# Tectonic and Climatic Controls on Shallow Marine Placer Gold Morphology

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## Summary
Sampling of beach sands in western Ghana, West Africa, has yielded several distinct populations of gold grains: 1) flattened and folded grains with rounded rims; 2) euhedral grains; and 3) gold coatings over marcasite and other grains, including spherical grains. The first two populations are typical of gold grains found in coastal settings and can be explained by transport by fluvial process or reworking in the swash zone, and by liberation of gold grains from cobbles or lode sources in the shallow marine setting respectively. The third population is characterized by gold spheres up to 40 μm in diameter and likely represent gold transported in solution in groundwater which crystallized in a reducing environment, such as mangrove swamp muds; and which were later mobilized by the erosion and reworked into beach sands. Samples of alluvial gold from two estuaries in different structural and tectonic settings reveal that the significance of differing populations of gold grains is controlled by climate, local structure, and bedrock type.

## Introduction
Exploration for gold in modern coastal placers is common, particularly with artisanal mining operations. Most of these operations operate in a completely practical fashion with no interest in the origin of the gold. The coast of Ghana has long been a source of alluvial gold and it is possible that there are gold placers in continental shelf sediments. The geology of Ghana favours the presence of alluvial gold, due to the presence of evenly spaced gold-bearing greenstone belts. The Ankobra and Pra rivers drain the Ashanti Belt (Fig. 1), which is the most prolific greenstone belt in Ghana; consequently, the seas near the mouths of these two rivers have been the focus of exploration for marine placers.

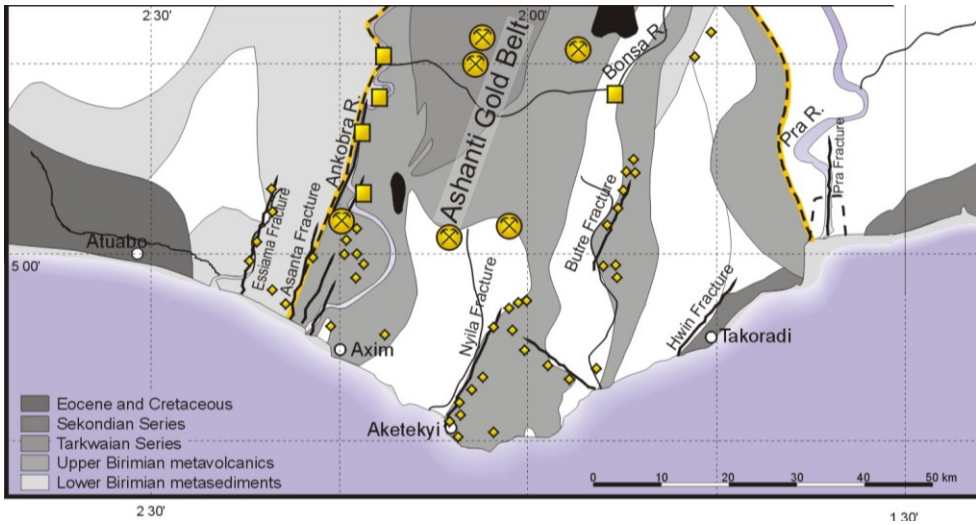


*Fig. 1. Geological map of southwestern Ghana, showing the location of the Pra and Ankobra Rivers and gold mines and prospects in the coastal region.*

Coastal fractures, related to Precambrian structures reactivated during Mesozoic rifting, are responsible for the physiography of the coastal area, which consists of high-relief horsts separated by grabens that have been occupied and infilled by rivers or by finer sediments during times of elevated sea level. These fractures were loci of gold mineralization during the Precambrian, and are the source of alluvial gold in rivers confined by them. Given the geology of the area and the history of artisanal mining operations, it was presumed that offshore placers would be found primarily in beach and fluvial deposits formed at times of lower sea level.

Despite the similarity of the source areas for possible gold placers at the mouths of the Pra and Ankobra rivers, there are significant changes in local climate, vegetation, bedrock, and current configurations which may result in significant differences in the nature of gold placers, if present, in the coastal setting.

## Sampling

Samples were collected from the modern and older raised beaches, as well as along the banks of the Ankobra River. Samples were collected and sluiced, using a fine wool blanket. After eight buckets of sediment were passed through the sluice, the blanket was washed, and the residues collected. The concentrate was further panned into a high-grade sample. This process was repeated until 40 buckets (approximately 0.24 $m^3$) had been concentrated through the sluice. Only one sample was collected at each site, generally representing about the top 50 cm of sediment. Samples were further panned to release gold grains, which were sieved and counted, to assess size distributions, and then mounted on SEM stubs.

Thirty-five samples were collected from shallow offshore samples using a suction dredge. The material was pumped to the surface and collected in burlap or other bags, which allow excess water to drain. With this system, sample size was poorly constrained, and losses will be expected during sampling due to overfilling the bags or loss of very fine grains through the pore spaces of the sample bags. Samples were recovered, brought ashore and panned to recover gold grains.

Samples were collected from the erosional remnant of a spit which had previously prograded across the mouth of the Pra River, and from beach sands east of the Pra River. These samples were panned and gold grains recovered.

## Observations

Gold grains recovered from coastal sediments in Ghana, West Africa, reflect at least three different methods by which gold has been transported to the coastal region (Ong, 1998). There are euhedral grains, many of which include rock matrix materials (Fig. 2); discoidal grains, some of which are folded, indicating transport in the swash zone (Fig. 3); and as gold coatings on marcasite or other grains (Fig. 4).

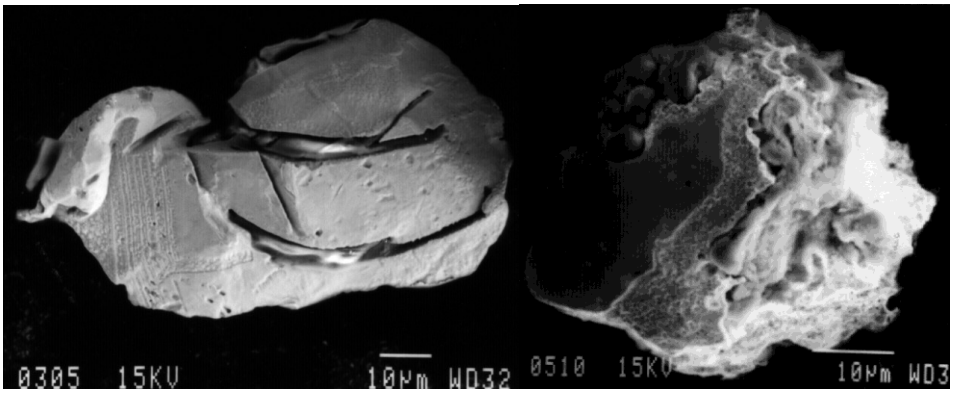


*Fig.2. Euhedral gold grains from beach sands, Ghana, West Africa. These grains have eroded locally from bedrock, or have been liberated from larger clasts in the swash zone. After Ong (1998).*

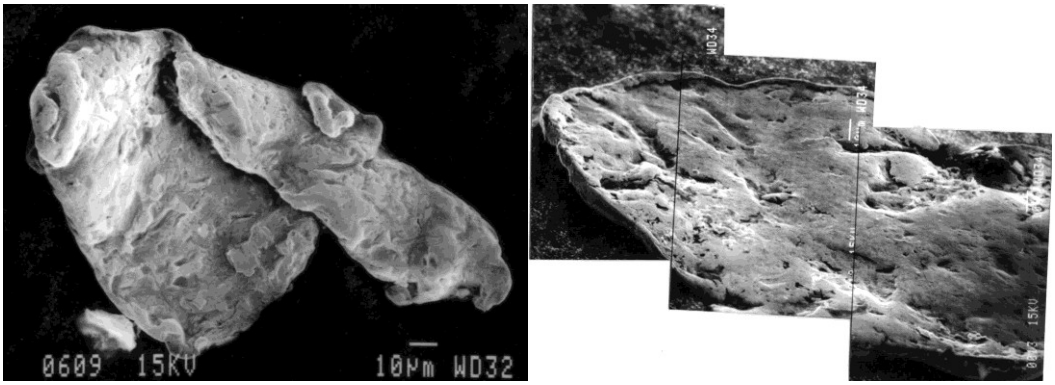


*Fig. 3. Gold flakes have been transported and worked in the swash zone. Folded grains and rolled edges are common. After Ong (1998).*

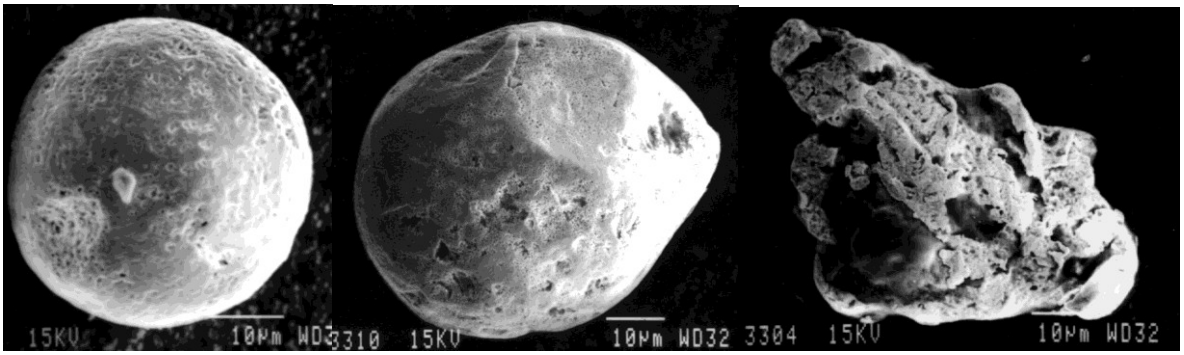


*Fig. 4. Gold found coating spherical grains (left and centre) and partially coating an irregular marcasite grain (right). After Ong (1998).*

The beach samples from the Ankobra estuary show examples of all three of the above populations, whereas those at the Pra were dominated by flakes. Samples from the seafloor of the Ankobra estuary show two populations of grains, but are dominated by euhedral grains, including some which show the imprint of neighbouring non-metallic grains (Fig. 5). There were a few spheres recovered, but none of them were gold grains.

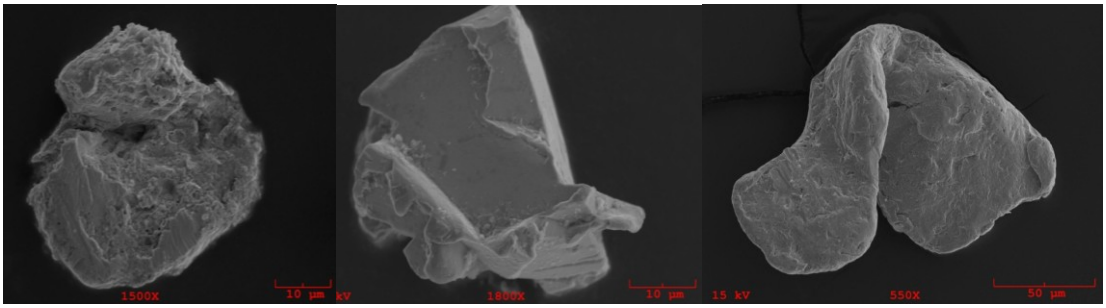


*Fig.5. Gold grains recovered from seafloor samples. Euhedral grains (left and centre); folded flake at right.*

## Discussion

The environmental conditions at the mouths of the Pra and Ankobra rivers can be distinguished on the basis of bedrock character, width of the continental shelf, recent sediment cover, and local climate. Bedrock near the mouth of the Ankobra River consists of Birimian metasedimentary and metavolcanic rocks of Precambrian age, whereas at the mouth of the Pra River, the bedrock is Paleozoic in age. The continental shelf near the Ankobra River is relatively narrow, whereas the

continental shelf at the Pra River is over twice as broad. The modern sediments in the beach and shallow marine setting at the Ankobra consist of very fine grey sandy silt, derived from local phyllites, resulting in typically very low beach profiles. The modern sands at the Pra estuary are coarse shelly sands, with abundant heavy mineral layers which can be traced to distant inland sources. The resulting beach profiles are much steeper than at the Ankobra. Lastly, the mean annual rainfall over the Ankobra River basin is considerably higher than that over the Pra River, leading to greater acidity in surface waters in the Ankobra estuary.

The euhedral grains and the flakes with rolled edges are typical of what would be expected in a placer deposit. The presence of the gold spheres was proposed by Ong (1998) to be due to crystallization of gold under reducing conditions, such as in lagoon muds—these grains were then remobilized by erosion and found their way into the beach sands. The lack of such spheres in the marine setting combined with observations of gold coating iron grains suggests that the gold spheres have resulted from gold either coating or replacing an iron sulfide or oxide sphere. The origin of the iron spheres is unclear, but we note that authigenic iron minerals readily form in marine sediments under bacterial influence (e.g., Konhauser, 1998; Merinero *et al*., 2008).

Native gold is inert in most oxidizing conditions, but solution can take place. Probably the most significant gold complex in the coastal environment is the gold chloride complex ($AuCl_4^-$), the solubility of which increases with acidity (Park and MacDiarmid, 1975). Under reducing conditions, but also in the presence of organic compounds or bacteria, gold chloride complexes are quickly reduced to colloidal gold (Lengke *et al*., 2006).

The importance of euhedral grains from the Ankobra estuary seafloor suggests an eluvial origin for the offshore gold grains, likely due to erosion of gold-bearing bedrock. The gold-coating of nearshore grains observed in the Ankobra estuary suggests that some gold is transported in chemical form by acidic surface and subsurface waters, and precipitates on suitable grains. The importance of the flakes in the Pra estuary, combined with the inland origin of other minerals, suggests that fluvial transport of gold is the most important source for gold. There are no primary eluvial sources for gold in the Pra River estuary, but eluvial gold may be sourced from Paleozoic paleoplacers, which may be expected to show the same morphology of gold grains. Although we cannot be sure there are no gold spheres, due to the smaller samples and the possible losses from the marine sediments, the size of those observed on the beach are so small that the expected recovery would normally be zero.

## Conclusions

There are three distinctive populations of gold grains observed in the beach zone, suggesting three methods of moving gold into the coastal region. There are only two such populations recovered from marine samples, most of which appear to be euhedral grains, suggesting that the most significant source of gold in the marine setting is gold grains which have been recently liberated from bedrock, and have not been transported. Marine placer gold in coastal Ghana is therefore most likely to be eluvial in origin.

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