.8          | 1.1            | 1.9             |
| Ky         |               | <0.1           |                 |              |              |             | <0.1         | 0.2            |                 |
| St         | 0.1           | <0.1           | 0.1             | 0.1          | 0.1          | 0.1         |              | 0.1            | 1.1             |
| Gr         |               |                |                 |              | 0.1          | 0.4         |              |                |                 |
| Ep         | <0.1          |                | 0.2             |              |              | 1.0         | 0.2          |                |                 |
| Si         |               |                |                 |              |              |             |              | 0.2            | 0.1             |
| Tm         |               |                |                 |              |              |             | 0.2          |                |                 |
| Mo/Xe      | 0.1           |                | 0.1             | 0.5          | 0.1          | 0.6         | 1.2          |                |                 |
| To         |               | <0.1           |                 |              |              |             |              |                |                 |
| Se         |               |                |                 |              |              |             | <0.1         |                |                 |
| At         |               |                |                 |              |              |             | 0.2          | 0.4            | 0.2             |
| Br         |               |                |                 |              |              |             |              |                | <0.1            |
| Cs         |               | <0.1           |                 |              |              |             |              | 0.3            | 0.2             |
| Quartz     |               | 0.2            |                 | <0.1         | 0.1          | <0.1        | <0.1         | <0.1           | <0.1            |
| mesh       |               |                |                 |              |              |             |              |                |                 |
| + 25       |               |                |                 |              |              | 0.004       |              |                |                 |
| 30         | 0.007         | 0.004          | 0.015           | 0.006        | 0.003        | 0.004       |              | 0.004          |                 |
| 35         | 0.005         | 0.016          | 0.021           | 0.003        | 0.006        | 0.005       | 0.002        | 0.006          | 0.005           |
| 40         | 0.005         | 0.070          | 0.034           | 0.007        | 0.006        | 0.005       | 0.003        | 0.011          | 0.011           |
| 45         | 0.013         | 0.211          | 0.031           | 0.014        | 0.005        | 0.008       | 0.006        | 0.014          | 0.019           |
| 50         | 0.194         | 1.249          | 0.011           | 0.020        | 0.016        | 0.025       | 0.010        | 0.134          | 0.116           |
| 60         | 2.396         | 2.755          | 0.031           | 0.058        | 0.051        | 0.075       | 0.013        | 1.929          | 1.618           |
| 70         | 11.349        | 8.184          | 0.176           | 0.254        | 0.247        | 0.286       | 0.007        | 6.169          | 7.166           |
| 80         | 16.884        | 11.768         | 0.774           | 0.787        | 0.833        | 0.834       | 0.010        | 9.761          | 10.736          |
| 100        | 19.859        | 18.932         | 2.250           | 1.981        | 1.891        | 1.932       | 0.032        | 13.713         | 16.197          |
| 120        | 27.797        | 25.094         | 16.100          | 10.395       | 9.321        | 8.433       | 1.500        | 23.862         | 20.393          |
| 140        | 13.405        | 21.800         | 38.726          | 33.102       | 28.272       | 25.857      | 11.262       | 17.779         | 20.609          |
| 170        | 5.223         | 7.089          | 34.490          | 36.857       | 40.378       | 42.204      | 32.679       | 11.869         | 10.498          |
| 200        | 1.634         | 1.691          | 6.296           | 13.898       | 16.077       | 17.146      | 38.082       | 6.359          | 5.180           |
| 230        | 0.578         | 0.470          | 0.838           | 2.445        | 2.672        | 2.974       | 14.577       | 3.726          | 3.301           |
| 270        | 0.065         | 0.204          | 0.089           | 0.079        | 0.080        | 0.101       | 1.303        | 2.502          | 2.107           |
| 325        | 0.268         | 0.094          | 0.023           | 0.049        | 0.057        | 0.052       | 0.436        | 0.788          | 0.840           |
| - 325      | 0.310         | 0.360          | 0.090           | 0.040        | 0.080        | 0.040       | 0.070        | 1.370          | 1.200           |
| mean (µm)  | 152.1         | 145.8          | 109.6           | 104.3        | 102.5        | 101.6       | 87.1         | 126.4          | 129.5           |
| mean (phi) | 2.717         | 2.778          | 3.190           | 3.261        | 3.286        | 3.299       | 3.521        | 2.984          | 2.949           |
| SD         | 0.423         | 0.447          | 0.262           | 0.277        | 0.280        | 0.282       | 0.254        | 0.557          | 0.545           |
| Sk         | 0.631         | 0.088          | -0.581          | -0.513       | -0.504       | -0.773      | -0.058       | 0.694          | 0.753           |
| K          | 5.479         | 5.089          | 10.231          | 6.146        | 6.352        | 6.960       | 5.259        | 4.380          | 4.512           |

Tab. 30: Mineralogical and granulometric composition of ilmenite and leucoxene concentrates produced in northeastern Florida

## Rutile

Rutile was or is being produced in northeastern Florida from the Ponte Vedra Beach, Jacksonville, and Green Cove Spring deposits. Rutile, which can be found in the Folkston, Boulogne and Trail Ridge placers, however, was and is not separated, but sold in form of high-grade titanium products.

### Jacksonville:

The following analyses of samples of rutile of the Jacksonville placer can be cited after several mostly unpublished reports:

|                                | TAMCO<br>(n = 1)<br>(5-16-1944) | HGC<br>(n = 1) | HGC<br>(n = 1)<br>(5-15-1962) | Du Pont<br>(n = 8)<br>(11-15-1962) | Lynd<br>(1960 a) |
|--------------------------------|---------------------------------|----------------|-------------------------------|------------------------------------|------------------|
| TiO <sub>2</sub>               | 92.80 %                         | 94.8 %         | 95.4 %                        | 96.2 %                             | 94.2 %           |
| SiO <sub>2</sub>               | 1.5 %                           | 1.04 %         |                               |                                    |                  |
| ZrO <sub>2</sub>               | 1.2 %                           | 1.00 %         |                               |                                    |                  |
| Fe <sub>2</sub> O <sub>3</sub> | 2.00 %                          | 1.35 %         | 1.62 %                        | 1.29 %                             | 1.71 %           |
| FeO                            |                                 | 0.0 %          | 1.02 %                        | 0.32 %                             |                  |
| Al <sub>2</sub> O <sub>3</sub> | 1.3 %                           | 0.047 %        |                               |                                    |                  |
| Cr <sub>2</sub> O <sub>3</sub> | 0.06 %                          | 0.16 %         |                               | 0.09 %                             | 0.10 %           |
| MgO                            | 0.10 %                          | 0.10 %         |                               |                                    |                  |
| MnO                            | 0.02 %                          | 0.03 %         |                               |                                    |                  |
| CaO                            | 0.17 %                          | 0.10 %         |                               |                                    |                  |
| Na <sub>2</sub> O              | 0.01 %                          |                |                               |                                    |                  |
| P <sub>2</sub> O <sub>5</sub>  | 0.08 %                          | 0.0 %          |                               | 0.16 %                             |                  |
| V <sub>2</sub> O <sub>5</sub>  | 0.30 %                          | 0.37 %         |                               | 0.28 %                             | 0.27 %           |
| B <sub>2</sub> O <sub>3</sub>  | 0.02 %                          |                |                               |                                    |                  |
| BaO                            | traces                          |                |                               |                                    |                  |
| CuO                            | 0.001 %                         |                |                               |                                    |                  |
| Nb <sub>2</sub> O <sub>5</sub> | 0.005 %                         |                |                               |                                    |                  |
| Ni <sub>2</sub> O <sub>3</sub> | 0.002 %                         |                |                               |                                    |                  |
| PbO                            | traces                          |                |                               |                                    |                  |
| SnO <sub>2</sub>               | 0.07 %                          |                |                               |                                    |                  |
| Ta <sub>2</sub> O <sub>3</sub> | 0.005 %                         |                |                               |                                    |                  |

Tab. 31: Chemical composition of Jacksonville rutile after various authors

The mean grain size of the rutile concentrate produced at Jacksonville was 3.255 phi (104.7 μm) in 1952 and 3.304 phi (101.3 μm) in 1962, respectively, after unpublished notes of HGC.

### Green Cove Springs:

According to one analysis of a bulk of rutile delivered to Kemira Oy Inc. at the end of 1989, which was kindly placed at the author's disposal by RGC, the chemical composition of this rutile was 94.6 % TiO<sub>2</sub>, 3.06 % Fe<sub>2</sub>O<sub>3</sub>, 0.41 % Al<sub>2</sub>O<sub>3</sub>, and 0.36 % SiO<sub>2</sub>.

For this investigation two of the rutile concentrates commercially produced in NE-Florida were at hand for analyses. Another rutile concentrate was produced in the lab using Folkston placer sands.

Explanations to data given in tab. 32 and 33 can be found on the previous pages.

|                                | I-G.C.S.-Rt. | II-F.-Rt. | I-J.-Rt. |
|--------------------------------|--------------|-----------|----------|
| TiO <sub>2</sub>               | 92.85 % (?)  | 95.09 %   | 94.65 %  |
| SiO <sub>2</sub>               | 0.09 %       | 0.31 %    | 0.11 %   |
| Zr/HfO <sub>2</sub>            | 0.11 %       | 0.73 %    | 0.37 %   |
| Al <sub>2</sub> O <sub>3</sub> | 0.62 %       | 0.81 %    | 0.43 %   |
| Fe <sub>2</sub> O <sub>3</sub> | 3.28 %       | 1.06 %    | 1.95 %   |
| MnO                            | 0.15 %       | 0.05 %    | 0.09 %   |
| MgO                            | 0.14 %       | 0.15 %    | 0.14 %   |
| CaO                            | 0.10 %       | 0.08 %    | 0.06 %   |
| Na <sub>2</sub> O              | 0.13 %       | 0.09 %    | <0.05 %  |
| K <sub>2</sub> O               | 0.01 %       | 0.02 %    | 0.01 %   |
| P <sub>2</sub> O <sub>5</sub>  | 0.16 %       | 0.10 %    | 0.08 %   |
| V <sub>2</sub> O <sub>5</sub>  | 0.22 %       | 0.27 %    | 0.27 %   |
| Cr <sub>2</sub> O <sub>3</sub> | 0.10 %       | 0.10 %    | 0.10 %   |
| (SO <sub>3</sub> )             | <0.05 %      | <0.05 %   | <0.05 %  |
| L.O.I.                         | 1.39 %       | 0.36 %    | 0.81 %   |
| (As)                           | 30 ppm       | 22 ppm    | 16 ppm   |
| Bi                             | <10 ppm      | <10 ppm   | <10 ppm  |
| Co                             | 19 ppm       | <7 ppm    | 16 ppm   |
| Cs                             | 131 ppm      | 138 ppm   | 137 ppm  |
| Cu                             | n.a.         | 67 ppm    | n.a.     |
| Ga                             | 128 ppm      | 25 ppm    | 55 ppm   |
| Hf                             | 60 ppm       | 110 ppm   | 59 ppm   |
| Mo                             | 57 ppm       | 37 ppm    | 10 ppm   |
| Nb                             | 2623 ppm     | 2955 ppm  | 3853 ppm |
| Ni                             | <7 ppm       | <7 ppm    | <7 ppm   |
| Pb                             | 144 ppm      | 81 ppm    | n.a.     |
| Rb                             | 12 ppm       | <5 ppm    | 7 ppm    |
| Sc                             | 39 ppm       | 36 ppm    | 40 ppm   |
| Sn                             | 166 ppm      | 179 ppm   | 205 ppm  |
| Sr                             | 18 ppm       | 26 ppm    | 9 ppm    |
| Ta                             | 258 ppm      | 267 ppm   | 350 ppm  |
| Th                             | 26 ppm       | 76 ppm    | 15 ppm   |
| U                              | <5 ppm       | 31 ppm    | <5 ppm   |
| W                              | 225 ppm      | 258 ppm   | 338 ppm  |
| Y                              | <5 ppm       | 119 ppm   | <5 ppm   |
| Zn                             | 198 ppm      | 14 ppm    | 78 ppm   |
| Zr                             | 760 ppm      | 5333 pm   | 2706 ppm |

High contents of SiO<sub>2</sub> and Zr can be explained by impurities by grains of zircon (compare with Baker, 1962, p. 120).

Tab. 32: Geochemical composition of rutile concentrates produced in northeastern Florida



|       | I-G.C.S.-Rt.  | II-F.-Rt.    | I-J.-Rt.      |
|-------|---------------|--------------|---------------|
| Il    | 6.5 %         | 20.1 %       | 3.4 %         |
| Lx    | 46.6 %        | 0.7 %        | 16.0 %        |
| Rt    | 46.7 %        | 74.9 %       | 77.2 %        |
| Zr    |               | 0.9 %        | 0.4 %         |
| Gr    |               |              | 0.2 %         |
| Mo/Xe | 0.2 %         |              |               |
| Se    |               | 0.1 %        |               |
| At    |               | 3.1 %        | 2.8 %         |
| Br    |               | 0.2 %        |               |
|       |               |              |               |
|       |               |              |               |
| mesh  |               |              |               |
| + 25  |               |              | 0.002 %       |
| 30    |               | 0.001 %      | 0.003 %       |
| 35    |               | 0.001 %      | 0.002 %       |
| 40    | 0.005 %       | 0.003 %      | 0.004 %       |
| 45    | 0.001 %       | 0.004 %      | 0.004 %       |
| 50    | 0.001 %       | 0.008 %      | 0.013 %       |
| 60    | 0.013 %       | 0.025 %      | 0.098 %       |
| 70    | 0.124 %       | 0.263 %      | 0.623 %       |
| 80    | 0.668 %       | 0.903 %      | 1.749 %       |
| 100   | 2.769 %       | 2.005 %      | 3.606 %       |
| 120   | 13.705 %      | 5.047 %      | 14.225 %      |
| 140   | 33.204 %      | 21.236 %     | 32.858 %      |
| 170   | 35.336 %      | 33.653 %     | 32.750 %      |
| 200   | 12.277 %      | 26.655 %     | 12.088 %      |
| 230   | 1.586 %       | 9.254 %      | 1.809 %       |
| 270   | 0.076 %       | 0.671 %      | 0.069 %       |
| 325   | 0.107 %       | 0.020 %      | 0.036 %       |
| - 325 | 0.120 %       | 0.060 %      | 0.050 %       |
|       |               |              |               |
| mean  | 106.1 $\mu$ m | 95.5 $\mu$ m | 108.2 $\mu$ m |
| mean  | 3.236 phi     | 3.389 phi    | 3.208 phi     |
| SD    | 0.277         | 0.314        | 0.306         |
| Sk    | 0.029         | -0.511       | -0.554        |
| K     | 5.592         | 4.802        | 5.236         |

Tab. 33: Mineralogical and granulometric composition of rutile concentrates produced in northeastern Florida

## Zircon

Zircon was or rather is being produced from all placer deposits in NE-Florida. Several information on these zircon concentrates is available from the literature and from unpublished reports:

|                                   | ZrO <sub>2</sub> + HfO <sub>2</sub><br>minimum % | TiO <sub>2</sub><br>maximum % | Fe <sub>2</sub> O <sub>3</sub><br>maximum % |
|-----------------------------------|--------------------------------------------------|-------------------------------|---------------------------------------------|
| <b>Standard</b>                   | 65.0                                             | 0.25                          | 0.15                                        |
| <b>Intermediate</b>               | 65.5 - 66.0                                      |                               | 0.06 - 0.10                                 |
| <b>Premium</b>                    | 66.0                                             | 0.10                          | 0.05                                        |
| <i>USA</i>                        |                                                  |                               |                                             |
| Du Pont - Standard                | 65.0                                             | 0.35                          | 0.05                                        |
| Du Pont - Premium                 | 65.0 - 66.0                                      | 0.15                          | 0.05                                        |
| RGC (G.C.S.)                      | 66.5                                             |                               |                                             |
| HGC (Jacksonville)                | 65.0                                             | 0.35                          | 0.05                                        |
| HGC (Folkston)                    | 65.0                                             | 0.25                          | 0.10                                        |
| <i>Australia</i>                  |                                                  |                               |                                             |
| RZ Mines - Premium                | 66.5                                             | 0.05                          | 0.10                                        |
| Allied Eneabba                    | 65.5                                             | 0.15                          | 0.10                                        |
| <i>South Africa</i>               |                                                  |                               |                                             |
| R. Bay Minerals - Standard        | 65.0                                             | 0.30                          | 0.30                                        |
| R. Bay Minerals - Prime           | 65.0                                             | 0.18                          | 0.10                                        |
| <i>Brasil</i>                     |                                                  |                               |                                             |
| Nuclemon - Standard               | 64.5                                             | 0.50                          | 0.30                                        |
| Nuclemon - Premium                | 65.5                                             | 0.10                          | 0.05                                        |
| <i>India, Malaysia, Sri Lanka</i> |                                                  |                               |                                             |
| Indian Rare Earths Ltd.           | 65.0                                             | 0.30                          | 0.08                                        |
| Malaysia Mining Corp.             | 65.5                                             | 0.30                          | 0.10                                        |
| Ceylon Mineral Sands Corp.        | 65.0                                             | 0.50                          | 0.20                                        |

Tab. 34: Typical specifications of commercial zircon concentrates, after Coope (1987), Clarke (1987), and an unpublished note of HGC.

### Green Cove Springs:

The zircon from the Green Cove Springs deposit is prismatic and much less rounded than the one from Trail Ridge (Garnar, 1978 b). Garnar (1980, 1983) stated a mean grain size of 98  $\mu\text{m}$ , and in 1985 of 100  $\mu\text{m}$ , respectively. In 1980 he published a photo of the zircon concentrate as sold by Titanium Enterprises.

The zircon currently sold by RGC is too fine to be used as foundry sand or in the manufacture of refractory bricks. For this reason it is ground to zircon flour and put to use in the ceramics industry.

AMU kindly offered results of two zircon analyses for publication. These stem from a delivery of a bulk of zircon to the Z - Tech Corporation, New Hampshire, at the end of 1989 and from the sample "II-G.C.S.-Zr." (see below) (AMU- #: 8941 - 9017):

|                                | Z - Tech            | II-G.C.S.-Zr.       |
|--------------------------------|---------------------|---------------------|
| (Zr+Hf)O <sub>2</sub>          | 66.66 %             | 66.19 %             |
| HfO <sub>2</sub>               |                     | 1.28 %              |
| SiO <sub>2</sub>               | 32.52 %             | 32.30 %             |
| TiO <sub>2</sub>               | 0.08 %              | 0.07 %              |
| Al <sub>2</sub> O <sub>3</sub> | 0.36 %              | 0.39 %              |
| Fe <sub>2</sub> O <sub>3</sub> | 0.046 %             | 0.040 %             |
| SiO <sub>2</sub> (free)        | 0.06 %              | 0.04 %              |
| L.O.D. ( @ 105 °C)             | <0.01 %             | 0.00 %              |
| L.O.I. ( @ 1000 °C)            | 0.02 %              | 0.02 %              |
| mean grain size                | 3.390 phi (95.4 μm) | 3.390 phi (95.4 μm) |

### Trail Ridge:

Zircon found in the Trail Ridge deposit is very uniform, regarding its size (relatively coarse), its morphology (well rounded), and its purity (see below). Coatings are nearly absent. Many grains are frosted by the eolian transport (Garnar, 1978 a, 1983, 1985). Garnar (1980) showed photos of these zircon grains and cited a mean grain size of the concentrate of 122 μm. Another grain size analysis (120 μm) can be found in Garnar (1983, 1985).

In the early '90s Du Pont was producing five different zircon concentrates from its Trail Ridge placer deposit. These were a premium-grade zircon and a standard-grade zircon for applications in the foundry, refractory and ceramics industry (Garnar, 1985, 1990; Clarke, 1987). The so-called Zirclean was used as a special abrasive, while Zircore, a mixture of zircon, kyanite, sillimanite, and corundum, was sold as foundry sand (Garnar, 1978 b, 1983, 1985, 1990; Clarke, 1987). This Zircore was a substitute for Kysill (T. E. Garnar, 1972, 1980, pers comm., 1991), which was developed upon first investigations by Browning et al. (1956). Also not on the market anymore is Zircon M, a mixture of zircon and some magnetic minerals (Garnar, 1983).

During a worldwide shortage of zircon at the end of the '60s Du Pont developed the Zircon T, which is a zircon concentrate compounded with up to two percent of titanium minerals. This Zircon T is still distributed as a special foundry sand (Clarke, 1987).

### Folkston:

Thompson & Whittle (1990) cited a (Zr+Hf)O<sub>2</sub> content of the Folkston zircon concentrate of ca. 66 %. After seven unpublished reports of chemical analyses of HGC the chemical composition of the zircon can be stated as follows:

|                                | mean    | standard deviation |
|--------------------------------|---------|--------------------|
| (Zr+Hf)O <sub>2</sub>          | 65.9 %  | 0.366 %            |
| TiO <sub>2</sub>               | 0.11 %  | 0.022 %            |
| Fe <sub>2</sub> O <sub>3</sub> | 0.031 % | 0.005 %            |
| Al <sub>2</sub> O <sub>3</sub> | 0.44 %  | 0.092 %            |
| P <sub>2</sub> O <sub>5</sub>  | 0.091 % | 0.035 %            |
| SiO <sub>2</sub> (free)        | 0.062 % | 0.035 %            |



After three unpublished notes to grain size analyses the mean grain size of the zircon concentrate was 3.690 phi (77.5  $\mu\text{m}$ ).

#### Boulogne:

Only little is known from the zircon concentrate, which was separated from the Boulogne placer sands. After data of five unpublished grain size analyses the mean grain size was 3.635 phi (80.5  $\mu\text{m}$ ). This is exactly the mean grain size (81  $\mu\text{m}$ ) published by Garnar in 1980. In this publication he also showed a photo of this zircon concentrate.

#### Jacksonville:

After unpublished notes of analyses for HGC on zircon produced from the Jacksonville deposit the following findings can be cited:

|                                                            | TAMCO<br>(1-17-1945) | Ledoux & Company, Inc.<br>(1-31-1945) |
|------------------------------------------------------------|----------------------|---------------------------------------|
| (Zr+Hf)O <sub>2</sub>                                      | 66.33 %              | 66.94 %                               |
| SiO <sub>2</sub>                                           | 32.14 %              | 31.34 %                               |
| TiO <sub>2</sub>                                           | 0.217 %              | 0.28 %                                |
| Fe <sub>2</sub> O <sub>3</sub>                             | 0.140 %              | 0.09 %                                |
| Al <sub>2</sub> O <sub>3</sub>                             | 0.23 %               | 0.60 %                                |
| MgO                                                        | 0.05 %               |                                       |
| CaO                                                        | 0.12 %               |                                       |
| Na <sub>2</sub> O                                          | 0.01 %               |                                       |
| P <sub>2</sub> O <sub>5</sub>                              | 0.25 %               |                                       |
| CeO <sub>2</sub>                                           | 0.12 %               |                                       |
| La <sub>2</sub> O <sub>3</sub>                             | 0.05 %               |                                       |
| Cr <sub>2</sub> O <sub>3</sub>                             | 0.002 %              |                                       |
| Ni <sub>2</sub> O <sub>3</sub>                             | 0.005 %              |                                       |
| CuO                                                        | 0.002 %              |                                       |
| PbO, MnO, SnO <sub>2</sub> , V <sub>2</sub> O <sub>5</sub> | traces               |                                       |

The mean grain size of the zircon concentrate in 1952 was 3.472 phi (90.1  $\mu\text{m}$ ), and in 1962 3.483 phi (89.4  $\mu\text{m}$ ), respectively.

For this work nearly all zircon concentrates produced in NE-Florida were available for analyses. On the next pages, findings of these geochemical, mineralogical, and granulometric analyses are compiled.

|                                | I-G.C.S. | II-G.C.S. | I-F.  | II-F. | I-T.R. | II-T.R. | II-T.R. | II-T.R. | II-T.R. | II-T.R. |
|--------------------------------|----------|-----------|-------|-------|--------|---------|---------|---------|---------|---------|
|                                | Zr.      | Zr.       | Zr.   | Zr.   | SZr.   | SZr.    | Zr.     | ZrT.    | Zrc.    | Zro.    |
| Zr/HfO <sub>2</sub>            | 64.74 ?  | 66.26     | 65.45 | 65.88 | 65.43  | 65.21   | 66.75   | 66.03   | 59.58   | 45.67   |
| HfO <sub>2</sub>               | 1.24     | 1.26      | 1.25  | 1.28  | 1.23   | 1.21    | 1.25    | 1.23    | 1.08    | 0.77    |
| SiO <sub>2</sub>               | 32.40    | 32.37     | 32.32 | 32.38 | 32.27  | 32.30   | 32.17   | 32.60   | 31.00   | 35.00   |
| TiO <sub>2</sub>               | 0.17     | 0.06      | 0.18  | 0.35  | 0.14   | 0.18    | 0.13    | 1.00    | 3.22    | 1.42    |
| Al <sub>2</sub> O <sub>3</sub> | 0.49     | 0.42      | 0.43  | 0.26  | 0.80   | 1.88    | 0.96    | 0.70    | 5.00    | 17.00   |
| Fe <sub>2</sub> O <sub>3</sub> | 0.10     | 0.05      | 0.09  | 0.04  | 0.07   | 0.07    | 0.06    | 0.11    | 0.98    | 0.55    |
| MnO                            | 0.03     | 0.04      | 0.03  | 0.04  | 0.03   | 0.04    | 0.04    | 0.04    | 0.06    | 0.04    |
| MgO                            | 0.11     | <0.10     | 0.09  | 0.10  | 0.16   | 0.28    | <0.10   | <0.10   | <0.10   | <0.10   |
| CaO                            | 0.04     | 0.04      | 0.05  | 0.03  | 0.03   | 0.02    | 0.03    | 0.03    | 0.04    | 0.03    |
| Na <sub>2</sub> O              | 0.07     | <0.10     | 0.07  | <0.10 | 0.09   | <0.10   | <0.10   | <0.10   | <0.10   | 0.19    |
| K <sub>2</sub> O               | 0.03     | 0.01      | 0.03  | 0.01  | 0.03   | 0.02    | 0.01    | 0.01    | 0.01    | 0.01    |
| P <sub>2</sub> O <sub>5</sub>  | 0.11     | 0.12      | 0.12  | 0.15  | 0.11   | 0.10    | 0.12    | 0.12    | 0.17    | 0.06    |
| (SO <sub>3</sub> )             | 0.16     | 0.17      | 0.09  | 0.05  | 0.13   | 0.10    | 0.11    | 0.09    | 0.08    | < 0.05  |
| L.O.I.                         | 0.10     | 0.90      | 0.48  | 1.10  | 0.50   | 1.77    | 1.40    | 1.27    | 2.23    | 1.53    |
| (As)                           | <7       | <7        | <7    | <7    | <7     | <7      | <7      | <7      | <7      | <7      |
| Ba                             | 196      | 184       | 171   | 174   | 155    | 183     | 199     | 129     | 169     | 68      |
| Bi                             | <10      | <10       | <10   | <10   | <10    | <10     | <10     | <10     | <10     | <10     |
| Ce                             | <35      | <35       | <35   | <35   | <35    | <35     | <35     | <35     | <35     | <35     |
| Co                             | n.a.     | <7        | n.a.  | <7    | n.a.   | <7      | <7      | <7      | <7      | <7      |
| Cr                             | <7       | <7        | <7    | <7    | <7     | <7      | <7      | <7      | 30      | 96      |
| Cu                             | n.a.     | 133       | n.a.  | 172   | n.a.   | 149     | 160     | 178     | 209     | 136     |
| Ga                             | 11       | <5        | 7     | <5    | <5     | <5      | <5      | <5      | <5      | 11      |
| Mo                             | <4       | <4        | <4    | <4    | <4     | <4      | <4      | <4      | <4      | <4      |
| Nb                             | <5       | <5        | <5    | <5    | <5     | <5      | <5      | <5      | 44      | <5      |
| Ni                             | <7       | <7        | <7    | <7    | <7     | <7      | <7      | <7      | <7      | <7      |
| Pb                             | 30       | 37        | 44    | 33    | 59     | 48      | 37      | 44      | 43      | 44      |
| Rb                             | <5       | <5        | <5    | <5    | <5     | <5      | <5      | <5      | <5      | <5      |
| Sn                             | 36       | <50       | 89    | <50   | 103    | <50     | <50     | <50     | <50     | <50     |
| Sr                             | <5       | <5        | <5    | <5    | <5     | <5      | <5      | <5      | <5      | <5      |
| Ta                             | <10      | <10       | <10   | <10   | <10    | <10     | <10     | <10     | <10     | <10     |
| Th                             | 138      | 184       | 148   | 229   | 193    | 200     | 174     | 200     | 290     | 129     |
| U                              | 200      | 210       | 203   | 220   | 231    | 227     | 247     | 254     | 234     | 159     |
| V                              | 12       | 19        | 12    | <10   | 24     | <10     | <10     | 27      | 49      | 87      |
| W                              | n.a.     | 117       | n.a.  | 142   | n.a.   | 126     | 112     | 125     | 120     | 104     |
| Y                              | 605      | 288       | 743   | 381   | 801    | 379     | 360     | 367     | 453     | 421     |
| Zn                             | 154      | 36        | 83    | 49    | 143    | 116     | 84      | 362     | 1592    | 245     |

In some samples impurities of grains of various titanium minerals (see Baker, 1962, p. 117), gahnite, or Al-silicates (see tab. 44) were found.

Tab. 35: Geochemical composition of zircon concentrates produced in northeastern Florida

|            | I-G.C.S. | II-G.C.S. | I-F    | II-F   | I-T.R  | II-T.R | II-T.R | II-T.R | II-T.R | II-T.R |
|------------|----------|-----------|--------|--------|--------|--------|--------|--------|--------|--------|
|            | Zr.      | Zr.       | Zr.    | Zr.    | SZr.   | SZr.   | Zr.    | ZrT.   | Zrc.   | Zro.   |
| Il         |          |           |        | <0.1   |        | 0.4    |        |        | 1.6    | 0.6    |
| Lx         |          |           |        |        |        | 0.2    |        | 0.2    | 0.4    | 0.6    |
| Rt         | 0.2      |           |        | 0.3    | 0.8    | 0.1    | 0.1    | 0.4    | 2.1    | 0.2    |
| Zr         | 99.3     | 99.2      | 97.6   | 99.2   | 98.9   | 97.7   | 98.2   | 98.3   | 86.2   | 65.6   |
| Ky         | 0.3      | 0.2       |        | 0.1    | 0.3    | 1.1    | 1.5    | 0.3    | 1.5    | 10.9   |
| St         | 0.2      | 0.2       | 0.4    |        |        | 0.1    | 0.1    | 0.5    | 7.2    | 3.5    |
| Gr         |          |           |        | <0.1   |        |        |        |        |        | 0.3    |
| Ep         |          | 0.1       |        |        |        |        |        |        |        |        |
| Si         |          |           | 0.6    | 0.1    |        |        | <0.1   | 0.2    | 0.1    | 6.0    |
| An         |          |           |        |        |        | 0.1    |        |        |        | 0.9    |
| Tm         |          |           |        |        |        |        |        |        | 0.1    | 1.3    |
| Mo/Xe      |          |           |        | 0.2    |        |        |        |        |        |        |
| To         |          | 0.1       |        |        |        |        |        |        | 0.1    | 1.2    |
| Sp         |          |           |        |        |        |        |        |        | 0.4    |        |
| Co         |          |           | 0.4    |        |        | 0.3    | 0.1    |        | 0.3    | 4.4    |
| Se         |          |           |        | 0.3    |        |        |        |        |        |        |
| At         |          |           | 0.3    |        |        |        |        |        |        |        |
| Br         |          | 0.2       |        |        |        |        |        |        |        |        |
| Quartz     |          |           | 0.4    | <0.1   | <0.1   | <0.1   | <0.1   |        |        | 4.5    |
| mesh       |          |           |        |        |        |        |        |        |        |        |
| + 20       |          |           |        |        |        |        |        |        |        | 0.004  |
| 25         |          |           |        |        |        |        |        |        | 0.002  | 0.010  |
| 30         |          |           |        |        | 0.001  |        |        |        | 0.000  | 0.024  |
| 35         |          | 0.001     |        |        | 0.003  |        |        | 0.002  | 0.004  | 0.052  |
| 40         |          | 0.001     | 0.001  | 0.002  | 0.002  | 0.002  | 0.001  | 0.005  | 0.025  | 0.190  |
| 45         | 0.003    | 0.002     | 0.003  | 0.001  | 0.002  | 0.006  | 0.004  | 0.013  | 0.070  | 0.683  |
| 50         | 0.005    | 0.003     | 0.006  | 0.002  | 0.009  | 0.052  | 0.009  | 0.138  | 0.337  | 2.296  |
| 60         | 0.007    | 0.005     | 0.006  | 0.007  | 0.012  | 0.570  | 0.129  | 0.910  | 1.235  | 4.307  |
| 70         | 0.013    | 0.005     | 0.016  | 0.011  | 0.046  | 2.861  | 1.051  | 3.843  | 4.196  | 9.819  |
| 80         | 0.059    | 0.012     | 0.253  | 0.024  | 0.540  | 6.066  | 3.359  | 7.168  | 6.188  | 11.850 |
| 100        | 0.453    | 0.025     | 1.115  | 0.113  | 2.843  | 10.663 | 8.778  | 11.913 | 10.292 | 13.771 |
| 120        | 5.136    | 2.396     | 3.768  | 0.484  | 18.879 | 21.503 | 21.286 | 23.916 | 19.486 | 17.521 |
| 140        | 21.364   | 23.158    | 11.379 | 3.101  | 36.025 | 35.295 | 40.040 | 34.466 | 32.208 | 23.115 |
| 170        | 40.412   | 42.163    | 36.417 | 19.636 | 29.685 | 18.313 | 20.505 | 14.535 | 18.620 | 12.834 |
| 200        | 24.988   | 24.684    | 32.168 | 45.971 | 9.421  | 4.160  | 4.332  | 2.651  | 6.063  | 3.140  |
| 230        | 6.521    | 6.468     | 13.376 | 22.819 | 1.847  | 0.351  | 0.340  | 0.227  | 0.955  | 0.240  |
| 270        | 0.461    | 0.542     | 1.061  | 5.543  | 0.291  | 0.052  | 0.047  | 0.070  | 0.099  | 0.027  |
| 325        | 0.337    | 0.192     | 0.362  | 2.158  | 0.171  | 0.014  | 0.016  | 0.017  | 0.051  | 0.009  |
| - 325      | 0.230    | 0.110     | 0.060  | 0.120  | 0.220  | 0.080  | 0.010  | 0.120  | 0.160  | 0.100  |
|            |          |           |        |        |        |        |        |        |        |        |
| mean (µm)  | 94.9     | 94.5      | 89.9   | 79.3   | 108.7  | 124.4  | 119.2  | 129.0  | 124.8  | 146.6  |
| mean (phi) | 3.397    | 3.404     | 3.476  | 3.657  | 3.202  | 3.007  | 3.068  | 2.954  | 3.002  | 2.770  |
| SD         | 0.271    | 0.247     | 0.284  | 0.258  | 0.287  | 0.356  | 0.305  | 0.366  | 0.412  | 0.508  |
| Sk         | 0.455    | 0.432     | -0.362 | 0.212  | 0.595  | -0.492 | -0.309 | -0.440 | -0.502 | -0.466 |
| K          | 6.120    | 5.507     | 4.684  | 5.536  | 6.793  | 4.175  | 5.176  | 4.483  | 4.380  | 3.170  |

Tab. 36: Mineralogical and granulometric composition of zircon concentrates produced in northeastern Florida

## Monazite and xenotime

The average content of  $\text{ThO}_2$  and  $\text{U}_3\text{O}_8$  in monazites ( $n = 53$ ) of the southeastern United States was found by Mertie (1975) to be 5.67 %, and 0.38 %, respectively.

Monazite concentrates were separated from all placer deposits in northeastern Florida except Trail Ridge. Xenotime was only separated from tailings of the Jacksonville deposit (see chapter on Jacksonville).

### Boulogne:

Photos of a monazite concentrate produced from the Boulogne sands were shown by Garnar (1980), who quoted a mean grain size of this concentrate of 69  $\mu\text{m}$ . After unpublished reports of two grain size analyses this mean grain size could be calculated as only 3.916 phi (66.2  $\mu\text{m}$ ).

### Jacksonville:

Nothing is known about the chemical composition of either the monazite or the xenotime concentrate produced at Jacksonville. After Carpenter & Griffith (1960) the mean grain size of the monazite concentrate was about 3.73 phi (75  $\mu\text{m}$ ), after unpublished reports of Humphreys (1962) it could be calculated as 3.795 phi (72.0  $\mu\text{m}$ ), after Mertie (1975) it was about 3.61 phi (82  $\mu\text{m}$ ) in the northern ore body.

### Folkston:

After unpublished reports of serial analyses of HGC (1970) and of the chemical company W.R. Grace & Co. a number of details are known about the monazite concentrate produced from the Folkston deposit. The average chemical composition ( $n = 74$ ) of this concentrate can be quoted as follows:

|                                                                                            | Mean    | Standard Deviation |
|--------------------------------------------------------------------------------------------|---------|--------------------|
| REO                                                                                        | 58.9 %  | 0.96 %             |
| $\text{ThO}_2$                                                                             | 4.2 %   | 0.60 %             |
| $\text{H}_2\text{SO}_4$ - insoluble<br>(i.e. zircon, staurolite, quartz, ilmenite, rutile) | 8.1 %   | 1.49 %             |
| $\text{SiO}_2$                                                                             | 2.6 %   | 0.49 %             |
| $\text{TiO}_2$                                                                             | 0.43 %  | 0.339 %            |
| $\text{ZrO}_2$                                                                             | 3.7 %   | 1.17 %             |
| $\text{Fe}_2\text{O}_3$                                                                    | 0.63 %  | 0.201 %            |
| $\text{Al}_2\text{O}_3$                                                                    | 1.7 %   | 0.47 %             |
| CaO                                                                                        | 1.1 %   | 0.20 %             |
| MnO                                                                                        | 0.107 % | 0.0832 %           |
| PbO                                                                                        | 0.16 %  | 0.05 %             |

The composition of the REO is given in tab. 37. Attention is called in this table to the high content of heavy RE, which must be explained by mixing monazite with xenotime (E. V. Whittle, pers. comm., 1990).

After unpublished results of three grain size analyses the mean grain size of the monazite concentrate was 3.970 phi (63.8  $\mu\text{m}$ ).

## Green Cove Springs:

In 1985 Hedrick was the first to publish a table of REO occurring in various RE mineral concentrates (republished in O'Driscoll, 1988). On request Dr. J. B. Hedrick (U.S. Bureau of Mines, pers. comm., 1989) certified that the sample "Florida" stem from the Green Cove Springs deposit. For this reason his data were presented in tab. 37, too, although at RGC nothing was known about the origin of this sample (F. Russell, pers. comm., 1990).

Garnar (1980) published a photo of the monazite concentrate separated by Titanium Enterprises from the Green Cove Springs placer sands and quoted a mean grain size of 79  $\mu\text{m}$ .

For this work RGC kindly offered results of three chemical analyses of its monazite concentrate for publication. Among these its sample # 3809 - 3842 is the same as sample "II-G.C.S.-Mo." of this bulletin:

|                               | # 3571 - 3672<br>(1990) | # 3809 - 3842<br>(1991) | Rhone-Poulenc<br>(1985) |
|-------------------------------|-------------------------|-------------------------|-------------------------|
| REO                           | 58.21 %                 | 59.16 %                 | 59.0 %                  |
| ThO <sub>2</sub>              | 4.19 %                  | 4.24 %                  | 4.0 %                   |
| insol.                        | 9.50 %                  | 8.25 %                  |                         |
| TiO <sub>2</sub>              | 0.08 %                  | 0.09 %                  | 0.14 %                  |
| SiO <sub>2</sub>              |                         |                         | 2.2 %                   |
| ZrO <sub>2</sub>              |                         |                         | 4.8 %                   |
| P <sub>2</sub> O <sub>5</sub> |                         |                         | 28.6 %                  |

Samples of monazite concentrates posed at the author's disposal for analyses were kindly spectrochemically analyzed by Spectro Analytical Instruments in Kleve, Germany. Unfortunately only data of the composition of the REO-fraction are available. These, however, can easily be compared with data from other analyses (tab. 37):

|                                 | Green Cove Springs |               |                         |                   | Folkston           |                             |
|---------------------------------|--------------------|---------------|-------------------------|-------------------|--------------------|-----------------------------|
|                                 | I-G.C.S.-Mo.       | II-G.C.S.-Mo. | Rhone-Poulenc<br>(1985) | Hedrick<br>(1985) | I-F.-Mo.<br>(1970) | W.R. Grace & Co.<br>(n = 4) |
| REO                             | 58.5663 %          | 55.0379 %     | 59.0 %                  | n.a.              | 60.5272 %          | mean = 59.4 %               |
| La <sub>2</sub> O <sub>3</sub>  | 20.45 %            | 18.23 %       | 20.3 %                  | 17.47 %           | 19.82 %            | mean = 17.7 %               |
| CeO <sub>2</sub>                | 45.22 %            | 49.27 %       | 43.8 %                  | 43.73 %           | 43.69 %            | mean = 42.0 %               |
| Pr <sub>6</sub> O <sub>11</sub> | 5.11 %             | 4.64 %        | 4.9 %                   | 4.98 %            | 5.07 %             | mean = 5.4 %                |
| Nd <sub>2</sub> O <sub>3</sub>  | 17.07 %            | 15.84 %       | 17.9 %                  | 17.47 %           | 17.52 %            | mean = 17.8 %               |
| Sm <sub>2</sub> O <sub>3</sub>  | 3.56 %             | 3.13 %        | 3.3 %                   | 4.87 %            | 3.45 %             | mean = 3.6 %                |
| Eu <sub>2</sub> O <sub>3</sub>  | 0.234 %            | 0.222 %       | 0.167 %                 | 0.16 %            | 0.266 %            | mean = 0.14 %               |
| Gd <sub>2</sub> O <sub>3</sub>  | 2.38 %             | 2.56 %        | 2.4 %                   | 6.56 %            | 2.28 %             | mean = 2.4 %                |
| Tb <sub>4</sub> O <sub>7</sub>  | 0.261 %            | 0.246 %       | 0.3 %                   | 0.26 %            | 0.272 %            | mean = 0.26 %               |
| Dy <sub>2</sub> O <sub>3</sub>  | 1.07 %             | 0.97 %        | 1.1 %                   | 0.90 %            | 1.27 %             | mean = 0.94 %               |
| Ho <sub>2</sub> O <sub>3</sub>  | 0.182 %            | 0.158 %       | n.a.                    | 0.11 %            | 0.232 %            | mean = n.a.                 |
| Er <sub>2</sub> O <sub>3</sub>  | 0.287 %            | 0.253 %       | n.a.                    | 0.04 %            | 0.516 %            | mean = n.a.                 |
| Tm <sub>2</sub> O <sub>3</sub>  | 0.0307 %           | 0.0255 %      | n.a.                    | 0.03 %            | 0.0623 %           | mean = n.a.                 |
| Yb <sub>2</sub> O <sub>3</sub>  | 0.112 %            | 0.106 %       | n.a.                    | 0.21 5            | 0.294 %            | mean = n.a.                 |
| Lu <sub>2</sub> O <sub>3</sub>  | 0.0153 %           | 0.0123 %      | n.a.                    | 0.03 %            | 0.0323 %           | mean = n.a.                 |
| Y <sub>2</sub> O <sub>3</sub>   | 4.02 %             | 4.35 %        | 3.3 %                   | 3.18 %            | 5.22 %             | mean = 2.9 %                |
| total                           | 100.0020 %         | 100.0028 %    | 97.467 %                | 100.00 %          | 99.9946 %          | mean = 93.14 %              |

Tab. 37: Composition of the REO-fraction of monazite concentrates produced in northeastern Florida (converted to 100 % REO)

|           | I-G.C.S.-Mo  | II-G.C.S.-Mo. | I-F.-Mo.     |
|-----------|--------------|---------------|--------------|
| Il        | 0.4 %        | 0.2 %         | 0.1 %        |
| Lx        |              | <0.1 %        |              |
| Rt        | 0.2 %        | <0.1 %        |              |
| Zr        | 5.2 %        | 6.6 %         | 3.9 %        |
| St        | 0.2 %        |               | 0.2 %        |
| Gr        | 1.3 %        | 1.3 %         | 0.3 %        |
| Ep        | <0.1 %       |               | 0.1 %        |
| Mo/Xe     | 92.1 %       | 91.7 %        | 95.3 %       |
| Sp        | 0.5 %        |               | 0.1 %        |
| Quartz    | 0.1 %        | 0.2 %         | <0.1 %       |
| ASTM mesh |              |               |              |
| + 40      |              | 0.001 %       |              |
| 45        | 0.003 %      | 0.002 %       |              |
| 50        | 0.002 %      | 0.002 %       | 0.001 %      |
| 60        | 0.004 %      | 0.003 %       | 0.002 %      |
| 70        | 0.004 %      | 0.002 %       | 0.001 %      |
| 80        | 0.011 %      | 0.004 %       | 0.003 %      |
| 100       | 0.032 %      | 0.025 %       | 0.006 %      |
| 120       | 0.501 %      | 0.512 %       | 0.125 %      |
| 140       | 2.627 %      | 6.049 %       | 1.052 %      |
| 170       | 16.852 %     | 31.718 %      | 5.330 %      |
| 200       | 45.473 %     | 41.002 %      | 31.158 %     |
| 230       | 31.099 %     | 18.875 %      | 46.730 %     |
| 270       | 1.836 %      | 1.373 %       | 13.319 %     |
| 325       | 1.476 %      | 0.369 %       | 1.907 %      |
| - 325     | 0.070 %      | 0.050 %       | 0.360 %      |
| mean      | 78.9 $\mu$ m | 84.3 $\mu$ m  | 71.4 $\mu$ m |
| mean      | 3.663 phi    | 3.568 phi     | 3.807 phi    |
| SD        | 0.230        | 0.232         | 0.231        |
| Sk        | -0.051       | 0.050         | 0.209        |
| K         | 5.565        | 4.579         | 6.078        |

Tab. 38: Mineralogical and granulometric composition of monazite concentrates produced in northeastern Florida

## Staurolite

Staurolite was first produced from the Trail Ridge deposit in June 1952 (Calver, 1957; Fulton, 1975, 1983) as a substitute for clay or clayey limestone in the cement industry of Florida.

During the following years staurolite made its way in abrasives. A sandblast abrasive can now be found on the market under the term "Starblast". Its favorable properties for the cleaning of metal and buildings, and for paint removal were described in detail by Fulton (1975, 1983) and Garnar (1989). A coarse staurolite concentrate, also called "Coarse Staurolite", is used to engrave and polish marble tombstones and cornerstones. In the late '60s Du Pont developed the so-called "Biasill" (Bi-Iron-Aluminum-Silicate) as a nonferrous foundry sand.

Till 1985 a staurolite concentrate was also sold by AMU for similar purposes (Garnar, 1980, 1987). Currently staurolite is worldwide produced only from the Trail Ridge deposit (Garnar, 1987).

### Green Cove Springs:

In 1980 Garnar published a photo of a staurolite concentrate produced for a short time only by Titanium Enterprises from its Green Cove Springs deposit. He quoted a mean grain size of this concentrate of 131  $\mu\text{m}$ .

### Trail Ridge:

The typical composition of the various staurolite concentrates produced by Du Pont is known very well in contrast to other h.m. concentrates:

|               | Staurolite        | Coarse Staurolite | Starblast         | Biasill           |
|---------------|-------------------|-------------------|-------------------|-------------------|
| Evans (1955)  | 189 $\mu\text{m}$ |                   |                   |                   |
| Fulton (1975) |                   | 384 $\mu\text{m}$ | 207 $\mu\text{m}$ | 188 $\mu\text{m}$ |
| Fulton (1983) |                   | 358 $\mu\text{m}$ | 189 $\mu\text{m}$ | 176 $\mu\text{m}$ |
| Garnar (1980) |                   | 317 $\mu\text{m}$ | 215 $\mu\text{m}$ | 188 $\mu\text{m}$ |

Tab. 39: Mean grain size of Trail Ridge staurolite concentrates after various authors

|                                                     | Evans (1955) | Fulton (1975) | Fulton (1983) |
|-----------------------------------------------------|--------------|---------------|---------------|
| Staurolite                                          | 82.7 %       | 77 %          | 89 %          |
| Tourmaline                                          | 10.5 %       | 10 %          |               |
| Quartz                                              | 2.1 %        | 4 %           | 4 %           |
| Zircon                                              | 2.0 %        | 3 %           | 2 %           |
| Titanium minerals                                   | 1.7 %        | 4 %           | 4 %           |
| Kyanite, corundum,<br>sillimanite, spinel, monazite | 1.0 %        | 2 %           | 1 %           |
| $\text{Al}_2\text{O}_3$                             | 50 %         | min. 45 %     | min. 45 %     |
| $\text{Fe}_2\text{O}_3$                             | 14 %         | max. 18 %     | max. 18 %     |
| $\text{TiO}_2$                                      | 1 - 2 %      | max. 5 %      | max. 5 %      |
| $\text{ZrO}_2$                                      | 1 - 2 %      | max. 3 %      | max. 3 %      |
| $\text{SiO}_2$                                      | 28 %         |               |               |
| $\text{SiO}_2$ (free)                               |              | max. 5 %      | max. 5 %      |

Tab. 40: Average mineralogical and granulometric composition of Trail Ridge staurolite concentrates after various authors



|                                | I-G.C.S.-St. | II-F.-St.A | II-F.-St.B | I-T.R.-Bia | II-T.R.-Bia. | II-T.R.-Stb. | II-T.R.-cSt. |
|--------------------------------|--------------|------------|------------|------------|--------------|--------------|--------------|
| SiO <sub>2</sub>               | 27.24        | 23.72      | 27.12      | 28.77      | 29.33        | 28.16        | 24.00        |
| TiO <sub>2</sub>               | 3.19         | 8.83       | 2.19       | 2.95       | 2.93         | 4.01         | 11.32        |
| Zr/HfO <sub>2</sub>            | 0.12         | 0.23       | 0.08       | 1.49       | 1.27         | 1.52         | 0.53         |
| ZnO <sub>2</sub>               | 0.42         | 0.44       | 0.23       | 0.51       | 0.48         | 0.54         | 0.34         |
| Al <sub>2</sub> O <sub>3</sub> | 46.08        | 45.02      | 46.86      | 47.26      | 47.40        | 47.05        | 42.87        |
| Fe <sub>2</sub> O <sub>3</sub> | 15.22        | 17.24      | 17.88      | 14.07      | 13.76        | 14.54        | 16.91        |
| MnO                            | 0.40         | 0.42       | 0.27       | 0.22       | 0.22         | 0.24         | 0.30         |
| MgO                            | 1.96         | 1.17       | 1.64       | 2.14       | 1.79         | 1.68         | 1.01         |
| CaO                            | 2.40         | 0.15       | 0.37       | 0.16       | 0.13         | 0.14         | 0.07         |
| K <sub>2</sub> O               | 0.01         | 0.01       | 0.08       | 0.02       | 0.01         | 0.01         | 0.01         |
| P <sub>2</sub> O <sub>5</sub>  | 0.07         | 0.28       | 0.22       | 0.04       | 0.03         | 0.06         | 0.02         |
| (SO <sub>3</sub> )             | 0.02         | <0.05      | <0.05      | 0.03       | <0.05        | <0.05        | <0.05        |
| L.O.I.                         | 1.76         | 1.54       | 2.18       | 1.40       | 2.23         | 1.60         | 1.86         |
| (As)                           | 8            | <7         | 11         | <7         | <7           | <7           | <7           |
| Ba                             | <50          | 34         | 41         | <50        | 15           | 28           | 32           |
| Bi                             | <10          | <10        | <10        | <10        | <10          | <10          | <10          |
| Ce                             | 380          | 1657       | 1566       | 115        | 89           | 367          | <15          |
| Co                             | n.a.         | 65         | 65         | n.a.       | 44           | 43           | 45           |
| Cr                             | 199          | 367        | 254        | 199        | 189          | 219          | 230          |
| Cs                             | n.a.         | 21         | 14         | n.a.       | 6            | 15           | 15           |
| Cu                             | 195          | 117        | 133        | n.a.       | 132          | 289          | 143          |
| Ga                             | 144          | 137        | 134        | 136        | 125          | 134          | 121          |
| Hf                             | 22           | 59         | 47         | 236        | 189          | 265          | 119          |
| La                             | n.a.         | 869        | 880        | n.a.       | 59           | 190          | 69           |
| Mo                             | <4           | 5          | <4         | <4         | <4           | <4           | <4           |
| Nb                             | 45           | 82         | 104        | 43         | 28           | 58           | 98           |
| Ni                             | 33           | 67         | 87         | 36         | 37           | 40           | 32           |
| Pb                             | 15           | 48         | 49         | 24         | 23           | 30           | 71           |
| Rb                             | 8            | 11         | 23         | <5         | <5           | 14           | 11           |
| Sc                             | n.a.         | 9          | 14         | n.a.       | 8            | 11           | 13           |
| Sn                             | 86           | <5         | 7          | 68         | 6            | 6            | 17           |
| Sr                             | 90           | 5          | 24         | 25         | 33           | 29           | 8            |
| Ta                             | 14           | <10        | 70         | <10        | <10          | <10          | 12           |
| Th                             | 83           | 297        | 410        | 29         | 35           | 79           | <10          |
| U                              | <5           | 72         | 49         | <5         | 24           | 19           | 11           |
| V                              | 189          | 226        | 231        | 186        | 180          | 169          | 275          |
| W                              | n.a.         | 34         | <10        | n.a.       | <10          | <10          | <10          |
| Y                              | 66           | 867        | 132        | 45         | 40           | 72           | <5           |
| Zr                             | 837          | 1634       | 545        | 10481      | 9265         | 10987        | 3833         |

Tab. 41: Geochemical composition of staurolite concentrates produced in northeastern Florida. The origin of samples "I-G.C.S.-St." and "II-F.-St.A/B" is described in the chapters on Green Cove Springs and Folkston, respectively.



|        | I-G.C.S.-St   | II-F.-St.A    | II-F.-St.B    | I-T.R.-Bia    | II-T.R.-Bia   | II-T.R.-Stb.  | II-T.R.-cSt   |
|--------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| Il     | 6.7 %         | 12.0 %        | 5.9 %         | 4.4 %         | 5.6 %         | 6.4 %         | 28.2 %        |
| Lx     | 0.1 %         | <0.1 %        |               | 2.5 %         | <0.1 %        | 0.3 %         | 0.7 %         |
| Rt     | 0.6 %         | 0.3 %         | 0.1 %         | 0.7 %         | 0.1 %         | <0.1 %        | 0.1 %         |
| Zr     | 0.4 %         | 0.3 %         | 0.2 %         | 2.8 %         | 1.7 %         | 2.5 %         | 0.7 %         |
| Ky     |               |               |               | 1.8 %         | 0.7 %         | 0.4 %         | 0.1 %         |
| St     | 71.6 %        | 85.4 %        | 84.8 %        | 77.3 %        | 78.7 %        | 79.0 %        | 67.1 %        |
| Gr     | 2.2 %         | 0.3 %         | 2.4 %         | <0.1 %        | 0.2 %         |               | 0.3 %         |
| Ep     | 15.0 %        | 0.6 %         | 0.3 %         | 0.2 %         | <0.1 %        |               |               |
| Si     |               | <0.1 %        | 0.1 %         | 1.3 %         | 0.4 %         | 0.1 %         | 0.1 %         |
| Hb     | 0.4 %         |               | 0.5 %         |               |               |               |               |
| Tm     | 1.9 %         | 0.2 %         | 4.6 %         | 6.3 %         | 10.1 %        | 8.9 %         | 0.6 %         |
| Mo/Xe  | 0.5 %         | 0.2 %         |               | 0.1 %         |               | 0.1 %         |               |
| To     |               |               | <0.1 %        | <0.1 %        | <0.1 %        | <0.1 %        |               |
| Sp     | 0.6 %         | 0.6 %         | 0.4 %         | 0.7 %         | 0.8 %         | 1.1 %         | 0.4 %         |
| Co     |               |               |               | 0.2 %         | <0.1 %        |               | 0.2 %         |
| At     |               |               |               | 0.3 %         |               |               |               |
| Quartz | <0.1 %        | <0.1 %        | 0.7 %         | 1.4 %         | 1.7 %         | 1.2 %         | 1.5 %         |
| mesh   |               |               |               |               |               |               |               |
| + 16   |               |               | 0.008 %       |               |               |               |               |
| 18     |               |               | 0.015 %       |               |               |               |               |
| 20     |               |               | 0.389 %       | 0.012 %       | 0.003 %       |               | 0.048 %       |
| 25     |               |               | 1.395 %       | 0.019 %       | 0.026 %       | 0.010 %       | 0.351 %       |
| 30     |               |               | 2.258 %       | 0.133 %       | 0.098 %       | 0.036 %       | 1.682 %       |
| 35     | 0.002 %       |               | 3.945 %       | 0.374 %       | 0.344 %       | 0.164 %       | 6.721 %       |
| 40     | 0.005 %       |               | 6.489 %       | 0.984 %       | 1.132 %       | 0.577 %       | 18.386 %      |
| 45     | 0.018 %       | 0.001 %       | 7.493 %       | 2.890 %       | 2.180 %       | 1.206 %       | 27.419 %      |
| 50     | 0.051 %       | 0.002 %       | 12.506 %      | 6.981 %       | 6.292 %       | 4.356 %       | 33.171 %      |
| 60     | 0.523 %       | 0.000 %       | 14.120 %      | 10.523 %      | 10.335 %      | 8.595 %       | 9.258 %       |
| 70     | 1.856 %       | 0.026 %       | 16.606 %      | 18.653 %      | 17.986 %      | 16.002 %      | 1.585 %       |
| 80     | 3.549 %       | 0.035 %       | 13.778 %      | 19.317 %      | 20.686 %      | 19.308 %      | 0.576 %       |
| 100    | 8.467 %       | 2.509 %       | 11.099 %      | 17.654 %      | 20.873 %      | 20.660 %      | 0.347 %       |
| 120    | 37.981 %      | 15.098 %      | 5.597 %       | 15.201 %      | 12.553 %      | 16.033 %      | 0.218 %       |
| 140    | 33.368 %      | 40.961 %      | 2.703 %       | 5.163 %       | 5.674 %       | 8.813 %       | 0.105 %       |
| 170    | 12.077 %      | 26.729 %      | 1.035 %       | 1.567 %       | 1.390 %       | 2.847 %       | 0.040 %       |
| 200    | 1.759 %       | 11.536 %      | 0.386 %       | 0.359 %       | 0.314 %       | 0.919 %       | 0.016 %       |
| 230    | 0.225 %       | 2.585 %       | 0.088 %       | 0.061 %       | 0.052 %       | 0.252 %       | 0.005 %       |
| 270    | 0.016 %       | 0.114 %       | 0.026 %       | 0.007 %       | 0.016 %       | 0.057 %       | 0.010 %       |
| 325    | 0.018 %       | 0.041 %       | 0.010 %       | 0.005 %       | 0.010 %       | 0.022 %       | 0.006 %       |
| - 325  | 0.080 %       | 0.040 %       | 0.050 %       | 0.090 %       | 0.030 %       | 0.140 %       | 0.050 %       |
| mean   | 127.0 $\mu$ m | 107.5 $\mu$ m | 255.1 $\mu$ m | 195.3 $\mu$ m | 194.1 $\mu$ m | 178.9 $\mu$ m | 369.1 $\mu$ m |
| mean   | 2.977 phi     | 3.218 phi     | 1.971 phi     | 2.356 phi     | 2.365 phi     | 2.483 phi     | 1.438 phi     |
| SD     | 0.297         | 0.269         | 0.650         | 0.492         | 0.473         | 0.483         | 0.347         |
| Sk     | -0.407        | 0.290         | -0.214        | -0.150        | -0.231        | 0.038         | 0.843         |
| K      | 6.338         | 4.085         | 3.094         | 3.662         | 3.499         | 3.973         | 10.719        |

Tab. 42: Mineralogical and granulometric composition of staurolite concentrates produced in northeastern Florida

## Garnet, kyanite, sillimanite

### Garnet

Garnet, which can be found in most of the placer deposits in northeastern Florida was only sold at the Jacksonville site. After E. V. Whittle (pers. comm., 1990) over several years commercial interest was shown by some small customers, who probably used this mineral for abrasive purposes (see chapter on Jacksonville). Unfortunately no details about this garnet concentrate are known.

In the finishing process of h. m. preconcentrates of the Folkston and Boulogne deposits small amounts of garnet also were left over. As far as known, these, however, were not sold on the market. For this work a garnet concentrate produced from the Folkston deposit was available for analyses (see chapter on Folkston).

In the mid '70s Titanium Enterprises was also planning to sell garnet from its Green Cove Springs deposit (see chapter on Green Cove Springs). A garnet concentrate produced in first test-runs at that time could also be analyzed.

Attention is directed to the different chemical composition of the various garnet concentrates. While the garnet of the Green Cove Springs deposit may be termed an almandine with pyrope and small amounts of spessartine, the garnet from the Folkston deposit is an almandine, enriched in spessartine with very low amounts of pyrope (see tab. 43).

### Kyanite and sillimanite

Over many years the aluminum-silicates kyanite and sillimanite were an important secondary ingredient of the so-called "Kyasill"-concentrate produced from the Trail Ridge deposit. Garnar (1971, p. 32) gave details of the separation and composition of this product. Its main application was as specialty foundry sand, but later it was substituted by the "Zircore" concentrate (see Zircon).

For this work only a kyanite-sillimanite concentrate produced in the separation process at Folkston (see chapter on Folkston deposits) was available for analyses.

|                                | I-G.C.S.-Gr. | II-F.-Gr. | II-F.-Kya |
|--------------------------------|--------------|-----------|-----------|
| SiO <sub>2</sub>               | 35.45 %      | 30.68 %   | 35.63 %   |
| TiO <sub>2</sub>               | 2.01 %       | 3.88 %    | 0.34 %    |
| Zr/HfO <sub>2</sub>            | 0.13 %       | 4.48 %    | 2.59 %    |
| Al <sub>2</sub> O <sub>3</sub> | 19.57 %      | 18.59 %   | 59.50 %   |
| Fe <sub>2</sub> O <sub>3</sub> | 32.57 %      | 15.97 %   | 0.32 %    |
| MnO                            | 1.05 %       | 11.26 %   | 0.01 %    |
| MgO                            | 6.59 %       | 0.83 %    | 0.03 %    |
| CaO                            | 2.19 %       | 3.13 %    | 0.05 %    |
| Na <sub>2</sub> O              | 0.08 %       | <0.10 %   | 0.12 %    |
| K <sub>2</sub> O               | 0.03 %       | 0.01 %    | <0.01 %   |
| P <sub>2</sub> O <sub>5</sub>  | 0.35 %       | 4.89 %    | <0.01 %   |
| (SO <sub>3</sub> )             | <0.05 %      | <0.05 %   | <0.05 %   |
| L.O.I.                         | -1.02 %      | 1.14 %    | 1.63 %    |
| (As)                           | 15 ppm       | 8 ppm     | <7 ppm    |
| Ba                             | 123 ppm      | 20 ppm    | 18 ppm    |
| Bi                             | <10 ppm      | 12 ppm    | <10 ppm   |
| Ce                             | 4053 ppm     | 13618 ppm | <15 ppm   |
| Co                             | 53 ppm       | n.a.      | <7 ppm    |
| Cr                             | 204 ppm      | 129 ppm   | 247 ppm   |
| Cs                             | n.a.         | <10 ppm   | 64 ppm    |
| Cu                             | n.a.         | <10 ppm   | 64 ppm    |
| Ga                             | 20 ppm       | <5 ppm    | 100 ppm   |
| Hf                             | 30 ppm       | 569 ppm   | 412 ppm   |
| La                             | n.a.         | 6737 ppm  | <5 pm     |
| Mo                             | <4 ppm       | <4 ppm    | <4 ppm    |
| Nb                             | 36 ppm       | 21 ppm    | <5 ppm    |
| Ni                             | 9 ppm        | 706 ppm   | <7 ppm    |
| Pb                             | 59 ppm       | 121 ppm   | <10 ppm   |
| Rb                             | 10 ppm       | <5 ppm    | <5 ppm    |
| Sc                             | n.a.         | 124 ppm   | 6 ppm     |
| Sn                             | 57 ppm       | 6 ppm     | <5 ppm    |
| Sr                             | 6 ppm        | <5 ppm    | 6 ppm     |
| Ta                             | <10 ppm      | <10 ppm   | <10 ppm   |
| Th                             | 1095 ppm     | 2144 ppm  | 42 ppm    |
| U                              | 13 ppm       | 1102 ppm  | 10 ppm    |
| V                              | 203 ppm      | 108 ppm   | 299 ppm   |
| W                              | 30 ppm       | n.a.      | <10 ppm   |
| Y                              | 555 ppm      | 31171 ppm | 39 ppm    |
| Zn                             | 277 ppm      | 1013 ppm  | 45 ppm    |
| Zr                             | 972 ppm      | 32649 ppm | 18837 ppm |

In some samples impurities by grains of monazite, xenotime, zircon, epidote, or gahnite were found (see tab. 44)

Tab. 43: Geochemical composition of garnet and aluminum-silicates concentrates produced in northeastern Florida

|        | I-G.C.S.-Gr.  | II-F.-Gr.    | II-F.-Kva     |
|--------|---------------|--------------|---------------|
| Il     | 9.1 %         | 7.6 %        | 0.9 %         |
| Lx     | 0.4 %         | <0.1 %       | 0.4 %         |
| Rt     | 0.1 %         | 0.2 %        | 0.4 %         |
| Zr     | 0.2 %         | 6.9 %        | 4.1 %         |
| Ky     |               | <0.1 %       | 27.7 %        |
| St     | 0.2 %         | 4.2 %        | 0.3 %         |
| Gr     | 85.8 %        | 63.4 %       | 0.2 %         |
| Ep     | 1.1 %         | 1.5 %        |               |
| Si     | <0.1 %        |              | 58.9 %        |
| An     | 0.2 %         |              | 1.2 %         |
| Hb     | 1.1 %         |              |               |
| Tm     | 0.2 %         |              |               |
| Mo/Xe  | 1.0 %         | 15.7 %       | 0.1 %         |
| To     | 0.1 %         |              | 5.5 %         |
| Sp     | 0.1 %         | 0.3 %        |               |
| Co     |               | <0.1 %       | 0.1 %         |
| Se     | <0.1 %        |              |               |
| At     | 0.3 %         |              |               |
| Br     | <0.1 %        |              |               |
| Quartz | <0.1 %        | <0.1 %       | 0.2 %         |
|        |               |              |               |
| mesh   |               |              |               |
| + 30   | 0.004 %       |              | 0.001 %       |
| 35     | 0.007 %       | 0.001 %      | 0.003 %       |
| 40     | 0.027 %       | 0.002 %      | 0.005 %       |
| 45     | 0.243 %       | 0.004 %      | 0.007 %       |
| 50     | 1.170 %       | 0.010 %      | 0.003 %       |
| 60     | 3.890 %       | 0.014 %      | 0.017 %       |
| 70     | 13.729 %      | 0.003 %      | 0.190 %       |
| 80     | 20.528 %      | 0.014 %      | 0.856 %       |
| 100    | 21.818 %      | 0.199 %      | 3.653 %       |
| 120    | 22.334 %      | 1.702 %      | 10.816 %      |
| 140    | 10.317 %      | 10.366 %     | 32.764 %      |
| 170    | 4.317 %       | 31.452 %     | 30.345 %      |
| 200    | 1.280 %       | 33.068 %     | 14.177 %      |
| 230    | 0.223 %       | 18.607 %     | 4.442 %       |
| 270    | 0.010 %       | 3.457 %      | 1.274 %       |
| 325    | 0.016 %       | 1.026 %      | 0.842 %       |
| - 325  | 0.080 %       | 0.070 %      | 0.600 %       |
|        |               |              |               |
| mean   | 162.9 $\mu$ m | 85.3 $\mu$ m | 102.6 $\mu$ m |
| mean   | 2.618 phi     | 3.551 phi    | 3.285 phi     |
| SD     | 0.413         | 0.284        | 0.352         |
| Sk     | 0.170         | 0.051        | 0.734         |
| K      | 3.712         | 4.317        | 6.593         |

Tab. 44: Mineralogical and granulometric composition of garnet and aluminum-silicates concentrates produced in northeastern Florida

## Figures

- 1 Map of h. m. placer deposits in northeastern Florida (after Elsner, 1992b)
- 2 Lithology, grain size variations, and mineralogical suite in core Trail Ridge 1. Granulometric units are phi units. Fine tail/heavy minerals are wt.-%. Heavy mineral species are wt.-% of the 2- to 4-phi fraction (63 - 250  $\mu$ m). Traces („+“) are defined as less than 0.5 wt.-%. Lx/Il is the leucoxene/ilmenite ratio. T.R.-S. = Trail Ridge Sands, T = Transition Zone, T.R.-O.Z. = Trail Ridge Organic Zone. For explanation of lithological symbols see fig. 2a.
- 2a Explanation of lithological symbols used in fig. 2, 3, 4, 5, 6, 15, 17, and 18.
- 3 Lithology, grain size variations, and mineralogical suite in core Trail Ridge 2. Granulometric units are phi units. Fine tail/heavy minerals are wt.-%. Heavy mineral species are wt.-% of the 2- to 4-phi fraction (63 - 250  $\mu$ m). Traces („+“) are defined as less than 0.5 wt.-%. Lx/Il is the leucoxene/ilmenite ratio. T.R.-S. = Trail Ridge Sands, T.R.-O.Z. = Trail Ridge Organic Zone, C.C.F. = Citronelle-Cypresshead Formation. For explanation of lithological symbols see fig. 2a.
- 4 Lithology, grain size variations, and mineralogical suite in core Highland 1. Granulometric units are phi units. Fine tail/heavy minerals are wt.-%. Heavy mineral species are wt.-% of the 2- to 4-phi fraction (63 - 250  $\mu$ m). Traces („+“) are defined as less than 0.5 wt.-%. Lx/Il is the leucoxene/ilmenite ratio. T.R.-S. = Trail Ridge Sands, O.Z. = Trail Ridge Organic Zone, C.C.F. = Citronelle-Cypresshead Formation. For explanation of lithological symbols see fig. 2a.
- 5 Lithology, grain size variations, and mineralogical suite in core Highland 2. Granulometric units are phi units. Fine tail/heavy minerals are wt.-%. Heavy mineral species are wt.-% of the 2- to 4-phi fraction (63 - 250  $\mu$ m). Traces („+“) are defined as less than 0.5 wt.-%. Lx/Il is the leucoxene/ilmenite ratio. T.R.-S. = Trail Ridge Sands, O.Z. = Trail Ridge Organic Zone, C.C.F. = Citronelle-Cypresshead Formation. For explanation of lithological symbols see fig. 2a.
- 6 Lithology, grain size variations, and mineralogical suite in core Trail Ridge 3. Granulometric units are phi units. Fine tail/heavy minerals are wt.-%. Heavy mineral species are wt.-% of the 2- to 4-phi fraction (63 - 250  $\mu$ m). Traces („+“) are defined as less than 0.5 wt.-%. Lx/Il is the leucoxene/ilmenite ratio. T.R.-S. = Trail Ridge Sands, C.C.F. = Citronelle-Cypresshead Formation. For explanation of lithological symbols see fig. 2a.
- 7 Average h. m. composition of ore sands in cores Trail Ridge 1, Trail Ridge 2, Highland 1, Highland 2, and Trail Ridge 3 (from south to north). Heavy mineral species are wt.-% of the 2- to 4-phi fraction (63 - 250  $\mu$ m). St is h.m. grade corrected for large staurolite grains coarser than 250  $\mu$ m. For abbreviations of mineral species see appendix II (Ot = others).
- 8 Map of the Trail Ridge h. m. placer deposit (modified after Elsner, 1992a).
- 9 Flow diagram showing the separation of h. m. at Trail Ridge by Du Pont (prepared by T. E. Garnar, Jr., 1991 for Elsner, 1992a).
- 10 Map of the Folkston h. m. placer deposit (modified after Elsner, 1992a).
- 11 Flow diagram showing the separation of h. m. at Folkston by Humphreys Gold Corporation (prepared by T. E. Garnar, Jr., 1991, modified after Humphreys Gold Corporation, 1959, and Humphreys Mining Company, 1974).
- 12 Map of the Boulogne h. m. placer deposit (modified after Elsner, 1992a).
- 13 Distribution of h. m. placer deposits in the Folkston-Boulogne placer district and the areas of radioactivity anomalies (after Moxham, 1954).

- 14 Average h. m. composition of ore sands in core Boulogne 1 and from the Folkston h. m. placer deposit. Heavy mineral species are wt.-% of the 2- to 4-phi fraction (63 - 250  $\mu$ m). For abbreviations of mineral species see appendix II (Ot = others).
- 15 Lithology, grain size variations, and mineralogical suite in core Boulogne 1. Granulometric units are phi units. Fine tail/heavy minerals are wt.-%. Heavy mineral species are wt.-% of the 2- to 4-phi fraction (63 - 250  $\mu$ m). Traces („+“) are defined as less than 0.5 wt.-%. Lx/Il is the leucoxene/ilmenite ratio. Units C, D, E, and F after Elsner (1992b). For explanation of lithological symbols see fig. 2a
- 16 Map of the Green Cove Springs h. m. placer deposit (modified after Elsner, 1992a).
- 17 Lithology, grain size variations, and mineralogical suite in core Union Camp 1. Granulometric units are phi units. Fine tail/heavy minerals are wt.-%. Heavy mineral species are wt.-% of the 2- to 4-phi fraction (63 - 250  $\mu$ m). Traces („+“) are defined as less than 0.5 wt.-%. Lx/Il is the leucoxene/ilmenite ratio. Units C, D, E, and F after Elsner (1992b). For explanation of lithological symbols see fig. 2a
- 18 Lithology, grain size variations, and mineralogical suite in core Union Camp 2. Granulometric units are phi units. Fine tail/heavy minerals are wt.-%. Heavy mineral species are wt.-% of the 2- to 4-phi fraction (63 - 250  $\mu$ m). Traces („+“) are defined as less than 0.5 wt.-%. Lx/Il is the leucoxene/ilmenite ratio. Units C, D, E, and F after Elsner (1992b). For explanation of lithological symbols see fig. 2a
- 19 Average h. m. composition of ore sands in cores Union Camp 1, and Union Camp 2 (Green Cove Springs main ore body) as well as of a typical sample of ore sand from the Green Cove Springs western ore body. Heavy mineral species are wt.-% of the 2- to 4-phi fraction (63 - 250  $\mu$ m). For abbreviations of mineral species see appendix II (Ot = others).
- 20 Map of the Jacksonville h. m. placer deposit (modified after Elsner, 1992a).
- 21 Cross-sections through the Skinner tract of the Jacksonville h. m. placer deposit (after Lewis, 1954). Location of cross-sections shown in fig. 20.
- 22 Map of the Yulee h. m. placer deposit (modified after Elsner, 1992a).
- 23 Map of Amelia Island (modified after Elsner, 1992 a).
- 24 Map of Little and Big Talbot Islands (modified after Elsner, 1992a).
- 25 Average h. m. composition of dune and beach sands of Little Talbot Island. Heavy mineral species are wt.-% of the 2- to 4-phi fraction (63 - 250  $\mu$ m). For abbreviations of mineral species see appendix II (Ot = others).
- 26 Time table of h. m. mining operations in Florida (after Elsner, 1992a).
- 27 Proposed target areas for future exploration for h. m. in northeastern Florida (after Elsner, 1992a).
- 28 Map of northeastern Florida showing locations of well cores stored in the Florida Geological Survey core library (after Elsner, 1992a).

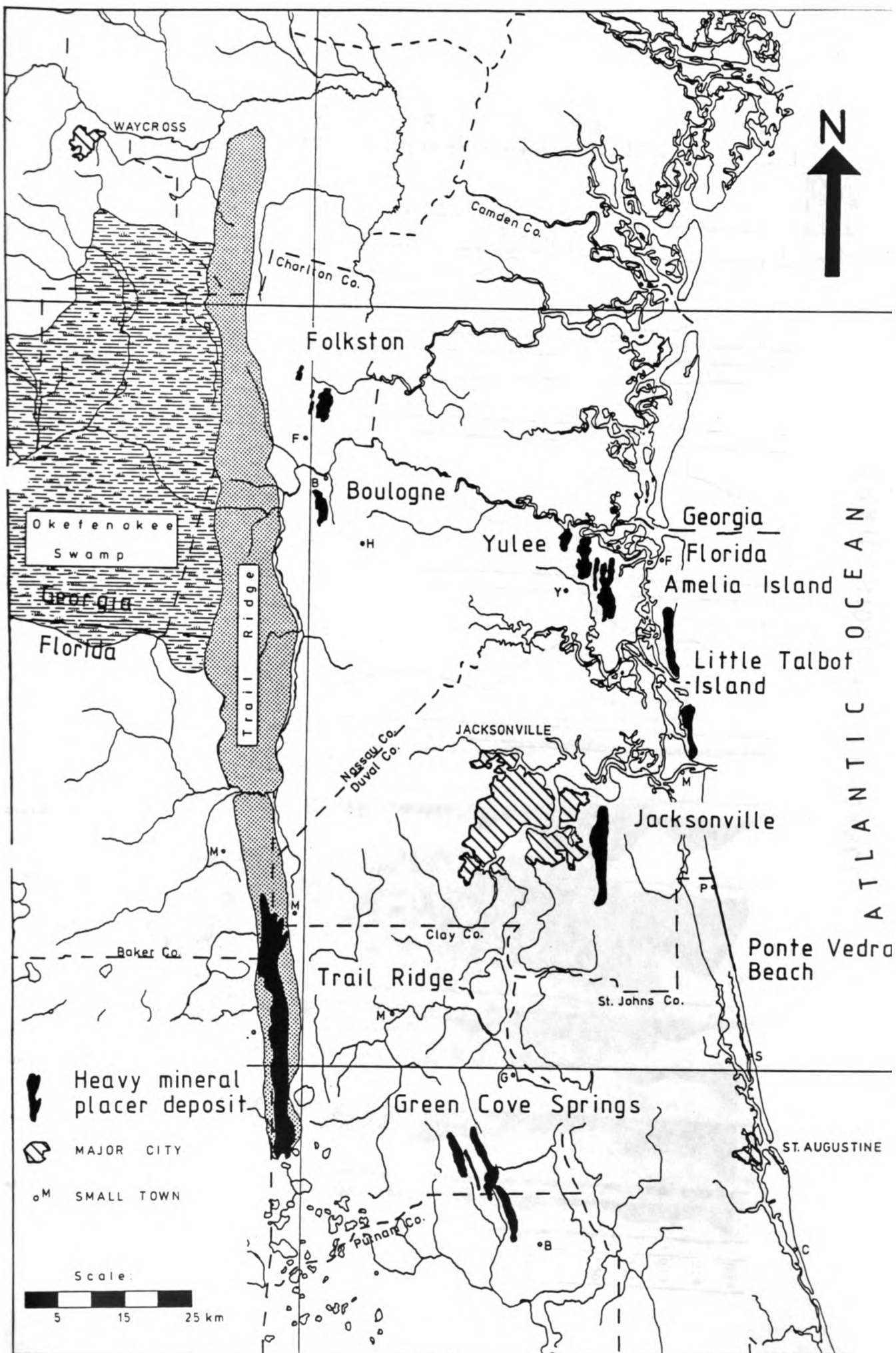
## Tables

- 22 Economic parameters of h. m. placer deposits in northeastern Florida (after Elsner, 1992a)
- 23 Economic parameters of selected h. m. placer deposits outside the USA after various authors: „WIM 150“, after Williams (1990), „Eneabba“, after Shepherd (1990), Richards Bay, after Bartlett (1987), and a brochure of Richards Bay Minerals, „Quilon“, after Ward & Tanner (w.o./yr.), „Midlum“, after Dr. P. Simon (pers. comm., 1991), and Elsner (1994)

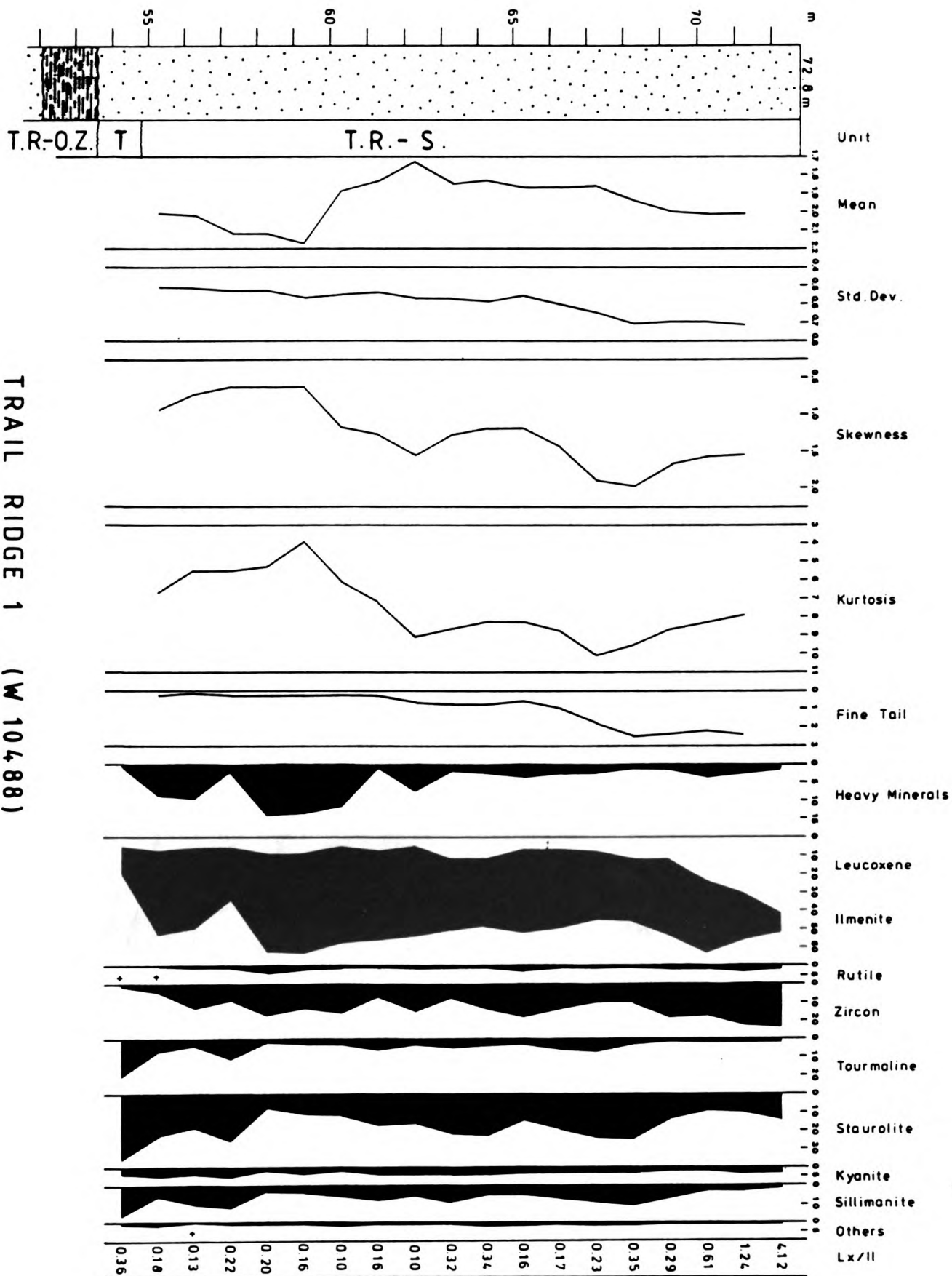
| MINERAL DEPOSIT                    | TRAIL RIDGE                    | FOLKSTON                     | BOULOGNE                     | GREEN COVE SPRINGS            | JACKSONVILLE                  | TULZER                                 | LITTLE TALBOT ISLAND         | AMELIA ISLAND                  | PONTE VEDRA BEACH            |
|------------------------------------|--------------------------------|------------------------------|------------------------------|-------------------------------|-------------------------------|----------------------------------------|------------------------------|--------------------------------|------------------------------|
| AGE                                | NE-Florida                     | SE-Georgia                   | NE-Florida                   | NE-Florida                    | NE-Florida                    | NE-Florida                             | NE-Florida                   | NE-Florida                     | NE-Florida                   |
| ENVIRONMENT OF DEPOSITION          | Pliocene<br>Wicomico           | Pleistocene<br>Penholoway    | Pleistocene<br>Penholoway    | Pleistocene<br>Penholoway     | Pleistocene<br>Pamlico        | Pleistocene<br>Pamlico + Princess Anne | Holocene                     | Holocene                       | Holocene                     |
| AREA OF MINERALIZATION             | dune                           | dune and beach               | "nearshore"                  | "nearshore" and dune          | dune                          | dune and beach                         | dune and beach               | dune                           | beach and dune               |
| AVERAGE THICKNESS OF ORE           | 77.6 km <sup>2</sup><br>10.7 m | 9.9 km <sup>2</sup><br>2.3 m | 4.1 km <sup>2</sup><br>4.5 m | 31.1 km <sup>2</sup><br>5.9 m | 36.8 km <sup>2</sup><br>4.1 m | 29.7 km <sup>2</sup><br>3.0 m          | 6.9 km <sup>2</sup><br>3.0 m | ca. 8 km <sup>2</sup><br>1.8 m | 8.4 km <sup>2</sup><br>3.9 m |
| AVERAGE GRADE                      | 3.9 wt.-%                      | ca. 4 wt.-%                  | 3.4 wt.-%                    | 6.0 wt.-%                     | 5.5 wt.-%                     | 3.1 wt.-%                              | 7.0 wt.-%                    | ca. 4 wt.-%                    | 2.9 wt.-%                    |
| ORE SAND                           | 1328 Mt                        | 38 Mt                        | 26 Mt                        | 274 Mt                        | 242 Mt                        | 143 Mt                                 | 33 Mt                        | 23 Mt                          | 53 Mt                        |
| TOTAL AVAILABLE H.M. BEFORE MINING | 51.8 Mt                        | 1.6 Mt                       | 0.9 Mt                       | 15.0 Mt                       | 13.3 Mt                       | 4.5 Mt                                 | 2.3 Mt                       | 0.9 Mt                         | 1.5 Mt                       |
| AVAILABLE:                         |                                |                              |                              |                               |                               |                                        |                              |                                |                              |
| ILMENITE/LEUCOXENE                 | 26.5 Mt                        | 0.9 Mt                       | 0.5 Mt                       | 8.0 Mt                        | ca. 6 Mt                      | 2.5 Mt                                 | 0.8 Mt                       | 0.4 Mt                         | 0.8 Mt                       |
| RUITLE                             | 0.9 Mt                         | 0.1 Mt                       | 60 kt                        | 1.3 Mt                        | ca. 1 Mt                      | 0.3 Mt                                 | 80 kt                        | 40 kt                          | 80 kt                        |
| ZIRCON                             | 7.8 Mt                         | 0.2 Mt                       | 0.1 Mt                       | 2.3 Mt                        | ca. 1.5 Mt                    | 0.7 Mt                                 | 0.1 Mt                       | 0.1 Mt                         | 0.2 Mt                       |
| MONAZITE/XENOTIME                  | 15 500 t                       | 16 000 t                     | 4 500 t                      | 105 000 t                     | ca. 80 000 t                  | 9 000 t                                | 2 300 t                      | 1 800 t                        | 12 000 t                     |
| H.M. COMPOSITION:                  |                                |                              |                              |                               |                               |                                        |                              |                                |                              |
| ILMENITE                           | 36.8 wt.-%                     | 31 wt.-%                     | 35.2 wt.-%                   | 33.8 wt.-%                    | 38 - 40 wt.-%                 | 52.7 wt.-%                             | 31.0 wt.-%                   | 37.0 wt.-%                     | ca. 47 wt.-%                 |
| LEUCOXENE                          | 14.3 wt.-%                     | 27 wt.-%                     | 19.8 wt.-%                   | 19.7 wt.-%                    | 4 - 10 wt.-%                  | 2.2 wt.-%                              | 4.8 wt.-%                    | 9.7 wt.-%                      | ca. 3 wt.-%                  |
| RUITLE                             | 1.7 wt.-%                      | 7 wt.-%                      | 6.8 wt.-%                    | 8.8 wt.-%                     | 7 - 10 wt.-%                  | 7.4 wt.-%                              | 3.4 wt.-%                    | 4.6 wt.-%                      | 5.4 wt.-%                    |
| ZIRCON                             | 15.0 wt.-%                     | 9 wt.-%                      | 13.0 wt.-%                   | 15.1 wt.-%                    | 10 - 15 wt.-%                 | 16.0 wt.-%                             | 4.9 wt.-%                    | 11.2 wt.-%                     | 11.1 wt.-%                   |
| MONAZITE/XENOTIME                  | 0.03 wt.-%                     | 1 wt.-%                      | 0.5 wt.-%                    | 0.7 wt.-%<br>(M.O.B.)         | 0.5 - 0.7 wt.-%               | 0.2 wt.-%                              | 0.1 wt.-%                    | 0.2 wt.-%                      | 0.8 wt.-%                    |

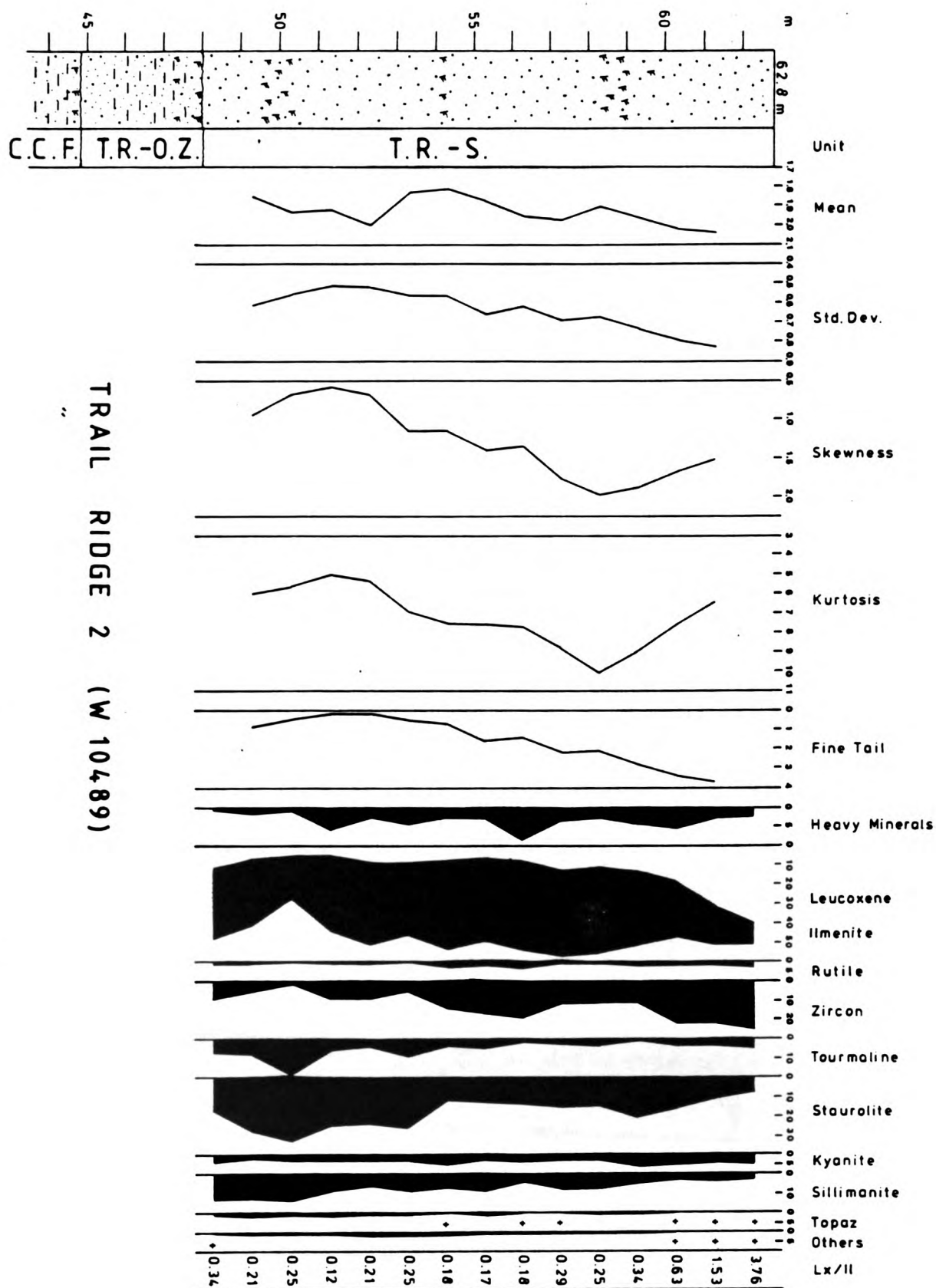
| MINERAL DEPOSIT                       | WIM 150<br>VA/Australia | ENEABBA<br>WA/Australia | RICHARDS BAY<br>South Africa | QUILON<br>India     | MIDLUM<br>Germany   |
|---------------------------------------|-------------------------|-------------------------|------------------------------|---------------------|---------------------|
| AGE                                   | Tertiary                | Plio-/Pleistocene       | Plio-/Pleistocene            | Holocene            | Early Pliocene      |
| ENVIRONMENT OF<br>DEPOSITION          | "offshore"              | beach and dune          | dune                         | beach and dune      | dune                |
| AREA OF<br>MINERALIZATION             | 220 km <sup>2</sup>     | > 30 km <sup>2</sup>    | > 70 km <sup>2</sup>         | 5.5 km <sup>2</sup> | 8.0 km <sup>2</sup> |
| AVERAGE THICKNESS<br>OF ORE           | 6 - 15 m                |                         | > 30 m                       | ca. 10 m            | 10.1 m              |
| AVERAGE GRADE                         | 2.8 wt.-%               | 15 - 38 wt.-%           | ca. 9 wt.-%                  | 18 wt.-%            | 9.3 wt.-%           |
| ORE SAND                              | 4900 Mt                 |                         | > 1700 Mt                    |                     | 115 Mt              |
| TOTAL AVAILABLE<br>H.M. BEFORE MINING | ca. 140 Mt              | > 30 Mt                 | > 150 Mt                     | ca. 26 Mt           | 10.8 Mt             |
| AVAILABLE:                            |                         |                         |                              |                     |                     |
| ILMENITE/LEUCOXENE                    |                         | 18.5 Mt                 | ca. 90 Mt                    | 17.5 Mt             | 4.7 Mt              |
| RUTILE                                |                         | 3.9 Mt                  | ca. 5 Mt                     | 1.3 Mt              | 0.5 Mt              |
| ZIRCON                                |                         | 7.0 Mt                  | 6 - 10 Mt                    | 1.3 Mt              | 0.9 Mt              |
| MONAZITE/XENOTIME                     |                         | ?                       | ?                            | 120 kt              | ?                   |
| H.M. COMPOSITION:                     |                         |                         |                              |                     |                     |
| ILMENITE                              | 31.6 wt.-%              | 21 - 57 wt.-%           | ca. 60 wt.-%                 | 68 wt.-%            | 44 - 49 %           |
| LEUCOXENE                             | 11.6 wt.-%              | 0.5 - 5 wt.-%           |                              | 2 wt.-%             |                     |
| RUTILE                                | 8.7 wt.-%               | 2 - 12 wt.-%            | ca. 3 wt.-%                  | 7 wt.-%             | 5 %                 |
| ZIRCON                                | 13.3 wt.-%              | 8 - 66 wt.-%            | ca. 4 - 7 wt.-%              | 6 wt.-%             | 9 %                 |
| MONAZITE/XENOTIME                     | 1.8 wt.-%               | 0.5 - 5 wt.-%           | Trace                        | 1 wt.-%             | Trace               |

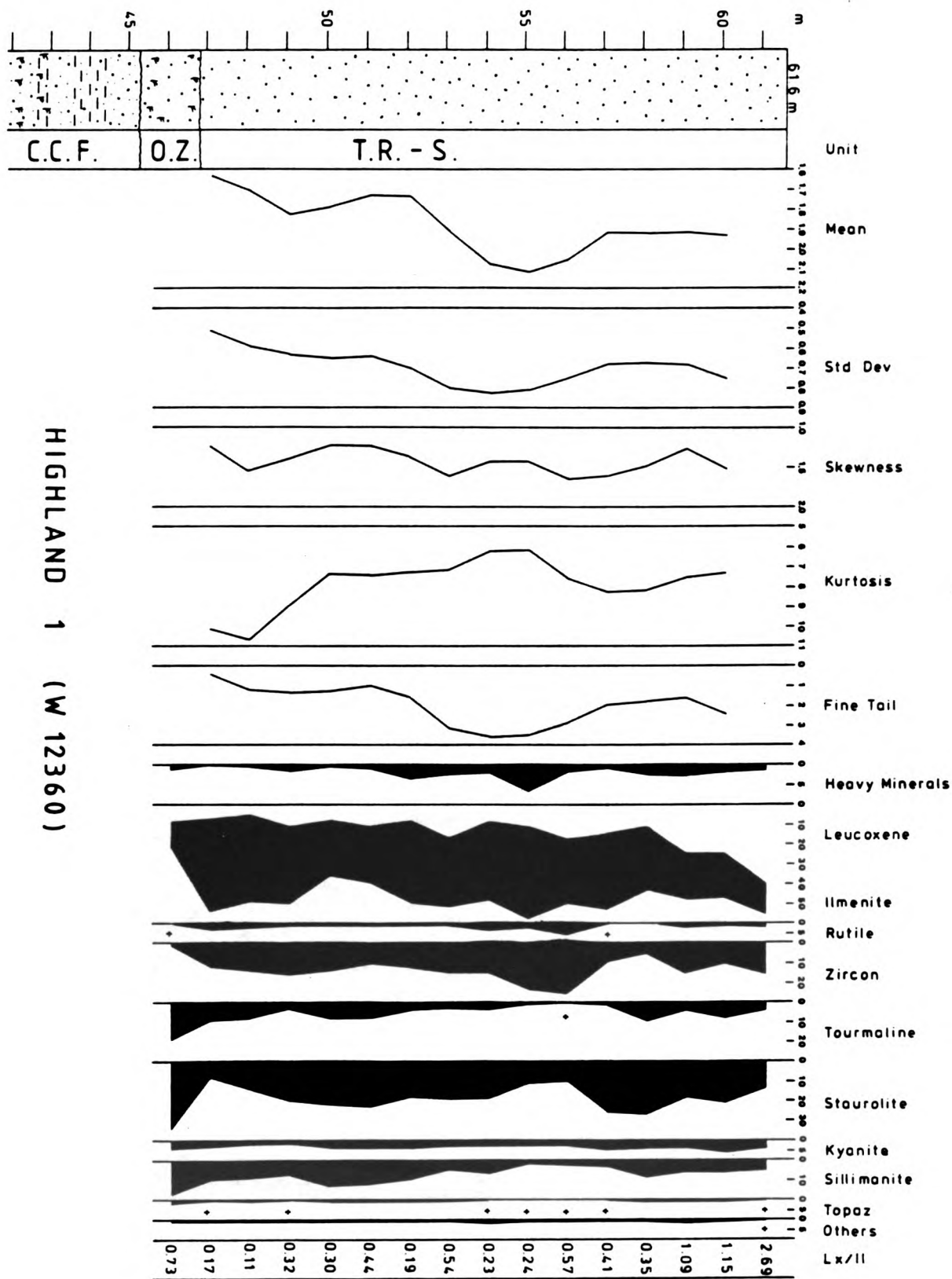


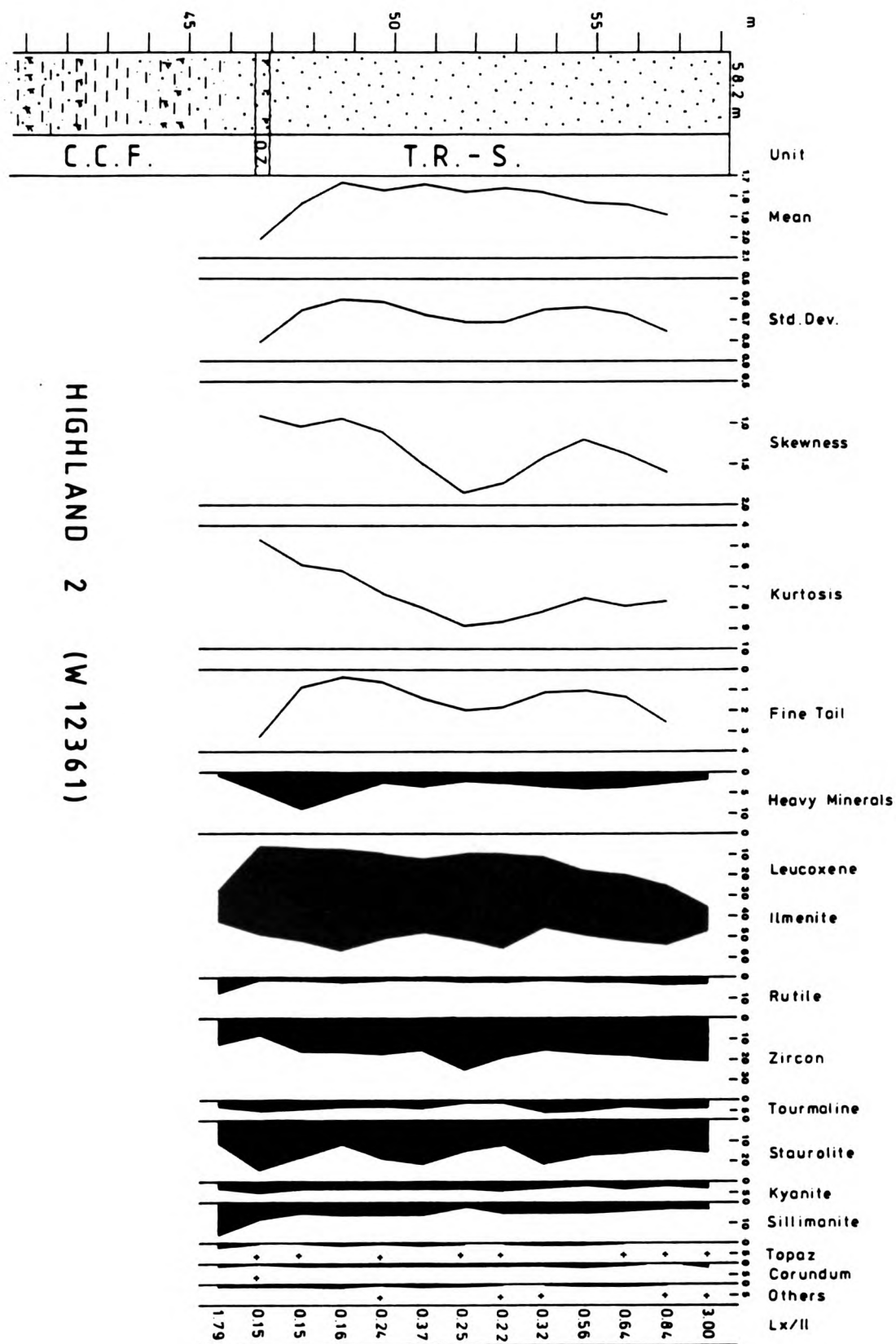


TRAIL RIDGE 1 (W 10488)

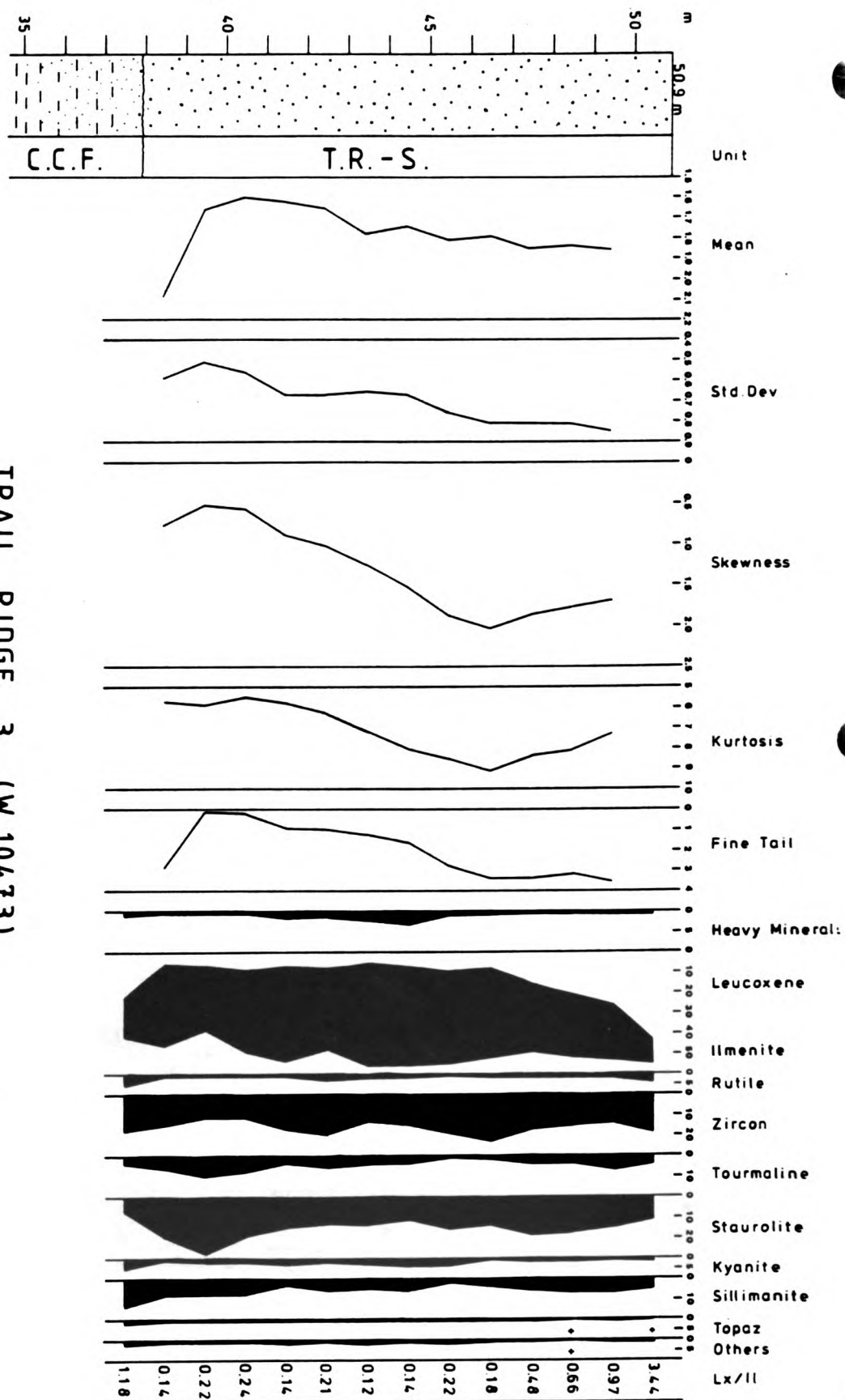








TRAIL RIDGE 3 (W 10473)





UNIT F



SILT/CLAY



UNIT E



FINE/MEDIUM SAND



UNIT D



MEDIUM/COARSE SAND



SILTY/CLAYEY SAND



RECENT BEACH



PEAT



RECENT DUNE



PLANT REMAINS

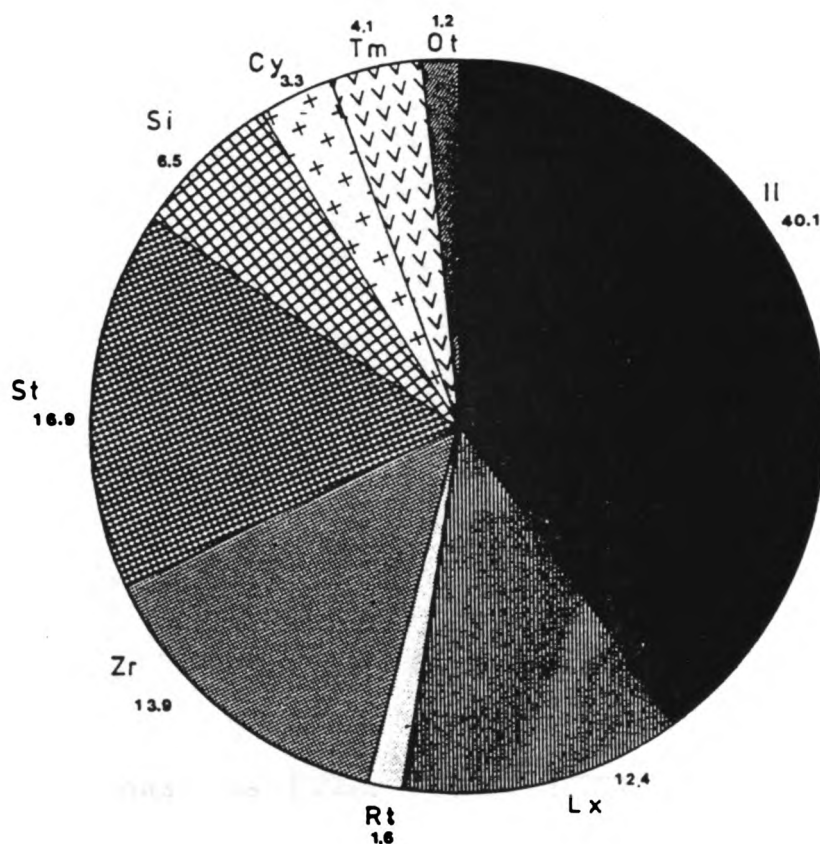


"BARRIER ISLAND"



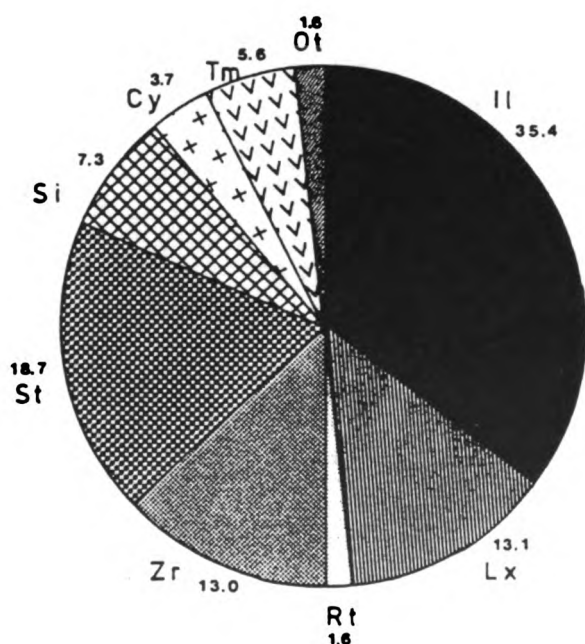
MOLLUSKS





## TRAIL RIDGE 1

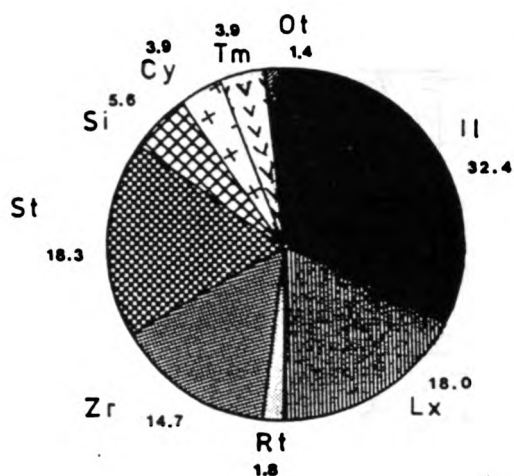
ore thickness : 18 m  
 h.m. grade : 5.14 %  
 st : 5.35 %  
 others : An = 0.5 % Ko = 0.2 %  
 To, Sp, Mo/Xe = 0.1 %  
 Gr, Ep, Ti, At, Br < 0.1 %



## TRAIL RIDGE 2

ore thickness : 14 m  
 h.m. grade : 3.66 %  
 st : 3.81 %  
 others : To = 0.7 % An = 0.4 %  
 Ko = 0.3 % Sp = 0.1 %  
 Gr, Ep, Mo/Xe, Ti < 0.1 %





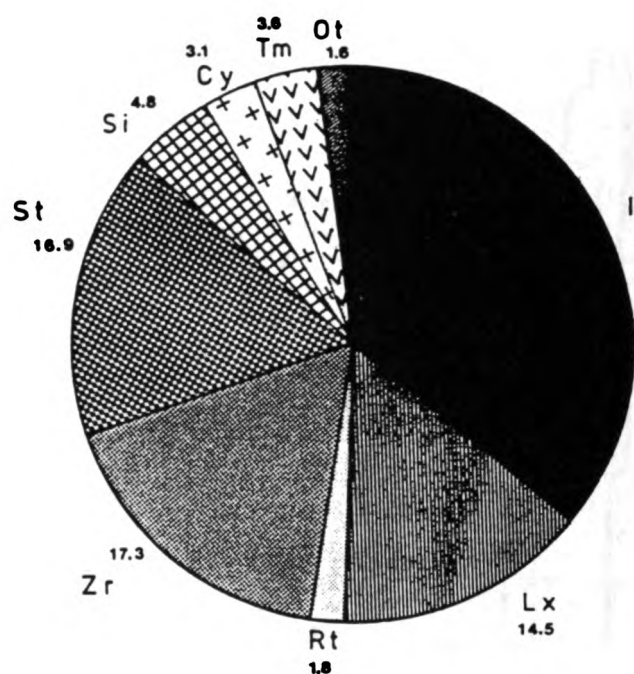
## HIGHLAND 1

ore thickness : 10 m

h.m. grade : 2.49 %

st : 2.58 %

others: To=0.6% Ko=0.3% An=0.3%  
 Gr,Ep,Mo/Xe,At,Br < 0.1%



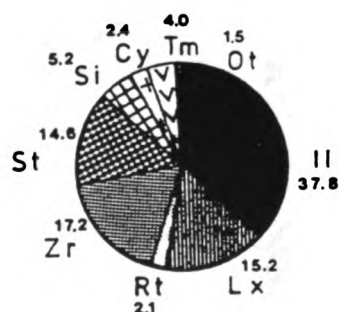
## HIGHLAND 2

ore thickness : 12 m

h.m. grade : 3.83 %

st : 3.97 %

others: Ko=0.8% To=0.4% An=0.2%  
 Sp=0.1%  
 Gr,Ep,Mo/Xe,Ti,Br < 0.1%



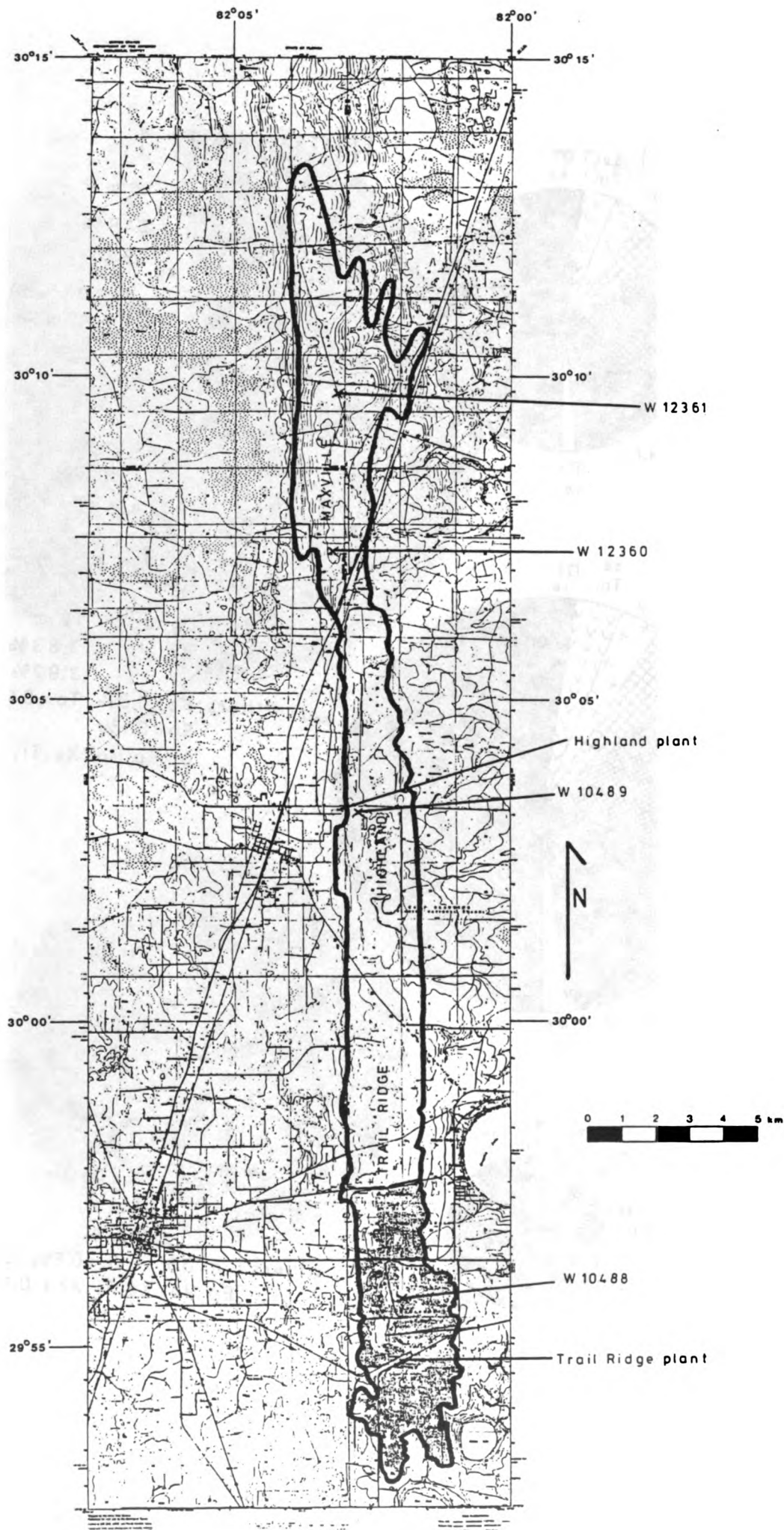
## TRAIL RIDGE 3

ore thickness : (10 m)

h.m. grade : 1.40 %

st : 1.44 %

others: To=0.6% Ko=0.5% Sp,Gr,An=0.1%  
 Ep,Mo/Xe,Ti,At < 0.1%



LAND CLEARING, MINING, FEED PREPARATION

3% H.M. | 1.0%  $TiO_2$   
GRAVITY SEPARATION

H. M. CONCENTRATE

80% H.M.

CHEMICAL SCRUBBING - NaOH

30%  $TiO_2$

DRY MILL

HI TENSION

COND.

H. I. MAGNETS

NONMAGS

ILMENITE  
(65%  $TiO_2$ )

SCREEN

COARSE  
STAUROLITE

HIGH TENSION

RESIDUE  
80%  $TiO_2$

NON-COND.

TO  
DRY MILL  
FEED

OTHER PRODUCTS

STARBLAST = mixture of Biasill & Coarse Staur.

PREMIUM ZIRCON = Regular zircon re-passed  
over high tension plate.  
0.05%  $TiO_2$

NON-COND.

H. I. MAGNETS

BIASILL  
90% Staurolite  
50%  $Al_2O_3$

NONMAGNETIC

GRAVITY SEPARATION

ZIRCORE

Mixture of zircon & kyanite

KILN

HI TENSION

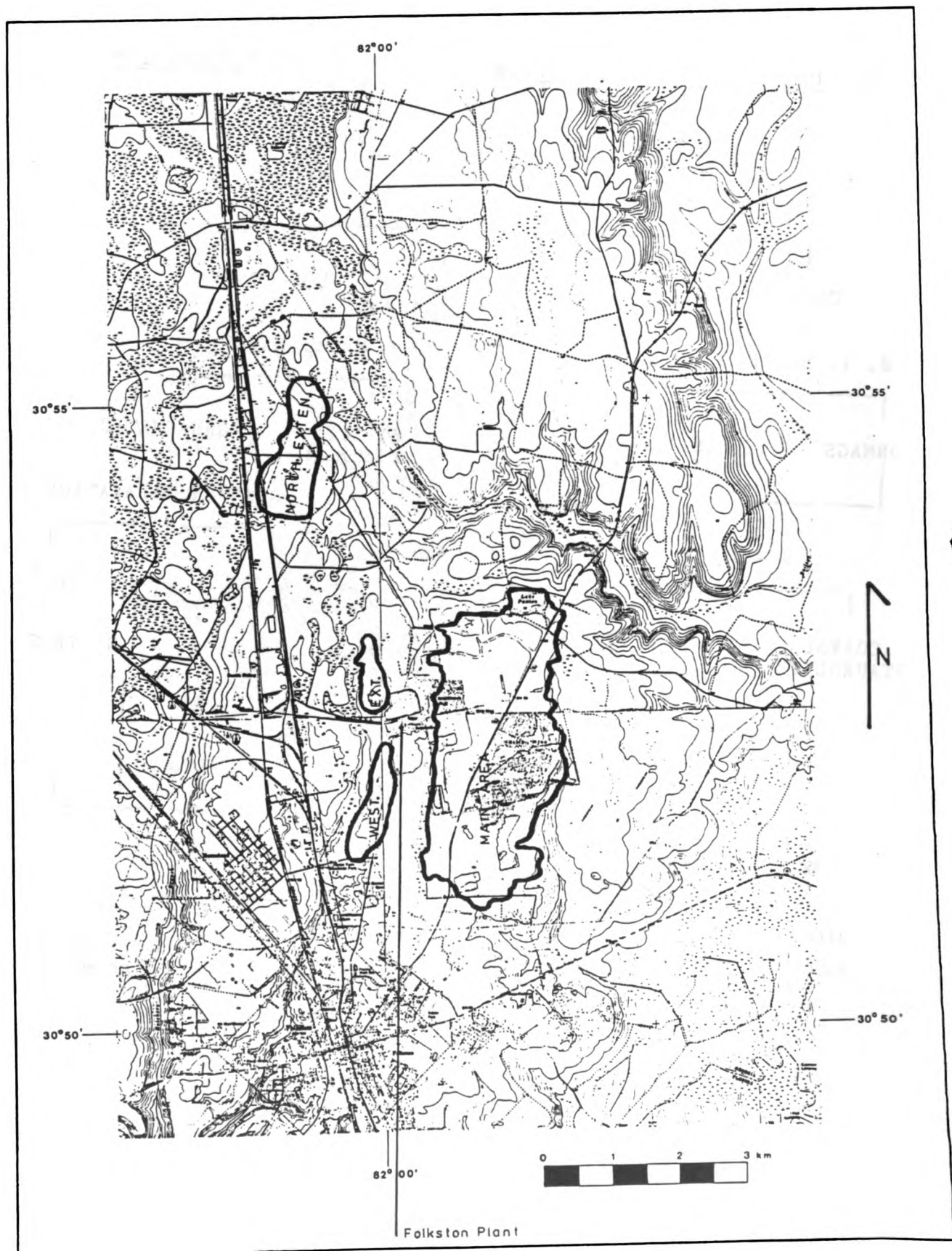
MAGNETS

REG.  
ZIRCON  
65%  $ZrO_2$  (min)

MAGNET

ZIRCLEAN  
(MAGNETIC)

ZIRCON-T  
(NONMAG) 2%  $TiO_2$



LAND CLEARING, MINING, FEED PREPARATION

(4.27 % H.M.)

(1.80 %  $\text{TiO}_2$ )

4.25 % H.M.

1.63 %  $\text{TiO}_2$

WET MILL

H. M. CONCENTRATE

(78.6 % H.M.)

(33.0 %  $\text{TiO}_2$ )

72.1 % H.M.

32.0 %  $\text{TiO}_2$ , 8.4 %  $\text{ZrO}_2$

O.I.: 86

CHEMICAL SCRUBBING - NaOH

O.I.: 20

DRY MILL

HIGH TENSION

COND.

(71.9 %  $\text{TiO}_2$ )

71.6 %  $\text{TiO}_2$

Ilmenite (I-F.-Ilmenite) +

Leucoxene (II-F.-Leucoxene) +

Rutile (II-F.-Rutile) =

TITANIUM PRODUCT

71.6 %  $\text{TiO}_2$ , 0.71 %  $\text{ZrO}_2$

NON-COND.

(2.95 %  $\text{TiO}_2$ )

49.9 % H.M.

3.68 %  $\text{TiO}_2$ , 14.6 %  $\text{ZrO}_2$

ZIRCON WET MILL

ZIRCON DRY MILL

TAILINGS

3.17 %  $\text{TiO}_2$ , 1.88 %  $\text{ZrO}_2$

36.1 % H.M.

HIGH TENSION

COND.

NON-COND.

H. I. MAGNETS

MAGNETIC

NONMAGNETIC

MAGNETIC CROSSBELT

ZIRCON

(I-, II-F.-Zircon)

65.5 %  $\text{ZrO}_2$ , 0.17 %  $\text{TiO}_2$ , 0.46 %  $\text{Al}_2\text{O}_3$

— TRACES — # 1: RUST, IRON FILLINGS, ETC.

— 15.2 % — # 2: GARNET + XENOTIME (II-F.-Garnet)

— 7.4 % — # 3: GARNET +

STAUROLITE (II-F.-Staurolite A)

— 7.3 % — # 4: MONAZITE +

STAUROLITE (II-F.-Staurolite B)

— 16.5 % — # 5: MONAZITE

— 22.4 % — # 6: MONAZITE

— 9.2 % — # 7: MONAZITE

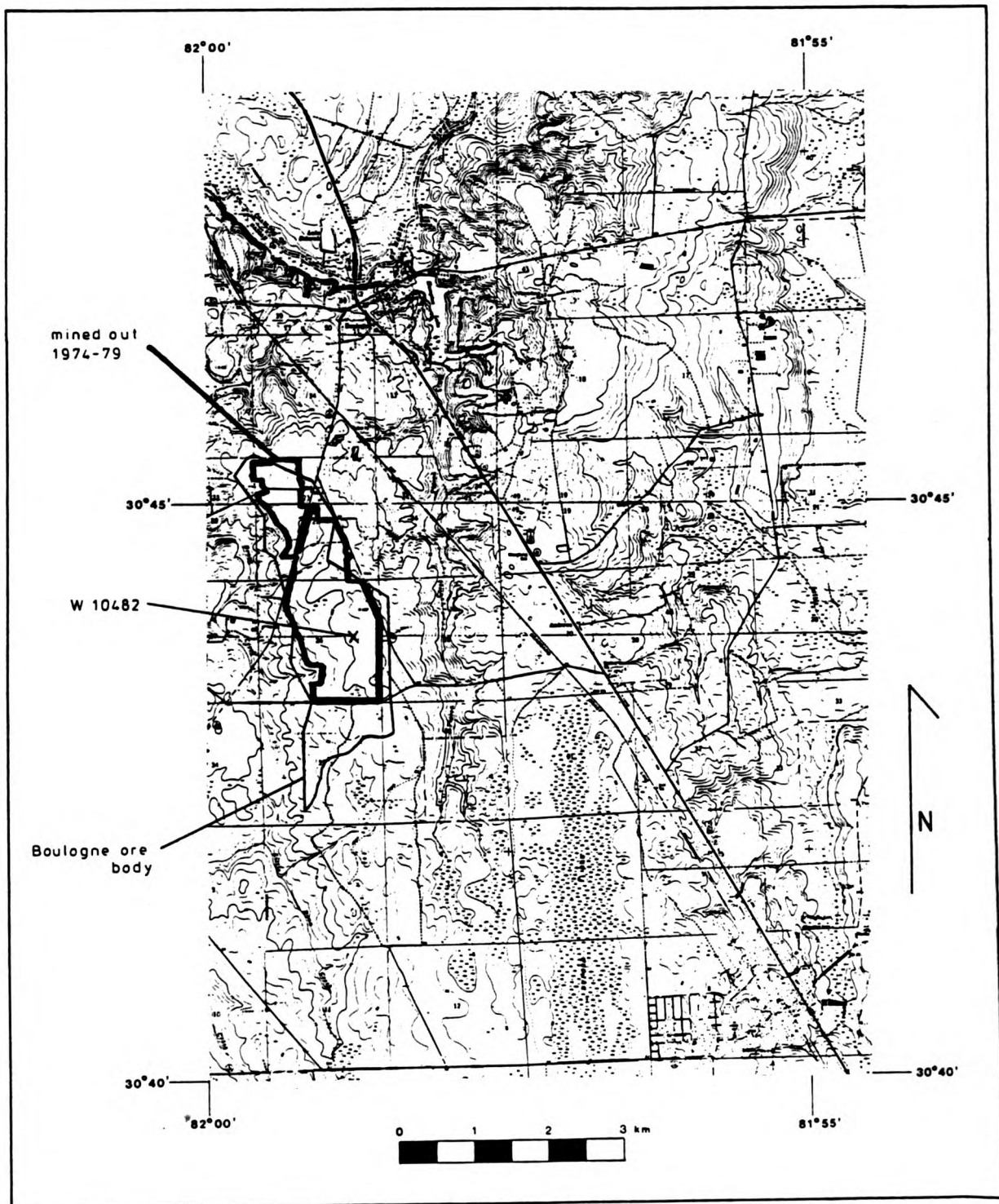
— 22.0 % — TAIL BELT: ZIRCON

→ MONAZITE

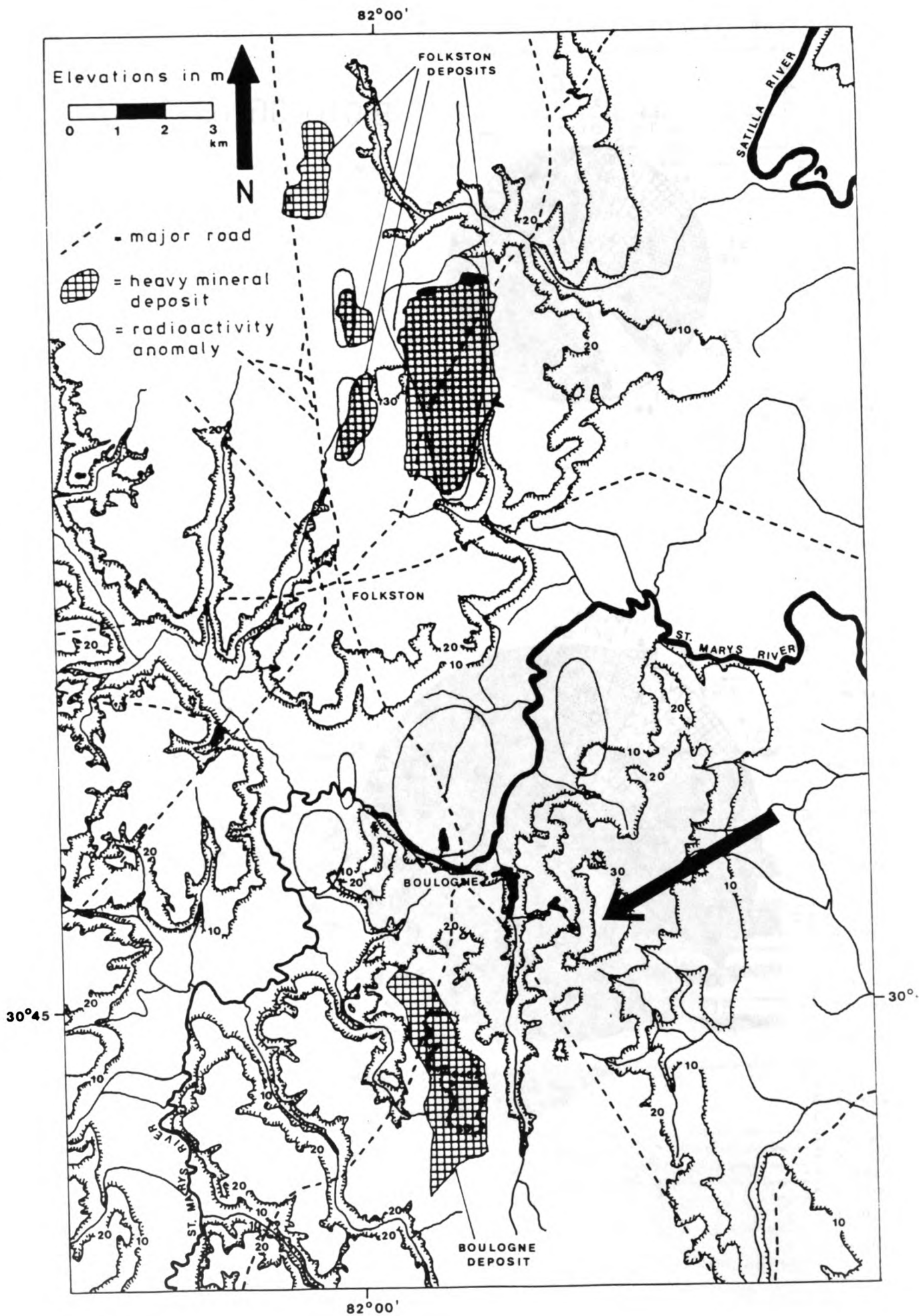
(I-F.-Monazite)

62.4 % T.O., 0.44 %  $\text{TiO}_2$ ,

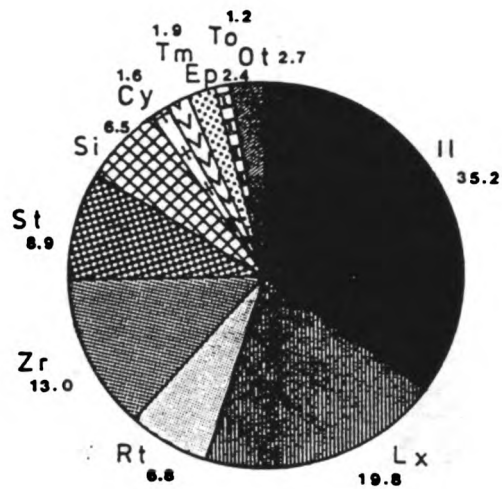
9.4 % Insol.



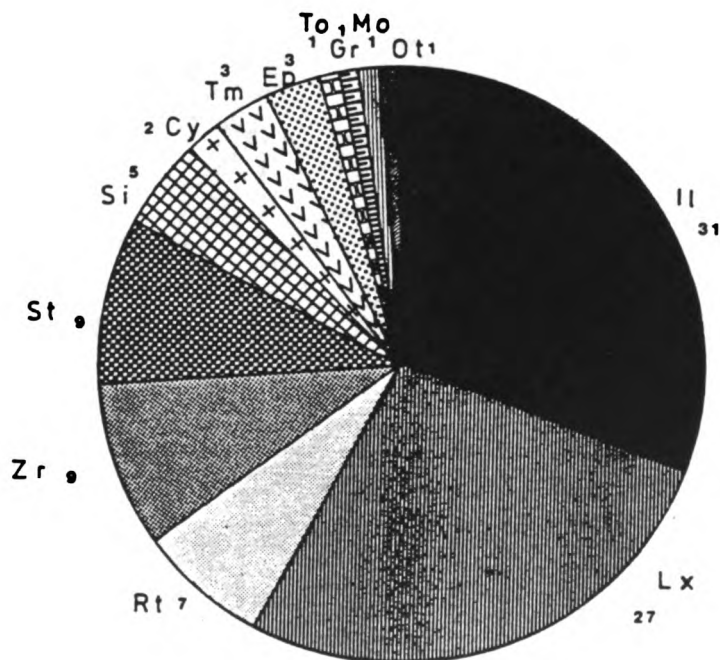




## BOULOGNE 1



ore thickness : 7 m  
h.m. grade : 2.71 %  
others : Hb, Ko = 0.6 % Mo/Xe = 0.5 %  
Gr = 0.4 % An = 0.3 %  
Sp, At, Ti = 0.1 % Cl < 0.1 %

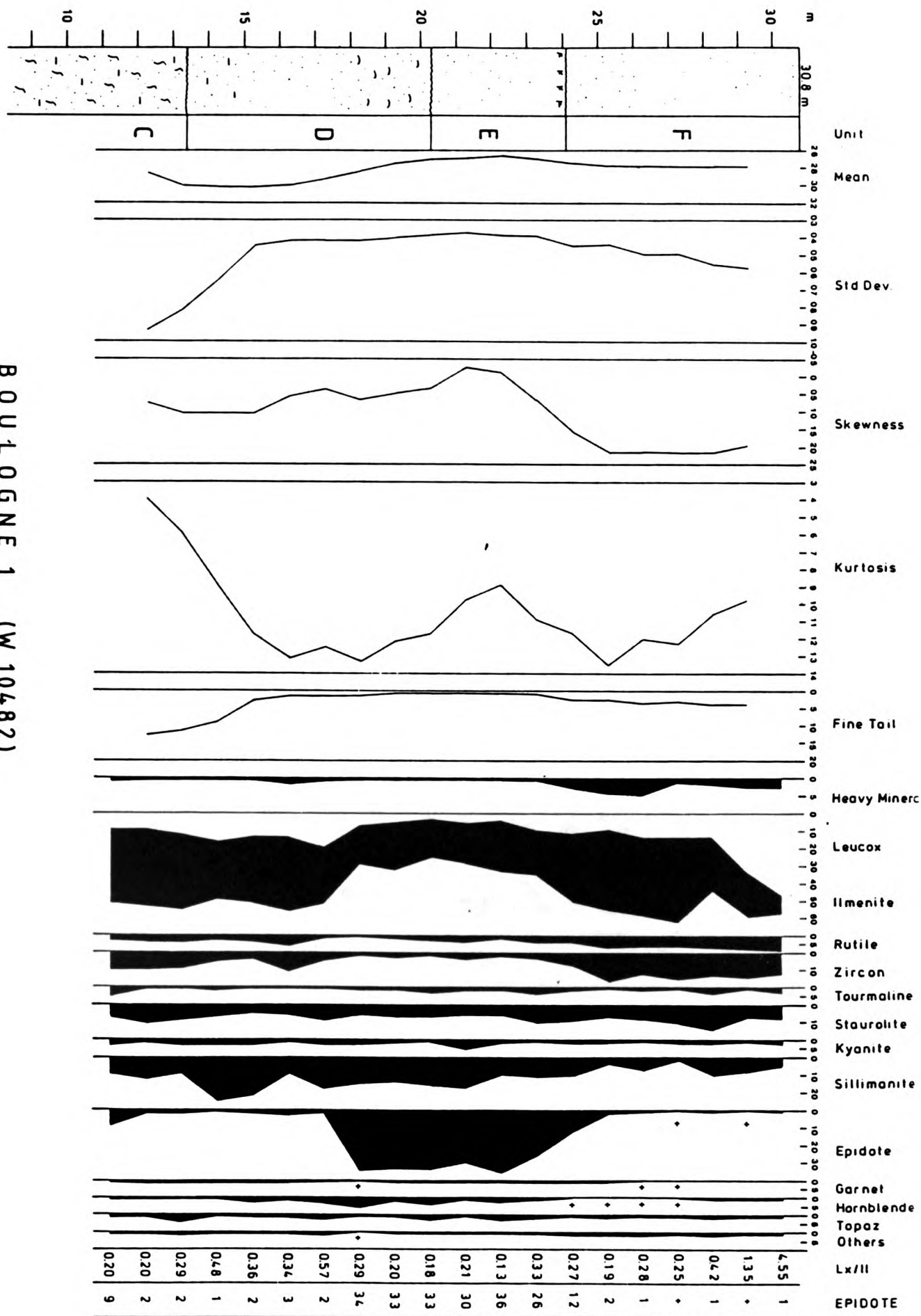


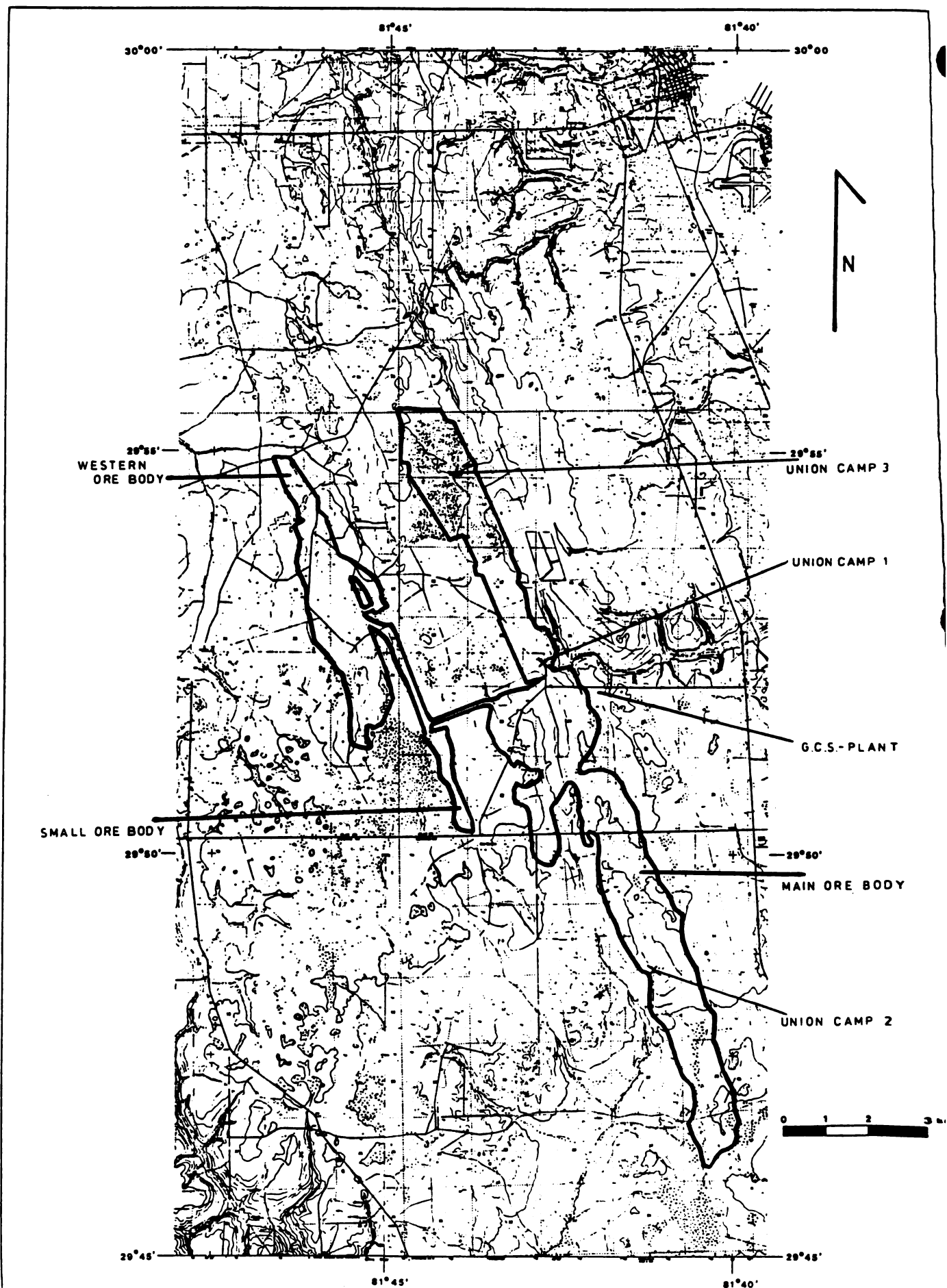
## FOLKSTON

average ore thickness : 2.4 m  
h.m. grade : 4.22 %  
average : 4.25 %  
others : An, Xe, At, Hb, Ti < 1 %

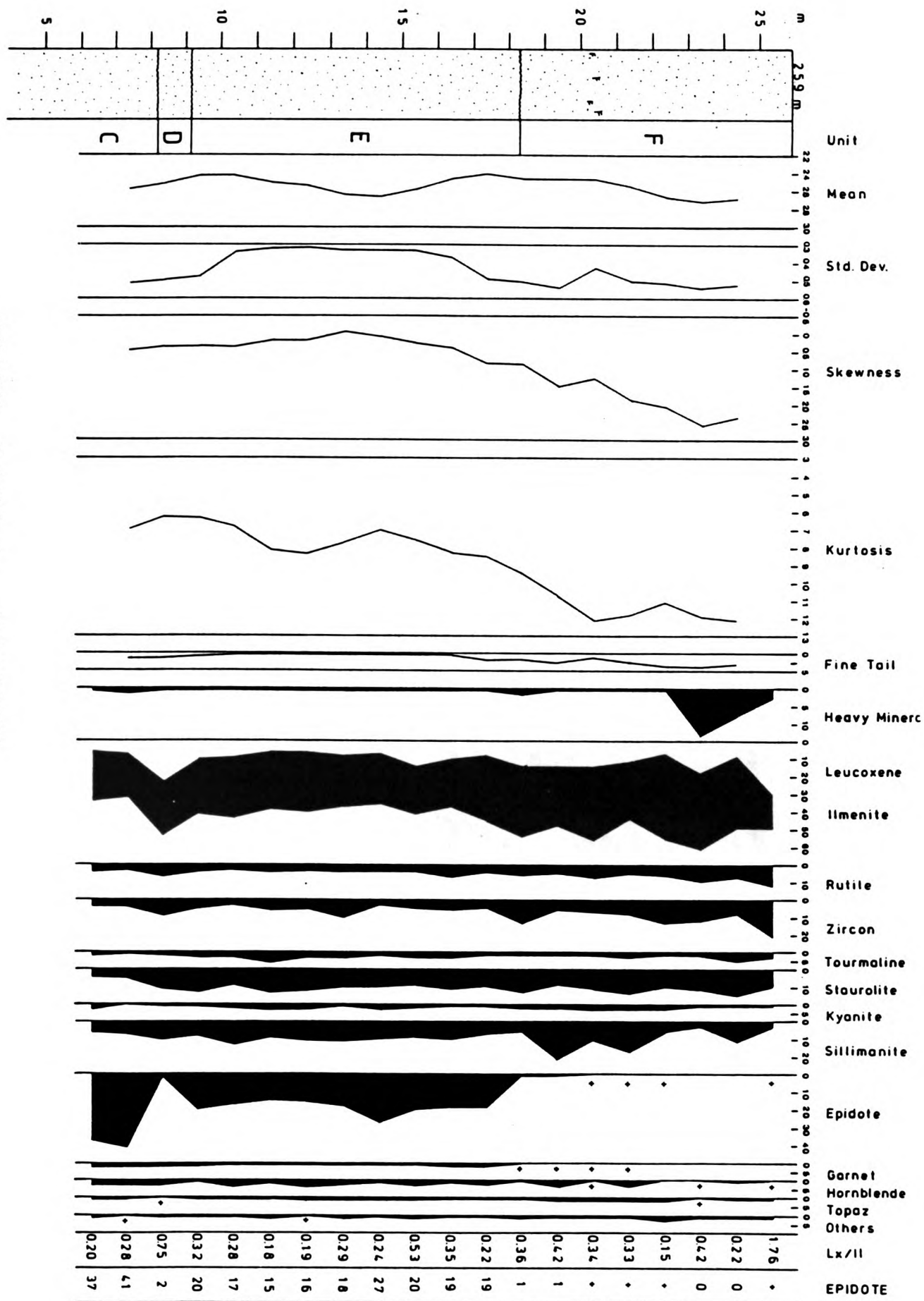


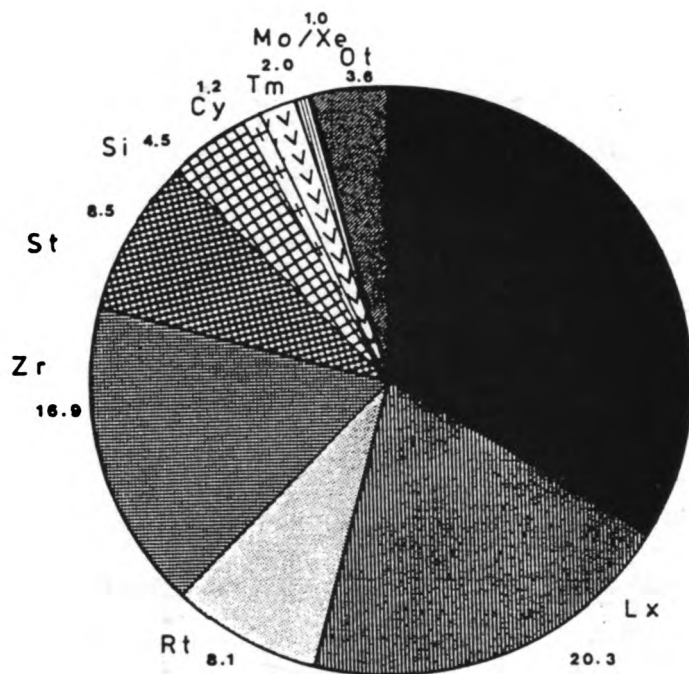
BOULOGNE 1 (W 10482)





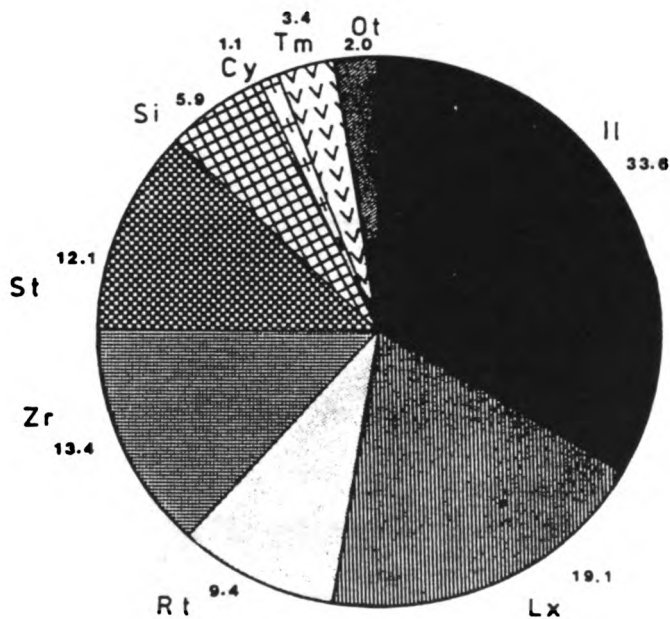
UNION CAMP 2 (W 12112)





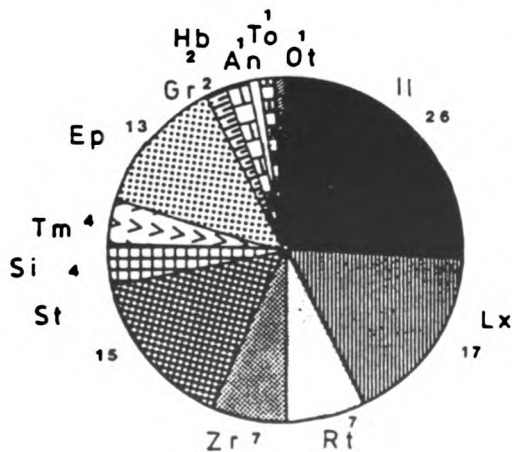
## UNION CAMP 1

ore thickness : 5 m  
 h.m. grade : 8.36 %  
 others : Hb=0.8 % Gr= 0.7 %  
 To=0.6 % At=0.5 % An=0.3 %  
 Ep, Ko, Ti = 0.2 %  
 Sp, Br < 0.1 %



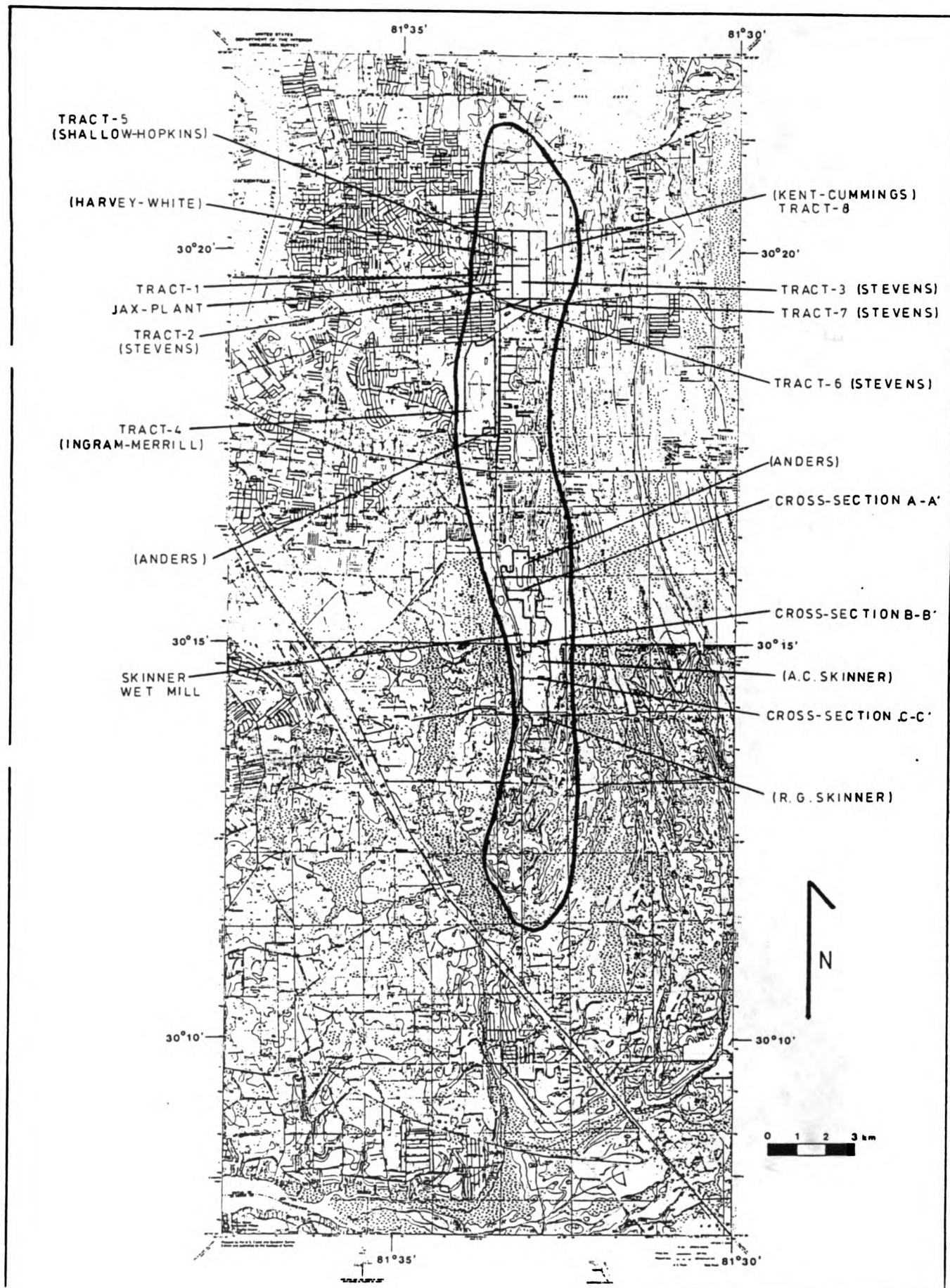
## UNION CAMP 2

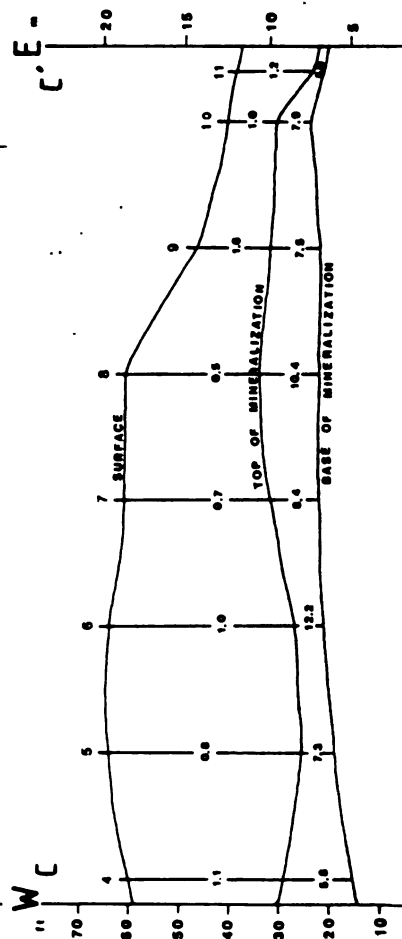
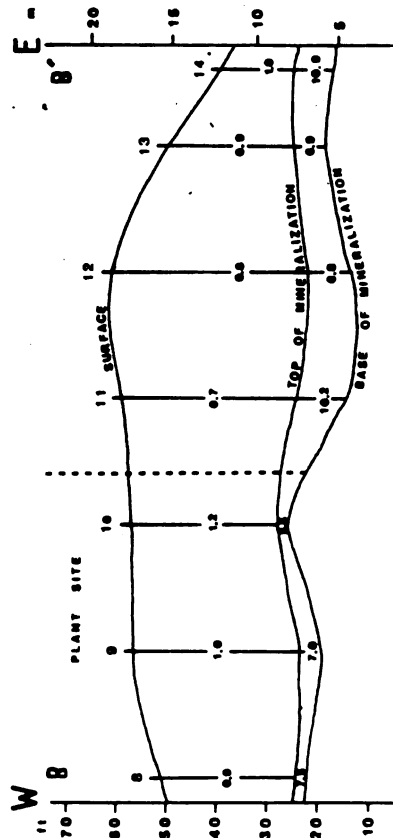
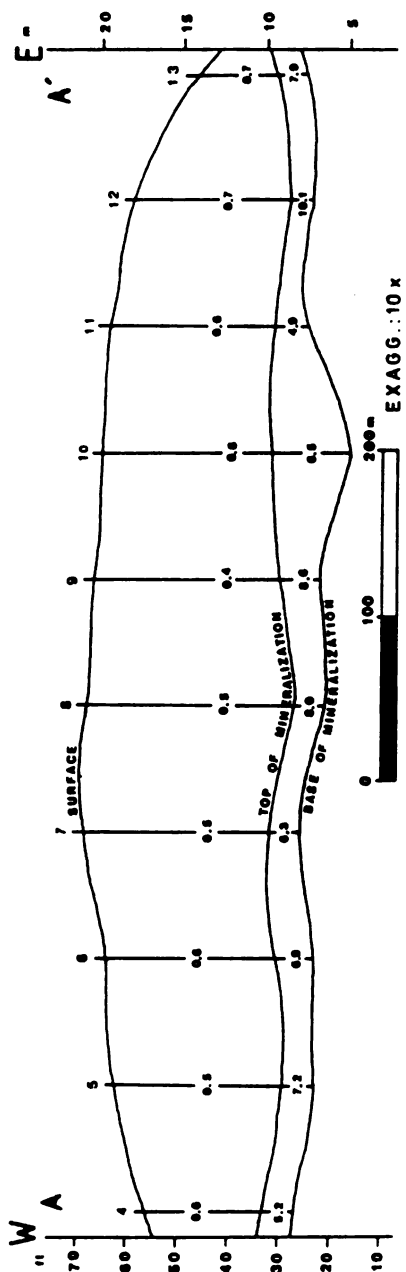
ore thickness : 3 m  
 h.m. grade : 7.92 %  
 others : To=0.8 % Hb, Ko, Mo/Xe=0.3 %  
 An=0.2 % Ti=0.1 % Ep<0.1 %



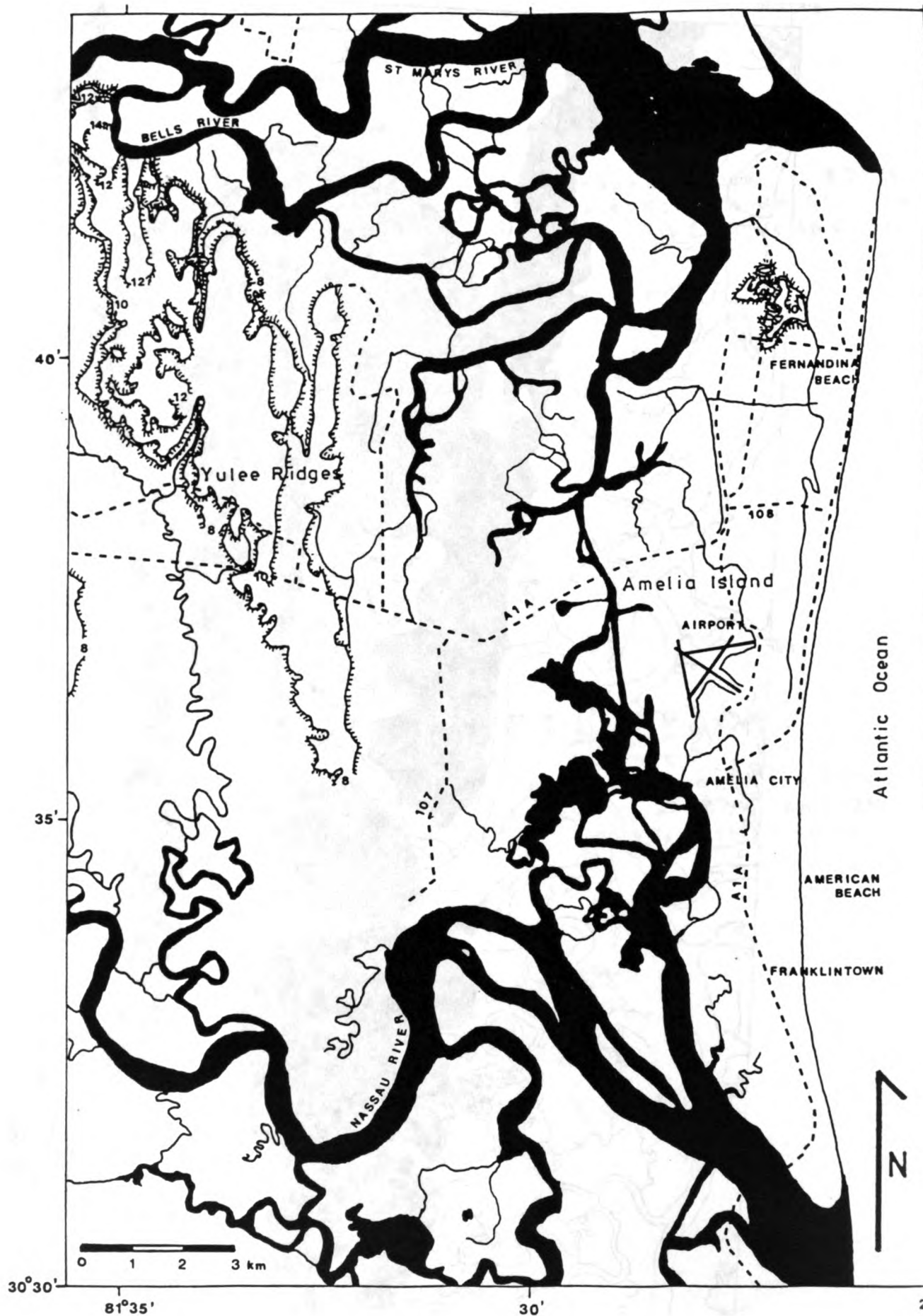
## G.C.S.-WESTERN ORE BOD

average ore thickness : 10 m  
 h.m. grade : 2.42 %  
 average : 3.25 %  
 others : Cy, Sp, Ko < 1 %

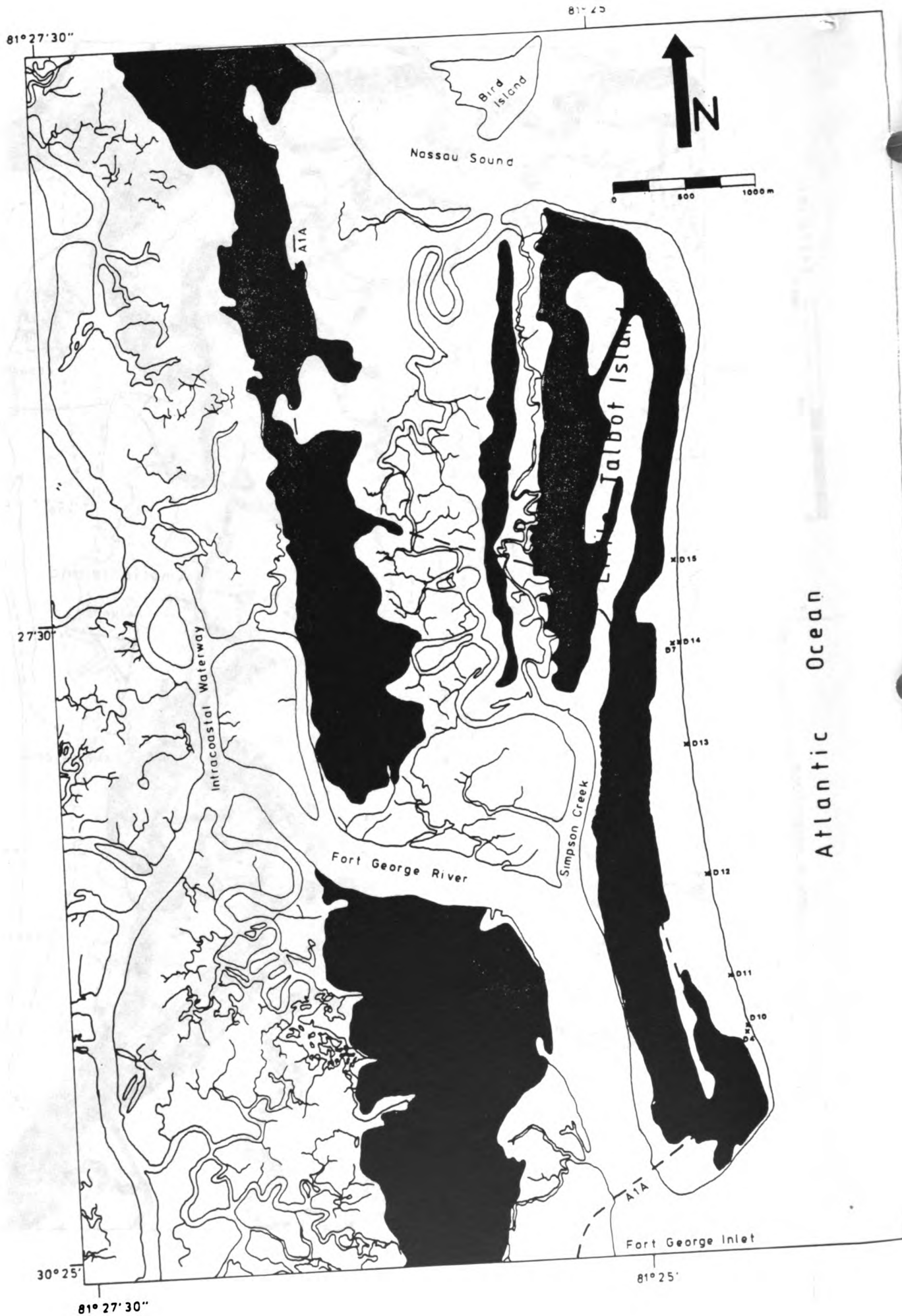


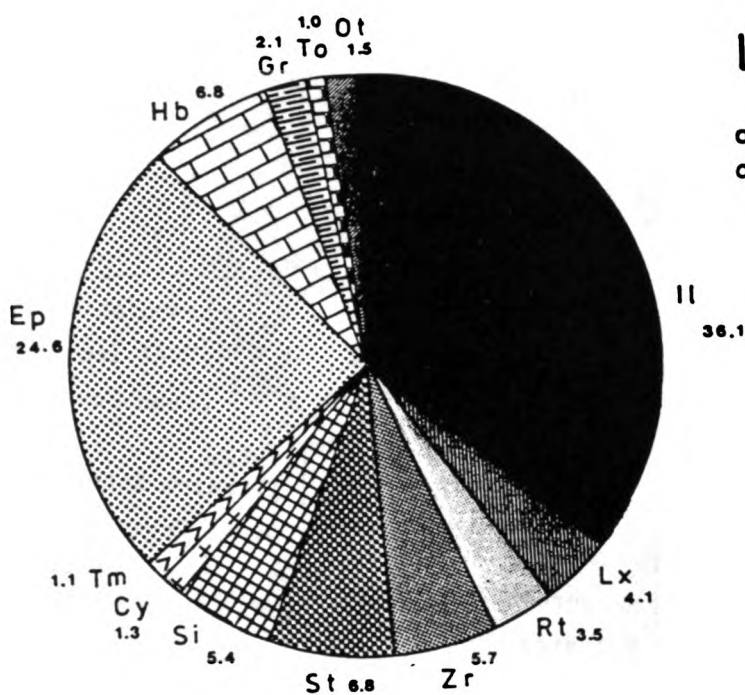






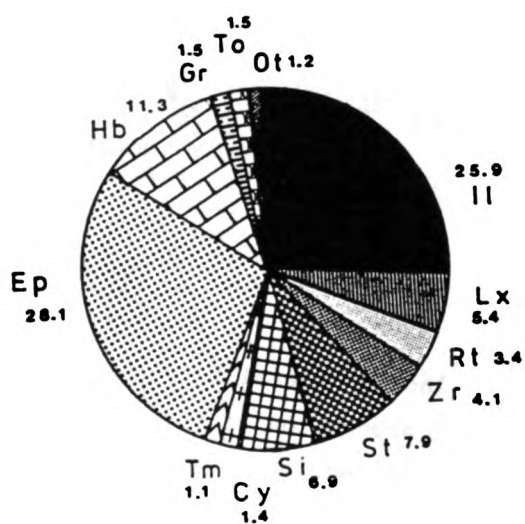






## L.T.I. DUNE

average h.m. grade : 8.27 %  
 others : Ko = 0.5% An, At = 0.4 %  
 Ti = 0.1% Mo, Sp, Cl, Br < 0.1%



## L.T.I. BEACH

average h.m. grade : 4.98 %  
 others : Ko, At = 0.4 % An = 0.2 %  
 Mo, Ti = 0.1% Cl < 0.1%

