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Changes in depositional environments from Ordovician to Tertiary of carbonate rocks in Tak-Mae Sod area, Northwest Thailand

BENJAVUN RATANASTHIEN
Department of Geological Sciences, Faculty of Science, Chiang Mai University, Chiang Mai 50002, Thailand

Abstract—Carbonate rocks ranging in age from Ordovician to Tertiary along the Tak-Mae Sod and Mae Sod–Umphang highways were analysed mineralogically, petrographically, and geochemically. The study revealed the depositional environment of the mainly chemical precipitated Ordovician carbonate rocks to be in shallow (lagoonal?) waters of a warm climate. The Carboniferous carbonates were chemically deposited in moderately deep to deep water as indicated by siliceous limestone composed mainly of calcite and radiolarian chert and/or interbedded chert bands. The environment changed to shallower water during the Permo-Carboniferous as seen in the Pra Woh Limestone. The carbonates are characterized by pale colour dolomite, dolomitic limestones and calcareous sandstone. They are sometimes, fossiliferous, mainly bryozoa, foraminifera, corals, gastropods and bivalves. During Triassic to Jurassic, the carbonates were deposited in comparatively shallow and/or closed basins as indicated by alternating sequences of dark to black limestone, calcareous shale and calcareous sandstone. The rocks are composed of high carbonaceous material and clays with few fossils associated. The environment changed to brackish and eventually to fresh water during the Tertiary indicated by fossiliferous limestone (pelycypods and gastropods) and dolomitic limestone which are chemically precipitated in fresh water.

INTRODUCTION

The Tak-Mae Sod area (Fig. 1) has one of the most complete sedimentary marine sequences in Thailand. The area has been referred to as part of the Western Thai Zone (Fig. 2) by Barr and MacDonald (1991). The rocks consist of Cambro-Ordovician siliciclastic and carbonates underlying fine-grained clastic sequences (phyllite?) with thin-bedded to nodular limestone and chert of the upper Paleozoic. The Mesozoic rocks comprised marine Triassic and Jurassic with granitic intrusions during the Triassic (200–209 Ma) and Cretaceous (140–93 Ma), from radiometric age dating of Mahawat *et al.* (1990). Tertiary and Quaternary deposits are said to be fresh water but littoral deposits occur at the lowermost part of Mae-Sod Tertiary basin.

GENERAL STRATIGRAPHY FROM CAMBRIAN TO TERTIARY

Bunopas (1981) described the lithostratigraphy of the area. The geologic setting from Cambrian to Tertiary can be simplified as follows:

Khlong Wang Chao group consists of:

Pong Nam Ron quartzite formation (Earliest Ordovician or Cambrian?). The rocks consist of thin-bedded quartzite, quartz-schist, pelitic schist and mica schist of the greenschist facies, faulted against the Precambrian Lansang Gneisses of high amphibolite facies. The Formation is lying beneath the Suan Mark Limestone.

Suan Mark limestone formation (Ordovician). The rocks consist mainly of well banded argillaceous limestone. The major part has been deformed into slate, recrystallized limestone and quartzite. The poorly preserved fossils and inferred lithology similar to that of the Manao Limestone suggest an Ordovician age.

Doi Musur Group (Silurian-Devonian to Early Permian). The name Doi Musur Group was proposed for a sedimentary sequences of quartzite, phillite, shale, siltstone, sandstone and banded limestone with chert nodules towards the top. Fossil bryozoa (km 49 and 50) indicated a probable Carboniferous to early Permian age and the fusulinid *Monodiexodina spiptoni* Dunbar, found in sandstone intercalation in the thin chert beds indicates a Lower Permian age.

Pra Woh limestone (Permian). The rocks consist mainly of dolomite with rare intercalations of quartzose sandstone, dolomitic limestone and chert, fossils are rare and not possible to be identified.

Mae Maei group (Late Middle Triassic to early Late Jurassic). The rocks named by von Braun and Jordan (1976) for the sedimentary sequence consisting mainly of sandstones, shale and limestone with ammonites, brachiopods *Phynchonella bambanagensis*, *R. concordia*, *R. fissicostata* and algae *Holosporella siamensis* of upper Triassic. In the Huai Hin Fon shale, siltstone and limestone, the ammonites *Erycytes* sp., *Tmetoceras* sp. and *Ludwigia* sp. and *Posidonia affornati* were found and an Aalenian age was suggested.

Mae Sod Group (Cenozoic). The rocks consist of the Mae Ramat gravel and Mae-Sod shale and oil shale with purplish to brown sandstone and thin lignite, underlying sandy shale with gastropods and thin-bedded limestone at the bottom of the sequence; *Viviparus* sp., bivalves, snakes and fishes.

MINERALOGY AND GEOCHEMISTRY OF THE LIMESTONES

Samples of limestone were collected along Tak-Mae Sod and Mae-Sod–Umphang Highway at the following localities:

Ordovician Limestone km 28–28.5, Tak-Mae Sod Highway;
Carboniferous-Lower Permian km 52–55, Tak-Mae Sod Highway;
Permian Limestone km 49–50, km 62–66, Tak-Mae Sod Highway;
Triassic Limestone km 67.5–69, Tak-Mae Sod Highway;
Jurassic Limestone km 69–73, Tak-Mae Sod Highway;
Tertiary Limestone km 19.5–20.5, Mae-Sod-Umphang Highway.

The samples were utilized for preparing thin sections, for petrographic study, and for X-ray and chemical analysis.

PETROLOGY

Ordovician limestone

The rocks have micaceous layers which show microfolds and lineations. Quartz fragments which are present are generally undulated fine-grained subangular to subrounded, embedded in recrystallized calcite and dolomite; laminations are easily observed in thin sections, possibly representing former structures.

Carboniferous limestone

The Carboniferous limestones are characterized by the presence of chert in the form of nodules or in banded association. In thin section, radiolarians were observed scattered in the calcite groundmass grading to pure chert. Dolomitization after siderite are common and resulted in traces of iron oxides along zoning structures of the overgrowth dolomite. The calcite groundmasses are generally recrystallized, sometimes replacing unidentified fossils.

Permian limestone

Permian limestones are characterized by pure dolomite and dolomitic limestone. Two sizes of grains are observed in thin sections and hand specimens. The lower part of the Pra Woh limestone is coarse-grained dolomite whereas the upper parts are fine-grained. Small chert nodules are observed in the lower part but nearly absent in the upper part. There are no traces of fossils. Owing to recrystallization it is very difficult to study the former structures before dolomitization.

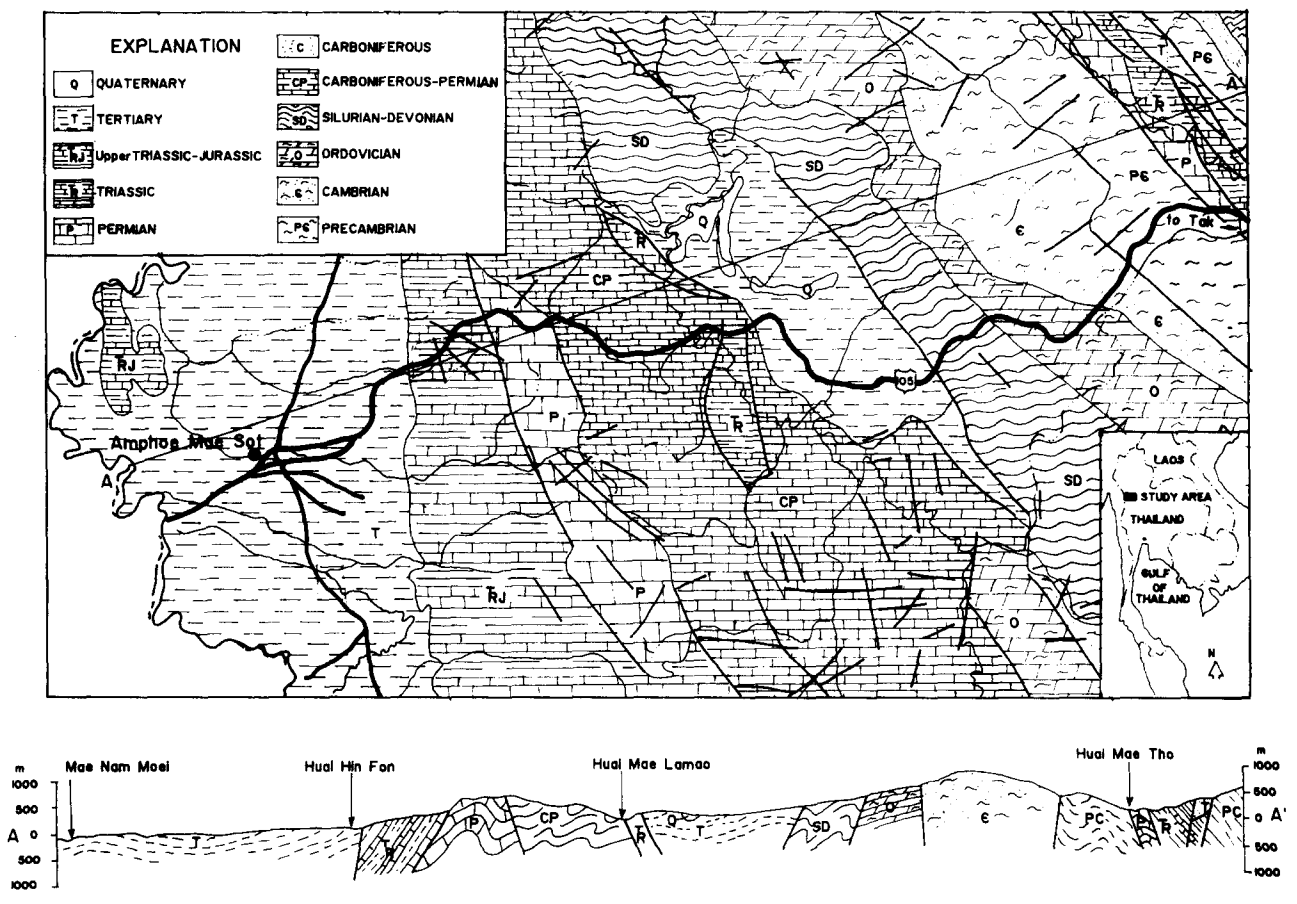

Fig. 1. Geological map of Tak-Mae Sod, showing the stratigraphic sequences (after Sukto *et al.* 1984).

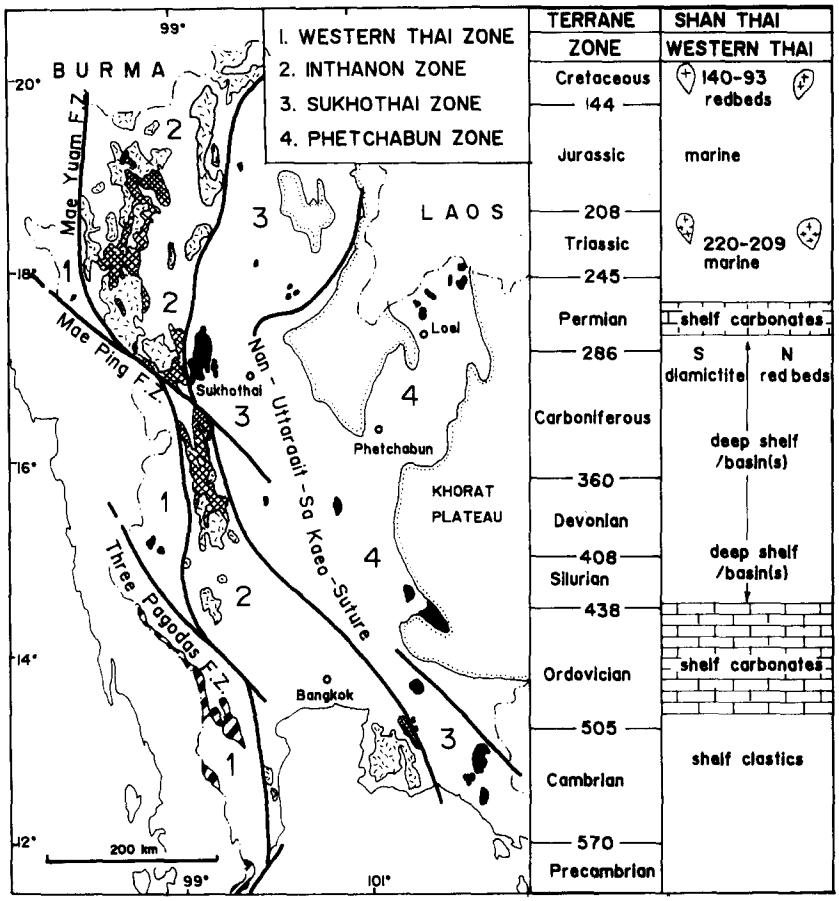

Fig. 2. Tectonostratigraphic zones and space–time diagram of western Thai zone, as described by Barr and MacDonald 1991. (Modified from Barr and MacDonald 1991). ‡ granitic intrusion with radiometric age.

Triassic limestone

The Triassic limestones are in fact siliceous limestone or calcareous sandstone. Subangular to subrounded sand to fine-silt size quartz grains are embedded in the micritic limestone matrix. Other minerals are mica, clay minerals and authigenic opaque minerals. The carbonates are essentially both detrital and chemical precipitation. No sparitic calcite was observed.

Jurassic carbonate

Jurassic limestones are mainly micritic limestone with abundance of fossils. They are composed of fine-grained calcite, with very fine-grained quartz or chert. Fossil traces are filled with calcite, chalcedony or are void. Shell and fish skeletal remains are found replaced by calcite and pyrite (already oxidized). The textures show loose compaction. Microlaminations are sometimes observed in the fine-grained quartz or chert.

Tertiary carbonate

Tertiary carbonates are similar to those of the Jurassic but only have more detrital quartz fragments and chert. Organic skeletal shell fragments and diatoms are of phosphate, silica, and calcite, sparry calcite and chert. The degree of void filling is higher than those of Jurassic carbonate and all the fractures and organic voids are filled. No lamination can be seen despite the thin-bedded nature of the carbonates.

MINERALOGY FROM X-RAY DIFFRACTIONS

Mineralogy of these limestones shows little dissimilarities according to the age of the rocks except the Permian Pra Woh limestone. However, metamorphism of the Ordovician limestone caused some dissimilarities (Table 1).

CHEMICAL ANALYSIS

Acid insoluble residue, ignition loss, and some major elements, i.e. Ca, Mg, and Fe were analysed. The results are shown in Table 2.

DISCUSSION

The compositions of limestone collected along Tak-Mae Sod and Mae-Sod–Umphang Highway can be used to interpret some aspects of the geological history of the so-called Western Thai Zone (Barr and MacDonald 1991). The deposition environments revealed by this

Table 1. X-ray diffractometric analysis of limestone collected in Tak-Mae Sod area

Rock age	Mica and clay minerals(%)	Quartz (%)	Calcite (%)	Dolomite (%)	Others (%)
Ordovician	8–10	30–40	35–48	5–8	0–7 (Plagioclase)
Carboniferous	—	30–45	40–50	5–15	0–5 Siderite (Trace)
Permian	—	5–10	5–7	88–90	—
Triassic	5–10 Mica, chlorite	50–55	30–35	0–5	0–5 Magnetite
Jurassic	0–5	5–10	80–85	0–5	—
Tertiary	0–5	10–20	45–60	30–45	0–5 Siderite, pyrite

study indicate that sea level changes in the area have played important roles. Major tectonic effects could be seen only in the calc-silicates of the Langsang suite and marble of the Ordovician limestone. Petrographic studies provide further evidence for interpretations of the geological history.

Petrographic studies

Ordovician limestone samples collected from the area near Doi Muser have subangular to subrounded, undulated quartz grains of fine-sand size embedded in recrystallized calcite and mica. Gradational amounts of quartz can be seen, varying from very rich in quartz to nearly pure calcite. The micas which are mainly phlogopite and muscovite could be altered from clay minerals deposited at the same time as the quartz and carbonates in shallow water of moderately weak energy, to account for their poor sorting. During alteration, clay minerals could pick up the magnesium released from dolomite in the limestone to form phlogopite. Iron oxides are sometimes found concentrated along the stylolithic boundaries between calcite and mica. The limestone could originate as a fine-grained chemical precipitate giving rise to comparatively fine-grained marble. After recrystallization, former structures cannot be identified.

Carboniferous limestones contain calcite, microcrystalline quartz or chert and dolomite. Chert bands and nodules are easily observed in the field. However, in thin sections, variable amounts of chert globules embedded in limestone, even up to pure chert, can be seen. These cherts sometimes show radiolarian structures and pelmatozoan fragments. In the limestone matrix, calcite grains are mainly recrystallized with dolomite overgrowth. Zoning structures made up by iron oxides are common with large crystal in calcite dominated areas and small crystals in chert dominated areas. The iron present could be altered from siderite or chamosite which are generally deposited in moderately deep water. For the presence of chert and limestone, according to Chilingar *et al.* (1967), the pH could be between 6 to 7.5 and Eh between +0.05 to −0.2, in the CO_2 zone where the most active agent is HCO_3—especially at the bottom part of the zone. In the upper part of this sequence, (Permian?) fossil traces increased, mainly bryozoa (*Fenestella* sp.) and sponge which can be clearly seen in hand specimens. In thin sections, these traces, mainly spicules, are filled with calcite, sometimes chert or partly with chert. The appearance of these features indicate the decreasing water depth towards the early Permian. At 50 km, the limestone facies changed to sandstone with chamosite.

Permian limestone, the term usually referred to the Pra Woh limestone, is dominated by dolomite. In these rocks, the presence of chert grains in the recrystallized limestone would indicate that the water level was moderately deep. In this section, the degree of different compression can be seen from the lower part (opposite Pra Woh Memorial) the dolomite where larger crystals as well as chert globules show welded and sutured edges.

At the upper part of the Pra Woh limestone the dolomite is finer grains with less degree of welding and increasing amount of calcite. Similar appearances are also common in the Umphang area. Magnesium impregnation into limestone along faults or rift structures could be the cause of the dolomitization. The degree of dolomitization is less in the adjacent Permo-Carboniferous rocks.

Triassic–Jurassic limestone (Mae Moei Group)

The Nern Pisawong area (km 67.5–68) could be underlain by a good representative of Triassic rocks, mainly

Table 2. Average contents of some limestones collected from Tak-Mae Sod area

Rock age	Acid insoluble residue(%)	Ignition loss(%)	CaO(%)	MgO(%)	FeO(%)
Ordovician	40.1–59.6	18.0–28.6	22.5–31.5	4.4–8.22	0.21–0.66
Carboniferous	28.0–45.2	23.7–31.6	21.0–37.2	1.64–12.7	0.3–0.57
Permian	7.9–11.9	42.0–43.7	26.8–28.0	19.2–20.0	0.1–0.68
Triassic	49.9–59.6	17.8–21.9	13.5–18.5	0.66–1.44	2.79–5.37
Jurassic	2.5–11.2	26.6–42.7	33.8–47.2	1.24–2.06	0.48–1.04
Tertiary	11.5–22.5	23.0–38.3	25.5–35.7	9.09–15.1	0.79–2.01

calcareous sandstone or calcarenite and mud rocks. The rocks are graded layers from muddy shale, siltstone to sandstone. The calcareous rocks have equal amounts of calcite and quartz with some clays and calcite cements. Sparry calcites are not common but the appearance of hexagonal shaped opaque minerals, probably magnetite after hematite or ilmenite, is common. Lamination are clearly seen from the arrangement of elongate or platy mineral grains, together with subangular to subrounded quartz, indicating energy of transportation to be moderately strong but no reworking from the poor sorting. The level of water should not be very deep. In the sequence, the quartz contents can be seen decreasing towards the upper part.

Huai Hin Fon limestone (Jurassic) at km 70–73 of the Tak-Mae Sod Highway is well-exposed but the section is mainly mudstone or shale. A good outcrop, about 1 km from Huai Hin Fon Village is mainly muddy limestone with alternated thin-bedded black shale and mudstone. This formation is well known for its rich fossils, e.g. *Posidonia* sp. and ammonite *Ericytes* sp. In thin sections, the rocks show chemical precipitation as lime mud. Fossil traces and bioturbation as well as fossil remains are common. Quartz grains range from fine-sand size to very fine silts dispersed in the rock and make up from 5–25%, sometimes as a mud lump in the lime groundmass. Round voids which could be fossil remains or gas bubbles after diagenesis, are found distributed in some parts of the rocks. Sparry calcites are rare, and found only as fossil fillings.

The Huai Hin Fon limestone, thus clearly indicate the environment of deposition to be a moderately deep but quiet water with reducing conditions.

Tertiary limestones are found mainly in the southern part of Mae Sod. It is thin-bedded, 20–50 cm, and associated with shale and sandstone. At km 20 Mae-Sod–Umphang Road, the reddish limestone containing *Viviparus* sp. was studied. The rocks in thin section indicate chemical precipitation with very rich fossil traces and remains. Voids are filled either with carbonate or microcrystalline quartz. It is denser than those found in the Huai Hin Fon limestone despite the younger age. Very fine-grained quartz in the rocks could be detrital or could also be chemical precipitation. Bedding or lamination features are not found in the rocks and this could indicate that deposition occurred in a closed, high salinity (carbonate-rich) basin.

The interesting point about this rock is the significant amount of Zn and Pb. The carbonates could have absorbed these elements from the solution during or after deposition due to its proximity to the source of the Pha Daeng zinc deposits.

The other Tertiary limestones in Mae Sod, Pob Pra and Umphang are also found to be fossiliferous. The lower part of the Tertiary, in Pob Pra and Umphang area has fossil remains similar to those found in the Krabi Basin, and could have a similar environment of deposition, brackish or littoral.

TECTONIC EVIDENCE FROM THESE CARBONATE DEPOSITS

The carbonate sequences of the Western Thai Zone in the area of Tak-Mae Sod show continuous marine influences from Ordovician to Permian. There are some breaks or unconformities during early Triassic to late Triassic when the Mae Moei Group of reducing marine origin was deposited. During the Cretaceous to Early Tertiary the marine carbonates changed from littoral to lacustrine environments in Middle Tertiary. During the Ordovician, the depth of the water was comparatively shallow when compared with the depth of the very fine-grained clastic sediment which formed slate in the Silurian-Devonian age. Metamorphism of this rock could have occurred at the same time as the Cambrian and Devonian rocks. During the Carboniferous, the level of water was even deeper, from the presence of non-clastic sediments. The depth of water decreased towards the Permian where shallow water fossils were found. There must have been some breaks during the Carboniferous to early Permian. It is also not comparable to the Phetchabun Zone where Carboniferous rocks in Loei Province are terrestrial (it changed to shallow marine during early Permian). During the Permian, limestone was deposited, associated with rifting. The input of magnesium was from the lower part of the rift which caused more complete dolomitization at the bottom part than the upper part. Barr and MacDonald (1991) remarked that during the Early Mesozoic this zone is a part of the foreland thrust belt verging westwards over the Shan–Thai craton. However, the reducing marine environment during the deposition of Triassic–Jurassic sequences would indicate that the deposition occurred in a euxinic basin.

During the Cretaceous, igneous intrusions of the Tak granitic belt caused uplift and erosion in the area. However, during the late Eocene to Oligocene, Mae Sod could be a graben connected to the sea along the western part which introduced littoral deposits at the lowermost sequences of the Tertiary. In the late Oligocene when coal and limestone beds were deposited, the overlying diatom-rich carbonates could indicate that the basin changed to a carbonate rich-oxidizing environment.

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