Chapter 4
Interpretation Emphasis on Mineral Deposit Type

4.1 Types of mineral deposit

Mineral deposits in the NUS zone can be classified into various types on the basis of their geneses, which are mainly related to the geological processes. Principally, the mineral deposits are grouped into those related to the Earth's interior geological processes and those related to the Earth's surface geological processes.

4.1.1 Mineral deposits related to the Earth's interior geological processes

The geological processes of the Earth's interior are those occurred under igneous and metamorphic environments. There are several types of mineral deposits that are related to the igneous process that forms mafic and ultramafic rocks. Precipitation of ore minerals as major or minor constituents of these igneous rocks is in the forms of disseminated grains or segregations (Guilbert and Park, 1985). Mineral deposits of this type included: chromite, platinum, nickel and cobalt in peridotite; and diamond in kimberlite. This type of deposit is usually low grade. Basalt plays a major role in the formation of this deposit type because it is a source rock for placer chromite and platinum deposits, and residual nickel and cobalt deposits (Jensen and Bateman, 1979).

The separation of ore minerals by fractional crystallization and related processes during magmatic differentiation is called magmatic segregation. Heavy metallic minerals separate from peridotite or dunite and sink to the lower part of the magma chamber and eventually become titanium or platinum-copper-nickel-cobalt deposits. Mineral deposits of this type which are found in this study area (Figure 4.1) include chromite deposits in Na Noi District of Nan, and Tha Pla District of Uttaradit. The later one is larger with an estimated economic ore reserve of about 1.24 million tonnes (Jeenawut, 1996).

Nickel sulphide ore was also found in this area (Yensabai and Watcharachaisuraphol, 1992) but the exact locality was not revealed because of the military security reason and no further study can be made. Pyrrhotite, associated with magnetite, located west of Ban Ngom Tham, Tha Pla District of Uttaradit (Figure 4.2) is believed to be associated with the NUS zone. In general, it is found in mafic and ultramafic rocks of early magmatic segregation. Association with pentlandite and/or cobalt and platinum minerals makes it a valuable and important mineral (nickel-bearing pyrrhotite). The ore is located within the serpentinized peridotite zone bounded by volcanic rocks (Figure 4.3). Tuffaceous sandstone and limestone are also found in this locality

Figure 4.1 Chromite ores found in the study area.

(a)

(b)

(a) Pyrrhotite in serpentinized peridotite

(b) Pyrrhotite sample

Figure 4.2 Pyrrhotite ores found in the study area.

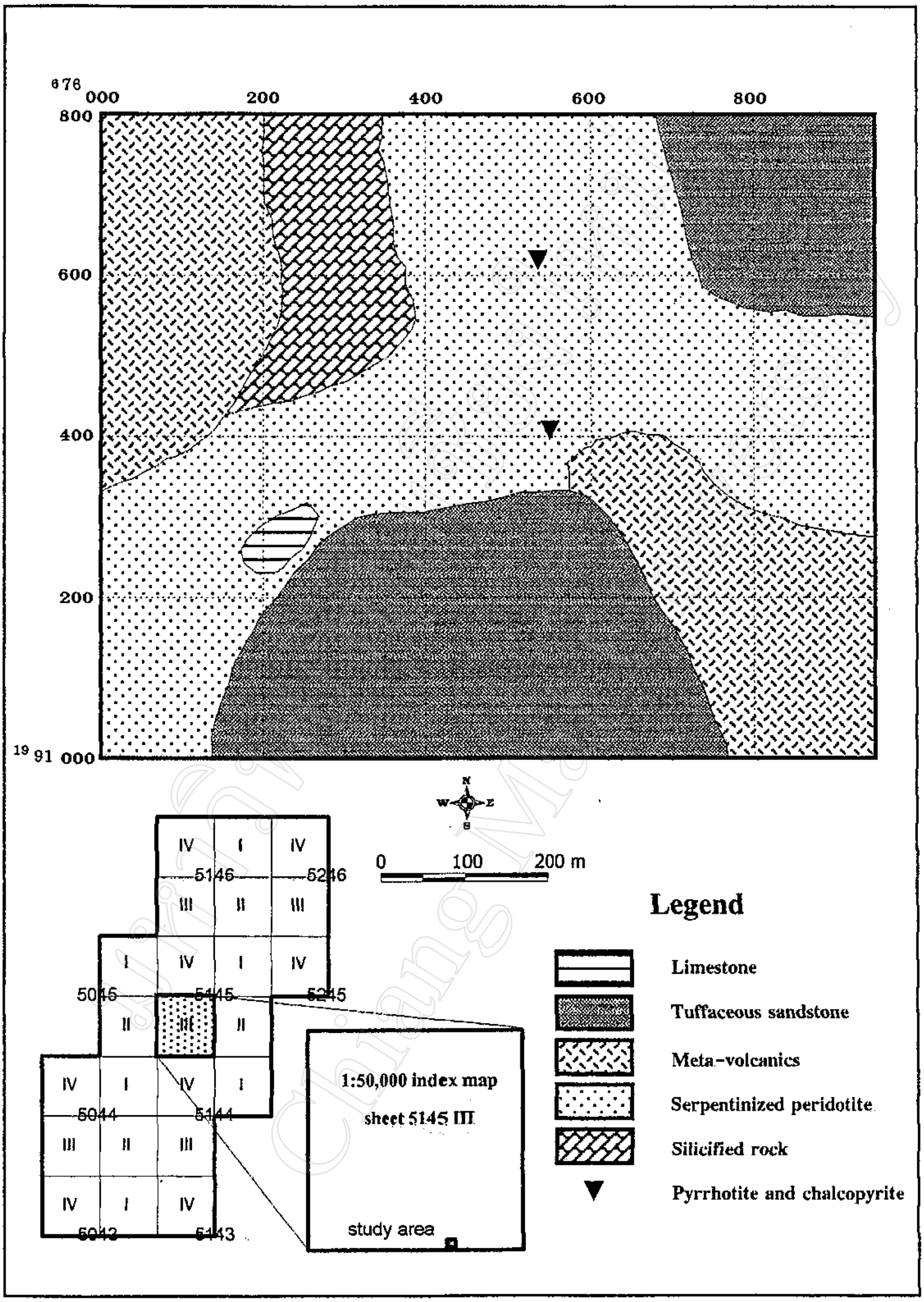


Figure 4.3 Geology of the pyrrhotite deposit.
(after Dejen , 1993)

(Dejen, 1993). Gold concentration, indicated by chemical analysis, was also reported (Jarach, pers. comm., 1997).

Many mineral deposit types derived from metamorphic process are found in this area. Chrysotile is the most common metamorphic alteration mineral within the ultramafic units, usually found along fractures (Figure 4.4). Actinolite occurs as splendid crystals at Doi Puk Champeng in Nan (Figure 4.5). It is commonly found in mafic metamorphic rocks of greenschist facies (Bunopas, 1981), in this area.

Marble in Khao Khee Nok area of Uttaradit is derived from fairly pure limestone, possibly through contact metamorphism (Figure 4.6) resulted from the intrusion of basaltic andesite and granite of Khao Yai. Nearby to the west, a zone of graphite is found along a narrow basin, possibly a metamorphic product of carbonaceous shale (Surinkum and Siripongsatian, 1992).

Alteration product minerals are also derived from both metamorphism and igneous activities. Talc is an alteration product of magnesium silicates in ultramafic rocks, and is commonly found in many parts of this study area (Figure 4.7), although there is only one active talc mine in the southern part (Figure 4.7b). Other alteration product mineral is magnesite formed by alteration of ultramafic rocks (peridotites and serpentinites) through the action of waters containing carbonic acid but it is less common (Jeenawut, 1996).

The alteration product mineral that has been most extensively mined in this area is illite (Figure 4.8). This is the so-called Uttaradit white clay, which has been mined for more than 30 years (Kuentag, 1995). The clay is composed of 60 % of illite with 10 % of kaolinite by volume. They were formed by hydrothermal alteration of feldspars and other aluminum-bearing minerals in the Triassic volcanic, Phra That Formation (Piyasin, 1975). The hydrothermal alteration effects are controlled by fracture systems.

4.1.2 Mineral deposits related to the Earth's surface geological processes

The Earth's surface geological processes, which contribute to the forming of a number of mineral deposits, are essentially weathering and erosion processes. Placer deposits form due to weathering and erosion processes of mineralized rocks resulting in the deposition of heavy and high resistive minerals.

Placer chromite is found as eluvial deposits along the stream branches of Nan River but none of them are reportedly economic. Paopongsawan and others (2000) found gold, by panning and geochemical analysis, in the Nam Phang area of Nan and more detailed investigation were being made by Yawichai and others (2001).

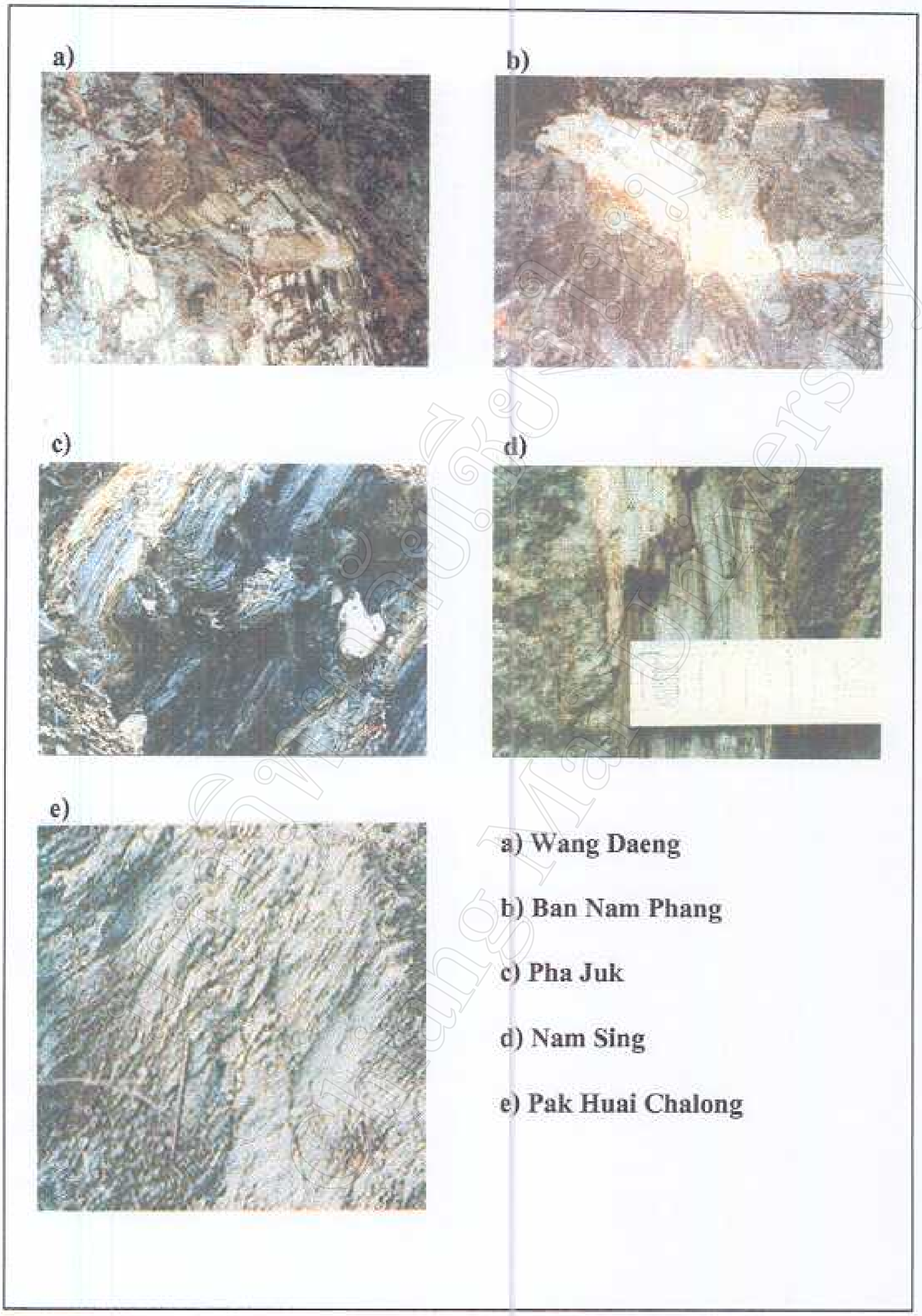


Figure 4.4 Chrysotile asbestos found in the study area.

a) Doi Puk Champeng

b) Typical plant in Doi Puk Champeng

c) Actinolite sample

Figure 4.5 Doi Puk Champeng where actinolite is found in the study area.

(a)

(b)

(c)

(a) Topography of marble intruded by granite

(b) Granite

(c) Andesite

Figure 4.6 Various rock types found in Khao Khee Nok area.

a)

b)

c)

a) Talc at Ban Nam Phang
b) Talc at Pak Huai Chalong
c) Talc in pit

Figure 4.7 Talc found in the study area.

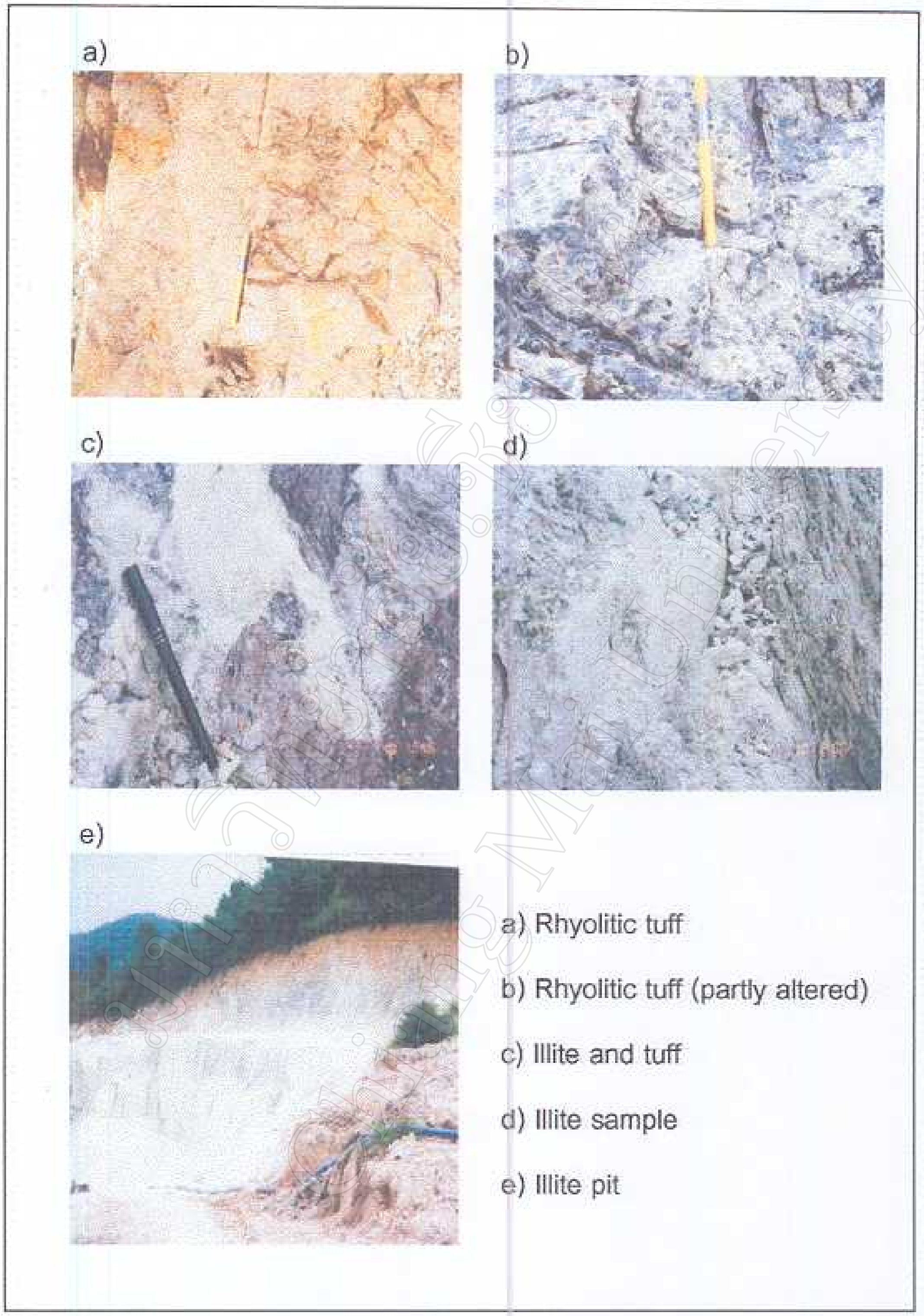


Figure 4.8 Alteration product of the volcanic rock (illite) found north of Uttaradit.

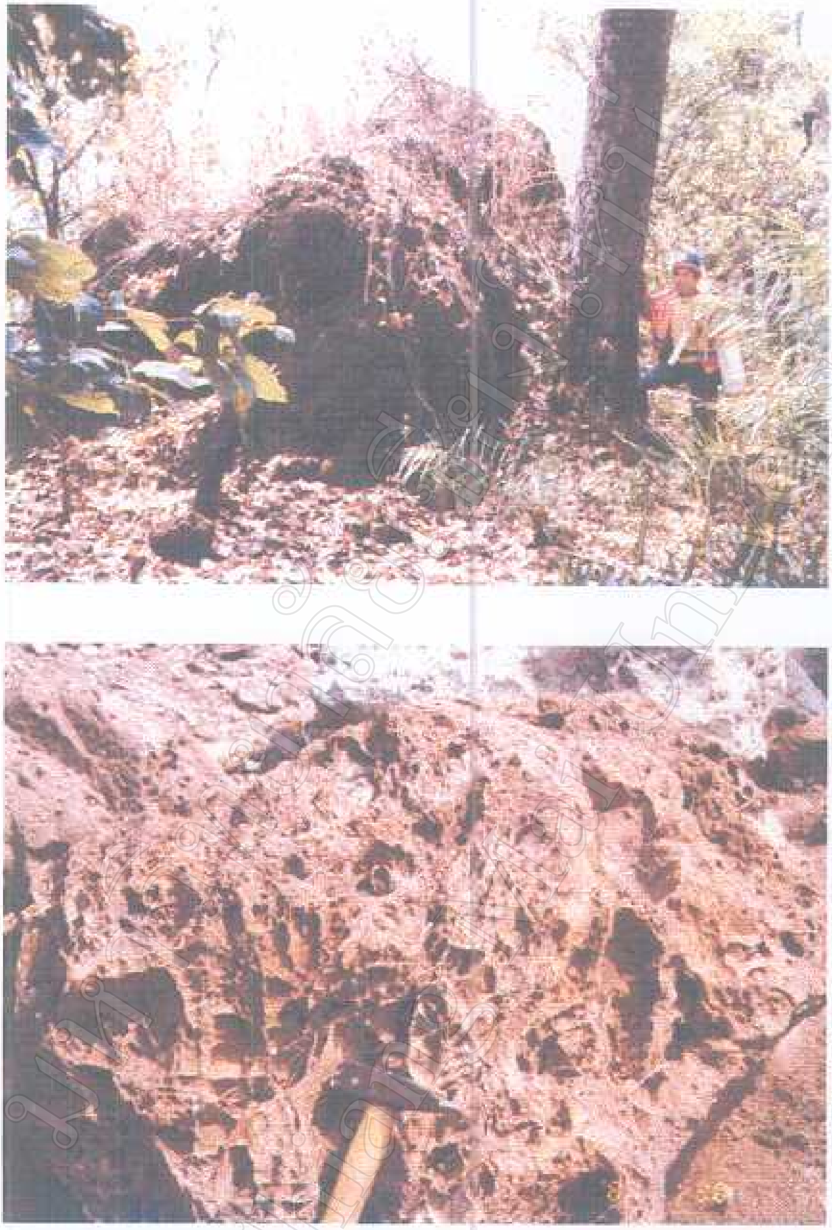
Other product of weathering process is residual deposit. This type of deposit tends to occur in tropical zone with a flat topography. Important residual deposits include kaolinite, bauxite and iron-manganese-nickel laterite. The most common nickel oxide mineral in the lateritic nickel area is garnierite. It is a hydrous nickel magnesium phyllosilicate of a serpentine group. It appears in bright-green aggregates with a form of crust and earthy masses. Half of world nickel production is extracted from this mineral type. Garnierite of Doi Kaew of Nan (Figure 4.9) is a residual deposit form as a result of chemical weathering of rocks and rock-forming minerals in the ultramafic units.

Water dissolves some minerals from the ultramafic rock leaving some chemical elements or compounds that are insoluble or difficult to dissolve. The rock would decompose giving a mixture of nickel, silica and alkali compounds. When such components are present in a certain condition, i.e. oxidation, silica and alkali compounds tend to be dissolved away by water leaving a nickel compound, which is difficult to be dissolved. If the process prolongs, the amounts of nickel compound increases.

Within the zone of the ultramafic units where sulphide minerals are abundant, supergene deposits usually occur under certain conditions. Weathering process tends to have great impact on disintegrating these sulphide minerals. The process develops best in tropical areas like Thailand. Chemical weathering of sulphide minerals produces sulphuric acid (H_2SO_4). This sulphuric acid contributes to the increase of metal contents in the solution by dissolving them. These dissolved metals then seep downward below groundwater table, and replace iron in pyrite. The process results in the formation of new sulphide minerals. The amount of these new forming sulphide minerals would increase with time. Unfortunately there is no great gossan as an indicator for this process except east of Mae Charim District where the courses of Nam Phang River and Nam Wa River intersect.

Outside the ultramafic zone, copper formed by supergene enrichment was found in many localities within a sedimentary sequence but their surficial expressions are not impressive enough to justify further studies (Chaleechan, 1954; Carrel, 1964; and Paopongsawan, 1996). These copper deposits are considered low-grade.

To the east and southeast of this study area, there are a few occurrences of sedimentary mineral deposit. Two well-known sedimentary deposit types found in the NUS zone are gypsum and limestone. Gypsum (Figure 4.10) is not mined because there is no local demand for the mineral. Limestone is mined for construction material (Figure 4.11).



(a)

(b)

(a) Gossan

(b) Silica boxwork

Figure 4.9 Lateritic nickel (garnierite) found in Doi Kaew area.

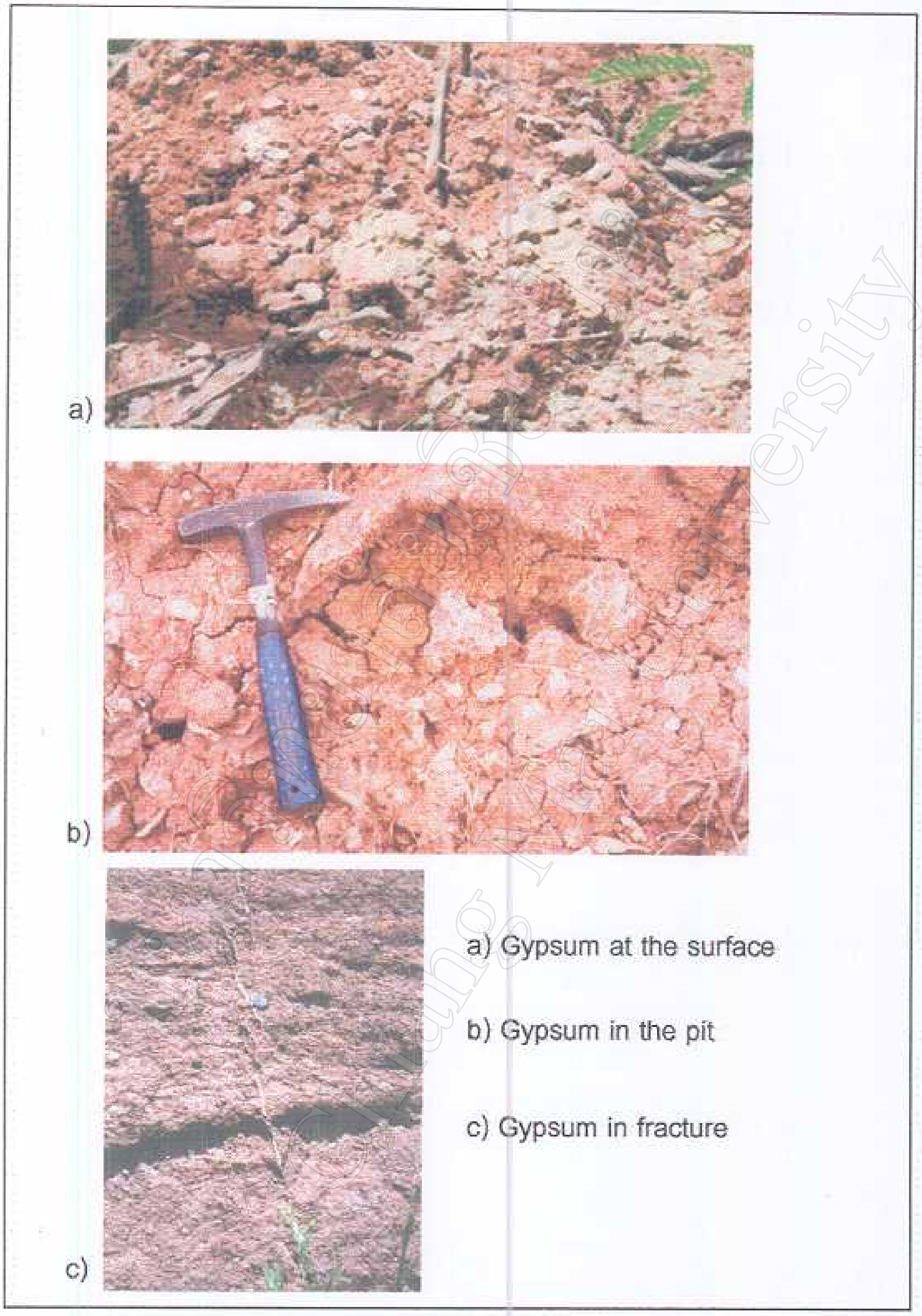


Figure 4.10 Gypsum found in Nam Pat and Fak Tha Districts of Uttaradit.

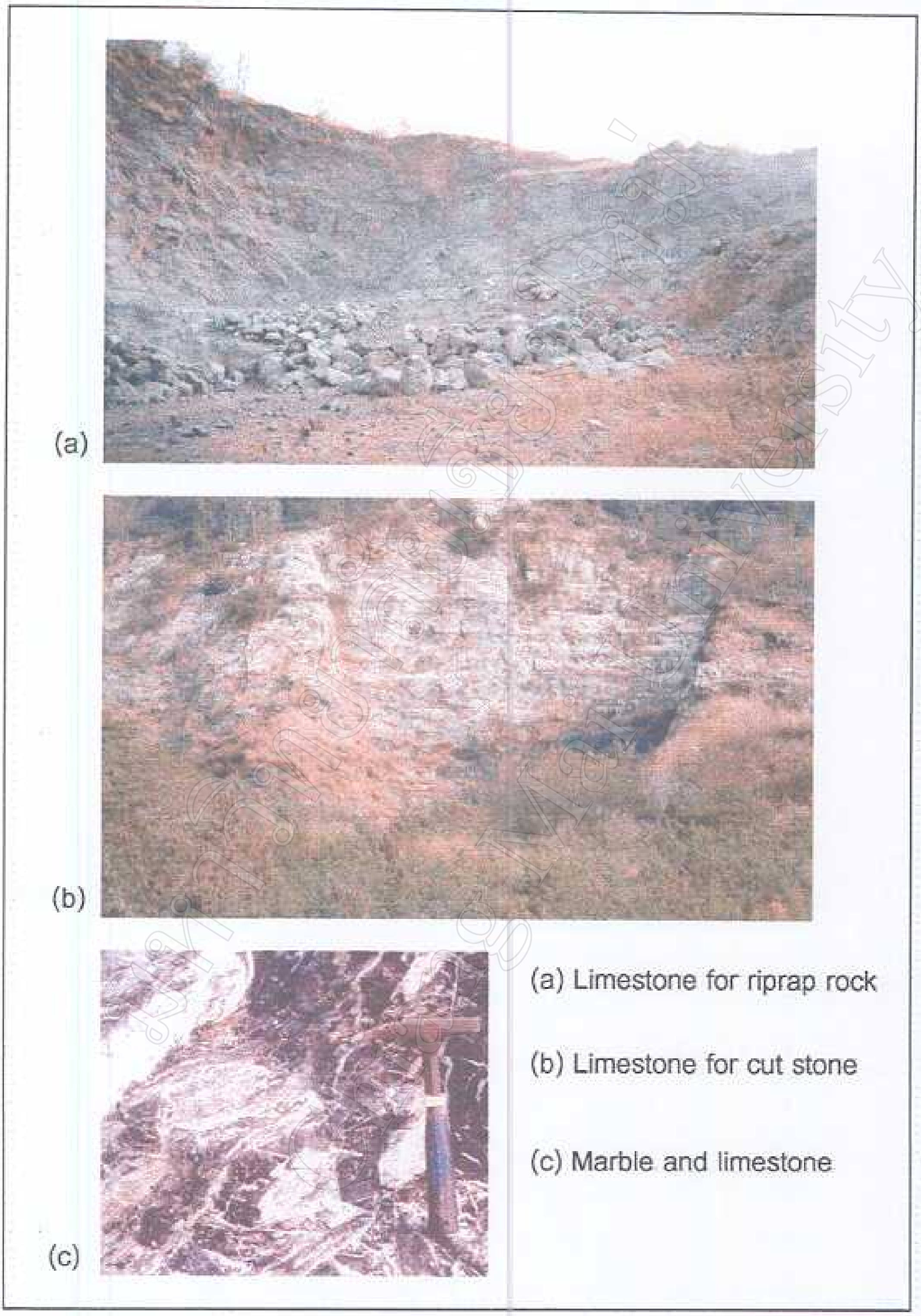


Figure 4.11 Limestone quarry and marble in the study area.

Oxidation process plays an important role in the enrichment of a well-known iron deposit in Uttaradit. The Uttaradit area is famous for nickel-chrome-iron production since Ayutthaya period (500-700 years ago). Buravas (1941) observed the characteristic of this deposit type in a pit dug in the area and outcrop along the road cut, and reported the association of manganese and limonite that were locally enriched. In general, the ore is produced from hematite and pisolitic limonite that were enriched to a compact limonite layer (Figure 4.12). The depth of the compact layers that is generally covered with soil and scarce vegetation varies from 2 to 4 m.

4.2 Interpretation techniques

4.2.1 Geophysical technique for magmatic mineral deposits

Magmatic deposits account for about half of the world nickel production and virtually the total production of platinum and chromite. All deposits of this type are associated with mafic and ultramafic igneous rocks and their origins are syngenetic (Edwards and Atkinson, 1986). Edwards and Atkinson (1986) also reported the result of geophysical orientation studies over known chromite ore bodies in California, USA. The techniques used include magnetic, VLF-EM, complex resistivity and seismic refraction. The most promising approach that indicated by this study is a combination of complex resistivity and seismic refraction, although neither technique produced anomalies of dramatic dimensions.

Nickel sulphide ores are dense, conductive and commonly magnetic, and therefore in principle, a wide range of geophysical techniques is appropriate for their exploration. However, in practice, there is considerable regional variation in the techniques that are preferred. Canadian geophysicists prefer magnetic and electromagnetic methods because they are cheap, provide good physical contrast and satisfactory depth penetration, and can be used in both airborne and rapid ground-based surveys. Becker (1979) reviewed developments in the use of airborne electromagnetic methods in Canada, whilst ground electromagnetic methods are described by Ward (1979). Gravity surveys can be used to locate the most likely site of intrusion and accurate modeling may indicate depth, but the topographic correction is not cost-effective. The magnetic induced polarization technique may be used in the search for this type of deposit but further work is required to prove the extents of its usefulness.

Electromagnetic methods have been extensively used in prospecting for ultramafic-associated nickel deposits in Canada (Palacky, 1988). The conductivity of these massive sulphide deposits means that they present very suitable targets for a variety of electromagnetic and electrical methods. In exploration for shallow massive sulphide deposits, SP must rank as one of the

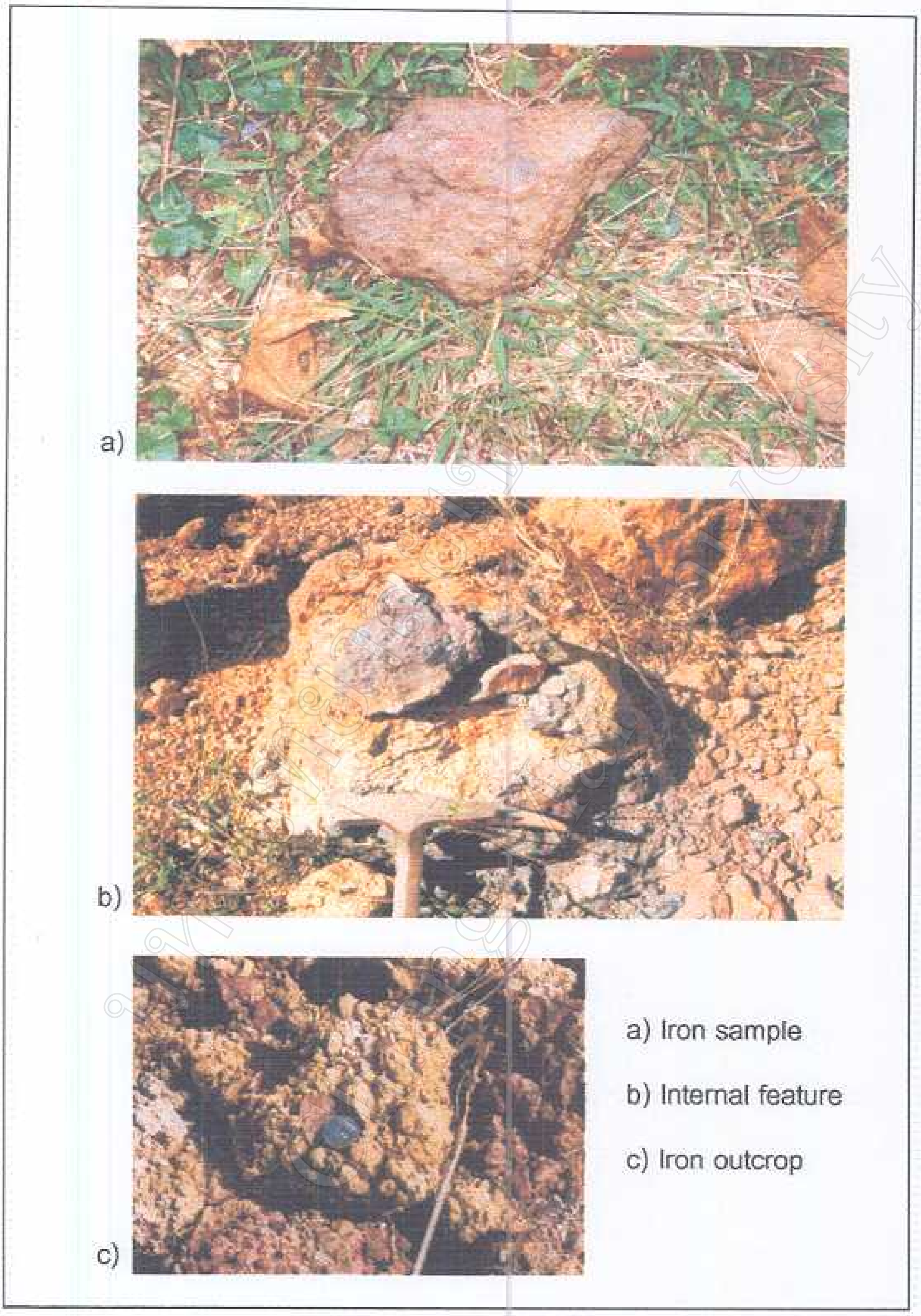


Figure 4.12 Limonite (nickel chrome iron) found in the study area.

most cost-effective methods. In recent year, the UTEM system has a great use in Australia because of its ability to penetrate to the deeper levels but in area of conductive overburden the model has limited use depending on the thickness of the overburden.

In Western Australia, geophysical survey is used both as an aid in reconnaissance mapping and, to a lesser extent, in the evaluation of gossan zones and geochemical anomalies. Detailed airborne magnetic surveys are used for reconnaissance mapping and may be used in conjugation with aerial photography to define the ultramafic zone that may host sulphide deposits. The effectiveness of electromagnetic is severely limited by the deep zone of oxidation, the presence of a conductive overburden and the association of sulphide ores with graphitic metasediments. However, the use of single-loop transient electromagnetic system has reduced the problem posed by conductive overburden.

Three different types of geophysical surveys, induced polarization, electromagnetic, and magnetic, were applied to locate chromite body at depth in this study area. Many geophysical survey types were applied because it was expected to find massive sulphide ore body over the HEM anomalies of this area. Only magnetic survey interpretation can be used to identify the chromite bodies but not the shape and orientation (Figure 4.13). This is because magnetic susceptibility, given by Charmicael (1982), of chromite (240-9400 x 10^{-6} emu/cc) is greater than that of serpentine and peridotite (140-485 x 10^{-6} emu/cc). So, the vector of magnetic expression of chromite is superimposed on that of serpentine and peridotite, and the highest expression is located over the chromite bodies.

4.2.2 Geophysical technique for metasomatic mineral deposits

Normally, there is no direct geophysical approach for detecting mineralizations of metasomatic affiliation, where the mineralogical and chemical changes occur in rocks as a result of interaction with fluids from external source, that is different from places to places. In a regional scale, radiometric survey can be used to detect and map potassium alteration associated with this type of mineralization (Shives and others, 2000). Shives and others (2000) also applied ground radiometric survey for alkalic porphyry copper-gold deposit in British Columbia to establish the applicability of the technique to porphyry deposit exploration. Gravity and ground magnetic, to determine the distribution of batholiths, would also be useful in indicating morphology for smaller stocks if there are sufficiently near-surface (Edwards and Atkinson, 1986). Surinkum and others (1987) made a geophysical survey, over a sulphide deposit of Ban Mae Ka Nai of Mae Hong Son and found that induced polarization is more suitable than

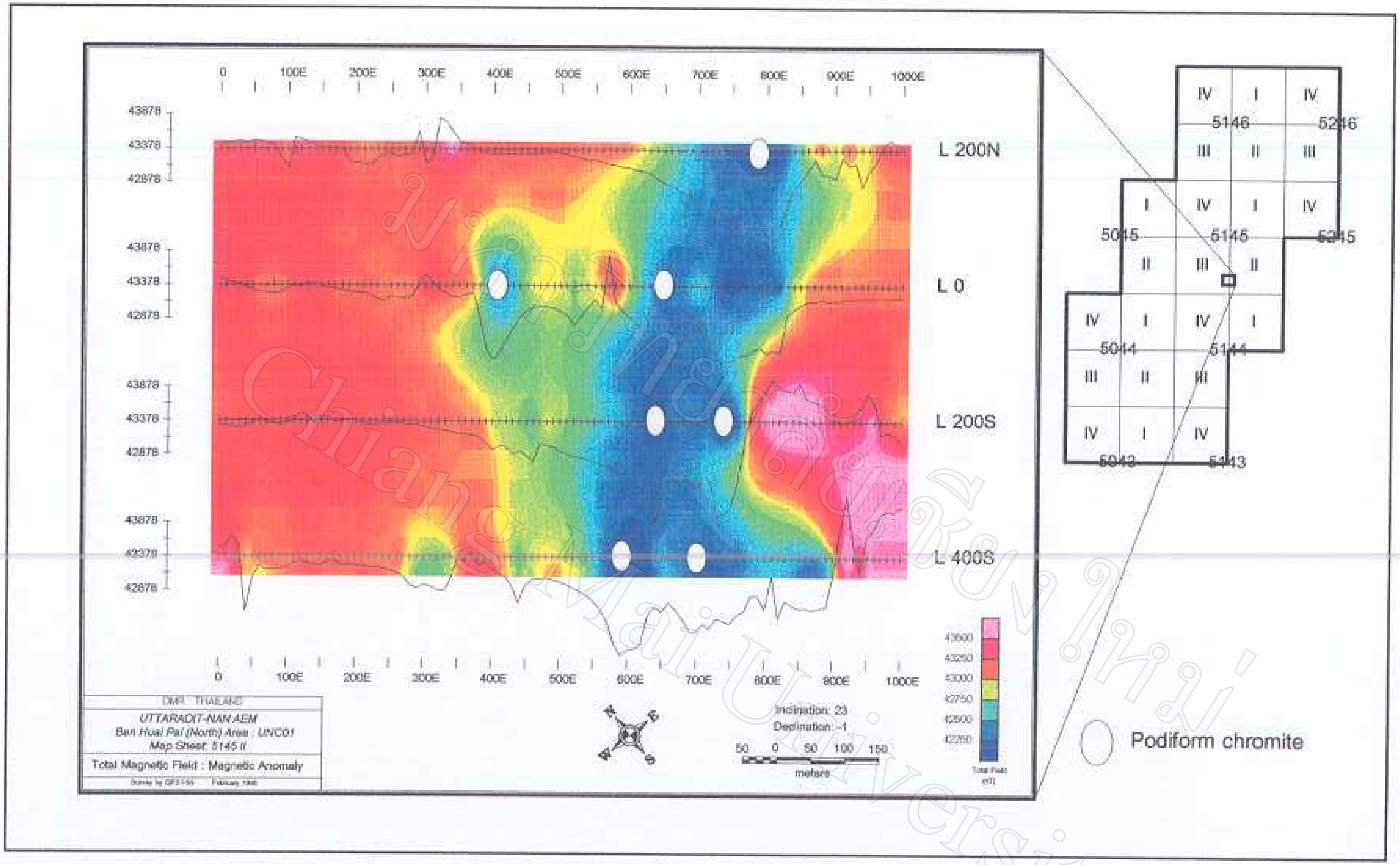


Figure 4.13 Ground magnetic survey result over the chromite deposit.
(after Paiyarom and Surinkum , 1997)

electromagnetic. However, induced polarization technique could not be used as mineral content estimation directly. The frequency effect was rather constant in all measurements. Therefore, its percentage alone would not be a very good guide to estimate of metallic content. Resistivity is interpreted to reflect porosity rather than mineralization, at these low sulphide contents. Even though there appears to be a direct relationship between sulphide content and resistivity, this fact alone cannot be used as a guide because of the common occurrence of low resistivity in unmineralized rocks elsewhere. However, fracture analysis using resistivity and electromagnetic anomalies is a good guideline since metasomatic development is favoured by enhanced permeability and fractured lithologies.

4.2.3 Geophysical technique for alteration product mineral deposits

If there is sufficient physical contrast between the alteration products and their parent or surrounding rocks, geophysical techniques may be used to delineate the deposits. The major contrast in Uttaradit white clay area is resistivity where clay is conductor compared to its parent rock of rhyolite. Radiometric survey, using intensity of gamma ray radiated from source rock or other minerals containing elements such as uranium, thorium and potassium-40, can distinguish acid rocks from basic rocks, or potassium-rich area from a normal one. Moreover, radiometric survey can be applied for locating type of igneous rocks depending on their U/Th ratios (Surinkum and Paiyarom, 2000).

Various techniques, VLF (Figure 4.14), HLEM (Figure 4.15) and terrain conductivity (Figure 4.16), were applied to illite deposit in Uttaradit (Surinkum and others, 1997). The survey results show that conductivity contrast of the illite and its host rock is clearly defined by means of many electromagnetic surveys. The main ore bodies are located at around 1100E-1200E and 1600E-2000E. It should be noted here that the HLEM survey could not be made over the mine pit, so part of the result is missing. A decision of how to make use of each technique depends upon the details needed from each technique.

4.2.4 Geophysical technique for residual mineral deposits

In the northern part of the NUS zone, fresh and slightly weathered ultramafic rocks are exposed only at few localities near the margin of Doi Kaew in Nan. The observations made in the garnierite potential area of Doi Kaew indicate that distribution of the nickel values depend upon the weathering characteristics of the parent rocks. This result in vertically and laterally changes in grade (Paopongsawan and others, 2000). Resistivity contrast at depth may be observed but the main focus is on the weathering layers not the buried bedrock or the capped rock.

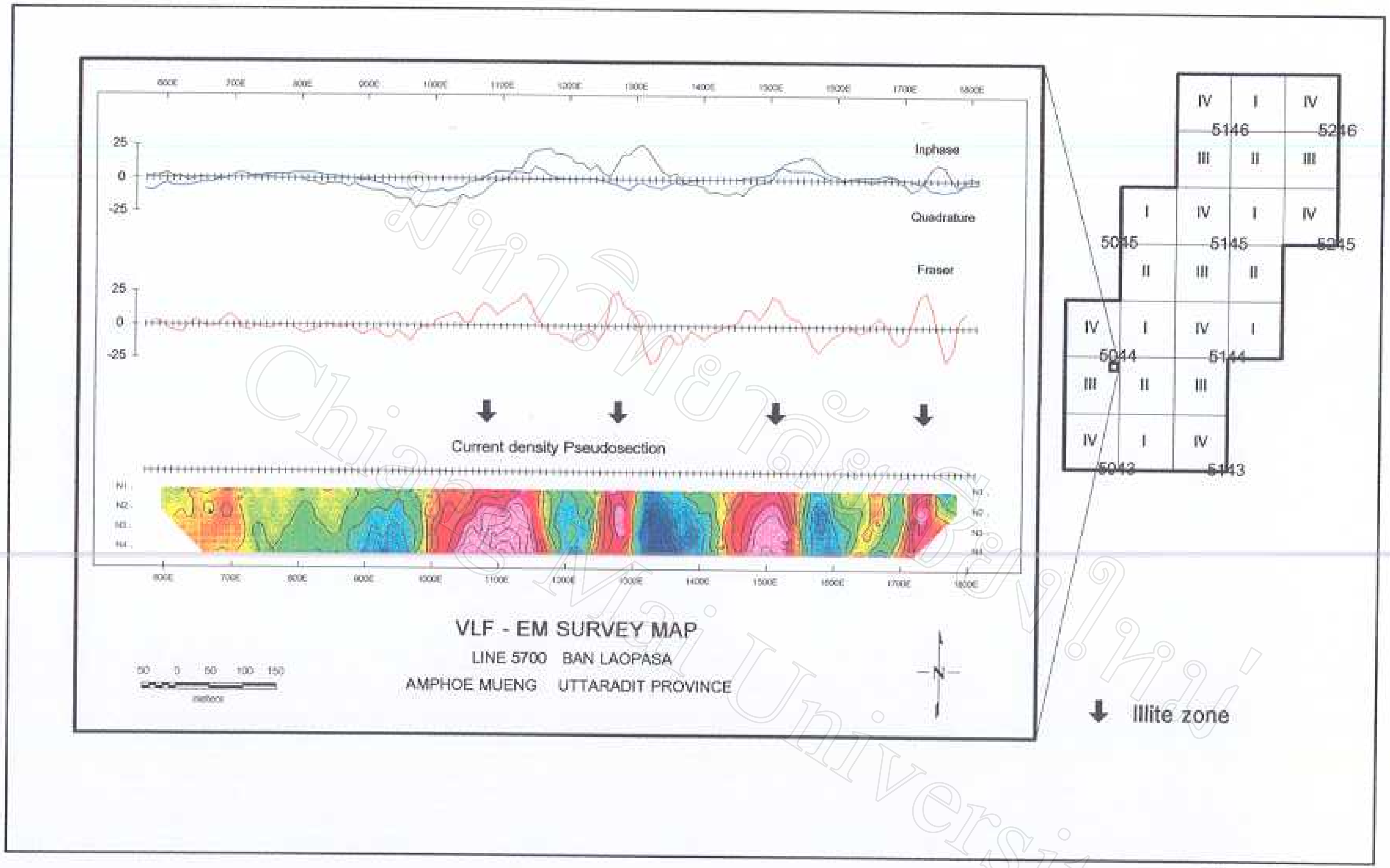


Figure 4.14 VLF electromagnetic survey result over the illite deposit.
(after Surinkum and others , 1997)

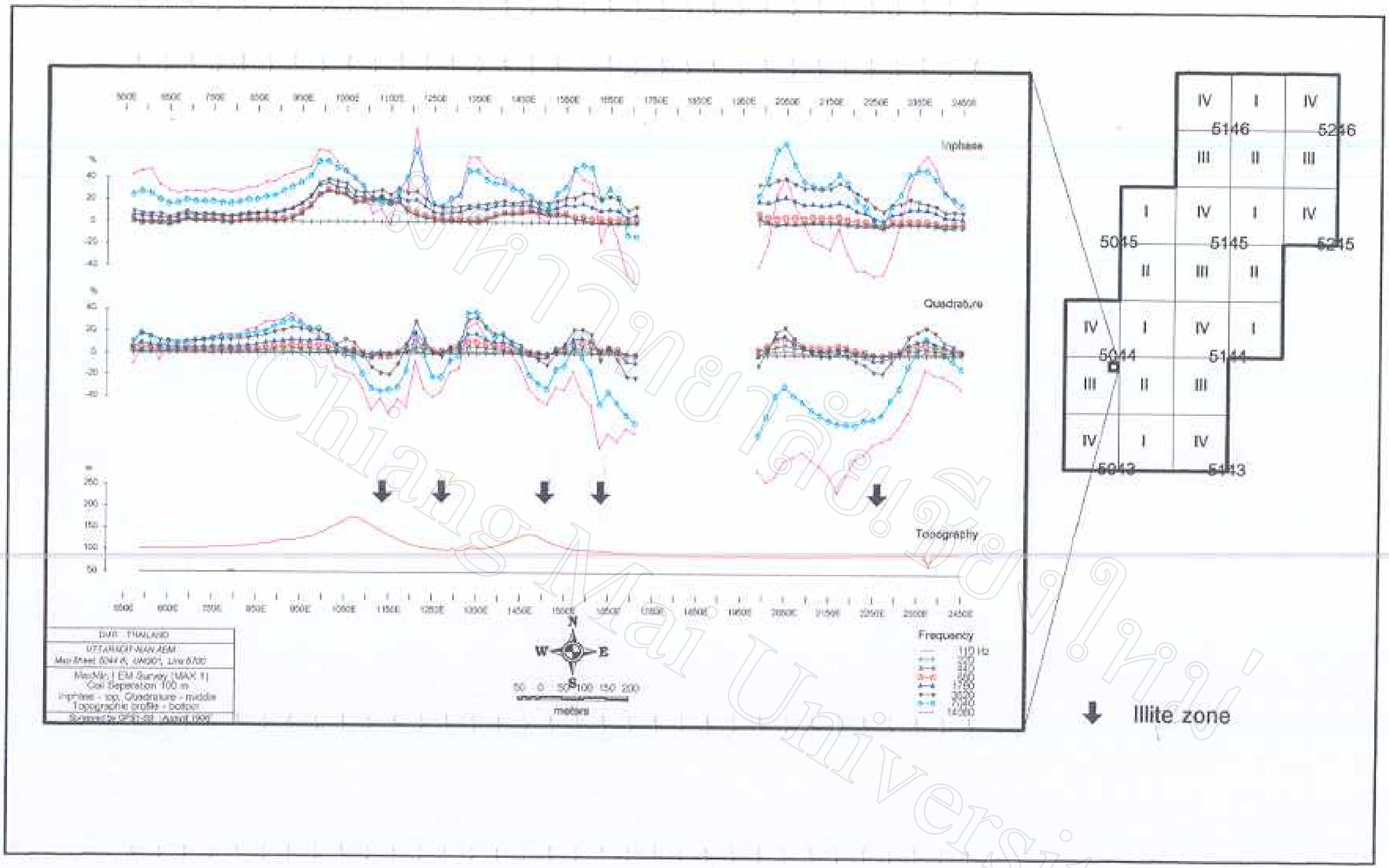


Figure 4.15 Horizontal loop electromagnetic survey result over the illite deposit.
(after Surinkum and others , 1997)

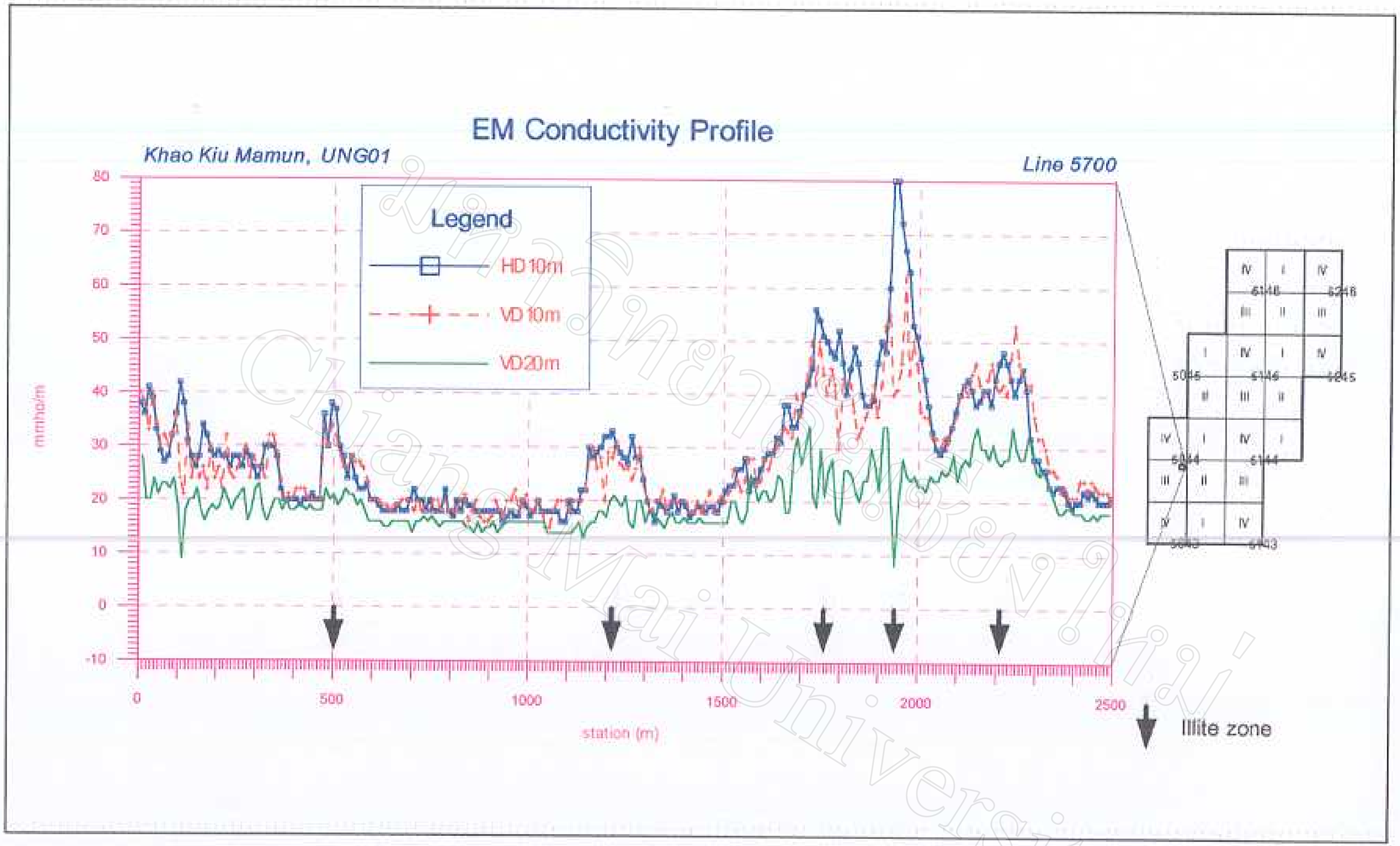


Figure 4.16 Terrain conductivity measurement result over the illite deposit.

Conductivity measurement was applied to this type of deposit by fixing the depth of investigation in order to find its lateral variation. The fine saprolite which form the thickest part of the soil profile is the most conductive layer but the coarse saprolite underneath is more economic (Poapongsawan and others, 2000). Magnetic expression reflects only the contact of ultramafic and sedimentary units and shows only high frequency anomalies.

4.2.5 Geophysical technique for sedimentary mineral deposits

Palacky (1987) described that electromagnetic surveys are suitable for clay mapping particularly in tropical regions where outcrops are often scarce. He used horizontal loop electromagnetic survey to differentiate soil profile (Palacky, 1991). These techniques were used to map not only topsoil thickness and bedrock structure but also sedimentary mineral deposit (Utha-aroon and Surinkum, 1995). Kuttikul and others (1997) applied both electromagnetic and gravity to successfully map gypsum deposit underlying the younger unconsolidated sediments. Electromagnetic technique was used to differentiate limestone and shale from gypsum, and anhydrite was outlined by its high gravity anomalies.

Electromagnetic survey can also be applied for dimension stone evaluations where high fracturing zones are conductor and hence not good for production. For placer deposits, magnetic expression of unconsolidated soil may be reflected from heavy minerals with magnetic susceptibility higher than normal clay and sediments.

4.2.6 Geophysical technique for metamorphic mineral deposits

Metamorphism is usually regarded as a relatively high-temperature and a high-pressure phenomenon, but much of the economic ore deposits are formed at much lower temperatures and pressures. Ores formed by metamorphism are mostly industrial minerals such as wollastonite, graphite, asbestos, and talc. Their specific physical properties are the controlling factors for any geophysical applications. Due to theirs low economic value and more diversity than the other type of ore deposits, there is not much attempts to delineate them from their surrounding rocks by geophysical surveys. Normal exploration program is focussed on site specifically to chemical rather than physical properties. However, some geophysical surveys were applied in this study area for such ore deposits that might be economic. Horizontal loop electromagnetic survey is proved to be the best to locate graphite (graphitic shale) deposit in the NUS zone (Figure 4.17). The graphite is located over the highest conductance of each surveyed line and its continuation can be made from connection of each high conductance. The deposit zone was noted even from an airborne electromagnetic survey, and the ground follow-up survey indicated that it was

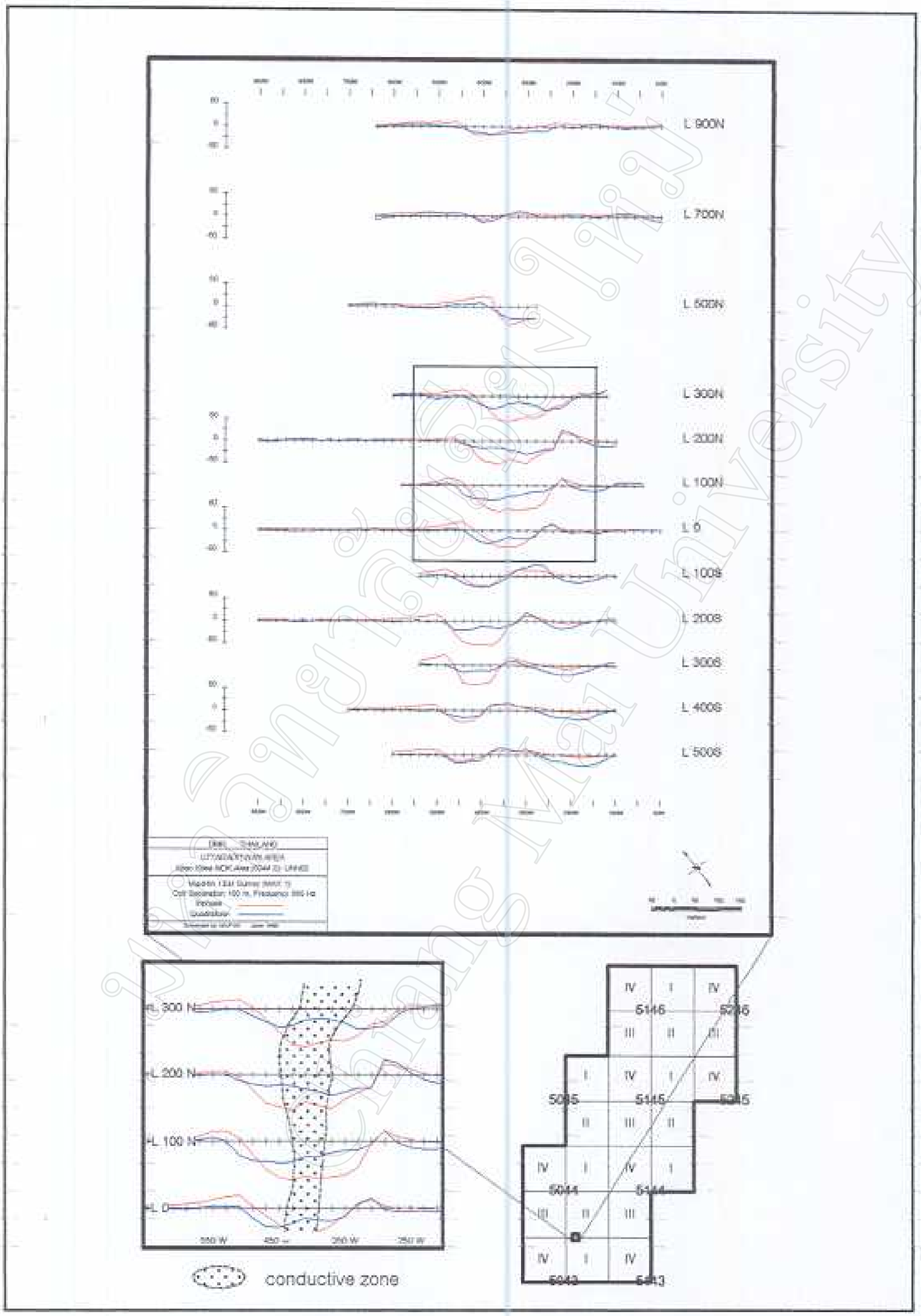


Figure 4.17 Horizontal loop electromagnetic survey result over the graphite deposit.
(after Surinkum and Siripongsatian , 1992)

metamorphosed carbonaceous shale (Surinkum and Siripongsatian, 1992). Surinkum and Siripongsatian (1992) made the quantitative interpretation of the HLEM and PEM data and found that both can be used efficiently but with a different degree. PEM data is better in quantitative interpretation but HLEM data is less difficult to acquire.

Magnetic survey (Figure 4.18) and electromagnetic survey (Figure 4.19) were also applied for talc deposit (Surinkum and others, 1995). The results show that electromagnetic data alone cannot be used to outline a talc potential area because serpentine and talc are both conductive minerals. Even though talc is more conductive than serpentine, the contrast is not great enough to indicate a definite boundary. On the other hand, there is no magnetic expression over talc ore body because it is a non-magnetic body. Therefore, a non-magnetic body within a magnetic expression zone with a relatively medium conductance is a talc ore body. However, electromagnetic signals are not significantly useful for asbestos because chrysotile that was formed from shear effects is not conductive and the zone is not big enough to be outlined by electromagnetic surveys (Figure 4.20).

Another metamorphic mineral that found in the NUS zone is actinolite. In general this mineral deposit is not directly related to any geophysical survey results due to its moderate conductance and low susceptibility. However, it was found at the contact between conglomeratic sandstone and peridotite where both have highly contrasted susceptibility (Figure 4.21).

4.2.7 Geophysical technique for oxidized mineral deposits

Hematite and nickel-chrome iron oxide in this NUS zone is associated with airborne electromagnetic anomalies with negative in-phase characters. Magnetic data with high frequency indicates that the body of these magnetic oxides is not continuous and lies not very deep from the surface. Electromagnetic profile over the magnetic oxide area is reflected by a step function series where resistive zone changes to moderate conductive zone (Figure 4.22).

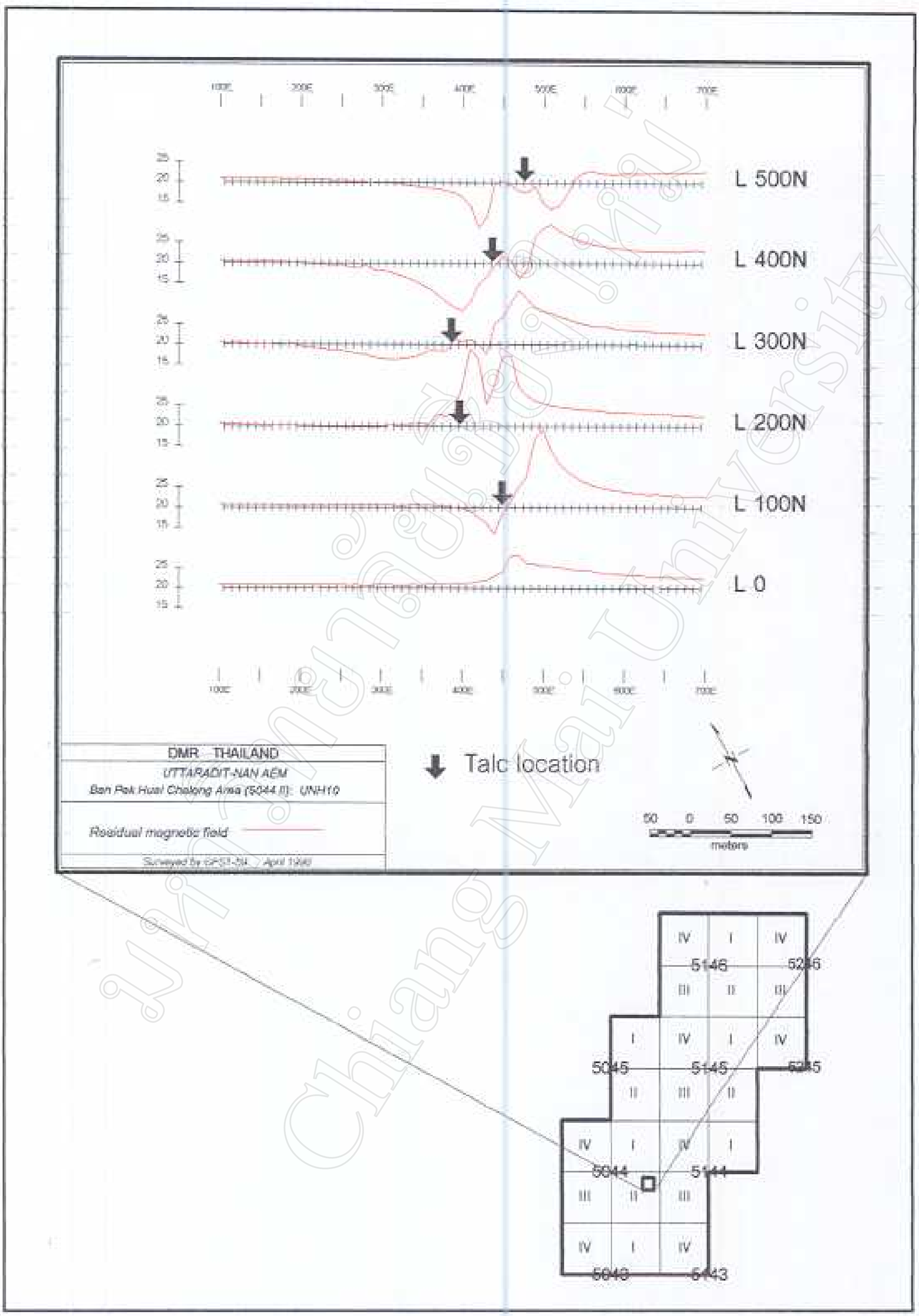


Figure 4.18 Ground magnetic survey result over the talc deposit.
(after Paiyarom and Surinkum , 1997)

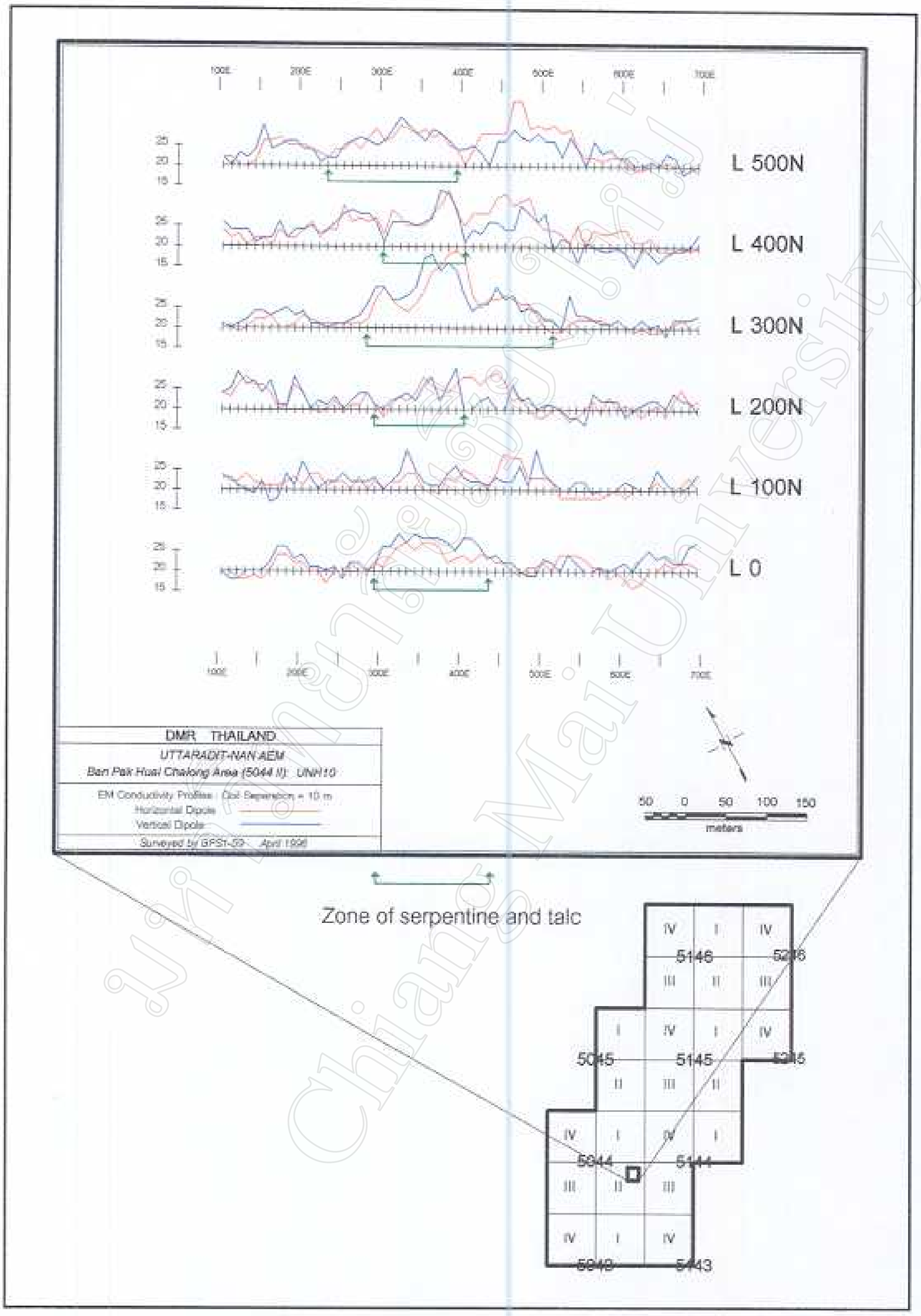


Figure 4.19 Ground electromagnetic survey result over the talc deposit.

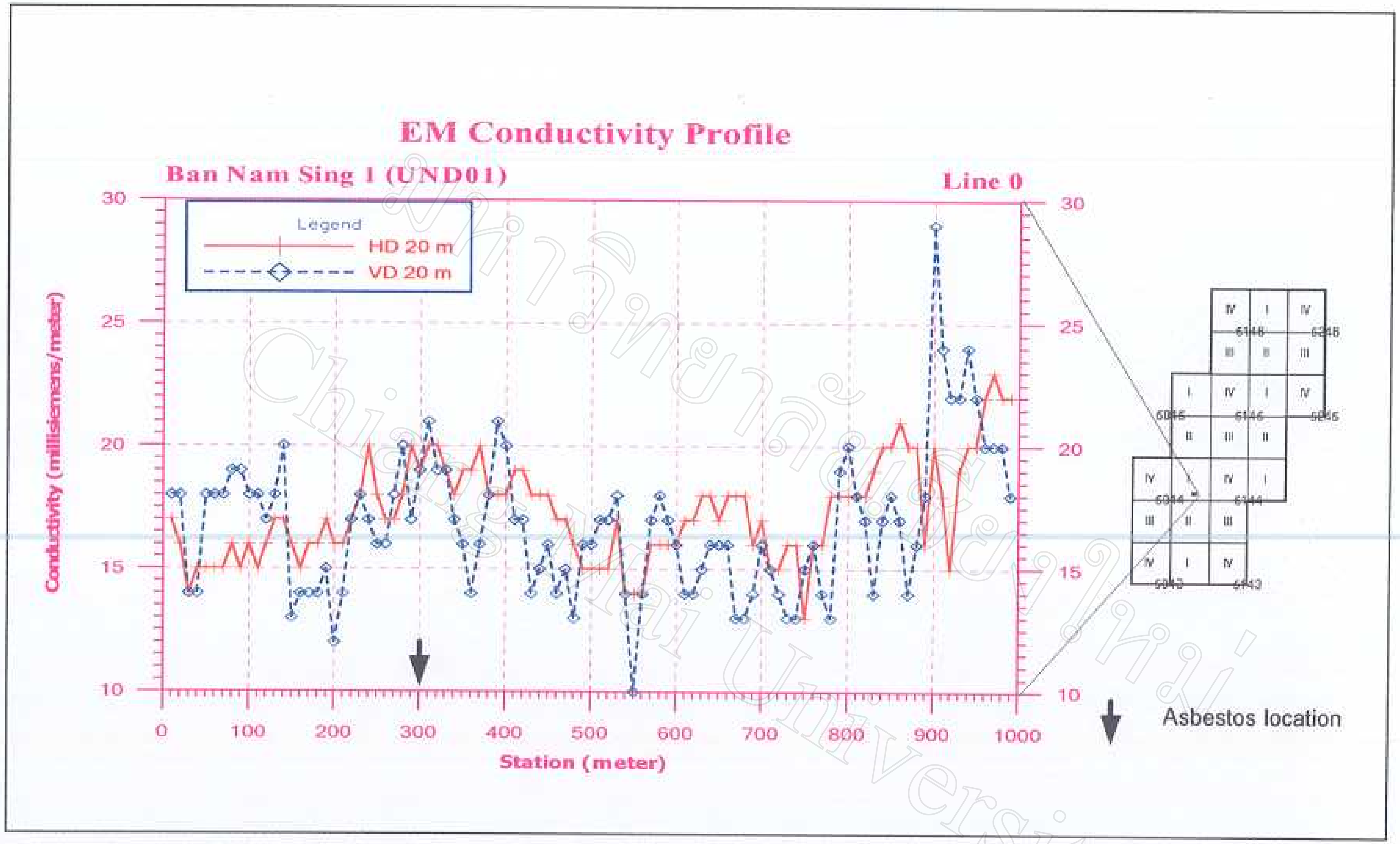


Figure 4.20 Ground electromagnetic survey result over the asbestos deposit.
(after Paiyarom and Surinkum , 1997)

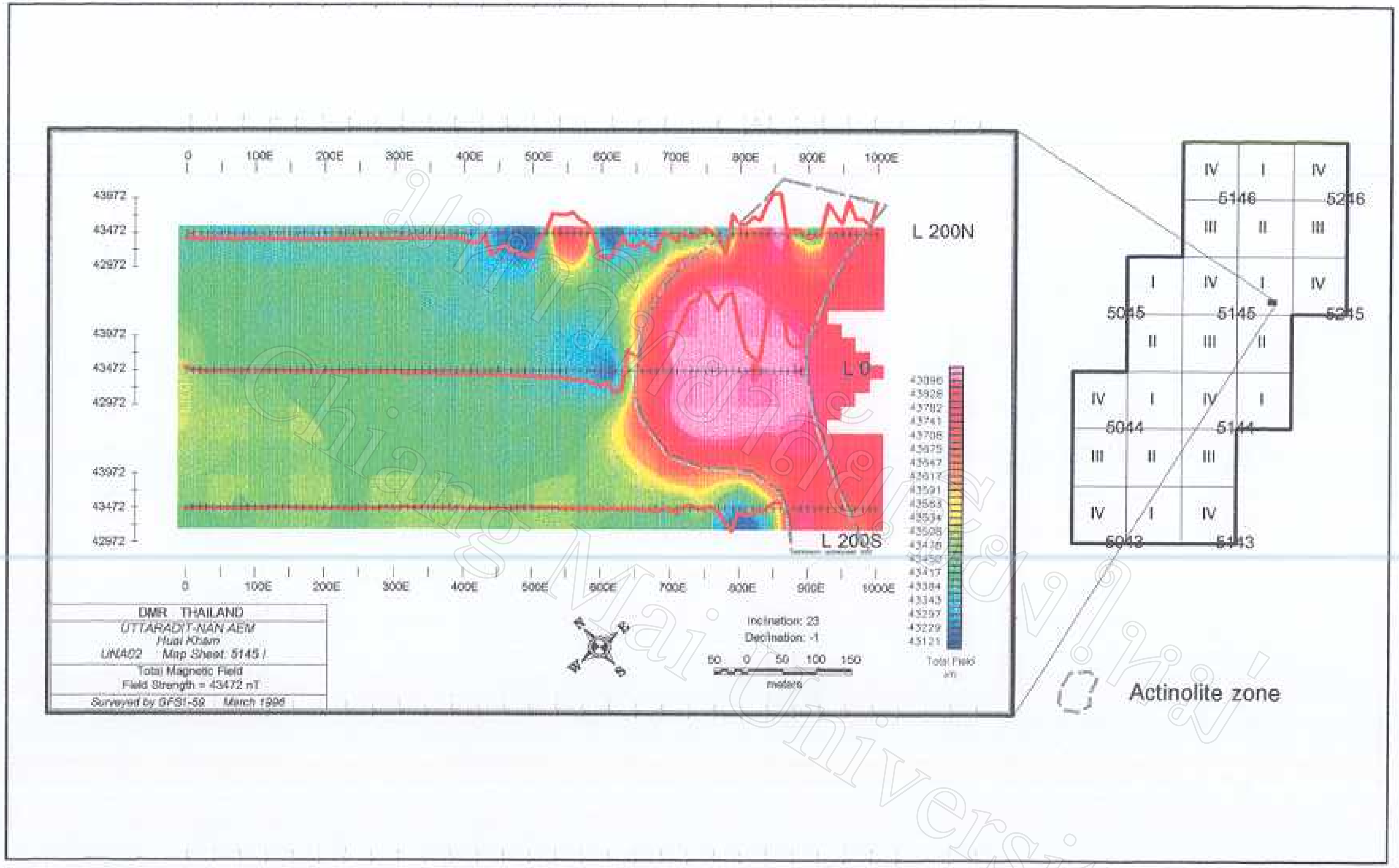


Figure 4.21 Ground magnetic survey result over the actinolite deposit.
(after Paiyarom and Surinkum , 1997)

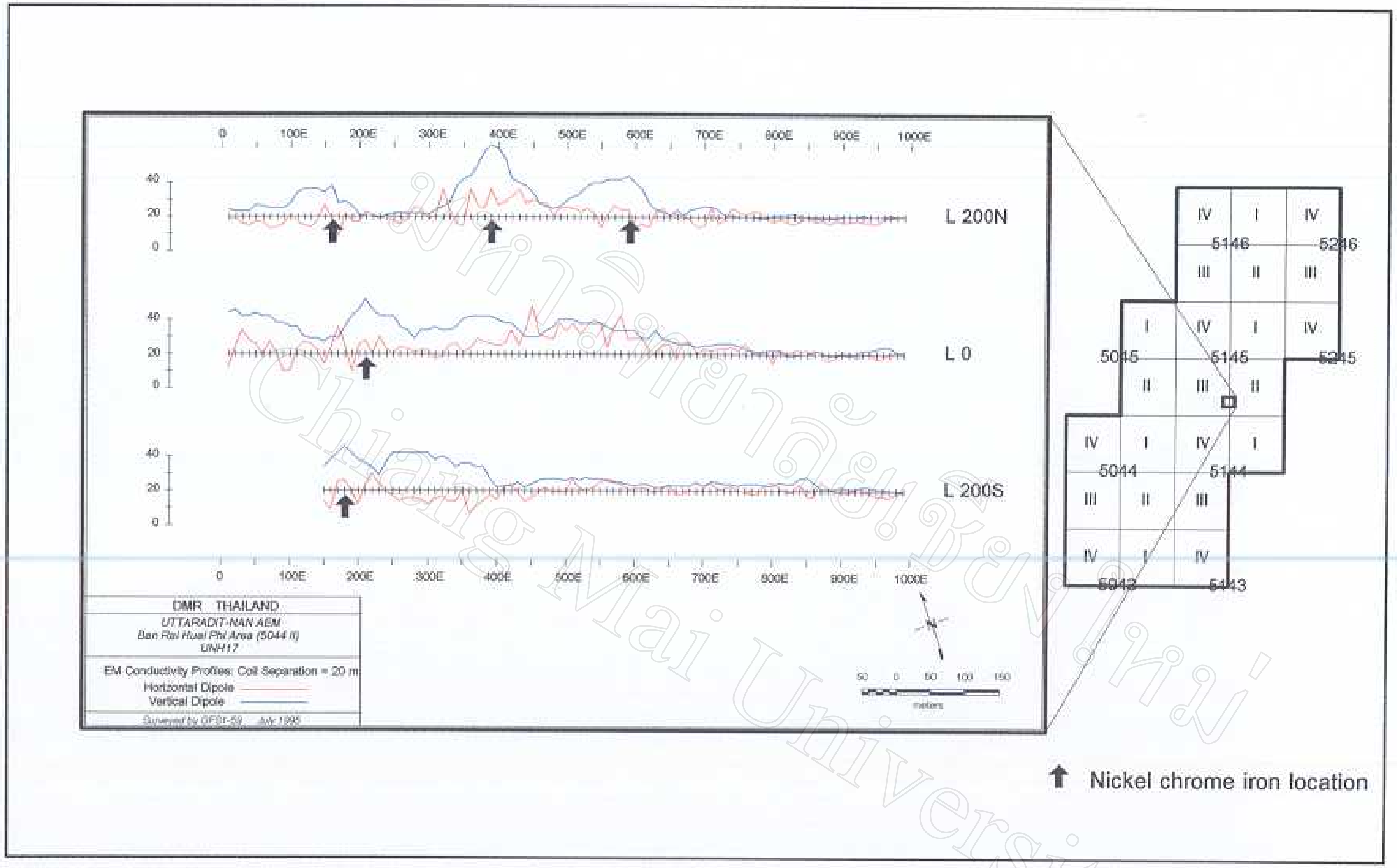


Figure 4.22 Geophysical survey result over the nickel chrome iron deposit.
(after Paiyarom and Surinkum , 1997)