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# OCCURRENCE OF GLAUCONITE AND PHOSPHATE IN THE SEDIMENTS FROM AYEYARWADY CONTINENTAL SHELF

Ko Yi Hla[1], Day Wa Aung[2], Moe Moe Lwin[3] and TunTun Zaw[4]

## Abstract

The study area is located in the northern part of Andaman Sea; bounded by Latitude 13º 25´ N and 15º 40´ N and Longitude 93º 15´ E and 97º 45´ E occupies the south and southwest oceanic area of Myanmar. Ayeyarwady continental shelf is a part of an area of a complex geological setting in Andaman basin, located in the south of Ayeyarwady delta surrounded by land area in north and east. In the present study,the formation and association of glauconite and phosphate were systematically studied. Sand of the study area is arkosic sand and lithic arkosic sand in composition derived from continental block and magmatic arc, subduction complex provenances. In the sediments, the glauconite constitutes 1 – 15.5 % of the total detrital fraction in some stations. The glauconite of biotite origin, fecal pellet conversations, foraminifera cavity fillings and replacements also occur. Phosphate constitutes 1 – 10 % of the sediment as replacement of bioclast, micro coprolite phosphate pellet and cement. The phosphates are formed in the shelf edge and slope where upwelling current favors the formation of phosphate. The association of glauconite and phosphate is and they were formed from during slow sedimentation in transgressive phase forming the condense horizon. Therefore, the shelf, shelf edge and slope area are the best fit for the formation of glauconite and phosphate in the present sea-level condition.

**Keywords:** glauconite, phosphate, transgressive phase, condense horizon.

## Introduction

### Location and size of the study area

The study area is located in northern Andaman Sea. It is bounded by Latitude 13 degree 25 minute N and 15 degree 40 minute N and Longitude 93 degree 15 minute E and 97 degree 45 minute E, occupies the south and southwest oceanic area of Myanmar. The area extends N-S in 225 km and E-W in 450 km respectively. The area extent of study area is approximately 101250 km$^2$. The study area is bounded by southern part of Ayeyarwady delta and Gulf of Martaban, and western part of Tanintharyi coast. Therefore, the area occupies the oceanic area around the Myanmar coast of northern Andaman Sea. The location map of the study area is shown in (Fig.1).

## Glauconite

Glauconite is yellowish green, dark green to greenish black colored, usually consisting of ovoid and\or lobate shape, sand size smooth grains, presented in sand of the study area.

Glauconite constitutes (1) % to (15.5) % of the total detrital fractions. The forms of glauconites are various. Likewise, a few quartz inclusions are present in some glauconite. Under microscopic examination, flaky materials in glauconite are randomly oriented but some are properly oriented in nature (Figs. 2, 3, 4 and 5). Sometimes, the included very fine silt size quartz is haphazardly arranged (Figs. 6 and 7). In some cases, no distinct internal structures are to be

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observed. Some glauconites are also frequently seen as internal fillings a few foraminifera tests as cavity fillings. Moreover, some labile grains stained and replaced by glauconite are observed as replacement glauconite. In addition, some glauconite coatings on some detrital grains are found. Most grains are weakly pleochroic.

Ovoid grains with shrinkage cracks as mentioning with their evolving stages are nascent, slightly evolved, evolved and highly evolved grains. In some case, no distinct internal structures are observed but the outer boundary of grain showing cracks or lobes and thesecracks showing wedge-shaped aperture. In some horizons, the replacement of volcanic rock fragments, siltstone fragments, fauna fragments, and feldspars by glauconite with greenish staining in noted (Figs. 8 and 9). A few of the phosphate (collophane) grains associated with glauconite are well marked. The concentric glauconitic coating or glauconitized grain is also noted.

Glauconite content is conspicuously higher in lower shelf area. The glauconitic content decreases towards Ayeyarwady Delta and Gulf of Martaban.

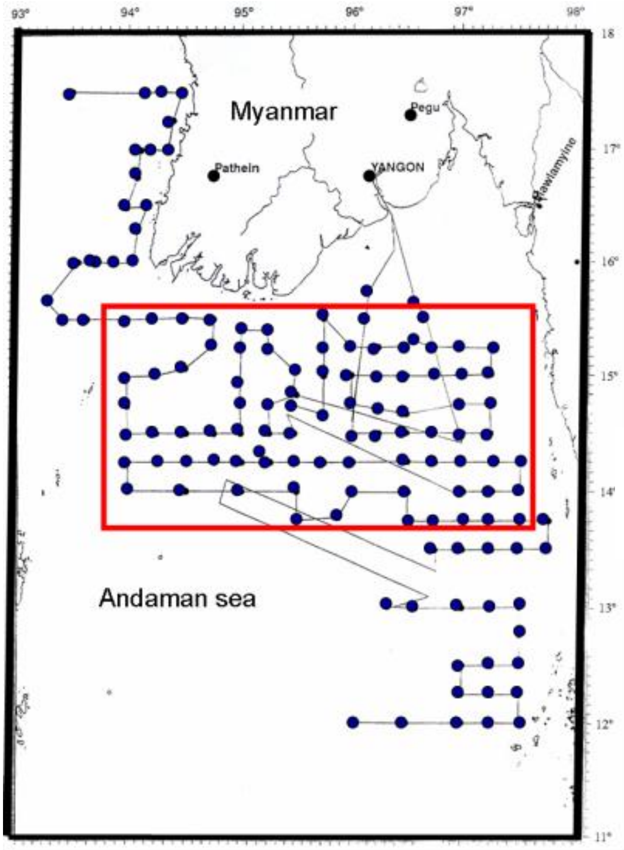


**Figure 1** Location map of the study area with sample location and geophysical lines.


**Figure 2** Photomicrograph showing glauconite grain with minute flakes (under PPL) (Sp. 63).

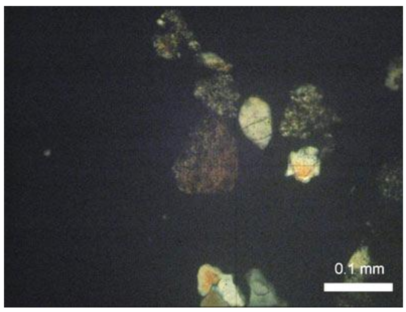


**Figure 3** The same view with Fig.2 (between XN).

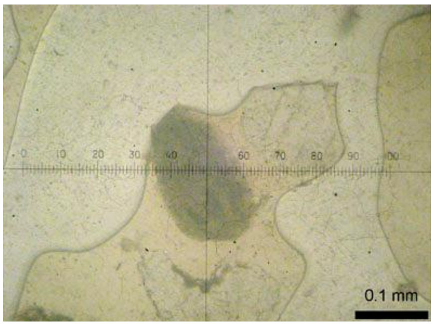


**Figure 4** Photomicrograph showing glauconite grain with alignment of flaky material (under PPL) (Sp. 65).

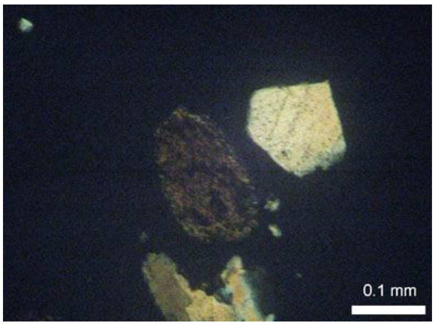


**Figure 5** The same view with Fig.4 (between XN).

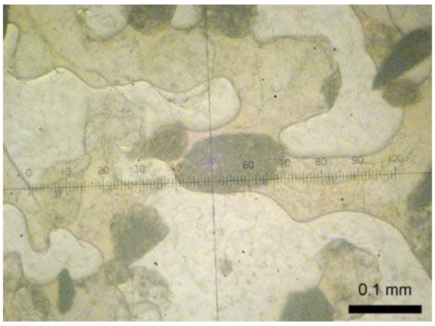


**Figure 6** Photomicrograph showing well rounded glauconite grain with faint alignment of flaky material (under PPL) (Sp. 77)

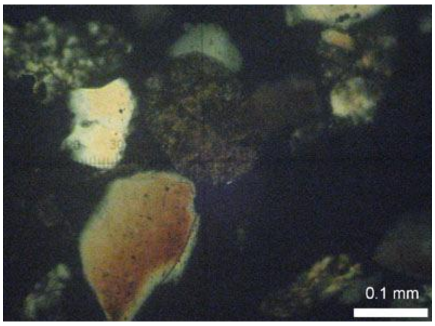


**Figure 7** The same view with Fig.6 (between XN)

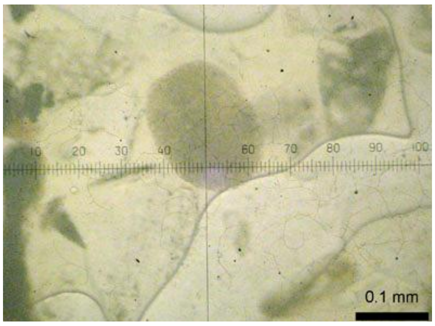


**Figure 8** Photomicrograph showing ovoid glauconite grain with some minute inclusion of quartz and feldspar grains (under PPL) (Sp. 63)

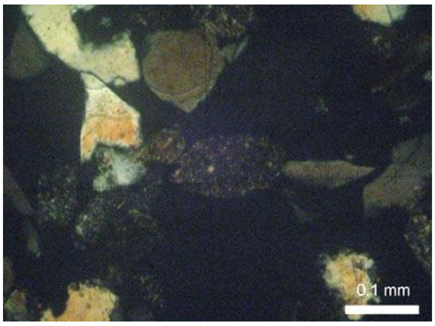


**Figure 9** The same view with Fig.8 (between XN)

**Formation of Glauconite**

The origins of glauconite have been discussed by many authors and put many theories and postulations. These are (1) fecal pellet conversion, (2) Foraminifera cavity filling, (3) alteration of biotite, and (4) clay pellet agglomeration in the sea (Ehlmann, et al, 1963). The most common methods of glauconite formation are internal moulds, fecal pellets, replacement of carbonate skeletal fragments and the coating and replacement of mineral or rock grains (Odin and Fullagar, 1988).

Glauconitisation of mineral grains or rock fragments can occur with quartz, feldspar, mica, calcite, phosphate and volcanic glass common minerals to be replaced or coated by glauconite. Replacement of the mineral grain occurs along fissures or cleavage planes and tends to produce vermicular morphology (Odin and Fullagar, 1988).

In the present research area, glauconite altered from biotite, fecal pellet and foraminifer's cavity fillings are recorded (see fig. 78 .10.). Galliher (1935) concluded that the glauconites are the derivatives of biotite by a process of submarine weathering. The present material of glauconites is stated by Hein, et al, (1974) match with the glauconites under discussion. Glauconite pellets which appear to have cleavages were probably derived from minerals with cleavages like coarse-grained feldspar or biotite.

Glauconite pellets without cleavages, but containing inclusion of silt size quartz and feldspar were probably altered from fecal pellets.

A third group belongs to the alteration product of clay minerals trapped within the microfossil tests. Ehlmann, et al. (1963) stated that the glauconites are the alteration product of mud filled foraminifera test. Foraminifer tests are the dominants host for internal moulds and the glauconite is precipitated directly into the test or replaces clay-sized material previously deposited in the test. Fecal pellets are also common, particularly in modern sediments, and are produced by filter feeding or soft-bodied organisms which consume mud. Glauconite appears to form in the pores of these pellets and slowly replaces the muddy material within the pellet (Odin and Fullagar, 1988).

Glauconites are formed only in marine water of normal salinity. It requires slightly reducing (Cloud, 1955), and weakly oxidizing condition (Chilingar, 1956), in the area of slow sedimentation.

Galliher (1935) stated that the formation of glauconite is favored in black mud and sands in anaerobic environment, where "oxidation" may occur, at the surface of the sediments.

Hadding (1932) suggested that the glauconite is always marine, always sub-littoral, and always a shallow sea formation. As a rule these are formed in agitated water, under decrease deposition and never form in highly oxygenous water.

Lochman (1949) presented that the glauconite essentially needs a moderately anaerobic environment.

Debrabant and Paquet (1975) stated that the glauconites usually associated with phosphates pellets and pyrites. This means that the prevailing of reducinf condition present.

The replacements, the concentric coating and the highly evolved glauconites are the products of submarine glauconitization process directly from seawater. (Amorosi, 1995).

Cloud (1935) stated that glauconites are formed only in marine water with normal salinity under slightly reducing condition. It also requires weekly oxidizing condition.

Galliher (1935) stated that the formation of glauconite is favored in black mud and sands in anaerobic environment, where oxidation may occur, at the surface of the sediments.

The glauconite is always marine, always sub-littoral, and always a shallow sea formation. As a rule these are formed in agitated water under decreased deposition and never form in highly oxygenous water. Therefore, the glauconite with concentric coatings is suggested to be formed under that condition.

Moreover, the glauconite essentially needs a moderately anaerobic environment and the rocks commonly associated with pyrite and siderite. So, the occurrence of pyrite associated with glauconites in some intervals is thought to be of reducing condition (Day Wa Aung, 1993).

Amorosi (1995) stated that the glauconites usually associated with phosphatic pellets and pyrites, which can also be documented in shelf sand of the area.

Odin and Matter (1981) mentioned that the parent of material of glauconites is carbonate particles, argillaceous (Kaolinitic) fecal pellets, infilling of foraminifer's tests, various mineral grains and rock fragments that pass gradually into the commonly occurring green grains, which is undoubtedly acceptable statement.

On a larger scale, the formation of glaucony is governed by the availability of iron and potassium and the balance between detrital influx and winnowing. (Odin and Matter, 1981).

Low accumulation rates expose grains to the open marine environment for sufficient long times ($10^6$ years) for highly evolved glaucony (Odin ad Metter, 1981). This means that the glauconitization is early diagenetic event under show sedimentation in open marine with slightly reducing, mildly oxidizing condition.

There are four main stages of glauconite formation: nascent, slightly evolved, evolved and highly evolved (Odin and Fullagar, 1988). At the nascent stage the glauconite is just beginning to form and is iron rich with $K_2O$ contents of 2-4%. Slightly evolved glauconite has $K_2O$ contents of 4-6% and most of the original grain (mineral, fecal pellet, clay has been replaced (Odin and Fullagar, 1988). Glauconite grains reach the evolved stage when their $K_2O$ contents are 6-8% and all of the original grains structure and texture have been lost. In highly evolved grains of glauconite any cracking of the grains is filled to produce smooth surfaces and the $K_2O$ content is greater than 8% (Odin and Fullagar, 1988). The glauconite infilling the cracks have less $K_2O$ and are less evolved as result. Based on $K_2O$ content, most of the glauconite falls within the evolved stage (five out of seven samples).

The ideal conditions for glauconite formation occur between 65 degree S and 80 degree N on continental shelves (<500 m water depth) with pH conditions that are slightly alkaline (7-8 pH) and a water temperature between 15 and 20 degree C (McRae, 1972). A slightly reducing environment with bacterial decomposition of organic matter is favored on modern shelves glauconite formation is often associated with areas of reduced sedimentation and relict sediment (McRae, 1972).

## Phosphate

Of some interest at present are the phosphorus deposits found on the shelves off the coasts of many countries of the world. Thus, phosphorus deposits have been found off Peru, Chile, Mexico, the west and east coasts of the United States, off Argentina, South Africa, Japan, and on the submerged parts of several islands around the Indian Ocean (Mero, 1966)

Phosphate consists of 1 to 10 % of sediment of the Ayeyarwady continental shelf. The phosphate occur in the study area are mostly collophane. The replacement of bioclast (Figs. 10, 11), cavity filling in fossil chambers (Fig. 12), micro coprolites phosphate pellet and cement

(Fig.13). Phosphate constitutes in shelf sediments of the study area. The association of glauconite and phosphate materials is conspicuously seen. It is light yellow to brown in color and isotropic between XN (Fig. 11). The form of phosphate such as micro coprolite, replacing of fauna and cement (Figs. 14, 15, 16, 17) are noted. The sediment of the study area yield different concentration especially in the shelf edge area. The sediments closed to the Ayeyarwady delta and shallow areas yield a trace amount of phosphates.

In the present research, the phosphate occurs as bioclast replacement, cavity filling in fossil chambers, phosphatized fecal pellet, and phosphate grains. It shows yellow in color under ppl and isotrophic between XN. Some bioclasts are partially or totally replaced by phosphate is well marked.

In the area, the phosphate occurs as cement and minute particles disseminating in sediments. Most of these phosphates occur in the sediment of shelf-edge and slope areas of the study area. Dispersed phosphate, biogenic fragments, coprolites, and pellets are noted. In thin section, skeletal phosphate is distinguished by its light-yellow to brown color and presence of a microstructure of regularly arranged canals (canaliculi) and growth lines.

Coprolites are commonly present in bioclasticphosphorites. They are generally spherical to elongate fecal pellets, up to 20 mm in diameter, composed of collophane.

Phosphatised skeletal fragments are broken rounded grains than in thin section re brown in plane light and anisotropic under cross-polarized light.

**Origin of marine phosphorites**

The marine phosphorite generally occurs in areas of slow sedimentation, on outer continental shelves and slopes, particularly on the tops and sides of local ridges and banks, on fault scarps and flanks of submarine canyons. Phosphate nodules and crusts generally occur at depths from 60 to 300 m (Tucker, 1991)

The phosphorite is developing on the upper continental slope as replacements of benthic foraminifera. Obliteration of the foraminifer's structure by the replacement leads to the production of phosphorite pellets.


**Figure10** Photomicrograph showing glauconite in fossil chamber (under PPL) (Sp. 75)


**Figure 11** The same view with Fig.10 (between XN)

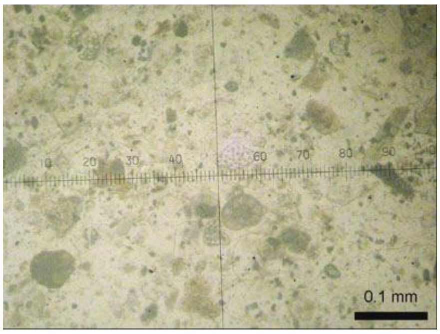


**Figure 12** Photomicrograph showing foram and phosphate (under PPL) (Sp. 103)

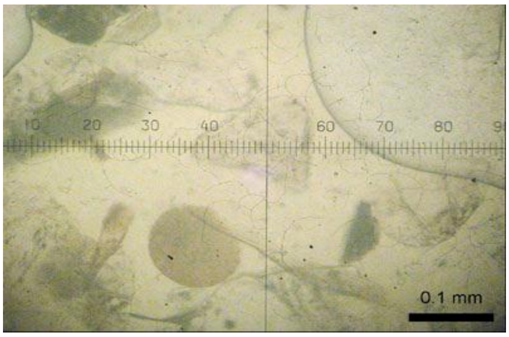


**Figure 13** Photomicrograph showing yellowish colored, rounded phosphate pellet (under PPL) (Sp. 77)

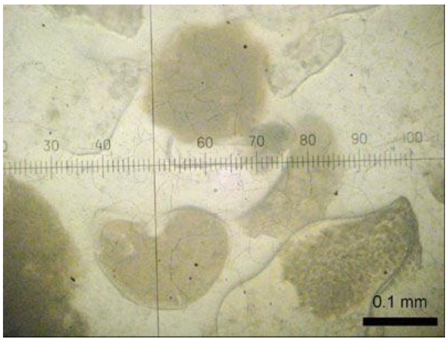


**Figure 14** Photomicrograph showing the Phosphate replacement of bioclast (under P.P.L) (sp.77).

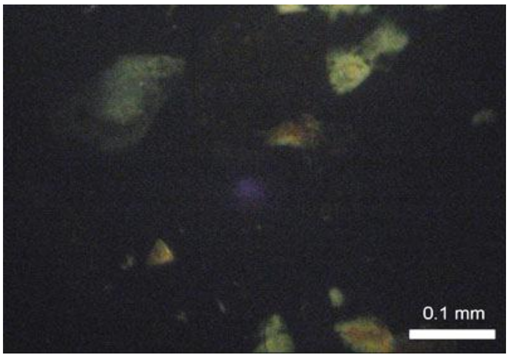


**Figure 15** The same view between X.N. (sp.77).

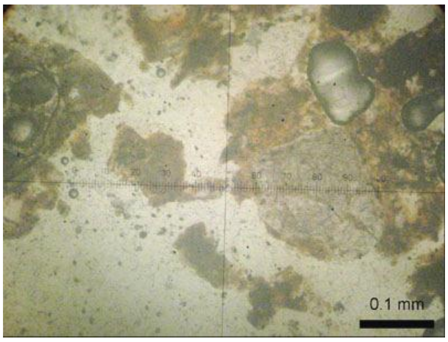


**Figure 16** Photomicrograph of the Phosphate replacement foraminifer's shell and phosphate cement (sp.112)

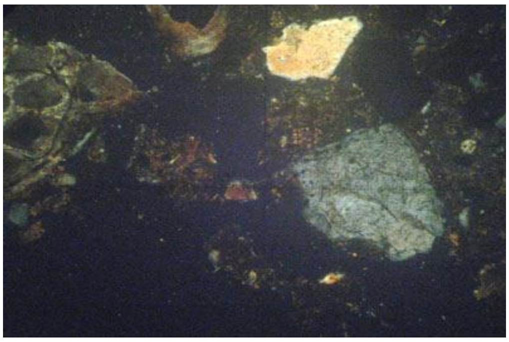

**Figure 17** The same view between X.N. (sp.112)

One popular mechanism has been upwelling, whereby cold waters containing nutrients rise from the depths towards the surface. Upwelling currents lead to high organic productivities and phytoplankton growth in surface waters which in turn results in organic rich (and so phosphate-enriched) sediments and oxygen-deficient waters overlying the sea floor.

Low sedimentation rates prevailed during phosphogenesis, and this is reflected in the associated sediments which may be organic-rich mud rocks, cherts, pelagic limes, hard grounds and glauconite. Ancient phosphorites are common constituents of condensed sequences. It occurs in condensation with very low rates of accumulation.

Although it was once thought that phosphorus was precipitated directly from sea water, perhaps as some type colloid, data from sites of active phosphorus formation indicate that much is being formed within the surface sediments, largely by replacement and impregnation of grains. The bacterial decay of organic matter in the sediment liberates phosphate which is precipitated in pellets and coprolites, and replaces siliceous and calcareous skeletons and lime mud, eventually giving rise to nodular masses of phosphorite. Micas and detrital clays may absorb phosphate into their lattices. The role of the phytoplankton is the crucial in transporting the phosphate from upwelling currents and near-surface waters to the sea floor.

Many of the phosphorite deposits of the geological record formed when sea level was relatively high or were associated with short-lived transgressions. During these times, shallow, fertile, shelf seas promoted phytoplankton blooms, which led to poorly oxygenated shallow sea floors where organic matter ( with its $PO_4^{2-}$ ) could accumulate.

Therefore, in the Ayeyarwady continental shelf, the phosphate deposition is formed in sea-level rise period. This is documented that the deposition of phosphate is confined in the shelf edge and slope area where the phytoplankton is flourished and upwelling prevails.

In the oceanic environment, phosphorus is relatively rare with an average of only 70 ppb in both organic and inorganic forms and surface water is further deplete of inorganic phosphorus by phytoplankton activity (Phillip, 1986). Phosphate-enriched water is mainly introduced to the shelf and slope through upwelling which increases the surface water concentration and, as a result, phytoplankton activity. Phosphate is incorporated into the sediment through the introduction of phytoplankton remains, which through decomposition result in the accumulation and concentration of inorganic phosphate in oxygen-poor sediments. Phosphate accumulation predominantly occurs in areas of upwelling currents and the optimum water depth for phosphate formation is from 30-200m (Phillip, 1986; Parrish et al., 2001; Coles et al., 2002).

Most phosphate minerals are formed close to the sediment/ water interface by precipitation from interstitial waters (Bentor, 1980) and phosphatization took place under anoxic conditions where interstitial waters become greatly enriched in phosphate compared with the concentration of phosphate in bulk sea water. Decomposition of organic phosphate causes the dissolved phosphate concentration in the interstitial water to rise (Berner, 1974).

These organic-rich sediments accumulated along the continental shelf, which had considerable bathymetric relief (Edman and Surdam, 1984). A widespread oxygen-minimum zone coincided either continually or frequently with the sea floor as deposition progressed, and upwelling was both strong and persistent (Edman & Surdam, 1984).

Thus the association of authigenic phosphate minerals with organic-rich sediments may be a consequence of the chemical reactions that are prerequisites for the precipitation of calcium phosphates (Edman and Surdam, 1984). The dissolution of fossil fragments immediately following the precipitation of calcium phosphates was probably related to removal of calcium from the pore water by the calcium phosphate minerals. As precipitation of apatite began, the concentration of calcium ion decreased, which resulted in the dissolution of the calcareous fossils.

## Glauconite and phosphate association

Glauconite and phosphate minerals occur in varying quantities in sediment continental margin of Ayeyarwady continental shelf. Glauconite, in particular, comprises a significant component of the siliciclastic-rich sediment with. Glauconite-phosphate associations are common features in marine environments with many examples known from continental margins in the rock record (e.g. Shublik Formation, Arctic Alaska (Parrish et al., 2001); Helvetic Shel, north Africa (Notholt and Jarvis, 1990)) and in the modern (e.g. East Australian continental margin, (James et al., 2004); outer continental shelf, Cape Canyon, South Africa, (Compton et al., 2004).

Glauconite is commonly associated with phosphate (McRae, 1972; Odin and Fullagar, 1988). These samples imply low sedimentation rates, which allowed a glauconite-phosphate association to form on the upper slope (Phillip, 1986).

Both phosphate and glauconite require slightly reducing conditions and organic decomposition and along with these analyses this indicates that phosphate and glauconite are being precipitated simultaneously on the Ayeyarwady continental shelf area. Slow deposition of phosphate and glauconite in condensed sections is common and often associated with sea level rise (Compton, 1989).

The skeletal grains are replaced by carbonate apatite. Both francolite and dahllite have been identified in these phosphorites, and glauconite is frequently found too.

Glaucony has also been inferred to be present both at the base of the transgressive systems tract (Baum and Vail, 1988). (Van Wagoner et.al. 1990; Vail et.al., 1991) and in the entire TST (Transgressive Systems Tract) (Mitchum and Van Wagoner, 1991).

Autochthonous glaucony in common at various stratigraphic levels in the transgressive systems tract (TST) and the lower highstand systems tract (HST), showing an upward increase (TST) and then decrease (HST) in abundance and maturity (Amoros,1995).

According to Amorosi (1995), glauconite can occur in most depositional sequences but is generally most common in the deposits of the transgressive systems tract (TST). The intrabasinalclasts such as glauconite and phosphate mostly occur in transgressive episode (Zuffa, 1980) (Fig.18). The condensed section can be distinguished by the higher concentration of glaucony (Fig.19). Therefore, the high glauconite concentration in study area can be regarded as TST which attained present sea level position (Fig.19). In condensed sections very high concentration of glauconite occur compared to the over- and underlying deposits. Differing rates of supply of siliciclastic sediment is the primary control on the presence of glauconite in depositional sequences and, as such, glauconite is considered one of the most reliable indicators of low sedimentation rates (Amorosi, 1995).

Phosphate grains, with abundant skeletal material, are common in condensed sections where the glauconite concentration and compositional maturity is greatest with dark green, evolved and highly evolved glauconite grains widespread.

Whichever, the relative sea level rise must have been rapid to promote the very low sedimentation rates conducive to glauconite formation (Amorosi, 1995). It can be concluded that, after the regression, which form the formation of relict sand followed by a sea level transgression which affecting present sea-level favors the formation of glauconite.

## Summary and Conclusion

The study area is located in northern part of Adman Sea bounded by latitude 13º 25´ N and 15º 40´ N and longitude 93º 15´ E and 97º 45´ E occupies the south and southwest oceanic area of Myanmar. The area extent is approximately 101250 km$^2$.

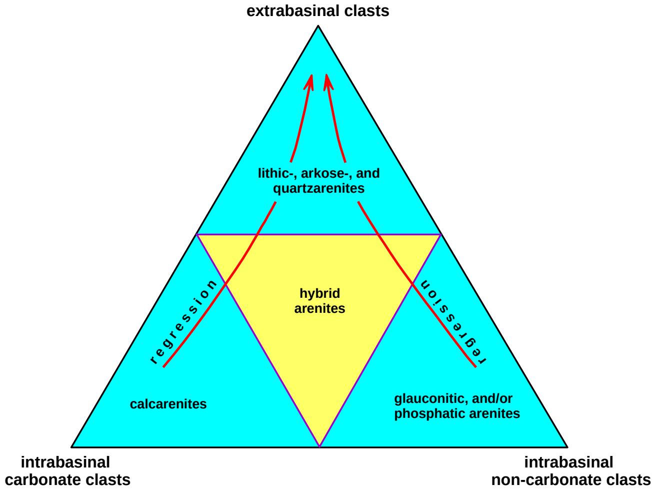


**Figure 18** Triangle showing possible changes in the proportion of extra-basinal and intra-basinal, framework grain composition of sandstones due to changes in the relative sea level (after Zuffa, 1980).

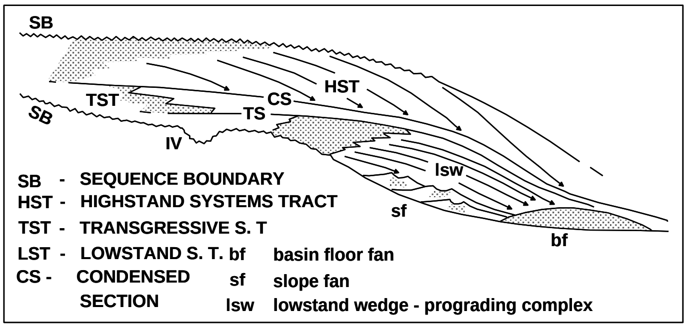


**Figure19** A sequence stratigraphic context showing the marine condensation (after Walker, 1992)

Ayeyarwady continental shelf is part of an area of a complex geological setting in Andaman basin, located in the south of Ayeyarwady delta surrounded by land area in north and east. Ayeyarwady continental shelf has a tidal range between 4m-7m is located in tropical climate and the Ayeyarwady, Thanlwin and Sittaung rivers flow into the study area. The glauconite and phosphate are especially focused as authigenic minerals of the study area. Glauconite constitutes 1-15.5% of the total detrital fraction in some station. The glauconite of biotite origin, fecal pellet conversions, foramifera cavity fillings and replacements also occur.

Phoshphate constitute 1-10% of the sediment as replacement of bioclast, micro coprolite phosphate pellet and cement. The phosphates are formed in the shelf edge and slope where upwelling current favours the formation of phosphate. The association of glauconite and phosphate are conspicuously occur in shelf edge sediment. They were form during slow sedimentation in transgressive phase forming the condense horizon. The formation of glauconite needs normal salinity, slightly reducing and weakly oxidizing condition in marine environment. It requires, 7-8 pH condition that is slightly alkaline condition, therefore it can form only in marine water. Therefore it can be concluded that glauconite and phosphate mostly occur in transgressive episode. In the present sea-level, the shelf, shelf edge and slope are the best fit for the formation of glauconite and phosphate.

## Acknowledgements

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