Chapter 2
Geology

2.1 Regional geology

There are several published papers regarding geology in Loei and neighbor areas. Brown et al. (1955); Bleakly et al. (1965); Jacobson et al. (1969); Workman (1975) and Bunopas (1981) have undertaken regional and local geological surveys. A number of geological reports and geological maps at 1:50,000 scale have been published by many investigators from the Geological Survey Division, Department of Mineral Resources (DMR) (Chairangsee et al., 1990; Chairangsee and Macharoensap, 1985; and Sillapalit and Chairandsee, 1982,1983). Bunopas (1988) complied the geology of the Loei AEM area at 1:100.000 scale under the Mineral Resources Development Project.

The regional geologic setting of the Loei area is summarized from the report of Bunopas (1988) at 1:100,000 scale and of Chairangsee et al. (1990) at 1:50,000 scale. Rock sequences begin with Middle Palaeozoic metamorphic rocks, which mainly include quartzite and phyllite in the eastern part of the area. These metamorphic rocks are unconformably overlain by alternated strata of shale and siltstone with tuff and intercalated limestone. Intensely folded chert of Middle to probably Palaeozoic age (Sashida et al., 1993) is restricted to the western part. The chert unit is situated adjacent to spilitic basaltic volcanic of the age ranging from Devonian to Permian (Intasopa and Dunn, 1994). Both chert and basalt units form a long, narrow north-trending belt. This sedimentary package likely represents an accretionary prism. This basaltic unit extruded on the sea floor forming huge masses of volcanic tuff and pillow lava associated with sporadic manganese deposits. In Late middle Devonian to Carboniferous, thick graywacke intercalated with shale and reef limestone, was discovered in several places. Late Palaeozoic, reef limestone lie unconformable over the older rocks. Felsic tuff and granodiorite rocks, such as rhyolitic tuff, granodiorite, etc., of mostly Triassic age (Charusiri, 1989) cover a large area located mostly in the central part of the investigated area.

Three major structural features, unconformities, folds and faults, are recognized by Bunopas (1988) and Chairangsee et al. (1990). The main faults and fold axes are oriented in a north-south direction. The unconformities have been stratigraphically poorly identified between strata of different ages, for example, between Permian and Late Triassic and between Lower Carboniferous and Devonian, etc.

Bunopas (1991) recognized the Loei area as part of the major fold belt called " Loei Fold Belt". Large anticlines and synclines, whose axes are mainly in the north-south direction, are recorded especially in Silurian and Permian rock sequences. Many folds are dislocated by several sets of faults. Strike-slip faults trending northeast-southwest seem dominant and they dislocate major folds and pre-existing thrust faults. Sinistral movement, which is more common than dextral movement, is present especially in the western part of Loei. This is probably due to the continuous clockwise rotation of continental southeast Asia (Bunopas, 1981). The large north-trending overthrust in the eastern part of Loei area separates Silurian-Devonian metamorphic rocks from Carboniferous sedimentary rocks.

2.2 Tectonic Setting

Several authors agree that Thailand is composed of two continental terraines, The Shan- Thai terraine in the west and the Indochina terraine in the east, where were welded together along the Nan Suture (Bunopas, 1991) as show in Fig 2.1.

The Shan- Thai terraine comprises eastern Myanmar, western Thailand, western Peninsular Malaysia and northern Sumatra. The terraine consists of Precambrian granitoids, and high-grade metamorphic rocks overlain by the Palaeozoic and Mesozoic rocks (Bunopas, 1981 and Fontain, 1986) intruded by the Carboniferous to Cretaceous granite.

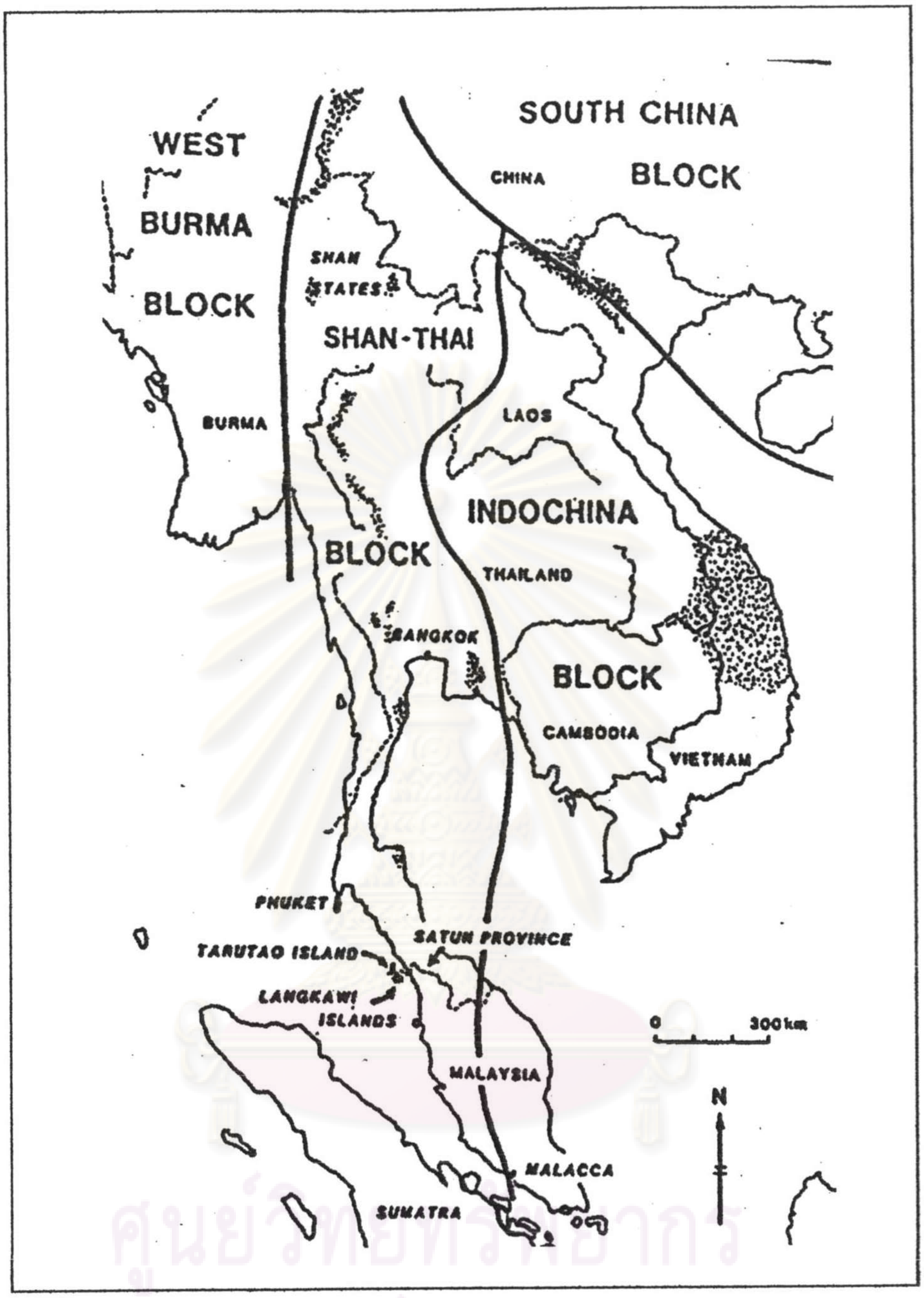

Figure 2.1. Regional map of mainland Southeast Asia showing the cratonic basement of Shan-Thai and Indochina plates (reproduced from Bunopas, 1991).

Several researchers (Bunopas and Vella, 1983,1992; Chantaramee, 1978; Bunopas, 1989) proposed westward subduction beneath Shan-Thai terraine, prior to collision. This is due to the wide distribution of Silurian-Devonian and Middle Permian-Early Triassic volcanism in central north Thailand and due to the westward structural variance. However, Beakinsale et al. (1979) and Cooper et al. (1989) suggested an eastward subduction beneath Indochina, based on the position of S-and I- type intrusive rocks.

The Indochina terraine consists of eastern Thailand, Laos, Cambodia and part of Vietnam. In Thailand, the terraine comprises mainly middle Palaeozoic rocks and Permian platform carbonate and deep-water clastic rocks (Wielchowsky and Young, 1985). These rocks were intruded by carboniferous to Cretaceous granite in Loei folds belt and are covered by gently folded Mesozoic continental sedimentary sequences of the Khorat Group.

The Indochina terraine probably rifted off from the Gondwanaland during Palaeozoic time. Although the precise rifting age is not known, the presence of a regional unconformity of the late Devonian-early Carboniferous period seems to support Devonian rifting (Bunopas, 1981 and Metcafe, 1990)

The boundary between the Shan-Thai and Indochina Terraines represents by the Nan-Chantaburi Suture Zone, which also called the Nan Suture or Nan-Uttraradit Suture by the others (Barr and Macdonald, 1991). This suture is the mobile area of repeated orogenic movements since the Palaeozoic and is mostly considered to be the late Triassic collision (e.g. Chaodumrong, 1992; Bunopas, 1981). In the late Permian times, the Shan-Thai terraine collided with Cathaysialand, and the suturing to the Indochina terraine was largely completed by the late Triassic (Bunopas, 1981 and Chaodumrong, 1992). Charusiri et al. (1997) described the Loei suture in the Indochina plate as shown in Fig. 2.2.

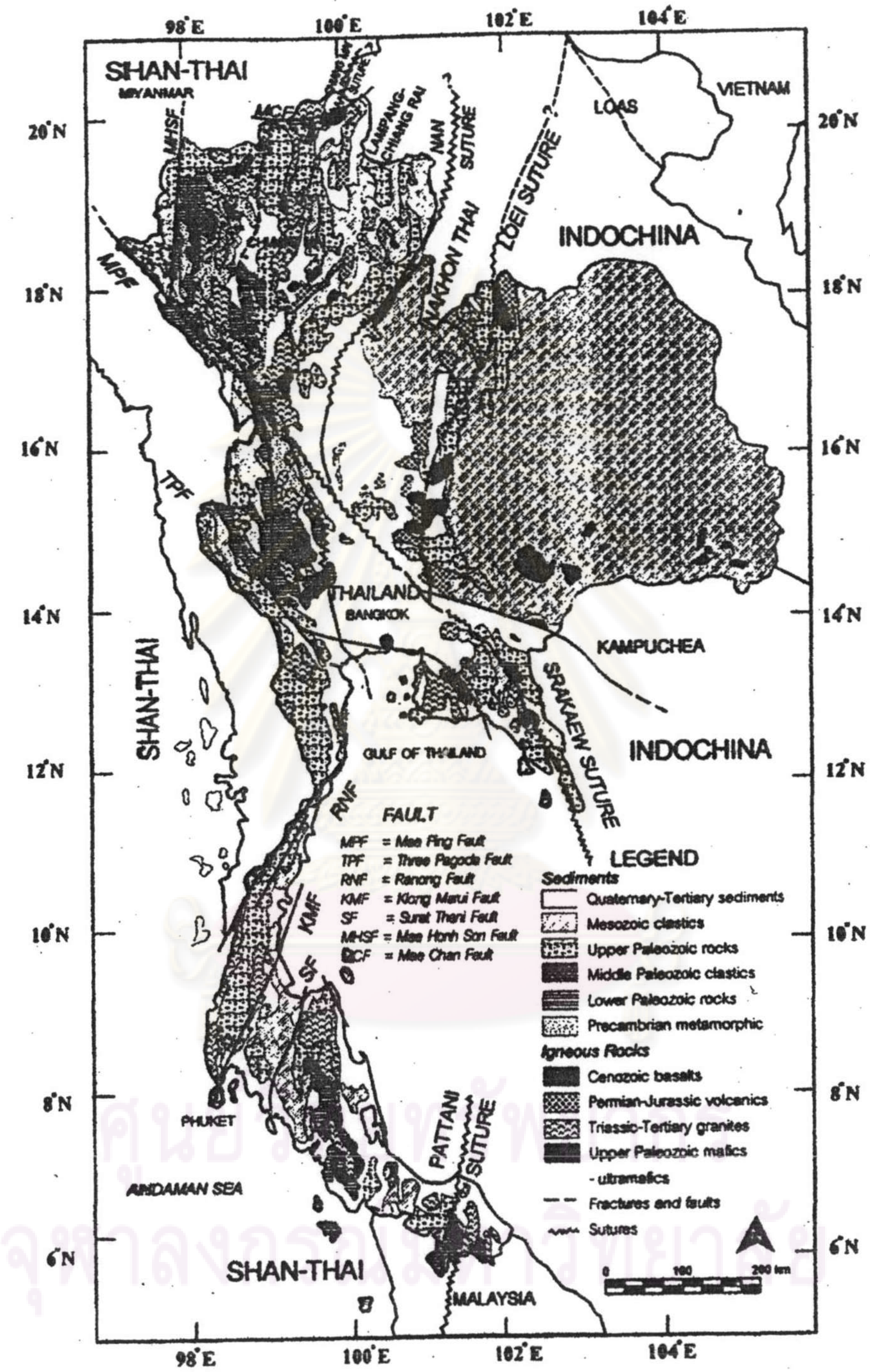

Figure 2.2 Location of Nan and Loei Suture Zones (reproduced from Charusiri et al., 1997).

As noted above, many researchers mostly studied the Shan-Thai terraine, but the characteristics and the evolution of the Indochina terraine is not fully understood. Chairangsee et al. (1990) reported the tectonic events by using the rock sequences in the Loei area as follows:

The oldest known orogeny in the study area, which produced the regional metamorphic basement, can be dated only as older than Late Silurian, because Upper Silurian sediments were not affected.

The next and most important orogenic cycle began during the Middle Devonian, with the almost syn-sedimentary deformation of chert associated with submarine volcanism. The tectonic activity gradually intensified. While sedimentation continued in most past of the area, vertical movements exposed certain areas to erosion, thus enabling the Bashkirian reef limestone to accumulate on Middle Devonian spilitic basalt, and the upper Carboniferous to Lower Permian coal series to be deposited on the Middle Devonian serpentinite. The orogeny reached its climax during the Late Carboniferous. The coal series and the Middle Permian limestone were still affected by the deformation, but to a lesser degree. The folding was complete before the Upper Permian-Triassic igneous activity commenced, i.e. emplacement of granodiorite and eruption of rhyolitic tuff. Later tectonic movements were restricted to some insignificant faults with unknown vertical displacement.

Very recent uplift elevated the Palaeozoic Rocks of the map area and exposed them at the surface. This movement is probably still going on. It has raised the north more than the south, with the result that whole structure plunges very gentle southward.

2.3 Lithology and stratigraphy

The compilation of a detailed geologic map can be explained by grouping of rock types and ages. Many sedimentary, igneous and metamorphic rock units raging in age represent the geology in the study area from Silurian to Quaternary (Fig 2.3).

The rock sequences are controlled by bedding and structure in a north-south trend. Most of the Palaeozoic rocks are deposited in a marine environment, whereas younger rocks are predominantly non-marine. The sequences of the Silurian to Triassic rocks are as follows:

2.3.1 Na Mo Formation (Silurian)

The oldest rocks in the Loei area are low-grade metamorphic rocks, which are distributed in the eastern part of the Loei. They consist of phyllite, chlorite and pelitic schists, meta-tuff and quartzite that make up a north-south trending escarpment in the eastern part of the Loei area. The quartzite and phyllite were obviously affected by tectonic deformation and metamorphism much more intensely than all other rocks in the map area. The ages of the oldest rocks are known of middle- late Silurian age (Chairangsee et al, 1990). The relationship with younger rocks is unknown because the eastern part is covered by the Permo-Triassic volcanic rocks and on the west it is a thrust fault contact with Carboniferous rocks (Bunopas, 1981).

2.3.2 Pak Chom Formation (Devonian)

The latest Silurian to Devonian sequences outcrop mainly east of Loei, and consists of two members (Bunopas, 1988). The lower part (*Ban Nong Shale Member*) from a narrow outcrop of mainly shale, thin bedded limestone, tuff and chert containing abundant Devonian corals. The upper part of the Pak Chom Formation (*Pak Chom Chert Member*) is more extended to the east of Loei, especially in Pak Chom district. It consists of abundant chert beds and the intercalation of tuff and limestone bands containing middle Devonian fossils (Fountain and Tantiwanit, 1987). The rocks of this member are thought to grade into Carboniferous rocks, but some conglomerates are found in many places in the lower part of these rocks.

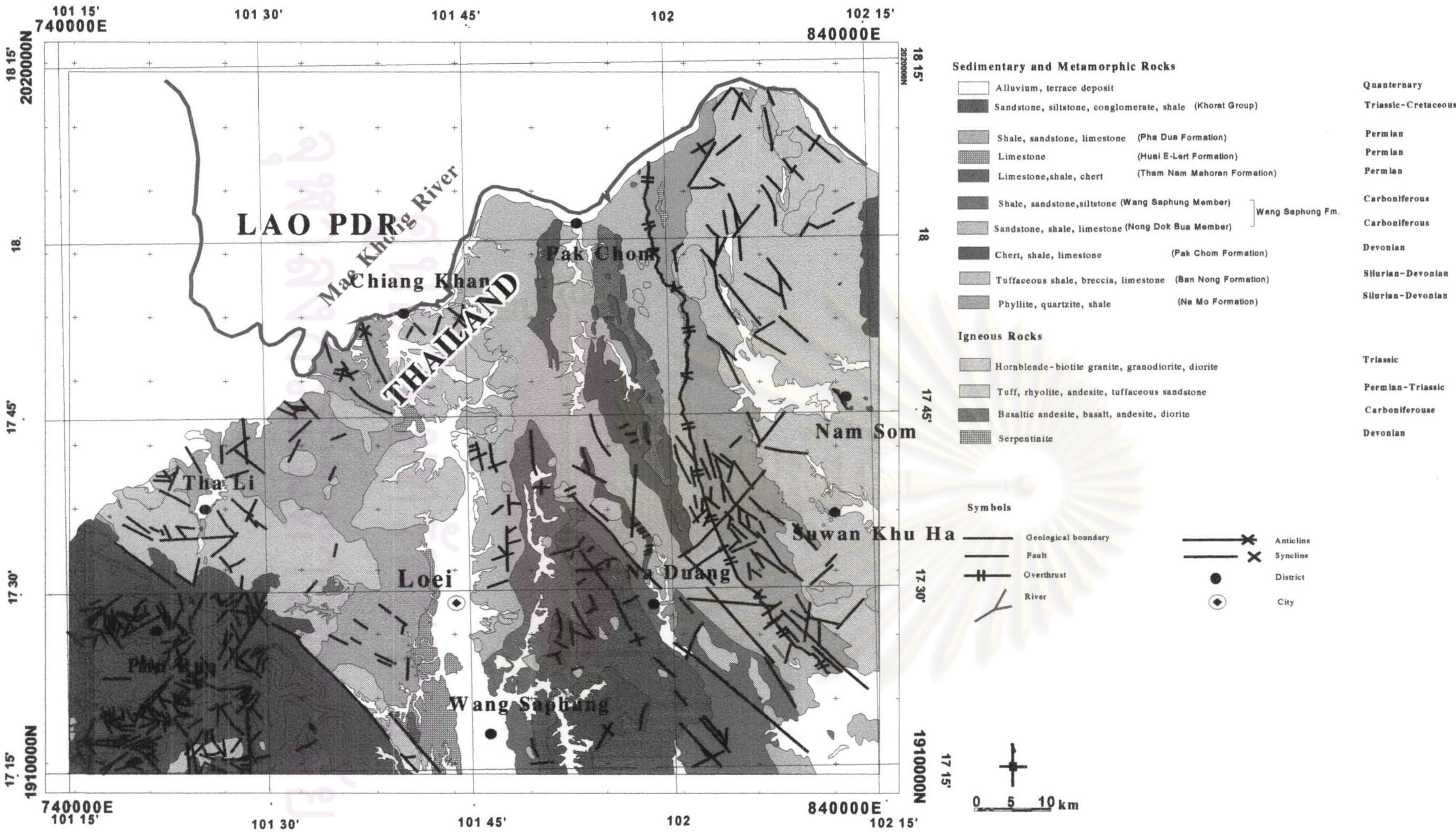

Figure 2.3 Geological map of the northern Loei area (modified from MRDP, 1987 and Chairangsee et al.,1990).

2.3.3 Wang Saphung Formation (Carboniferous)

Wang Saphung Formation (Bunopas et al., 1988) consists mainly of sandstone, shale with some thin limestone beds and conglomerate. These rocks are mainly shallow marine in origin with some fossil leaves and corals near the lower part, indicating more intervening of continental deposits in this area during the late Palaeozoic time. The formation is divided into 2 members from top to bottom.

The lower member (*Nong Dok Bua Member*) covers a wide area in Pak Chom, consisting of thin bedded chert, sandstone, silstone, tuff and limestone lens with some conglomerate containing Devonian-Carboniferous fossils (Fountain et al., 1982; Chareonprawat and Wongwanich, 1976; MRDP, 1988). The upper member (*Wang Saphung Member*) consists of shale, sandstone silstone and limestone lens containing Carboniferous brachiopods (Yanagida, 1975; Waterhouse, 1982; Fountain et al., 1994).

2.3.4 Saraburi Group (Permian)

The Saraburi group (Bunopas, 1981, 1988) forms a succession at dominantly massive and bedded limestone, some shale and sandstone. It mainly occurs to the west of Loei area, consisting of 3 formations from bottom to top strata as follows:

2.3.5 Tham Nam Maholan Formation

The Tham Nam Maholan Formation consists mainly of thick-bedded limestone with occasionally interbedded shale, sandstone and chert. The formation conformably overlies and/or interfingers with the marine clastic–carbonate facies of the Wang Saphung Formation. It is believed that the lateral and vertical facies variation or the interfigering characteristic relation between the Tham Nam Maholan and Huai E-Lert Formations on the basis of the existing relative age, as determined from the fossil record to be Lower Permian (Yanagida, 1967). Fossils from the Saraburi Group indicate a marine shelf environment, and their different relative abundance suggest shallow water to the east and deeper water to the west (Bunopas, 1992).

2.3.6 Huai E-Lert Formation

The formation was assigned to the Middle Permian sequence (Charoenprawat and Wongwanich, 1976). The sequence is mainly exposed as long narrow trends, sub-parallel to the western side of the Loei River. The formation is represent by mainly shale interbedded with chert and occasionally tuffaceous and limestone lends. Thin-bedded limestone and chert are present at the lower part where thin-bedded sandstone, shale and silstone are intercalated at the upper part of the sequences.

2.3.7 Pha Dua Formation

The Pha Due Formation is probably to the upper most Permian succession in the Loei area, and is clastics in nature. It consists of alternating shale, silstone, sandstone and pyroclastic tuff. Most of the Pha Due sedimentary rocks have been gently to intensively folds. This formation is believed to unconformably underlie the Mesozoic strata without any field evidence, and conformably overlies the Huai E-Lert Formation. Several plant fossils indicate the age to be Middle Permian.

2.3.8 Volcanic Rocks (Permo-Triassic)

The distribution of volcanic rocks has been separated in three north-south belts along the eastern, central, and western parts of the Loei area (Jungyusuk and Khositanont, 1992; Panjasawatwong et al., 1997). These rocks include Devonian rhyolite, Middle Devonian-lower Carboniferous Basalts and Permo-Triassic andesite, respectively (Intasopa, 1993). They are included the Loei-Phetchabun volcanic belts (Barr and Macdonal, 1991), or in the east-central Thailand volcanic belt (Intasopa, 1993).

The volcanic rocks are andesite, dacite, rhyolite, agglomerate and tuff that earlier mapped as Permo-Triassic age (DMR, 1988). Small bodies of granite, granodiorite and diorite intruded them. The volcanic rocks unconformably overlie the Permian carbonates and unconformably underlie the upper Triassic conglomerate. Chairangsee et al., (1990) pointed that the tuff unconformably underlie the Nam Pong Formation, and locally underlies the Huai Hin Lat Formation (Jungyusuk and Khositanont, 1992). The occurrence of these volcanic rocks has been interpreted to be the products of arc volcanism (Panjasawatwong et al., 1997) and have formed above an eastward dipping subduction zone (Bunopas, 1981; Hutchison, 1985). The volcanic facies was developed due to the emplacement of subduction related I-type plutonic activity (Charusiri, 1989; Charusiri et al., 1994) in the Late Palaeozoic before the suturing between the Shan-Thai and Indochina terraines

2.3.9 Granite-Granodiorite (Triassic)

The granitic rocks of the Loei area belong to the Eastern Granitic Belt of Thailand. They form batholiths and small stocks intruding Carboniferous and Permian rocks. The I-type granite (Charusiri, 1989; Nakapadungrat and Putthapiban, 1992; Putthapiban, 2002) has been recognized, representing a characteristic arc-type-arc-alkali tonolite of monzo–granite series. The variation in composition from granite to tonalitic granite and granodiorite suites is apparent. Medium-coarse grained pinkish granites contemporaneously occur with coarse-grained biotite hornblende granite and diorite as well as hornblendite. Results of $^{40}Ar/^{39}Ar$ dating (Charusiri, 1989; Charusiri et al, 1991) and K/Ar isotopic age determination (Jacobson et al., 1969) indicated a narrow time interval (227Ma to 235Ma) in early to middle Triassic. The occurrences of theses granites has been considered to be due to collision between the Shan-Thai and the Indochina terraines (Charusiri, 1989).

2.3.10 Quaternary Sediments

Because of the high rate of eroded degradation, Cenozoic colluviums and related residual sediments resulting from active weathering, cover most of the Loei area. Exposed rock usually occurs with thin lateritic soil. Nevertheless, Quaternary sediments can be subdivided into 3 units from older to younger as follows:

1. Colluvium, terrace and residual deposits (Qt) which consists of undulating colluvial high terraces from 250-300 m above the sea level. The thickness of the colluvial and alluvial fan deposits ranges from 2-7 m and is observed showing lateritization.

2. Alluvium and valley deposits (Qa) consist of silt sand and gravel covering alluvial plains and valley plains on distributary's channels. Because of the high erosion gradient, sediments of this type are rather different from place to place.

3. Meandering belt and channel deposits (Qc) are the youngest debris in Loei and Nam Mae Khong. The form meandering scar, oxbow lake, abandon channel, natural levee and recent terraces. The sediments are composed of silt, sand and gravel occurring in the point bar and mid channel bar.

2.4 Mineralization

Mineral occurrences in the study area, and have been reported by Bleakley et al. (1965); Jacopson et al. (1969); Chaodumrong et al. (1983); Laosu (1988); Phuttapiban (1987) and Kulmarajan (1987). They found that the Loei province has been considered as a high potential area for mineral occurrences for example, gold, copper, lead, zinc, manganese, coal, barite, and industrial mineral (Fig.2.4). Some of these mineral occurrences are economic in size and grade, and are occasionally mined using modern methods.

The Permo-Triassic volcanic deposits and plutonic intrusions appeared to be parental sources to various kinds of mineral occurrences. These igneous rocks are all I-type affinity, which was characteristically formed under the thin accretionary crust of Indochina. Distinctive gold, copper, lead and zinc mineralization (Jumnongthai, 1992 and Charusiri et al., 1995) are fairly common to the Loei fold belt of the Indochina terraine. Manganese, barite, and iron ores are the additional mineral occurrences characterize of the terraine.

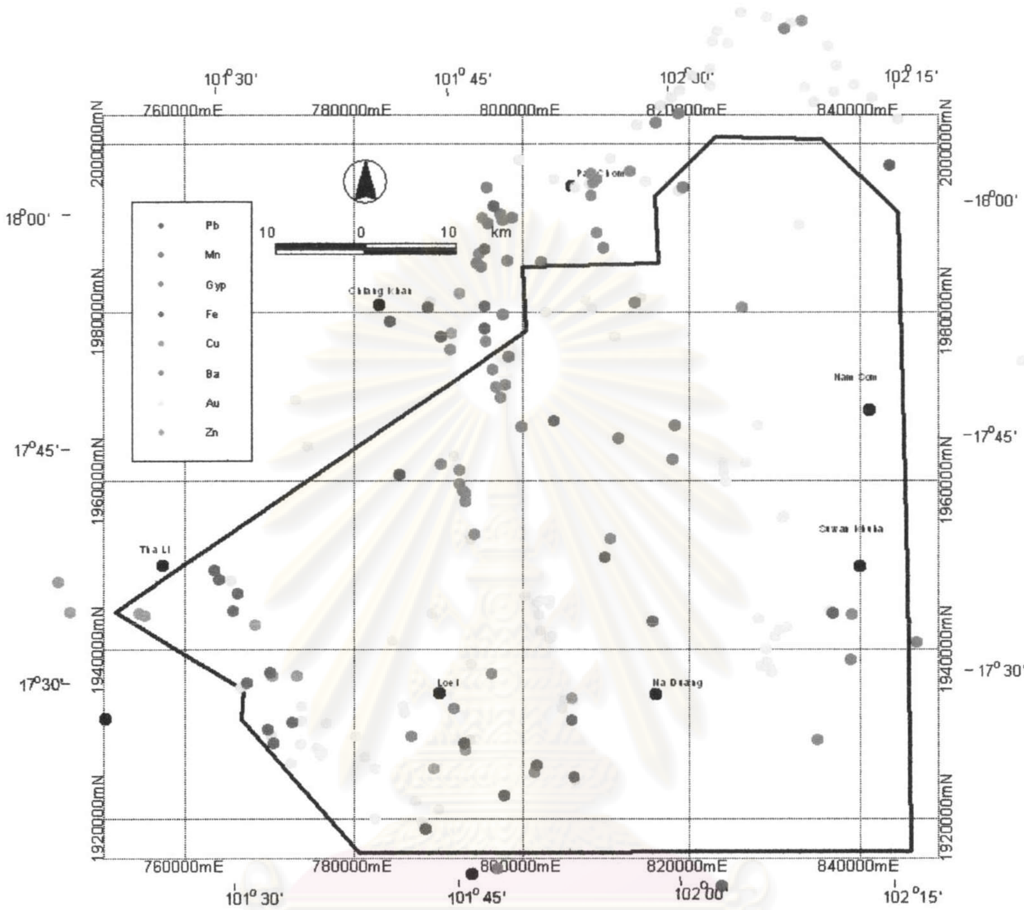

Figure 2.4 Mineral occurrences in the Loei study area.

In the southeast extension of the Indochina terraine, there are only gold and sedimentary or hydrothermal manganese, which had been activity, mined in the past. Iron ore, chromite, magesite, stibnite and fluorite are considered to be minor in term of their economic occurrence.

Chairangsee at al. (1990) summarized characteristic of main mineral occurrences in the Loei area as following:

2.4.1 Barite

Most barite occurs in vein type deposit in north-south trending geological structures. They are concentrated in volcanic breccia and form a straight line coincident with the long axis of spilitic basalt. Barite should was deposited by the hydrothermal solutions that were probably mobilized from the Permo-Triassic granodiorite intrusions.

2.4.2 Copper

Copper ores have been found in the form of malachite, chalcopyrite, bornite and native copper, which are associated igneous with hematite and magnetite. The Ban Nong copper occurrence (798100E, 2014700N) was found by using geochemical exploration from DMR and proved that the strike of copper mineralization corresponds to spilitic basalt (Yamniyom, 1985).

2.4.3 Galena

Galena occurs in fault breccia zone trending east-west, cross-cutting the general north-south geological strike. It was considered to be younger than the sedimentation and folding of the country rocks and formed from hydrothermal solutions mobilized from the intrusion of granodiorite.

2.4.4 Iron

Iron ores consist of magnetite, hematite and pyrite. Most occurrences are situated at the contact of carbonate rocks and granodiorite intrusions (skarn deposits). They were most probably originated from the exhalations from the igneous bodies into the surrounding sediments.

2.4.5 Gold

Most gold occurrences are found as placer deposits in stream near the granite intrusions. At the location of Thung Khum mining (783,520E, 1,920,800N), gold occurs in the sedimentary rock beneath the regolith zone and is associated with the rhyorite and chalcopyrite.

2.4.6 Manganese

Manganese ores are concentrated in the central part of the study area. They are commonly distributed rather than showing any relation to the geological structure. They occur as irregular bodies associated with siliceous sediments, mainly chert. It was believed that manganese was formed as precipitates from hydrothermal solutions on the sea floor. The hydrothermal solutions that precipitated the manganese ore seem to have been related to the basic igneous activity. This view corresponds with the fact that manganese ore occurs only in the central part of study area, where spilitic basalts are widespread.