Heavy minerals in marine and fluvial sediments: provenance indicators and distributions in the tropical southeastern shelf of the Gulf of Carpentaria and its hinterland North Australia

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Chapter Eleven – Summary and conclusions

In addition to opaque minerals, seventeen translucent heavy mineral types were identified in the very fine sand fractions (63-125μm) of 365 sediment samples recovered from the tropical southeastern shelf of the Gulf of Carpentaria and its surrounding fluvial systems. The translucent heavy minerals comprise zircon, tourmaline, epidote, hornblende, sillimanite, rutile, garnet, andalusite, staurolite, kyanite, titanite (sphene), spinel, augite, titanaugite, chlorite, biotite, glauconite and weathered grains, with the first seven of these forming 80-100% of the total translucent heavy mineral assemblage. The opaque minerals comprise chromite, opaque rutile, ilmenite, manganoan ilmenite, titanomagnetite and other altered grains.

The chemical compositions of approximately 600 heavy mineral grains, including the chemically variable tourmaline, hornblende, epidote and garnet grains reflect the complexity heavy mineral assemblages in the tropical hinterland of the Gulf of Carpentaria and its southeastern shelf. Tourmaline covers a considerable compositional range mainly between schorl and dravite, together with very rare uvite. Amphibole grains mainly consist of calcic-amphibole and very rare magnesium-iron-manganese-lithium amphibole. The calcic-amphibole grains cover a considerable compositional range that is mostly concentrated within the hornblende solid solution series with very small amounts of actinolite and tremolite. Epidote also shows a wide compositional range, while garnet is dominated by andradite and almandine together with minor andradite-grossular, almandine-pyrope, spessartine, pyrope and grossular.

The chemical variability within these heavy mineral suites, together with the occurrence of other minor heavy minerals and a variety of zircon morphologies, reflect a mixing of detritus from heterogenous source areas that contain a variety of earlier sedimentary successions together with metamorphic and igneous rocks. The chemical and petrographic characteristics of the heavy minerals in the southeastern shelf of the gulf, as well as their spatial distribution and facies characteristics, reflect the signatures of the local lithologies in the gulf hinterland, especially the Georgetown Inlier, Mt Isa Inlier and Coen Inlier-Carpentaria Basin divisions. The shelf sediments however, probably contain zircon, rutile and tourmaline from non-local sources derived, for example, by reworking of quartz sand from the northwestern shelf to the southeastern shelf and coastal environments of the Gulf of Carpentaria during the last marine transgression. In addition, in the hinterland of the gulf, metamorphic tourmaline and garnet in the McArthur Basin division were probably sourced from the adjacent older metamorphic lithologies (e.g. Arnhem Inlier, Pine Creek Inlier and Murphy Inlier).

In the upper fluvial reaches, where streams are incised into igneous and/or metamorphic rocks, the sediment samples contain primary heavy mineral grains, including, for example, euhedral zircon grains. The high concentrations of unstable and metastable heavy minerals in these sediment samples confirm their direct derivation from the adjacent primary sources. Reworked heavy minerals, which represent second or third cycle grains and high ultrastable mineral (zircon, tourmaline and rutile) contents, are characteristic of fluvial sediment samples located within the sedimentary Carpentaria and Karumba Basins in the gulf hinterland.

Although the study area is located in a tropical region where chemical weathering would be expected, the very rare occurrence of unstable minerals such as augite, titanaugite, chlorite and biotite, is attributed mainly to the lack of appropriate source rocks within the catchments of the studied rivers in the hinterland of the Gulf of Carpentaria.

The spatial distribution of heavy minerals in the southeastern shelf of the Gulf of Carpentaria and its surrounding river sediments is influenced by several factors including the provenance, high rate of fluvial supply caused by monsoon cycles, embayments and river morphology, marine regressions and subsequent transgressions during the Quaternary period, and hydrodynamic conditions.

The significant variation in lithology around the gulf is the main factor influencing the heavy mineral assemblages in river sediments within the six geological divisions in the hinterland of the Gulf of Carpentaria. Similarly, the differences in heavy mineral assemblages between the various nearshore environments in the Gulf of Carpentaria are attributed to changes in provenance. Fluvial sediments are trapped in the immediate nearshore areas forming beach ridges, cheniers and associated coastal progradation. The heavy mineral assemblages in these nearshore features directly reflect the signature of source rocks located in the adjacent hinterland.

Estuarine sediment samples along the southern coastal line of the Gulf of Carpentaria show remarkably different heavy mineral suites in comparison to their stream samples. The combined effect of tidal current and wave action (relatively low hydrodynamic energy level) associated with the platy to tabular habit of amphibole and the low density of both epidote and amphibole minerals, means that these heavy minerals were transported from the nearshore sand in the gulf into the estuaries. Therefore, the proportions and/or types of heavy minerals vary between the riverine and estuarine sediment samples of a given fluvial system.

Ultrastable minerals are concentrated as lag deposits in the channel margins (low current velocity unable to move dense fine grains) of the studied fluvial systems, deltas and along troughs between the curved and linear ridges in the shelfal area of Bryomol Reef (wave and current action entrain and transport less dense and larger grains). The increased overall gravel concentrations in the Bryomol Reef area and the occurrence of coarse talus deposits in the southern margins of the northern submerged coral reefs enhanced the ability of high density fine particles to become trapped in voids between coarse grains and thus be sheltered from current transportation, leaving lag deposits of ultrastable minerals in these two areas. In addition, the concentrations of unstable minerals in the shelf area of the gulf decreased as a result of subaerial weathering processes during glacial regressions and abrasion during the subsequent post-glacial transgressions, thus increasing the relative concentrations of ultrastable minerals in the shelfal areas of Bryomol Reef, the centre of the SE gulf and around the northern submerged coral reefs.

The spatial variability of heavy minerals provide the basis for recognition of twelve distinct heavy mineral facies (identified through Q-mode cluster analysis) that characterise the surface and sub-surface sediments of the southeastern shelf of the Gulf of Carpentaria, as well as the fluvial sediments in the gulf hinterland. The shelf surface facies include the surface of the northern submerged coral reef heavy mineral-free facies (SCRHMFF), the heavy mineral facies of the middle part of the southeastern shelf together with the surrounding area of the northern submerged coral reefs (MCRHMF), the Bryomol Reef heavy mineral facies (BRHMF) and the heavy mineral facies of the nearshore area together with the western margin of the middle part of the southeastern shelf (NWMHMF). The shelf sub-surface heavy mineral facies (SSHMF1-6) comprise three facies (SSHMF1-2 and SSHMF5) dominated by terrigenous sediments that reflect the signature of the adjacent sources, two reworked sub-surface heavy mineral facies (SSHMF3-4), and finally heavy mineral-free SSHMF6 mainly consists of calcareous marine sediments. The fluvial facies in the hinterland include the heavy mineral sedimentary succession facies (HMSSF) and the heavy mineral metamorphic inlier facies (HMMIF). The HMMIF is divided into three distinct sub-facies (HMMIF1-3).

The formation, distributions and relationships between these facies provide insights into the sedimentation history and transportation pathways in the southeastern shelf of the Gulf of Carpentaria during the Holocene.

The main source of terrigenous sediments in the southeastern shelf of the Gulf of Carpentaria is the fluvial HMMIF that includes 17 fluvial systems draining the Coen Inlier-Carpentaria Basin, Georgetown Inlier and Mt Isa Inlier divisions, and the mixed source division of the Georgetown-Mt Isa Inliers-Great Australia Basin. This fluvial facies is characterised by high concentrations of particularly metastable minerals, epidote and hornblende.

The shelfal NWMHMF and SSHMF1 reflect the signature of the fluvial HMMIF with significant contributions from the HMMIF3 with its heavy mineral suite enriched in hornblende and epidote. These shelfal facies suggest a high terrigenous input in the Early Holocene (~8.9 ka radiocarbon years) from river systems draining the Georgetown and Mt

Isa Inlier divisions, especially the Gilbert River system and Leichhardt River, respectively. Minor contributions also come from the Mitchell River system that drains the southern Coen Inlier-Carpentaria Basin division. The similarities in heavy mineral associations between rivers that drained the southern Coen Inlier, Georgetown and Mt Isa Inliers (HMMIF3), and the shelfal NWMHMF and SSHMF1 show a direct link between the shelf sediments and the adjacent local lithologies.

Also, the shelfal SSHMF2 and SSHMF5 reflect the signature of the fluvial HMMIF with considerable input from the HMMIF2 (characterised by the highest garnet content) into the SSHMF2 and from the HMMIF1 (with the highest metamorphic aluminum silicate content) into the SSHMF5. These relationships also suggest direct filling of the fluvial channels within the southeastern shelf of the Gulf of Carpentaria from the adjacent lithologies in the gulf hinterland.

However, abrasion and sorting during the last marine transgression probably modified the heavy mineral content in the SSHMF2, resulting in a slightly higher content of ultrastable heavy minerals than in the SSHMF1 and SSHMF5. Alternatively, cyclones and/or large storm events could have reworked sediment by strong near-bottom currents. In the context of these scenarios, less dense and large heavy mineral grains are entrained and transported away as a result of sediment reworking processes during the transgression, cyclone or large storm events, increasing the concentration of ultrastable heavy minerals.

The occurrences of the SSHMF2 and SSHMF5 on top of the SSHMF1 suggest an increase in fluvial input from Flinders and Bynoe Rivers from the HMMIF2 and the Norman River from the HMMIF1 in the Late Holocene, relative to the contribution from the HMMIF3 via the Leichhardt and Gilbert Rivers. This suggestion is based on the available radiocarbon dates whereby the SSHMF2 and SSHMF5 record a younger age range (8.9-0.4 ka), while the SSHMF1 shows an older age range (8.9-5.1 ka radiocarbon years) in the southeastern shelf of the Gulf of Carpentaria.

The shelfal MCRHMF reflects the signature of the fluvial HMMIF, with a significant contribution from the HMMIF1, suggesting reworking of terrigenous sediments by the clockwise tidal circulation pattern from the northeastern nearshore environment between Archer Bay and the Coleman River Inlet. This nearshore zone receives fluvial sediments rich in metamorphic aluminum silicates from the Archer, Coen and Coleman Rivers that drain the upper Coen Inlier-Carpentaria Basin division (HMMIF1). In addition, as a result of chemical decomposition and hydraulic fractionation during the processes of sea level changes, a high concentration of ultrastable heavy minerals appears in the surface sediments of the central part of the southeastern middle gulf area, showing a similar possible formation process to the SSHMF2.

The heavy mineral assemblages of the shelfal BRHMF and SSHM3-4 are characterised by the highest content of ultrastable heavy minerals, suggesting reworking of marine sediments from the northwestern shelf of the Gulf of Carpentaria during the post-glacial marine transgression that also increased the concentration of ultrastable heavy minerals in the MCRHMF. In addition, terrigenous sediments within the southeastern shelf of the gulf were transported and reworked by clockwise tidal currents and wave action, associated with cyclones and large storms that probably suspend the nearshore sands. The SSHMF3 probably received a mixture of reworked terrigenous sediments from the Archer, Coen and Coleman Rivers that drain the upper Coen Inlier-Carpentaria Basin division (HMMIF1) and the Wenlock River from the HMSSF. The BRHMF and SSHMF4 however, probably contain a mixture of reworked fluvial sediments from the entire HMMIF.

Although the heavy mineral assemblages of the fluvial HMSSF and the shelfal BRHMF and SSHMF4 show high concentration of ultrastable heavy minerals, there is no direct link to the surrounding lithologies, including the Helby Beds and McArthur Basin divisions within the fluvial HMSSF and the shelfal BRHMF and SSHMF4. The similarities between these heavy mineral facies are attributed mainly to the high chemical and physical stability levels of zircon, tourmaline and rutile, as well as their hydrodynamic properties being mostly the denser small grains in comparison to other translucent heavy minerals.

The shelfal SCRHMFF and SSHMF6 are characterised by the absence of heavy minerals. The formation of these facies is related mainly to growth and development of reef structures over several sea level cycles during the Quaternary. Fine sediments were removed mainly by wave and current action during the reef growth. In addition, current strength and even storm conditions would be unable to lift heavy minerals to these elevated environments. As a result of these processes and the positive relief of the reef surface, no heavy minerals were found in the very fine sand fraction on the reef surfaces.

Conclusions

The strong affinity between the fluvial and shelfal heavy mineral facies is explained by the high rate of fluvial supply caused by monsoonal climate conditions. The expected affects of strong chemical weathering under humid tropical climate conditions over the gulf region are suppressed and diluted by the high rate of monsoonal river runoff that rapidly transports detritus and sediments along the rivers into the gulf. Such a mechanism minimises the mineral residence time in the alluvial storage and thus reduces the effects of chemical weathering. Therefore, unstable heavy minerals are preserved together with stable and ultrastable minerals in the assemblages. The overall low feldspar weathering index supports the weathering-limited conditions, whereby the transportation processes are faster than the weathering rate. The short fluvial distances associated with this intense transportation reduce the effects of physical abrasion and thus minimises the loss of unstable minerals. In addition to low chemical weathering caused by monsoonal climate conditions (dry for 8-9 months of the year), the dominance of physical disintegration in this tropical climate reduces the effects of weathering of exposed source rocks in the gulf hinterland.

As a result of weathering-limited conditions and short fluvial transport distances, the southeastern shelf of the Gulf of Carpentaria and its hinterland form a unique tropical heavy mineral facies that reflect the signature of the local source lithologies.

The relationship between the fluvial and shelfal surface and sub-surface heavy mineral facies identify pathways for marine sediment transport within the southeastern shelf of the Gulf of Carpentaria. Marine transport pathways are controlled mainly by clockwise tidal circulation patterns within the gulf. In addition, cyclone conditions or large storm events are likely to enhance, but not control, the formation of the heavy mineral facies.

Finally, the light mineral fractions in the study area are mostly quartz-dominated, except for the carbonate reef areas that are composed of shell materials. As a result of the limited differential hydrodynamic properties between the silicate- and carbonate-dominated particles, light mineral fractions in the southeastern shelf of the Gulf of Carpentaria and its hinterland provide poor mineralogical facies recognition. Therefore, heavy minerals are more effective than the light minerals in defining provenance, distribution patterns and transportation pathways in the southeastern shelf of the Gulf of Carpentaria.