Chapter 4

The study area and potting clays

4.1 Introduction

Ceramic industries employing simple manufacturing techniques of the kinds extant in Northeast Thailand today, and postulated as extending back into the prehistoric periods under question here, are closely affected by their environment. Raw materials are distributed according to geological processes (Shepard 1956), and their acquisition involves a detailed knowledge of the areal terrain. Potting clay distributions and climatic conditions can constrain clay extraction and pottery manufacture (Arnold 1985). The availability of quality materials can determine the location of production centres (Shepard 1956, Arnold 1985), and weather conditions may restrict potting to favourable climatic zones and seasons (Arnold 1985). In this chapter we will briefly examine the geography, geomorphology and climate of Northeast Thailand. The geology of the Khorat Plateau, and its implications for pottery production, will also be touched on. Finally, the clay mineralogy of 14 Sakon Nakhon Basin potting clays will be considered in detail.

4.2 Geography, geomorphology and climate

The following geomorphological outline is derived mainly from Cruijs (1964, 1978), Moorman et al. (1964), and Thiramongkol and Pisutha-Arnond (1983).

Ban Na Di is situated in the Sakon Nakhon Basin, the smaller of two located within Thailand’s northeastern Khorat Plateau (fig. 4.1). The Khorat Plateau comprises an area of about 170,000 km$^2$, and is bounded to the north and much of the east by the Mekong River. Its western, southern and southeastern natural boundaries are formed by steep escarpments of uplifted Mesozoic strata. These vary in elevation from about 250 m to 900 m above sea level (m.a.s.l.). Bordering the western plateau perimeter are combinations of sedimentary, igneous and metamorphic formations which together comprise the Central Highlands. In places these combinations are complex. This includes the 1,300 m high Phu Kradung “mesa-like outlier” (Cruijs 1978).

The plateau’s two basins have surface elevations ranging from about 100 to 300 m.a.s.l. Their principal landscape features are the river terraces located in plane to gently undulating surfaces, while mounds and hills are common microreliefs (Cruijs 1978, Moorman et al. 1964). The plateau is located between 14° to 19° north, and 101° to 106° east. It gently slopes down towards the east and southeast. Stream patterns are directed principally to the east, and the major Khorat Basin is entirely drained eastwards into the Mekong River by the Mun and
CHAPTER 4. THE STUDY AREA AND POTTING CLAYS

Chi Rivers and their numerous tributaries. Both these rivers originate in the western hilly zones of the Central Highlands. The smaller northern Sakon Nakhon Basin is principally drained by the Songkram and its tributaries northeastwards into the Mekong. The Songkram originates in the Phu Phan Range. Ban Na Di falls within the Lake Kumphawapi catchment, and adjacent streams drain south into the lake which in turn discharges into the Pao River. The Pao flows south through the Phu Phan Range to join the Chi River (figs. 4.2 and 4.3).

Moorman (et al. 1964), interpreted the Northeastern (i.e. Khorat Plateau), landforms as largely alluvial in origin, the result of a series of depositional and erosional events. They argue that the plateau's geomorphological features “are predominantly determined by tremendous alluvial deposits of the Mekong River and its tributaries” (Moorman et al. 1964:4), several such sedimentation phases being separated by erosional periods to form four main sedimentation levels (high, middle and low alluvial terraces, and the present day alluvial plain), of the existing landscape.

This widely accepted “terrace model” has recently been questioned by Loffler (et al. 1983:123-130), who argue for essentially erosional Northeast uplands and slopes with the larger valleys representing filled-in valleys. Sedimentation “was more or less continuous following a period of pronounced incision”,”due to a rise in base level near the Mun River-Mekong River confluence”. Changing environmental conditions are held to be reflected in the character of the sediments with glacial period aeolian material “masking much of the erosional landscape with a blanket of sand”. The glacial period coincided with pronounced dryness in the Northeast due to the “greatly extended land area” during climatically induced low sea levels. “Climatic change however was not the controlling mechanism for incision or sedimentation. This was controlled by changes in base level which in turn were controlled by tectonic events” (Loffler et al. 1983:130).

Thailand lies in the monsoon (Koppen Aw) tropical zone of Southeast Asia (Strahler 1973). Extremes in wet-dry seasons typify this zone with intermittent heavy rains normally producing extensive seasonal riverplain flooding. Local annual rainfalls are affected by, and vary in accordance with, topography. Wet-season rains and resultant heavy leaching promote laterisation (Press and Siever 1974:211-212). According to Hope and Hope (1976), New Guinea montane evidence suggests that, for the last 5,000 years, the climate has been relatively stable. Sea level stability also reflects these conditions (Galloway and Loffler 1972, Chappell 1976, Chappell and Thom 1977). These data are supported by recent Thailand montane evidence which suggests that the climate has been wet and warm for about the last 11,000 years, and that the present conditions have been experienced for at least the last 4,300 years (Hastings and Liengsakul 1983).

Arnold (1985:66-79) reports that in climates subjected to substantial rainy seasons, and consequent high humidity, ceramic industries are seriously affected. Because of excess atmospheric moisture, and/or long periods of heavy rainfall, plastic pottery fabrics often cannot be dried enough to ensure they will hold their shape. These conditions may also cause unfired pottery to crack. Firing under these conditions is hazardous, and in addition moving unfired pottery risks damage. In such conditions manufacture is not warranted and production ceases in the wet season. This regulatory effect can have important implications for the integration of subsistence and technology.
4.3 The geological setting and its implications

In this section, in addition to the sources quoted above, geological maps published by the Royal Thai Survey Department (1978, 1980, 1982, 1984), the Geological Survey Division of the Department of Mineral Resources ((DMR): 1971, 1974, 1976, 1980, 1984), and the Federal Institute for Geosciences and Natural Resources (1975, 1976, 1977, 1978, 1979, 1981), have also been considered. To date, detailed 1:250,000 scale maps covering the study area are unavailable, although they are currently in preparation (Cruiks 1978:4). Such maps are available for the western plateau margins (NE 47-12, NE 47-16, ND 47-4), Mun Valley, and Central Highlands. They have all been considered, because these areas include strata relevant to the present work.

In stark contrast to the Rio Grande, Shepard’s study area, the lowlands of the Khorat Plateau are blanketed almost entirely by Quaternary sediments (Cruiks 1978, and fig. 4.4). These are underlain by very thick Mesozoic sedimentary deposits of the Khorat Group (Cruiks 1978). The two structural basins are without large exposures of Mesozoic bedrock. Outcrops of these rocks are usually lacking, apart from a few small and scattered outcrops of strata belonging to the Upper Khorat Group, within the plateau. The Sakon Nakhon and Khorat Basins are composed of basement Mesozoic sedimentary rocks extensively overlain by alluvium and colluvium sediments and mantles of sand of aeolian origin (Cruiks 1978, Loffler et al. 1983).

Igneous rocks are absent except for Tertiary and/or Quaternary basalts which occur in the Mun River basin mainly near the southern edge of the plateau. Some high terrace gravels contain, principally Palaeozoic, remnant igneous rocks in various proportions. All are resistant or very resistant, and are thought to represent fluvial deposition from remote Central Highland sources (Cruiks 1978:28).

The Phu Phan Range, which separates the Sakon Nakhon and Khorat Basins, consists of folded Mesozoic rocks of the Khorat Group (Cruiks 1978). The Khorat Group contains a series of six sedimentary formations. A 1:1,000,000 scale generalized DMR map (Javanaphet 1969), shows the Phu Phan Range as comprising the Phu Phan, Phra Wihan and Phu Krudung Formations. According to Cruiks (1978:35-37), the Phu Phan Range is comprised principally of the Phra Wihan, Sao Khua and Phu Phan Formations. The Khok Kruat Formation only occurs in large synclines at lower elevations, and the Upper Triassic-Lower Jurassic Phu Krudung Formation may also be present. The Mahasarakham (or Salt) Formation, which is the highest Mesozoic stratigraphic unit, has been totally removed from outcrops. The Royal Thai Survey Department (1980), in a 1:2,500,000 scale geological atlas of Thailand, show the Upper Khorat Group underlying both major basins, with Middle and Lower Khorat Groups comprising the Phu Phan Range.

Chongpan and Nares (1979), note the following associations, in descending order, for Khorat Group Formations in Changwat Petchabun (map NE 47-16). This area lies about 120 km west-south-west of Ban Na Di. The Khok Kruat contains micaceous sandstone, shale and siltstone, lime-nodule and conglomerate. The Phu Phan is comprised of a sandstone containing pebbles consisting of quartz, chert, siltstone and igneous rocks up to 5 cm in diameter intercalated with shale and conglomerate. The Sao Khua consists of micaceous sandstone and shale, and lime-nodule conglomerate. The Phra Wihan contains an orthoquartzitic sandstone with some intercalations of shale. The Phu Krudung consists of micaceous shale, siltstone and sandstone, with some lime-nodule conglomerate.

According to Cruiks (1978:13), the above geomorphological and geological evidence is based on drillings, exposed outcrops and satellite remote sensing studies. He notes that the Phu Phan sandstone caps numerous mesa-like hills around the rim of the Khorat Plateau and
eroded anticlines in the Phu Phan hills. It contains resistant layers of arkosic and conglomeratic sandstones and conglomerate. These formations also outcrop along the western and southwestern margins of the plateau (Cruïjs 1978:14).

As the above geomorphology suggests, the Khorat Plateau was uplifted, tilted principally towards the southeast, and only slightly warped into a huge shallow basin. Apart from the Phu Phan anticlines, little deformation is apparent. According to Cruïjs (1978:10), Cenozoic epirogenic movements were mainly responsible for the present plateau structure. Folding, faulting and volcanism associated with a Late Tertiary-Early Quaternary orogeny saw the emplacement of igneous intrusives along the western plateau margins, and in isolated locations within the southern plateau boundaries (Cruïjs 1978:18, 33–34).

Extensive salt deposits occur within the Mesozoic formations, although their precise distributions and/or origins are not fully understood (Cruïjs 1978:39–45). Outcrops of the Mahasarakham Formation, comprising mainly “siltstone, sandy shale, mudstone, evaporites (rock salt/halite, gypsum-anhydrite and potassium minerals) and minor sandstone”, are “sparse and small” (Cruïjs 1978:15). It is thought to form the major portion of the bedrocks of both basins. “No outcrops of solid, primary sedimentary or structural controlled salt deposits appear to exist, because, according to Gardner et al. (1967), they have been dissolved everywhere to depths of as much as 61 to 76 metres or more by deep leaching facilitated by heavy seasonal rainfall and fluctuating groundwater level that characterises the region” (Cruïjs 1978:39).

Geological maps and cross sections published by the Royal Thai Survey Department and the DMR (1969, 1976), show the Khorat Group as the basement structure underlying the entire Khorat Plateau. Various Khorat Group formations are shown outcropping so as to almost encircle the Khorat Basin. Minor local outcrops also occur in the northern portion of the Sakon Nakhon Basin. The overall geological structure features little displacement of the Mesozoic strata and this is typical of epirogenic processes. It may have important implications for pre- and post-epirogenic sedimentary deposits now present as residuum. Unfortunately, the clastic sediments of the Khorat Group have not been subjected to a detailed and systematic sedimentological study (Cruïjs 1978).

As noted above, detailed small scale geological maps are not yet available for much of the study area, including Ban Na Di and many related Sakon Nakhon Basin sites. Löffler et al. (1983), on the basis of 35 m deep drillings at Tung Kula Ronghai (TKR), argue for tectonic-derived pronounced incision and sedimentation, on which was superimposed climatic related sedimentation. They consider that these processes are relevant to the whole plateau. Their cores revealed a present land surface of 2-4 m thick clay to sandy silty clay, overlying fine to coarse non-organic sands which vary widely in depth but rarely exceed 8 m. Beneath this is an organically rich sand unit 10-20 m thick, C14 dated to c. 34,000 to c. 20,000 years ago. The oldest sediments were cut at 30-35 m deep, and consist of non-organic very fine to medium sands.

Hastings and Liengsakul (1983:26) consider that the TKR organic sands represent a late Pleistocene deposition. It is unclear whether the TKR sediments relate to the Sakon Nakhon Basin clays. Detailed mineralogical descriptions are not given by Löffler et al. (1983). The youngest clay deposition forms a cap overlying an alluvial substratum. It is thus consistent with transported clay. There is no evidence to suggest that it results from modern sedimentation. The potting clays discussed below were quarried 1-2 m below the present land surface at most sites (fig. 4.5). They are considered to have been deposited prior to the first occupation of Ban Na Di c. 3,500 years ago.
4.4. ANALYSIS OF SAKON NAKHON BASIN POTTING CLAYS

Discussion

In a sense the Khorat Plateau represents a textbook example of geological processes where tectonism has transformed a large subcontinental Mesozoic limnic and paralic sedimentary basin into a post-Mesozoic terrestrial structure (Crujjs 1978). Recent data suggests tectonic activity continued during the Quaternary. In addition, climate induced environmental changes, which featured alternating drier and more humid phases, were superimposed onto these latter tectonic events. These are reflected in the present stratigraphic sediment variations (Loffler et al. 1983).

Tectonism, erosion, sedimentation and climatic fluctuations have together produced a geologically homogeneous and therefore discrete region. Clays within the plateau will reflect this homogeneity to varying degrees, dependant upon the nature of the local geology. Thus pottery made of clays derived from sources exotic to such homogeneous areas are likely to stand out because the geology is more mineralogically distinctive. Hence ceramics originating in the Phu Phan Hills, the western margins, southern igneous zone, and the Central Highlands, can be expected to be, mineralogically, clearly distinctive.

Gradational changes in the overall mineralogy should be apparent downstream from the source rock outcrops. Due to the mainly west to east internal drainage patterns, increasing quantities of distinctive inclusions should become evident the further west towards the Central Highlands the clays are quarried. Within the Sakon Nakhon Basin, sources close to the Phu Phan Range are similarly likely to prove distinctive. These distinctive mineral assemblages are unlikely to be obvious except in clays relatively close to parent rock outcrops because of rapid weathering.

Thus this huge plateau is composed almost entirely of sedimentary strata, and as the data set out below demonstrate, the associated potting clays often contain common mineral suites which are undiagnostic for sourcing purposes without intensive analysis. Several potentially rewarding methods are available to cope with such circumstances. Similar sourcing questions have been resolved using textural (Peacock 1971, Streten 1982), or heavy mineral analysis (Peacock 1967, 1970, 1973; Williams 1977). Heavy mineral analysis probably holds the best potential for the characterisation of pottery and clays not already distinguishable using standard thin-section petrography. This approach was not undertaken because the method is excessively laborious without necessarily providing clear conclusions, particularly where two differently sourced clays have been combined (Williams and Jenkins 1976). In view of the extensive scope of the present enquiry, quantitative applications of such intensive methods were considered impracticable.

The above discussion is not meant to imply that distinctive sedimentary deposits are non-existent within the Khorat Plateau. The results of a petrographic analysis of various modern Sakon Nakhon Basin potting clays, set out in chapter five, show that several are distinguishable petrographically. The X-ray diffraction data presented below complements optical evidence discussed in the following chapter. These source materials were obtained during fieldwork undertaken by the author.

4.4 Analysis of Sakon Nakhon Basin potting clays

Introduction

A total of 14 clays have been examined using standard X-ray diffraction methods. As the spectrographs set out in figures 4.16 to 4.17 show, they contain a variety of clay mineral species
in varying proportions and combinations. Several include clay minerals that hydrate excessively. Smectites, for example, are present in clays 2, 4, 10, 12 and 14. While this is only one factor in their usefulness, it suggests that overall these raw clays are therefore of varying quality as potting clays. Samples 8, 11, 13 and 14 derive from locations that were unable to be unequivocally verified as genuine sources in the field, because the original precise quarry locations were uncertain. This was due in some cases to their long term abandonment. However they have been included because they were identified by local informants as having once been exploited by potters, and all possible sources were considered as potentially crucial to the study.

Discussion

Generally potting clays containing a high proportion of kaolinite $Al_2O_3.2SiO_2.2H_2O$ are preferred by potters. This reflects both its contribution to a potting clay’s “workability”, and its strength on firing due to the chemical change promoted via the dehydration of the aluminium silicate compound to form a metakaolinite or ceramic fabric. Rigby (1948:96) describes kaolinite as the “primary constituent of china clay and fireclays”. Hamer and Hamer (1977:3-4), from a potter’s perspective, consider kaolinite as a pure clay. Disordered kaolinite, although less pure, also qualifies as a clay. According to Hamer and Hamer, however, any other mineral, mica and montmorillonite for example, does not. This concept, apparently common among potters, and until recently among many geologists (Grim 1968:14), is not accepted by clay mineralogists who have clearly established “that there are many clay materials in which there is no kaolinite present” (Grim 1968:15). While universal agreement has yet to be reached on a precise detailed classification, the basic major clay mineral groups, although some contain complex individual species and relationships, are well understood and generally accepted (Grim 1968:34, Folk 1980:89-94, Williams et al. 1982:317-324, Lewis 1984:151-157).

Kerr (1977:454), tabulates clay minerals into four groups, kaolins (kandites), including kaolinite, anauxite, dickite, nacrite, halloysite, hydrohalloysite, and allophane, montmorillonites (smectites), including montmorillonite, beidellite, nontronite, saponite, and hectorite, illite (hydromuscovite), and palygorskites, including palygorskite, attapulgite and sepiolite, as distinct clay mineral groups. Many modern researchers include dickite and nacrite (both rare) with kaolinite (Grim 1968:38, McConchie 1978). Grim (1968:38), argues “that halloysite is distinct from kaolinite and warrants a separate specific name”. Many authors, however, (Mason 1966, Folk 1980, Tucker 1981, Williams et al. 1982, Lewis 1984), include halloysite with kaolinite. Williams et al. (1982:317-320), recognize illites, smectites, kaolinites, chlorite, gibbsite, and halloysite. An alternative classification identifies kandites (kaolinite, dickite, nacrite and halloysite), illites (illite, and the so-called hydromicas including sericite), smectites (montmorillonite), vermiculites and palygorskite. Chlorite is not included in this system (Deer, Howie and Zussman 1966:253-254). Montmorillonite is now tended to be recognized as a member of the smectite group.

The important factors for ceramic purposes are crystallinity, manner and perfection of the stacking of layers, and the number and type of chemically bound layers present in any given clay mineral. This latter factor in particular is directly related to the amount of water the clay will adsorb (Grim 1968:234-235), and crucially affects its suitability for ceramics. A schematic summary of the principle clay mineral structures is set out in figure 4.6 below.

Kaolinite has a dioctahedral structure comprising one silica tetrahedral sheet and one alumina octahedral sheet combined to form a common layer (Grim 1968:58 Fig. 4-4). These layers form sheets stacked vertically along the C crystallographic axis (Deer et al. 1966:256,
4.4. **ANALYSIS OF SAKON NAKHON BASIN POTTING CLAYS**

Fig. 87). Kaolinite normally is well crystalline and subject to little substitution. Within-layer sharing of atoms results in relatively few hydroxyls in comparison to other clay minerals. The layers are bound by hydrogen- or hydroxyl-type bonds (Deer et al. 1966:256, Fig. 88). The OH lattice water is lost beginning at temperatures above about 300°C with most of the dehydration occurring between about 400°C and 525°C, and at about 750°C to 800°C dehydration is essentially complete (Grim 1968:298). The resultant loss of oxygen atoms in metakaolin almost certainly reflects a tetrahedral aluminium coordination, and it is this new structure which gives rise to the strength of metakaolin (Grim 1968:298-301). Adsorbed water (i.e. in pores, on surfaces and edges of mineral particles), is lost at little above ordinary room temperatures. For clay minerals other than well crystalline kaolinite adsorbed water is normally driven off at temperatures well below 300°C. Pore water is usually lost at 120°C to 150°C. Air drying is sufficient to remove the balance of adsorbed water.

Disordered kaolinite is normally poorly crystalline with imperfections in the stacking of layers. Grim (1968:66), suggests gradations from well crystallized kaolinite to complete randomness in layer organization and populations of aluminium positions for disordered kaolinite. Substitutions, usually of titanium or iron for aluminium, only occur in poorly crystalline (i.e. disordered) kaolinite. According to Hamer (1975:100) such clay minerals form the fine and plastic portion of the so-called secondary clays (e.g. ball clays, stoneware clays and low grade fire clays).

In the case of smectites, vermiculites and the hydrated form of halloysite, the interlayer water requires temperatures of up to 400°C for complete removal. Smectites have either a dioctahedral or trioctahedral structure comprising Si-Al-Si units with the O layers of each unit adjacent to O layers of neighbouring unit (Grim 1968:79, Fig. 4-13). This results in a very weak bond. Water can readily enter between the unit layers causing the lattice to expand substantially. Dehydration of interlayer water is rapid upon heating and is probably complete at about 300°C. This is accompanied by a marked reduction in C axis dimensions. Rates for the loss of OH lattice water vary widely for smectites. However normal montmorillonites lose OH water rapidly from about 500°C, and dehydration is practically complete at 800°C (Grim 1968:314-315).

Smectites, illites and vermiculites are all structurally related to the micas, with illites showing the closest similarity. Micas have the same basic structure as “montmorillonite except that some of the silicons are always replaced by aluminum” (Grim 1968:93-98). The resultant charge deficiency is balanced by potassium ions located between unit layers. As a consequence micas generally contain little interlayer water. In illites this substitution occurs close to the layer surface thus preventing the ready entry of polar ions. Illites differ from the well-crystallized micas in their Al for Si substitution ratios and this gives rise to a charge deficiency reduction. Some potassium ions between unit layers may be replaced by other cations. Stacking of layers in the C direction is somewhat random and illites have smaller particles than micas. Illites lose adsorbed water rapidly below 100°C, gradually between 100°C and 350°C, a large relatively abrupt loss occurs from about 350°C to 600°C, and above 600°C water is gradually lost (Grim 1968:334). The OH lattice water is gradually lost from 300°C to 600°C (Grim 1968:334-335).

Smectites may contain randomly mixed cells and this results in a variety of water contents with basal spacings ranging from between about 10 to 21 Å (Deer et al. 1966:265). Hence they are often referred to as swelling clays.

Sericite is characterised principally as a degraded mica, or alternatively as a true clay mineral. Folk (1980:90), describes it as a clay mineral that is “probably just fine-grained
slightly impure or K-deficient muscovite". Grim (1968:42), however, objects to the definition of sericite as a clay mineral and prefers illite "for clay-mineral micas of both dioctahedral and trioctahedral types and of muscovite and biotite crystallizations". Others, (Kerr 1977:430, 433, 461, Heinrich 1965:28, 281), consider sericite is either a hydrothermal secondary mineral or a weathered mica. Deer et al. (1966:202, 261), note that the term is "generally used to describe a fine-grained white mica which may be muscovite or paragonite". Lewis (1984:151), argues that "illite (hydromuscovite) grades into sericite". From a purely petrographic viewpoint, however, Williams et al. (1982), avoid the term entirely preferring to describe such material as "fined-grained muscovite" or "white mica". In light of these variations in definition and terminology, Grim's characterization of illite, because it refers to the chemical structure of the mineral, will be applied to chemical and X-ray clay mineral data included here. The term sericite will be used for fine grained, optically identifiable, muscovite.

Vermiculites are often associated with muscites in mixed-layer structures. The vermiculite structure consists of an alternation of either dioctahedral or trioctahedral mica or talc-like layers and double water layers. It is similar to the smectites in that it has an expanding structure but differs in that its expansion with water is limited to about 4.98 Å (Grim 1968:104-111). Vermiculite dehydrates in steps from a normal C-axis dimension of 14.36 Å down to 9.02 Å as the interlayer water is gradually lost and the silicate stacking sequence changes (Grim 1968:108-110). When heated rapidly to about 300° C, vermiculite exfoliates with a marked expansion. If it is heated slowly up to about 250° C, however, exfoliation does not occur (Deer et al. 1966:272).

Chlorite consists of alternate trioctahedral mica-like and brucite-like layers (Grim 1968:100). Dependent on the cation present, chlorites show very little water loss prior to about 500° C, although this may vary dependent on particle size and layer orientation. After a sharp loss between 500° to 550° C most chlorites completely dehydrate at about 850° C. A mineral with a 14 Å spacing, which expands slightly on glycolation to about 16 Å to 18 Å, has been described as a "swelling chlorite". Such minerals probably have discontinuous brucite layers insufficient to prevent expansion on glycolation (Grim 1968:103-104). Septechlorites are closely related to chlorites chemically but structurally have serpentine-like layers with a 7 angstrom basal spacing (Deer et al. 1966:241, Lewis 1984:152).

Palygorskite, attapulgite and sepiolite have an amphibole- like double chain structure. They are not important ceramic clay minerals.

Kaolinite alone, however, does not ensure a quality potting clay because the potter also requires the clay to be "workable". This means it must be strong, plastic and thixotropic. Hamer (1975:295), describes this latter property as the ability of clay to retain its shape while remaining viscous and thus easily worked. Grim (1968:236-238), also ascribes this property to thixotropy, although geologists may consider the term to refer to the property of some gels to become fluid when shaken (American Geological Institute 1976).

Plasticity is the property of moistened clay to be reformed when subjected to mechanical pressure, with the new form retaining its shape when the pressure is removed. This property is developed by clays mixed with a limited amount of water until readily workable. Excessive water creates a clay which is too fluid. Plasticity is primarily due to the adsorption of water by clay minerals. In potting clays it is also dependent on several other factors including the relative proportions of nonplastic and other non clay inclusions in addition to the overall clay-mineral composition. Particle size, uniformity, texture and shape influence plasticity in both clay minerals and colloidal nonplastics.
4.4. ANALYSIS OF SAKON NAKHON BASIN POTTING CLAYS

Clay-mineral composition “refers to the identity and relative abundance of all the clay-mineral components” (Grim 1968:4). It is crucial to the overall composition of the potting clay. A quality potting clay, therefore, must include either a mixture of clay minerals or, as in the case of the lower fired wares such as biscuit and/or stoneware, a mixture of clay mineral(s) and non-plastic material. This latter component may form from 25 to 50% of the total mix.

Many commercial clay materials contain kaolinite and illite in about equal amounts, often with small additional amounts of chlorite. Montmorillonite is acceptable only in small quantities as large amounts cause catastrophic shrinkage and drying problems. Overall these clays generally display relatively low shrinkage, good plasticity and firing properties (Grim 1962:131).

4.4.1 Methods

In the field, spot samples of small representative areas of potting clay, weighing about 1 kg, were taken. In the laboratory, dry samples each weighing about 50 grams were immersed in 400 ml of distilled water for about 30 minutes until fully flocculated. They were then thoroughly stirred and allowed to settle for 90 seconds when the upper part of the column was decanted into another beaker. This fine fraction was allowed to settle for a further 24 hours when the excess water was decanted and the residual < 2 µ fraction was gently poured onto a glass slide and allowed to dry for at least 24 hours. The resultant dried samples were then examined in the X-Ray diffractometer employing a Cu Kα radiation at 50 KV and 20 MA.

Where initial counting produced relatively weak clay mineral peak distributions the counts per second were reduced in order to give a more well-defined spectrograph. Several gave diffraction intensities of a 14 Å crystal lattice consistent with either chlorite or smectite. In these cases the samples were left in an ethylene glycol atmosphere overnight (for 16 hours), and then re-examined in the diffractometer.

A variety of preparation methods were considered prior to settling on the method outlined above. Gibbs (1971) recommends either the “smear-on-glass slide technique” or the “suction-on-ceramic tile technique”. He regards using a pipette or dropper, pouring from a beaker, the centrifuge on glass slide, as well as the centrifuge through ceramic-tile techniques as “generally unacceptable” for mounting sample material because of segregation error (Gibbs 1971:535).

Comparative tests, using three separate slides of clay 2, were undertaken to assess if any variation in the spectrograph resulted from the preparation method. This could give different proportions of coarse particles on each slide. No significant variation was evident. Care must be taken when pouring the <2 µ fraction onto the glass slide, however, as suspensions which are too aqueous will result in a “lean” coating (i.e. lacking in sufficient solid particles for a homogeneous coating). Such heterogeneous preparations may give weak spectral peaks which could be mistaken for poorly crystalline clay minerals.

As 5 µ particles fall 1 mm in about 30 seconds and 2 µ about 1 mm in 4.8 minutes (Gibbs 1971:534), the decanting used is considered satisfactory. Although particles >2 µ will probably be included in the initial decant, the second 24 hour settling period means that the <2 µ fraction will settle last. Only the upper portion of the second preparation is used, thus a homogeneous <2 µ coating should result.

This study is primarily concerned with the characterisation of the overall spectrum in terms of both the presence and relative proportions of clay minerals. For ceramic purposes the clay mineral composition of clay materials is of crucial importance. Thus, because these determinations were undertaken in order to assess the quality of the clay material as a potting clay, and
to complement petrographic data, the quantitative amount of individual clay species with respect to the overall sample has not been assessed. Results of the tests outlined above indicated that the pour-on-glass-slide method was suitable. Indeed Dr. A. Reay (pers. comm.), favours this method because of its simplicity and minimal experimental error.

4.4.2 Results

XRD results are set out in figures 4.8 to 4.21, and should be compared with the shrinkage tests (Table 4.2), and petrographic data set out in chapter five. A consideration of the XRD results is set out below. Samples 8, 13, and 14 were identified by non-potters as having once been quarried by potters. Because many clays potentially suitable for potting purposes occur in small localized deposits, and most require modification, it is likely that these clay materials require the addition of suitable clay minerals if they are to become viable potting materials. Thus these results highlight the need to ensure, where possible, that verified production clays are collected for analysis.

Each sample contains more than one clay mineral species, and hence they are mixed-layer clay materials (Grim 1968:121). These are different to mixed-layer clay mineral structures which result from the interstratification of individual layers of single, or a few, alumino-silicate sheets. Mixed layer clay materials are those where, within any given naturally occurring clay material deposit, the mixture is of discrete clay-mineral particles which are not orientated in any geometrically preferred manner with respect to their clay-mineral neighbours. A deposit which contains kaolinite and smectite, for example, is a mixed-layer clay material. Mica-vermiculite and mica-montmorillonite interstratifications are common examples of mixed-layer clay minerals (Carroll 1970:38).

Where the reflections at about 14 Å have shifted following glycolation to about 17 Å the clay mineral is considered to be a smectite (Grim 1968:143). Some samples probably also contain mixed-layer clay minerals. While it is not possible to be certain, it is likely that the stable 14 Å peaks are consistent with chlorite. Grim (1968:147) notes that because of their small size, and less regular crystallinity, chlorite clay-mineral particles often give diffuse reflections, and some ordinary reflections may be absent. Chlorite is unlikely to affect the suitability of these clay materials for ceramic purposes. It should be noted that these potting clays can be divided into those which contain "swelling" clay minerals and those which do not.

In samples 1, 5, 6, 7, 8, 9, 11, and 13, no shift in the 14 Å peaks occurred, although samples 6, 7, 9, 11, and 13 display a slight decrease in spectrum height particularly at the low incident beam angles. This is probably due to the ethylene glycol producing a coating effect which has muted these signals slightly.

The spectrographs are set out below. In each case the chart speed was 20 mm per minute. The location of each clay source is set out in figure 4.7.
FIGURE 4.1: GENERAL MAP OF THE KHORAT PLATEAU.
FIGURE 4.2: THE KUMPHAWAPI STUDY AREA.
FIGURE 4.3: THE KHORAT PLATEAU.


B: Regolith formation (undifferentiated): various alluvial and colluvial sediments, colluviated residuum, alluvial middle terraces, and (dissected) erosion surfaces. Holocene and Pleistocene.

C: Basalts. Volcano remnants (cones etc.), dikes and flows. Holocene and Pleistocene.

D: Alluvial high terraces. Middle Pleistocene high terraces (containing tektites) and Plio-Pleistocene non-reworked terraces. Middle Pleistocene and Plio-Pleistocene.

E: Khorat Group, evaporite/molasse bedrock sequence comprising in descending order: Upper Cretaceous Mahasarakham Formation, Middle-Lower Cretaceous Khok Kruat Formation, Upper-Middle Jurassic Phu Phan Formation and Lower Jurassic -Upper Triassic Phu Kradung Formation.

F: Possible (non-exposed) salt dome or plug.
FIGURE 4.5: QUARRYING CLAY AT NONG I LAENG (clay site 12).
FIGURE 4.6: SCHEMATIC SUMMARY OF THE PRINCIPLE CLAY MINERAL STRUCTURES (after Tucker 1981:82.)
FIGURE 4.7: SAKON NAKHON BASIN POTTING CLAY SOURCES.
CHAPTER 4. THE STUDY AREA AND POTTING CLAYS

FIGURE 4.8: CLAY 1 (BAN KHAM O). 10,000 counts per second.

FIGURE 4.9: CLAY 2 (BAN PLUAI). 20,000 counts per second.
4.4. ANALYSIS OF SAKON NAKHON BASIN POTTING CLAYS

FIGURE 4.10: CLAY 3 (BAN NONG THAN). 10,000 counts per second.

FIGURE 4.11: CLAY 4 (NONG HOI KHAN). 10,000 counts per second.
CHAPTER 4. THE STUDY AREA AND POTTING CLAYS

FIGURE 4.12: CLAY 5 (near BAN KHAM O). 10,000 counts per second.

FIGURE 4.13: CLAY 6 (NONG SUNG, near BAN PANG NGU). 10,000 counts per second.
FIGURE 4.14: CLAY 7 (BAN NONG PHAI). 40,000 counts per second.

FIGURE 4.15: CLAY 8 (BAN MUANG (Hua Din)). 10,000 counts per second.
CHAPTER 4. THE STUDY AREA AND POTTING CLAYS

FIGURE 4.16: CLAY 9 (BAN THUM). 10,000 counts per second.

FIGURE 4.17: CLAY 10 (NONG KHAM DIN). 20,000 counts per second.
4.4. ANALYSIS OF SAKON NA KHON BASIN POTTING CLAYS

FIGURE 4.18: CLAY 11 (BAN LAO SUAN KLAUAI). 10,000 counts per second.

FIGURE 4.19: CLAY 12 (NONG I LAENG). 10,000 counts per second.
FIGURE 4.20: CLAY 13 (BAN NA DI (Huai Wang Duan Ha)). 10,000 counts per second.

FIGURE 4.21: CLAY 14 (BAN NA DI (Nong Haeo)). 10,000 counts per second.
4.5 Summary of potting clay qualities

From the perspective of ceramic manufacture, potting clays need a range of inter-related physical and chemical qualities. The type and relative quantities of clay minerals present in any potting clay may have important effects on its quality. Variations in the quality of clay minerals may influence the overall technological processes required to produce a viable ceramic material. Of the clays described above, detailed information regarding methods of tempering are not known for samples 5, 6, 8, 9, 10, 11, 12, 13, and 14. Clays 1, 2, and 7, and possibly 12, were tempered with the bleb species of grog.

Clay 7 featured heavy rice tempering in association with the blebs. The clay was quarried a metre below a rice field to reach clay considered sticky enough. Less sticky clay was rejected as too sandy and therefore likely to crack on firing. The high proportion of clay minerals is correlated with what, in thin-section, appears to be a high silt content. Clay 3 was not tempered. It was kiln-fired into stoneware. Clay 4 was rice-tempered. The amount of temper used is not known.

Perhaps the outstanding overall feature of these clays is their mineralogical variability. This factor demonstrates the expertise required in identifying suitable raw clay deposits and preparing these clays for ceramic manufacture. It also emphasizes the skilful approach employed by potters undertaking their craft often under the most rudimentary of conditions. Samples 2 and 4 contain swelling clays, while sample 7 does not but is silty, yet, in each case, they are successfully exploited. Tables 4.1 and 4.2 below set out the quality of the unmodified clays from a potter’s subjective perspective, and the results of shrinkage tests respectively. Bisques used in the shrinkage tests measured 15 x 2.5 x 0.8 cm when formed. A 10 cm long mark was incised into their surfaces when soft to enable the shrinkage rates to be calculated (Howard 1982).

<table>
<thead>
<tr>
<th>Clay No.</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>moderately plastic</td>
</tr>
<tr>
<td>2.</td>
<td>moderately plastic</td>
</tr>
<tr>
<td>3.</td>
<td>short and coarse</td>
</tr>
<tr>
<td>4.</td>
<td>plastic and fine</td>
</tr>
<tr>
<td>5.</td>
<td>moderately plastic</td>
</tr>
<tr>
<td>6.</td>
<td>plastic and smooth</td>
</tr>
<tr>
<td>7.</td>
<td>short and fine</td>
</tr>
<tr>
<td>8.</td>
<td>very short and sandy</td>
</tr>
<tr>
<td>9.</td>
<td>plastic and smooth</td>
</tr>
<tr>
<td>10.</td>
<td>plastic, very fine and sticky</td>
</tr>
<tr>
<td>11.</td>
<td>slightly plastic, fine and sandy</td>
</tr>
<tr>
<td>12.</td>
<td>moderately plastic</td>
</tr>
<tr>
<td>13.</td>
<td>moderately plastic and fine</td>
</tr>
<tr>
<td>14.</td>
<td>short, fine and sandy</td>
</tr>
</tbody>
</table>

All of the bisques were fired in an oxidizing atmosphere after air-drying to the leather hard
TABLE 4.2: The shrinkage rates of Sakon Nakhon Basin potting clays

<table>
<thead>
<tr>
<th>clay</th>
<th>test 1. 800C</th>
<th></th>
<th>test 2. 900C</th>
<th></th>
<th>test 3. 1000C</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>dry</td>
<td>fired</td>
<td>dry</td>
<td>fired</td>
<td>dry</td>
<td>fired</td>
</tr>
<tr>
<td>1</td>
<td>90.5</td>
<td>90.0</td>
<td>90.0</td>
<td>89.5</td>
<td>90.0</td>
<td>88.0</td>
</tr>
<tr>
<td>2</td>
<td>90.5</td>
<td>90.0</td>
<td>90.5</td>
<td>90.0</td>
<td>90.0</td>
<td>89.0</td>
</tr>
<tr>
<td>3</td>
<td>90.0</td>
<td>90.0</td>
<td>90.0</td>
<td>90.0</td>
<td>88.5</td>
<td>86.0</td>
</tr>
<tr>
<td>4</td>
<td>90.0</td>
<td>89.5</td>
<td>90.0</td>
<td>89.0</td>
<td>90.0</td>
<td>87.0</td>
</tr>
<tr>
<td>5</td>
<td>93.0</td>
<td>93.0</td>
<td>93.0</td>
<td>93.0</td>
<td>92.5</td>
<td>92.0</td>
</tr>
<tr>
<td>6</td>
<td>91.0</td>
<td>90.0</td>
<td>91.5</td>
<td>90.0</td>
<td>91.5</td>
<td>90.0</td>
</tr>
<tr>
<td>7</td>
<td>92.0</td>
<td>90.0</td>
<td>92.5</td>
<td>92.0</td>
<td>90.0</td>
<td>88.5</td>
</tr>
<tr>
<td>8</td>
<td>96.0</td>
<td>96.0</td>
<td>96.5</td>
<td>96.5</td>
<td>96.5</td>
<td>96.5</td>
</tr>
<tr>
<td>9</td>
<td>90.5</td>
<td>90.0</td>
<td>90.0</td>
<td>90.0</td>
<td>90.0</td>
<td>90.0</td>
</tr>
<tr>
<td>10</td>
<td>90.0</td>
<td>89.0</td>
<td>90.0</td>
<td>89.0</td>
<td>90.0</td>
<td>86.5</td>
</tr>
<tr>
<td>11</td>
<td>97.0</td>
<td>97.0</td>
<td>96.5</td>
<td>96.5</td>
<td>96.0</td>
<td>96.0</td>
</tr>
<tr>
<td>12</td>
<td>91.0</td>
<td>90.0</td>
<td>92.5</td>
<td>91.5</td>
<td>92.0</td>
<td>89.5</td>
</tr>
<tr>
<td>13</td>
<td>94.5</td>
<td>93.5</td>
<td>95.0</td>
<td>95.0</td>
<td>94.5</td>
<td>94.5</td>
</tr>
<tr>
<td>14</td>
<td>97.0</td>
<td>97.0</td>
<td>97.0</td>
<td>96.5</td>
<td>96.0</td>
<td>96.0</td>
</tr>
</tbody>
</table>

stage, following standard modern potting practice, to test their likely firing behaviour (Howard 1982). Clays 8, 11, 13 and 14 were collected unaccompanied by a potter. Significantly they displayed the least shrinkage. Clays 3, 7, 8 and 14 have little plasticity due to a disproportionate amount of non-plastics. In modern potting terminology they can be described as "short". The shrinkage rates do not disqualify any of the clays for potting. A high proportion of non-plastics in the "short" clays is not enough to render them unsuitable, however a lack of sufficient suitable clay minerals would be critical to their use as potting material. It is likely that these clays would not fire well, given their natural composition, without modification. It should be noted that while non-plastic inclusions serve to reduce shrinkage, by coarsening and opening the texture of the material they allow the more rapid escape of gases, they may also weaken the clay by reducing the proportion of clay minerals. Thus the amount of non-plastic material a clay may accommodate is limited. The normal modern potting practice is to blend a "plastic" (i.e. high in suitable clay minerals), clay with the "short" clay (Hamer 1975:264).
Chapter 5

The petrology of Sakon Nakhon Basin potting clays

5.1 Introduction

The following potting clays were collected from quarries either in current production or utilized in living memory. Clays from sites 5, 8, 11, 13, and 14 were collected unaccompanied by a potter. The shrinkage and XRD data set out in chapter four suggest that these raw clays are of poor quality. Thus their usefulness as potting clays is uncertain. It is postulated that clays petrographically consistent with 13 and/or 14 and 10, were blended in order to produce fabric group 3 at Ban Na Di (fig. 7.22, appendix one, and Table 5.1 below).

Each clay was fired at 50°C increments from 700°C to 1050°C, in an oxidising atmosphere, and then thin-sectioned. Thus eight sections of each clay have been examined. Prior to covering with a glass slip, the sections were etched with hydrofluoric acid fumes and then stained successively with sodium cobaltinitrate, a 5% barium chloride solution, and finally with a near-saturated amaranth solution. The latter two chemicals stain plagioclase feldspar red, the first stains potassium feldspar yellow. A full description of the procedure is set out by Norman (1974). Lewis (1984:144-145) gives an alternative method. Staining assisted in identifying fine to very fine sand-sized feldspars. Roundness and sorting have been visually estimated. Colours represent firings to 1000°C recorded under the Munsell notation system.

Point counting has helped differentiate sources through the quantification of their various nonplastic contents. The Glagolev-Chayes method (Galehouse 1971:385-407) was used. The results are set out in Tables 5.1 and 5.6. These should be treated as a guide only because the difficulties encountered in evaluating sedimentary fabrics (Lewis 1984:66-67), are increased in ceramics for two important reasons.

First, the mixing of nonplastics in clays is not always homogeneous. Heterogeneous mixing may be natural, or promoted by “wedging”, a process designed to exclude air prior to firing. Therefore some areas often contain less nonplastics than the overall average, but other areas contain more. These differences are often not easily discernible, or readily accommodated, in ceramic thin-sections.

Second, a wide variation in nonplastic size range is common both within and between clays. It is often difficult, therefore, to decide optimum magnification levels. Magnifications too low may mean that important cryptocrystalline inclusions are not discernible, and thus erroneously counted as clay matrix. These nonplastic particles are often important to the potting mixture. They perform a different role, however, to clay minerals (see chapter four).