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).

An 100x magnification was adopted as this allowed for the recognition of silt-sized non-plastic particles. In Table 5.1 phytoliths, diatoms and unidentifiable fragmentary microfossils have been grouped together. Table 5.2 sets out the relationships between spicules, fragmentary fossils including diatoms, and phytoliths. Spicules and phytoliths are treated separately. No attempt has been made to identify diatoms or phytoliths. A detailed examination of microfossils lies outside the scope of the present study.

Heavy minerals have been examined in thin-section and washed samples. Tourmaline, zircon, and rutile have been identified optically. This is a restricted suite. Many grains occur as silt- sized particles. This is probably common to heavy minerals in most sediments (Blatt *et al.* 1980:306). Their size means they can be difficult to identify. Zircon, tourmaline and rutile are probably present in most, if not all, Khorat sediments. ZTR percentages are often useful in determining the maturity of terrigenous sediments and sandstones (liwHubert 1962).

Local concentrations of heavy minerals may be generated by chance depositional conditions such as tectonic and sea level stability. Such asymmetry may require intensive sampling to allow interpretation. In addition, weathering-induced differential destruction, particularly in more tropical climates, may also pose serious interpretive problems (Blatt *et al.* 1980:286, 305- 309). Rutile, for example, while very stable in sedimentary environments, may merely reflect regional weathering conditions rather than distance from, or abundance in, igneous source rocks (Blatt *et al.* 1980:252-257). Results set out below suggest that for the present sourcing and petrogenetic purposes intensive heavy mineral techniques are unwarranted. This is not intended to suggest that heavy mineral analysis would not be useful, but that present analytical techniques are excessively laborious, and thus impractical, in studies which involve large quantities of pottery from many sites.

Recognition of some potentially important silt or smaller sized minerals initially caused some difficulty. At the standard 30 μ thin-section thickness they may be masked by the clay matrix. Calcite, for example, is often present as a drusy sparite or a micritic scatter. Some threads of flakey "white mica" are a similar dimension. Thus both are readily disguised by the fabric matrix. Such minerals may only be visible if the thin-section is thinner than normal. This also applies to many heavy mineral particles, especially zircon and rutile.

5.2 Results

The overall composition of each clay is described below. Tables setting out the relationships between important minerals are given to provide an overall outline. Clay compositions and mineral associations help in the interpretation of the clays' geological paragenesis.

(a) Tables

Table 5.1 sets out point counts of the major components. In each sample 500 points were counted. Although some inclusions occasionally failed to register, each is present, at least in trace amounts, in all clays. In clay 3, the most outstanding example, only two spicule fragments were noted in the eight thin- sections. They did not register in the point counts.

TABLE 5.1: Point counting analysis of major components

Clay	Matrix	Quartz	Kspar	Fe	Spicules	Microfossils
1	68.8	24.8	0.2	4.0	0.8	0.2
2	81.0	10.2	0.0	3.0	0.6	5.2
3	70.8	22.8	0.6	5.8	0.0	0.0
4	80.2	13.2	0.0	3.8	1.2	1.6
5	61.4	30.0	1.6	2.8	1.0	3.2
6	86.2	9.6	0.0	0.0	1.0	1.2
7	91.8	3.6	0.0	2.8	0.4	1.4
8	62.6	36.2	0.8	0.2	0.2	0.0
9	82.2	6.8	0.0	2.4	4.8	3.8
10	78.6	5.2	0.2	5.2	7.6	3.2
11	75.0	23.4	0.4	1.2	0.8	0.0
12	65.2	18.8	0.4	2.0	11.2	2.4
13	75.0	23.8	0.0	0.4	0.4	0.4
14	65.0	33.6	0.2	0.4	0.2	0.6

Notes: All chert varieties were counted with quartz. Fe includes limonite and all other hydrous ferric iron compounds. Plagioclase is only rarely present (see Table 5.6 below).

Spicule, diatom and other unidentified microfossils, and phytolith proportions are given separately in Table 5.2 below. They are important in assessing possible paragenetic variabilities.

TABLE 5.2: Relationships between microfossils (expressed as percentage of total sample).

clay	Spicules	Diatoms etc.	Phytoliths
1	0.8	0.2	0.0
2	0.6	3.0	2.2
3	0.0	0.0	0.0
4	1.2	1.6	0.0
5	1.0	0.8	2.4
6	1.0	1.0	0.2
7	0.4	1.0	0.4
8	0.2	0.0	0.0
9	4.8	2.8	1.0
10	7.6	1.8	1.4
11	0.8	0.0	0.0
12	11.2	1.4	1.0
13	0.4	0.0	0.4
14	0.2	0.2	0.4

Quartz, in a variety of forms, is prominent throughout, and monocrystalline quartz always dominates. Many grains display overgrowths. Chert is also ubiquitous. Both are highly diagnostic of sedimentary authigenic processes (Folk 1980, Tucker 1981). Many monocrystalline, and most polycrystalline, quartz grains display undulose extinction. This is occasionally intense and results in extinction shadows which sweep across the grain in a radial fashion when the stage is rotated more than 5° (Folk 1980:72). Igneous and metamorphic quartz may each feature this phenomenon. Their abundance and type, when coupled with the species of heavy minerals present, however, suggests many may have a metamorphic origin (Tucker 1981:44, Folk 1980:95-97). Table 5.3 below sets out quartz and chert components.

TABLE 5.3: The quartz and chert component

clay	overgrowths	poly quartz	chert	quartz %+	shape	sorting
1	several	9.09	17.53	24.8	A-SR	M-P
2	few	14.54	7.14	10.2	A-R	M-P
3	few	1.81	9.09	22.8	A-SR	P
4	several	14.54	16.20	13.2	A-SR	M
5	rare	9.09	5.84	30.0	A-SR	M
6	few	1.81	0.64	9.6	A-R	P
7	v. rare	10.90	1.94	3.6	A-SR	M
8	none	1.81	6.49	36.2	A-SR	M
9	rare	1.81	5.19	6.8	A-SR	M
10	few	5.45	1.29	5.2	A-SR	M
11	many	10.90	6.49	23.4	A-R	P
12	few	9.09	20.77	18.8	A-R	P
13	many	7.27	0.64	23.8	A-R	P
14	few	1.81	0.64	33.6	A-R	P

Notes: Quartz %+ refers to the total point counted quartz fraction. This includes mono- and polycrystalline varieties and chert. The overgrowth quantities are subjective estimates. Chert and polycrystalline quartz quantities are given as percentages of the quartz count not as percentages of the overall non-plastic fraction. Shape, sorting and the total quartz fraction are included for convenience.

TABLE 5.4: Shape, sorting and maximum size of nonplastics.

clay	quartz %+	shape range	sorting	max size
1	24.8	Angular/subrounded	Moderate/poor	0.55mm
2	10.2	Angular/rounded	Moderate/poor	0.50mm
3	22.8	++++ Angular/subrounded	Poor	0.50mm
4	13.2	Angular/subrounded	Moderate	0.60mm
5	30.0	+++ Angular/subrounded	Moderate	0.25mm
6	9.6	Angular/rounded	Very Poor	1.20mm
7	3.6	Angular/subrounded	Moderate	0.40mm
8	36.2	++ Angular/subrounded	Moderate	0.50mm
9	6.8	+++ Angular/subrounded	Moderate	0.30mm
10	5.2	Angular/subrounded	Moderate	0.40mm
11	23.4	Angular/rounded	Poor	0.70mm
12	18.8	Angular/rounded	Poor	0.65mm
13	23.8	++++ Angular/rounded	Poor	0.90mm
14	33.6	++++ Angular/rounded	Poor	0.50mm

Notes: ++++ rarely well rounded
+++ rarely rounded
++ mainly angular
+ total quartz fraction including mono and polycrystalline as well as chert varieties.
Shape has been visually estimated using Russell and Taylors' roundness chart (1937, after Pryor 1971). Sorting after Folk (1980). Chance-packing variability in thin-sections requires caution in interpreting sorting estimates (Williams *et al.* 1982:309). "Maximum size" correlates with Folk's (1980:10), "least projection length", not the actual long dimension.

TABLE 5.5: Heavy minerals and metamorphic quartz.

clay	zircon	tourmaline	quartz "twins"	stretched
1	0.10mm	0.04mm	several	?
2	0.13mm	0.10mm	several	?
3	0.10mm	0.05mm	several	-
4	0.15mm	0.10mm	several	-
5	0.03mm	0.03mm	several	?
6	0.06mm	0.08mm	-	-
7	0.08mm	0.07mm	several	?
8	0.08mm	0.14mm	rare	-
9	0.08mm	0.08mm *	rare	-
10	0.03mm	0.03mm	rare	0.40mm
11	0.22mm	0.04mm	several	?
12	0.10mm	0.15mm +	several	0.50mm
13	0.10mm	0.03mm	several	-
14	0.10mm	0.12mm	several	-

Notes: * many very fine

+ numerous

? probably metamorphic

The above values are maximum grain size in millimetres for heavy minerals. Quartz "twins" refers to composite grains with sharp twin-like boundaries which have been formed as the result of strain and subsequently annealed during the final stages of metamorphism (Williams *et al.* 1982:332). Stretched metamorphic follows Folk's genetic classification (1980:69-72). Particular attention has been paid to the orientation of microcrystals.

TABLE 5.6: Feldspars and weathered nonplastic proportions.

	quartz				
clay	total +	weathered	"fresh"	kspar +++	plagioclase +++
1	24.8	50%	50%	0.22	-
2	10.2	50%	50%	0.10	-
3	22.8	50%	50%	0.10	-
4	13.2	50%	50%	0.20	-
5	30.0	mainly fresh	-	0.15	-
6	9.6	50%	50%	0.28	0.06
7	3.6	50%	50%	0.25	-
8	36.2	mainly fresh	-	0.20	0.10
9	6.8	30%	70%	0.16	-
10	5.2	++ 50%	50%	0.18	0.07
11	23.4	50%	50%	0.18	0.05
12	18.8	60%	40%	0.08	-
13	23.8	60%	40%	0.10	0.09
14	33.6	50%	50%	0.42	0.08

Notes: + total quartz fraction including mono and polycrystalline as well as chert varieties
++ none heavily weathered
+++ values for feldspars are maximum size in millimeters.

(b) Clay descriptions

Many inclusions are common to all the clays. Important qualitative variations will only be described in detail when first encountered. Except for clay 10, monocrystalline quartz dominates the nonplastics. Quartz is described in detail for clay 1. The more salient features only are given subsequently.

Several heavy minerals are evident. Zircon, tourmaline, rutile, hematite, limonite, and micas have been noted. Many are probably ubiquitous as minute, optically undiagnostic, particles in thin-section. Hence only those readily detected, or highly diagnostic of source rocks, have been considered. Terms used to describe features common to many quartz grains have the following meanings: cracks are shallow valley shaped features to grain surfaces, fissures are deep narrow features, and fractures traverse the entire grain to leave narrow gaps.

Clay 1.

A texturally immature silty pink (7.5YR/7/4) clay. The clay matrix is dull, and this corroborates XRD results which indicate the presence of mixed-layer clay minerals.

Monocrystalline quartz dominates the nonplastic inclusions. It is principally anhedral, but the origin of many grains is reflected in their euhedral shape. Many are strained and undulose extinction is common. Several grains contain vacuoles often as trails. Quartz ranges in size from coarse sand to fine silt, being poorly to moderately sorted, and angular to subrounded in form. Overgrowths are common (fig. 5.1), and some grains have several well-developed crystal faces (Tucker 1981:56, fig. 2.44). Occasional quartz grains are wholly or partly encased in a red-brown iron oxide, probably hematite (Birkeland 1974:86; Kerr 1977:227). Hematite can also be identified in hand specimen. Earthy, ochreous, and giving a red streak, it is mainly scattered throughout as sand-sized irregular nodules or pellets.

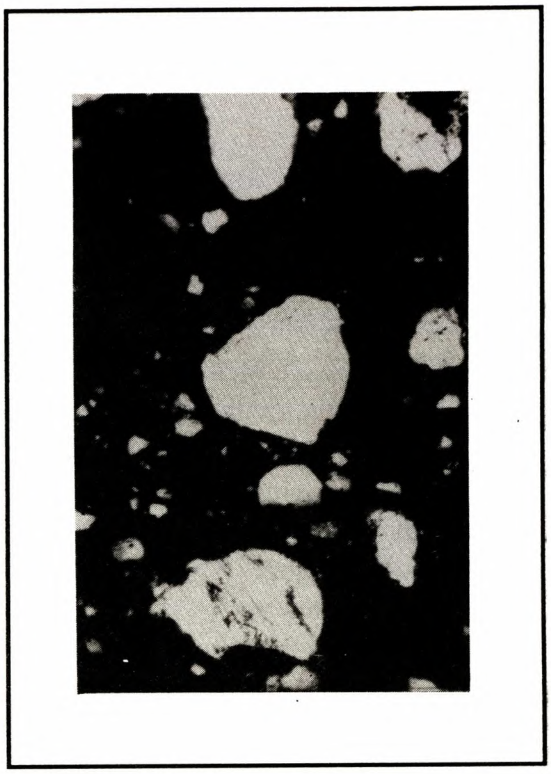

FIGURE 5.1: MICROPHOTOGRAPH OF QUARTZ OVERGROWTHS.

Monocrystalline quartz with either fractures, pits, crevices or rough, sometimes puckered surfaces, is common. Many grains show weathering to edges. Often fissures have been penetrated by dark red-brown limonite. This limonitic "staining" often delineates subrounded to rounded subsequently overgrown "host" grains. One angular grain is cemented to a chert grain which displays mosaic pin-point extinction. Both mono and polycrystalline grains are occasionally intensely strained. "Twins" are prominent (Williams *et al.* 1982:332). Composite grains, in which microlites behave as "negative " crystals and extinguish in the opposite position to the host grain, are common (Carozzi 1960:41). The microlites appear to be siliceous. Many grains have inclusions, and/or vacuoles, either abundant, diffusely scattered throughout, or as well defined trails (Folk 1980:69-72).

Polycrystalline quartz falls into several varietal groups. They are discussed in descending order of frequency. Group 1 includes many medium sand sized grains which show distinct internal sutures between crystal boundaries. Extinction ranges from slightly to strongly undulose (Folk 1980:72). The internal crystals are either roughly equant or comprise one or more larger crystals bounded or intermeshed by smaller ones. These sutured grains suggest authigenic silica cementing of very coarse silt to very fine sand. They are best described as quartzite although their paragenesis is uncertain. The clarity of crystal boundaries grades from clear to invisible. In the latter case individual crystals are only apparent when the microscope stage is rotated under crossed polars and the internal crystallographic structure is revealed.

Group 2 polycrystalline quartz grains are composed of either roughly equant, or slightly subequant anhedral crystals, with clear unsutured boundaries. These are either irregular or almost straight. Extinction tends to be moderately undulose or inclined. Several entire polycrystalline grains are partially overgrown. In rare cases "normal" quartz crystals are interspersed with one or more grains of mosaic microcrystalline chert.

Group 3 grains are comprised of irregular elongate, subequant and roughly parallel, larger crystals sometimes with many smaller crystals randomly distributed between them. Crystal boundaries are often crenulate. Extinction is always strongly undulose or distorted. Individual crystals generally approximate parallel crystallographic orientation, although some entire grains are severely contorted. This contrasts with groups 1 and 2, where crystals tend to be randomly distributed. Sharp boundaries between neighbouring sectors which each differ in extinction by a few degrees, plus internal strain suggests that these grains are metamorphic in origin. Group 3 grains are of fine sand size.

Chert is present in three forms, microquartz, chalcedonic quartz and megaquartz. The latter can be identified in composite grains. The former two varieties occur either as individual or composite grains (Folk 1980:79, Tucker 1981:210). Overall, cherts are mainly subrounded, but some are angular or rounded, of very coarse silt to medium sand size. Microquartz chert is composed of a finely crystalline equant mosaic with pin-point extinction. Megaquartz chert crystals are larger, up to fine sand size, often with unit extinction. Chalcedonic chert has fibrous crystals. These often display a radiating arrangement, some forming wedge-shaped or mammillated structures which are subrounded to rounded and up to medium sand size (Tucker 1981:210-211). Many grains are markedly graded. Some include both micro and megaquartz. A few composite grains also include wedge shaped chalcedonic and mosaic chert arrangements. Within chalcedonic mammillated quartz internal sector boundaries move sequentially into extinction as the microscope stage is rotated.

All of these cherts are diagnostic of an eroded older sedimentary source (Folk 1980:80). They probably represent the weathered remains of a chalcedonic cement pore filling. Such cements are characteristically associated with quartz arenites. The microquartz, megaquartz and chalcedonic quartz could all derive from such a source (Tucker 1981:211, fig. 9.1).

Calcite is principally dispersed sparsely throughout the clay matrix as a micrite (Tucker 1981:116), or microcrystalline irregular grains of up to 0.01 mm. It occasionally occurs as very fine sand sized euhedral crystals, or in groups of irregular sized euhedral crystals. These often display multiple twinning.

Potassium feldspar is rare, angular, and of very fine to fine sand size. No plagioclase feldspar was present.

Both tourmaline and zircon are prominent, but not numerous. Tourmaline is angular, either bladed and euhedral, or corroded and anhedral, to very coarse silt size. Zircon principally occurs as angular, very fine sand sized, detrital grains. A few grains are euhedral.

Hematite occurs as red to dark brown semi-opaque round pellets of medium sand size. They often contain angular silt sized quartz inclusions (see also above and clay 2).

Fragments of fresh water sponge spicules are rare. These spicules have kindly been identified for the writer by Professor F.W. Harrison, head of biology, Western Carolina University, as belonging to the genus *Ephydatia meyeni*. Harrison reports that these sponges are presently found in the region. The genus was probably abundant in the Mesozoic (Bergquist 1978). They occur in each of the clays examined. Diatoms and phytoliths are rare.

Phytoliths are ubiquitous in Sakon Nakhon Basin clays. An analysis of their origins lies outside the scope of the present work. A very brief summary of the major types noted is necessary, however, because some are considered to represent deliberately added rice plant remains in some ceramic fabrics (Appendix one). Some inclusions are optically consistent with rice phytoliths. In shape, subrounded to rounded, birefringence and refractive index (less than 1.54 determined by Becke line test), and size, 5 to 10 μ, they parallel siliceous depositions within rice leaf and husk (Yoshida *et al.* 1962). Phytolith quantities vary widely between clays, and as they never exceed 40 μ in diameter, they may easily escape detection in thin-section, if they are rare. Given that rice cultivation is currently widespread, their presence in modern sediments is predictable. Phytoliths in the Sakon Nakhon Basin clays are probably related to earlier processes, however, because these are excavated as much as 2 metres below the present land surfaces.

Twiss *et al.* (1969:109-114), include a morphological classification of grass phytoliths, both class 3 (panicoid), and 4 (elongate), are present in the above clay sample. Brydon *et al.* (1963:476-477), describe and illustrate shard-like silicified plant asterosclereids of similar shape and optical properties to inclusions noted. Wilding and Drees (1973:647-650), illustrate (Fig. 1-f), opaline bodies which are also similar to inclusions observed in Sakon Nakhon Basin clays. None of these are like the rice phytoliths described by Yoshida *et al* (1962), or the inclusions referred to as rice phytoliths in the Sakon Nakhon Basin clays.

Clay 2.

A texturally immature silty (10YR /8/4) clay. Mica is evident in the XRD spectograph. Detailed optical examination revealed very fine sand sized bleached biotite. Biotite often alters to chlorite or vermiculite (Kerr 1977:439-440), and soils may contain vermiculite (Battey 1972:276). The 14 ÅXRD peak discussed in chapter four could represent a vermiculite. This is equivocal because of similarities with smectite (Grim 1968:104-113). Alternatively, mixed-layer clay minerals, possibly involving vermiculite, may be present (see chapter four).

Micritic and microcrystalline to finely crystalline calcite (Folk 1980:164), is diffuse throughout the clay matrix as a mosaic of numerous clusters of euhedral or subhedral crystals. The diagenesis of freshwater calcareous cements often involves the reprecipitation, as calcite, of dissolved aragonite from, for example, ancient undolomitized limestones (Tucker 1981:130). These are chiefly described as "drusy sparites" (Tucker 1981:126- 127). Calcite is common in recent sediments (Folk 1980:98).

Monocrystalline quartz is mainly anhedral but some grains are subhedral. It spans from silt to medium sand size. A few grains are strained. Several display undulose extinction. A few include overgrowths. One authigenic (?) grain has overgrown a sponge spicule. Several contain vacuoles, some as trails. Several have fractures, cracks and micro pits. Some show crescentic marks. Many grains are deeply weathered. In a few limonite has penetrated into cracks and fractures. One grain contains a 0.05 mm long euhedral tourmaline inclusion.

Polycrystalline quartz is prominent. Group 1 is rare, group 2 common, and group 3 is well represented. Most grains display undulose and/or inclined extinction often with clear crystal boundaries. These grains have crystals that are mainly uniform in size with irregular, rarely sutured, boundaries. Some grains have unclear crystal boundaries, and most of these are subequant. A few grains with clear crystal boundaries contain numerous vacuoles often as trails.

Microquartz, megaquartz and chalcedonic chert as described for clay 1 are present. Two composite grains are evident. One is part mosaic, part chalcedonic. The other is chalcedonic, part wedge and part mammillate.

A red to dark brown iron oxide compound, probably hematite, or the hydrous oxide goethite, occurs in various forms. They are probably weather-induced precipitates (Birkeland 1974:66-68). They occur as dense, almost opaque, pellets or as a stain which lightly coats the clay matrix (Folk 1980:99). Rock fragments, cemented by dark red-brown hematite or goethite, are present in two forms. One form is angular of a very coarse sand size. The other rock fragment is well rounded ooid-like of granule size. Both contain angular, silt to fine sand sized, quartz inclusions. In some, iron encases angular to rounded single grains of quartz to form, fine sand sized, ooid-like pellets.

Potassium feldspar occurs as subangular to subrounded very fine to medium sand. At 100x magnification no potassium feldspar registered during point counting. It formed 0.4% of the sample at 200x. No plagioclase feldspar was evident.

Zircon, of very fine sand size, is mainly detrital. One euhedral grain is 0.13 mm long. Angular tourmaline of the same size is also present.

Sponge spicules occur in minor amounts, but diatoms and phytoliths are relatively abundant.

Clay 3.

A texturally immature micaceous (7.5YR/7.5/6) clay. The overall appearance of the matrix, in thin-section, is of numerous flakes of fine muscovite or "white mica". These, and rare fine sand sized grains of kaolinite, are probably derived from the weathering of feldspar. Fine, sand-sized muscovite pseudomorphs of potassium feldspar, identified provisionally by their "dusty" appearance and blocky shape (Tucker 1981:45), also rarely occur. Kaolinite and weathered muscovite may measure < 30 μ in cross section thus, at normal thickness, they can be disguised by the matrix. Slightly thinner sections revealed the "white mica" abundance.

Monocrystalline grains clearly dominate the quartz fraction. They are mainly anhedral, but some are subhedral, and many display undulose extinction. Cracks, fissures and fractures are common. Many grains are weathered. This shows on the surfaces and interstices of cracks, but limonitic weathering is rare. Overall, they range widely between well weathered to relatively fresh. Fresh grains tend to display straight extinction. A few strained grains contain diffuse vacuoles. Some grains show overgrowths, and one has a microlite tourmaline intergrowth.

Polycrystalline quartz is extremely rare. Only one weathered group 2 grain of fine sand size was observed.

Chert is mainly mosaic, with a few chalcedonic and one composite grain. All are angular to subrounded of fine sand size.

Calcite is not prominent, only occurring as sparse, micritic, and mainly anhedral, crystals.

Ferruginous inclusions are numerous to abundant. They fall into two distinct groups. In both, grains range in shape from angular to rounded, and in size, from fine sand to very fine pebbles. One group is texturally and minerally consistent with the overall clay fabric. These generally contain quartz, mica and chert inclusions, of silt to fine sand size, although some single grains of quartz, of up to medium sand size, are partially or totally iron-encased. The cement appears to be an authigenic chemical precipitate of hematite or goethite. It is red to dark brown and often almost opaque. It also occurs as discrete pellets of up to medium sand size.

The second group is black and opaque, mainly without, but often with, silt-sized inclusions. Inclusion-rich examples in the first group often give the appearance of sand or siltstone fragments. It is likely, however, that they represent the clay fabric cemented by chemical precipitates. Where this ferruginous material has subsequently been subjected to dehydration and hardening, it is best described as laterite, in contrast to the hematite/goethite discussed above (Birkeland 1974:114-115). Dehydration cements these latter minerals into the rigid network of crystals. This hardness characterises laterite. Dehydration may be promoted by forest clearance (Birkeland 1974:*op.cit.*).

Potassium feldspar is rare, angular, of very fine to medium sand size. Some grains may be weathering to muscovite or kaolinite. Plagioclase feldspar was not present.

Detrital, sometimes angular, zircon and tourmaline, of very fine sand size, is rare.

Sponge spicule fragments, diatoms and phytoliths are each extremely rare.

Clay 4.

A texturally immature silty (5YR/7/6) clay. Monocrystalline quartz is mainly anhedral, a few grains are subhedral. Undulose extinction, cracks, fractures and micro pits are common. In several cases limonite has penetrated fractures, but weathering to edges and internal surfaces is generally rare. A few grains contain vacuoles. These are usually diffuse and rarely as trails. Several grains have overgrowths. One has acicular microlitic inclusions of rutile (?).

Polycrystalline quartz of groups 1 and 2 is prominent, and of group 3 rare. One composite, very fine sand-sized grain is cemented to mosaic chert.

Chert is common, angular to subrounded, mainly mosaic, and never exceeds medium sand size. Chalcedonic chert is fine sand size. Graded chalcedonic, and composite mosaic/chalcedonic grains are both evident.

Potassium feldspar is represented by a few angular, very fine sand sized grains. No plagioclase feldspar was evident.

Micritic calcite can be prominent or sparse. It is either concentrated in small isolated patches, or as diffuse crystals. In clay 4, it is often barely discernible in some thin-sections, but obvious in others.

Zircon and tourmaline grains are anhedral, angular to fine sand size and rare.

Hematite, or goethite, pellets and angular lumps occur as a semi-opaque reddish brown precipitate. They are few and never exceed coarse sand dimensions.

Sponge spicules and diatoms are well represented. Phytoliths are rare.

Clay 5.

A texturally immature and very silty (10YR/8/3) clay. The XRD spectrograph indicates the presence of poorly crystalline clay minerals. Overall there are few nonplastics of > silt size. They display little mineralogical variability.

Monocrystalline quartz is mainly anhedral, but sometimes subhedral. Grains generally range in size from very fine silt to very fine sand. Most are fresh. Undulose extinction is common in the few fine sand-sized grains. Weathering to edges, fractures or fissures is uncommon. Internal surfaces rarely include limonite. Overgrown grains are rare. A few have diffuse vacuoles.

Polycrystalline quartz is moderately well represented. It includes groups 1 and 2 grains. These are angular to fine sand size. One grain is intensely strained and may belong to group 3.

Significantly, although sparse, all three varieties of chert are present. Mosaic and chalcedonic cherts range in shape from angular to subrounded. They never exceed very fine sand size. Mammillated grains, displaying sector extinction, are subrounded and of fine sand dimension.

Potassium feldspar is angular, to fine sand size, and is poorly represented. Plagioclase feldspar was not present.

Calcite occurs in two forms. First as numerous to abundant micritic crystals which are spread diffusely throughout the fabric. Secondly, a few isolated euhedral crystals, which measure up to fine sand size, are also present. A composite grain, composed of euhedral calcite on anhedral quartz, suggests the calcite may derive from a silica calcite sandstone cement (Williams *et al.* 1982:339-341). Drusy sparites are common forms of calcitic sedimentary cements (Tucker 1981:57).

Hematite, or goethite, is mainly present as a few angular to subrounded pellets of up to very fine pebble size. One rounded ooid-like grain is of fine pebble size. It encases spicules, potassium feldspar, and silt-sized quartz grains, all of which are consistent with the composition of the overall fabric.

Zircon and tourmaline are rare. They occur as detrital, angular to subangular, grains of very coarse silt size.

Sponge spicules are rare and fragmentary, diatoms rare, and phytoliths relatively abundant.

Clay 6.

Another texturally immature and silty (10YR/8/3) clay. Many quartz grains have extensive, and apparently fresh, fractures.

Monocrystalline quartz is mainly anhedral, but some grains are subhedral. Many grains show undulose extinction. Weathering to surfaces, and the interstices of fissures and fractures, is common. The latter often contain limonite. Some grains have micro pits. A few have overgrowths. Vacuoles are rare.

Polycrystalline quartz is extremely rare. Only one group 2 grain, of medium sand size was observed. It had been overgrown by authigenic quartz. One medium sand-sized grain has an intergrowth of zircon.

Chert is also extremely rare. Only one grain of subrounded, very fine sand-sized chalcedonic chert was observed.

Potassium feldspar is angular to subrounded, from coarse silt to medium sand size, and rare. Plagioclase feldspar is extremely rare. Only two coarse silt-sized grains were noted.

Calcite rarely exceeds 0.05 mm. It takes two forms. First, as a diffuse micritic "dust" throughout the fabric. These crystals are generally anhedral. Secondly, one very fine subrounded pebble (2.25 mm), is composed of calcite-cemented, fine sand-sized, quartz grains. One of these quartz grains appears to have authigenically overgrown a sponge spicule. The calcite crystals, within the pebble, range from silt to fine sand size. They are euhedral or subhedral and often twinned. A thin band of clay matrix adjacent to this pebble forms a darker "corona". The pebble is probably authigenic to the sediment and not detrital. Similar calcitic aggregates are common within the interstices and on the surfaces of prehistoric potsherds, which suggests they represent authigenic deposits.

Zircon and tourmaline occur as rounded, detrital, grains of very fine sand size.

Fragmentary spicules, diatoms and phytoliths are rare.

Clay 7.

This is a texturally immature (10YR/7.5/4) clay. A sharp variation in texture is evident between individual thin-sections. Some are silty. Others are substantially micaceous. In these latter sections the particles are preferentually orientated so that as the microscope stage is rotated the majority of field of view sweeps in and out of extinction in broad parallel bands.

Monocrystalline quartz is mainly anhedral. A few grains are subhedral. Several have undulose extinction. In many this is very strong. Vacuoles are present as diffuse scatters in a few grains. Fractures, and weathering to edges and internal surfaces are rare. Only one grain displays overgrowths.

Polycrystalline quartz is principally of the group 1 variety, with irregular-sized crystals and boundaries. These grains are angular and from very fine to fine sand size. One subangular fine sand-sized may belong to group 3, but this is equivocal.

Chert is chalcedonic only, and very rare. It is angular and of very fine to fine sand size.

Potassium feldspar is rare, and angular to subrounded. It ranges in size from very fine sand to fine sand. Plagioclase feldspar is absent.

Calcite abundance varies markedly between sections. The crystals are micritic. Never prominent, they often occur in dense, approximately 10 mm to 30 mm diameter, isolated patches. In addition to these aggregations, individual crystals may also be spread diffusely through the matrix. They are mainly anhedral, but occasionally euhedral.

Hematite, or goethite, is present as angular to well rounded precipitates of up to medium sand size. Its abundance varies considerably between sections, from rare to numerous.

Zircon occurs as angular, very coarse silt to very fine sand sized, detrital grains. It is very rare.

Tourmaline is represented by a single fragmented, euhedral, very fine sand-sized grain.

Fragmentary spicules, diatoms and phytoliths are rare.

Clay 8.

This clay is texturally immature. As with clay 5, clay minerals are poorly crystalline. Although grain size distribution ranges from fine silt to medium sand the median is 0.084 mm ($n = 30$, $S.D. = 0.04$, $V = 0.001$). Thus the majority of grains are of fine sand size. No hematite, or goethite, is apparent. A reddish yellow (5YR/7/8) matrix, however, suggests the presence of cryptocrystalline ferruginous minerals.

Monocrystalline quartz clearly dominates the nonplastics. In general they have fresh surfaces. Although a few fragmentary euhedral grains were noted, no overgrowths were observed. Many grains display intense undulose extinction. Grains with small cracks or complete fractures are numerous. Many contain negative crystals, suggestive of an igneous source (Folk 1980:69). A few have micro pits, or vacuoles. The latter are mainly diffusely distributed but in some grains they occur as trails. Weathering, either with or without limonite to surfaces, is common.

Polycrystalline quartz is rare. Only a few group 2 grains were noted. They were angular and of fine sand size. The single group 1 grain observed contained "white mica" inclusions.

Chert is rare. It is restricted to mosaic or chalcedonic, very fine to fine sand-sized, grains. These are mainly angular but a few are subrounded. One composite grain grades between mosaic and chalcedonic.

Potassium feldspar is angular to subrounded, and from very fine sand to medium sand size. One grain is overgrown, suggesting a sandstone source (Tucker 1981:58). Plagioclase feldspar is present as a single angular, very fine sand-sized, detrital grain, and an almost euhedral fine sand-sized grain. Both have very clear polysynthetic twins. Symmetrical extinction angles of 5° and 12° respectively, although insufficient for application of the Michel-Levy method, suggest a sodium-rich composition.

Calcite is present as a diffuse, mainly micritic, aggregate of different shapes and sizes. It is numerous to abundant. A few fragmentary or intact euhedral plates reach fine sand size. Most calcite occurs as tiny euhedral crystals.

Zircon is rare. It occurs as angular, very fine sand-sized, detrital grains.

Tourmaline is present as rare, anhedral, very fine to fine sand-sized, detrital grains.

Fragmentary sponge spicules, phytoliths and diatoms are rare.

Clay 9.

A texturally immature silty (10YR/7.5/6) clay.

Monocrystalline quartz displays mainly undulose extinction. Weathered grains, some with surfaces stained by limonite, are rare. Grains with vacuoles or overgrowths are also rare. These two factors suggest this may be a well-weathered, mineralogically mature, fabric. The overall quartz fraction is low.

Polycrystalline quartz is extremely rare. Only two grains were noted. One belongs to group 2, and the other possibly to group 1.

Chert is similarly rare. Both mosaic and chalcedonic varieties, angular to subrounded, and from very coarse silt to fine sand size, are present.

Potassium feldspar occurs as very coarse silt to fine sand-sized, subangular to subrounded, grains. Plagioclase feldspar is not present.

Calcite is prominent but not abundant. It is principally scattered throughout the matrix as diffuse micritic individual crystals. There are also some fine sand-sized anhedral crystals. The abundance of calcite varies widely between sections, and it may be masked in thicker sections by the clay matrix.

Hematite, or goethite, is present either as subrounded, very fine sand to medium sand-sized pellets, or as a staining to clay-sized particles.

Zircon occurs as heavily weathered, to coarse silt size, detrital grains. It is rare.

Tourmaline is well represented by anhedral, coarse silt-sized, detrital grains.

Sponge spicules are numerous, rarely intact, but many are only slightly fragmented. Diatoms and phytoliths are prominent.

Clay 10.

A texturally immature and moderately micaceous (10YR/7.5/6) clay.

Monocrystalline quartz is almost entirely anhedral, with rare fragments of euhedral grains. Many grains are fractured. Undulose extinction is common, and grains with diffuse vacuoles are prominent. Several grains are weathered, but none heavily. In many grains both external and fracture surfaces have limonite stains. A few are free of limonite. Only a few overgrowths were noted. One grain has cryptocrystalline mica (?) inclusions.

Polycrystalline quartz is very rare. It ranges in size from fine to medium sand, and is either angular or subrounded. Each of the three groups is represented by just one grain. Crenulated crystal boundaries are absent from the group 3 grain. It is, however, very heavily strained into subparallel bands. Such stress bands characterise quartz derived from some varieties of mechanically strained metamorphic rocks (Williams *et al.* 1982:503-504).

Chert is rare. It is represented by a few mosaic, and one mammillated chalcedonic grain, with sector extinction. All were angular, and of fine sand size.

Potassium feldspar ranges in size from very fine to fine sand, and from angular to subangular in shape. It is rare. Plagioclase feldspar is angular and represented by very fine sand-sized grains, and is also rare.

Calcite occurs throughout the matrix. Many dense patches contain aggregates of mainly micritic crystals interspersed with larger euhedral crystals. These patches are usually about 0.25 mm in diameter. Euhedral platey crystals, of very fine sand size, are scattered throughout the fabric. A few, fine sand-sized, anhedral, crystals occupy voids. In each case these crystals suggest an orthochemical origin.

Hematite, or goethite, is scattered through the fabric. It appears to have precipitated into subrounded, or rounded, pellets and areas of stained clay. These are up to fine sand size.

Zircon and tourmaline, from coarse to very coarse silt size, are both present as detrital grains. They are rare.

Sponge spicules are numerous to abundant. Many are only slightly imperfect, and several are intact. Fragments tend to be well preserved. Diatoms and phytoliths are numerous.

Clay 11.

This texturally immature clay is dominated by silt to coarse sand-sized nonplastics. It is a brownish yellow (10YR/7.5/6).

Monocrystalline quartz is mainly anhedral, often subhedral, and abundant. Overgrowths are numerous. Many grains show severe strain with undulose extinction being common. Several have fractures, and micro pits. Grains which have been heavily weathered mainly to internal surfaces and edges are few. Heavy weathering with limonite to fractures and external surfaces is common. Several grains have diffuse vacuoles and in a few vacuoles occur as well defined trails. Some of these grains are extensively strained. Negative crystals are common. A notably wide range of surface textures, from crisp and fresh to heavily weathered, is represented.

Polycrystalline grains are relatively rare. All three groups are present as angular, fine to medium-sized sand. One grain was heavily weathered. Another group 2 grain is severely strained.

Chert is also rare. It mainly occurs as mosaic, very fine to fine sand-sized, angular to subrounded, grains. Also present is angular chalcedonic chert, of very fine or medium sand size.

Potassium feldspar occurs as very fine to fine sand of angular to rounded shape. It is rare. Plagioclase feldspar is extremely rare. Only one rounded, very fine sand-sized, grain was detected.

Calcite is scattered lightly throughout some sections as diffuse micritic crystals. It is not generally prominent.

Hematite, or goethite, occurs apparently as a precipitate. It is often present as rounded, but with some well rounded, pellets of mainly fine sand, but also up to coarse sand size.

Zircon is rare. It ranges in size from very fine to fine sand. Tourmaline and rutile are extremely rare, angular, and of very coarse silt size.

Sponge spicules and phytoliths are well represented. Diatoms are not prominent.

Clay 12.

Another texturally immature and silty (10YR/7.5/6) clay, it contains the highest density of sponge spicules, tourmaline and chert encountered in the sample.

Monocrystalline quartz is dominated by anhedral grains, but many are subhedral. Many grains are strained, undulose extinction being common. Fractures and micro pits are prominent. Several grains are weathered, but only a few have limonite coatings to such surfaces. Internal fracture surfaces, and weathered external grain surfaces are commonly limonite free. Vacuoles, which are either diffuse or occur as trails, are rare. Grains with acicular inclusions of tourmaline are also rare. These inclusions are up to 0.025 mm long. One quartz grain contains a prismatic tourmaline intergrowth 0.02 mm wide by 0.07 mm long. Quartz grains with overgrowths are common. Some apparently authigenic subhedral grains, however, do not display overgrowths. A wide range of shapes are evident. They vary from angular to rounded. Some are almost well rounded.

Polycrystalline quartz is not abundant. All three groups, however, are present. They range in size from fine to medium sand. They are all angular and one is heavily weathered. A group 3 grain, probably metamorphic in origin, is stretched and granulated (Folk 1980:69-72).

Chert, both mosaic and chalcedonic, is prominent. Both varieties range from very coarse silt to fine sand in size, and from angular to subrounded in shape.

Potassium feldspar is rare, angular, and of fine sand size. Plagioclase feldspar is absent.

Calcite is scattered thinly throughout the fabric as anhedral micritic crystals. Euhedral micritic crystals surround a few quartz grains. Many voids are full of authigenic euhedral plates and anhedral crystals, of up to very fine sand size.

Hematite, or goethite, occurs as angular to rounded pellets and clay stainings, of mainly very fine, but also up to medium, sand size. Anisotropic black laterite is present as well rounded very coarse sand. A pore filling of micritic calcite crystals in some cases bounds the laterite-clay-matrix interface. A few quartz grains are encased in ferruginous material. This has produced ooid-like shapes.

Zircon is rare, detrital, and from very coarse silt to very fine sand in size. Tourmaline is well represented. It occurs mainly as angular to rounded, detrital grains. These are of coarse silt to fine sand size. In addition, several acicular rods ranging from 0.05 mm to 0.07 mm in length are present. One euhedral crystal, with rhombohedronal terminals, measured 0.05 mm in length.

Sponge spicules are abundant. They are often well preserved. Diatoms and phytoliths are numerous.

Clay 13.

A texturally immature, (10YR/7.5/4), clay.

Monocrystalline quartz is mainly anhedral, often subhedral. Many grains are strained. Undulose extinction is common. Several grains have fractures or micro pits. Weathering to internal and external surfaces, either with or without limonite staining, is often present. Many grains contain numerous, but diffusely spread, vacuoles. Overgrowths are common. A few grains contain tourmaline inclusions (fig. 5.2).

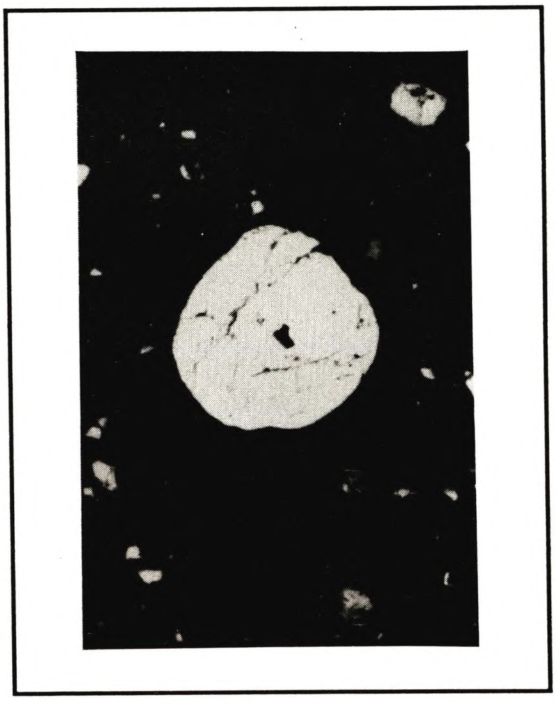

FIGURE 5.2: TOURMALINE INCLUSION IN A WELL-ROUNDED QUARTZ GRAIN.

Polycrystalline quartz is not prominent. A few group 2 angular, very fine to coarse sand-sized, grains were noted. A group 3 grain, probably metamorphic in origin, is stretched and granulated (Folk 1980:69-72).

Chert is rare. It is represented principally by angular to subrounded, fine to medium sand-sized, mosaic grains. One composite grain, which is graded between mosaic and chalcedonic, and one ordinary chalcedonic grain were also noted.

Potassium feldspar is a minor component. Although none were recorded during point counting, several angular, very fine to fine sand-sized, grains were observed. Plagioclase feldspar is very rare. Two angular grains, one of very coarse silt and the other of very fine sand size, are present. Symmetrical extinction angles suggest a sodium-rich composition.

Calcite generally occurs as a numerous scatter of micritic crystals throughout the fabric. In places this may be abundant. Its presence is highly variable, however, and some sections have little. A few larger, often euhedral, platey crystals of up to fine sand size also occur.

Hematite, or goethite, is represented by several angular to rounded pellets, or clay stainings, of up to fine sand size. One rounded grain, of very coarse sand size, contains several quartz grains. The ferruginous material in this latter grain is dense, and mainly opaque in thin-section. It grades from brown to black and is thus optically consistent with a hematitic ironstone (Williams *et al.* 1982:415). This material may thus represent the dehydrated goethite and hematite characteristic of laterite (Birkeland 1974:114).

"White mica" is present as threads up to 0.05 mm long. It is very rare.

Zircon is also rare. It occurs as angular, very fine sand-sized, detrital grains. Tourmaline is of coarse silt size and very rare.

Fragmentary sponge spicules, diatoms and phytoliths are rare.

Clay 14.

A texturally immature (10YR/7.5/4) clay.

Monocrystalline quartz is substantially as for clay 13. It has slightly fewer grains with overgrowths. One grain has a subhedral tourmaline intergrowth 0.08 mm long.

Polycrystalline quartz of group 2, and mosaic chert are each represented by a single fine sand-sized grain.

Potassium feldspar is again minor. It ranges from very coarse silt to medium sand in size, and in shape from angular to subangular. Three angular, very fine to fine sand-sized, grains of plagioclase feldspar were noted. Their symmetrical extinction angles suggest a sodium-rich composition.

Calcite is not abundant. It is present as a diffuse scatter of micritic crystals in most thin-sections.

Ferruginous minerals are the same as described for clay 13.

Several grains of zircon were noted. It occurs either as angular, very coarse silt or very fine sand. Tourmaline, of the same dimensions but usually bladed rather than granular, is rare.

Sponge spicules, diatoms and phytoliths are rare.

5.3 Summary and concluding remarks

Sakon Nakhon Basin clays can be characterised by a dominance of minerals derived from older sedimentary sources. They are reworked sediments. The sponge spicule deposits are consistent with transported clay. There is no evidence to suggest they result from modern sedimentation (see also chapter four). Given the depth that the potting clays are quarried, even if they relate to the latest deposition of sediments documented by Loffler *et al.* (1983), they predate the occupation of Ban Na Di. The nonplastics are mineralogically mature, but their texture appears immature. A full textural analysis is beyond the scope of the present work. Although the shape and sorting of nonplastics have been estimated in thin-section, these, along with the surface textures of grains and fabric composition, suggest textural immaturity. According to Folk's (1980:26) sediment scheme, the clays can be considered sandy (> 10% but < 50% nonplastics). Sediment fabrics with a high matrix component suggest textural immaturity

(Tucker 1981:20). Older sedimentary source sediments may have a "generally low" textural maturity (Folk 1980:140). Differences in textural and mineralogical maturities are common in sediments, and this is related to their sedimentation history (Williams *et al.* 1982:328).

The Sakon Nakhon Basin regional geology is reflected in the clay mineralogy. Thus the clays contain reworked sedimentary minerals, often with much chert. The quartz fraction in these clays displays a wide variation in surface texture. Much is fresh and displays little evidence of weathering. These clays can be conceived as being compositionally immature. They will increase in maturity with distance from source and variations in weathering. Because of this, a textural definition of maturity is preferred.

The mineralogical maturity of the Sakon Nakhon Basin clays is characterised by a lack of all but the stable and ultrastable heavy minerals (Hubert 1971:459), in association with cherts and quartz overgrowths. Detailed maps are not available for the area. As Mesozoic strata are thought to underlie the entire plateau, however, we can anticipate that the same rocks are present and exposed in the Phu Phan Range (Cruijs 1978). The Mesozoic strata is comprised of the Khorat Group. According to Javanaphet (1969) the Phu Phan Range includes the Phu Phan, Phra Wihan and Phu Kradung Formations, and these form part of the Khorat Group. Exposures of these Formations, which border the Petchabun Range and western plateau margins, have been geologically mapped.

Chongpan and Nares (1979), note that the Phu Phan Formation contains a pebbly sandstone. The pebbles consist of quartz, chert, red siltstone and igneous rocks up to 5 cm in diameter. They are intercalated with shale and conglomerate. The Phra Wihan is comprised of an orthoquartzitic sandstone with some intercalations of reddish-brown and gray shale. The Phu Kradung comprises micaceous shale, siltstone and sandstone, with some lime-nodule conglomerate. Thus the Sakon Nakhon Basin clays are readily understood in terms of the regional geology.

5.4 Mineralogical zones

In terms of the nonplastic components of the clays described above, four mineral zones are evident (fig. 5.3).

Micaceous zone

Two quite highly micaceous clays are restricted to a small zone bordering the northern margins of the Phu Phan Range. In clay 3, muscovite is generally present as sericite threads. It occasionally occurs as sericitic inclusions in both mono- and polycrystalline quartz. The association of muscovite pseudomorphs of potassium feldspar, sericite threads and kaolinite, in clay 3, suggests deeply weathered potassium feldspars. Bleached biotite and associated vermiculite occurs in clay 2. It lies upstream of clay 3. These two clays are the only samples containing "large" optically identifiable micas (Folk 1980:86).

Micas in the remaining Sakon Nakhon Basin clays are mainly cryptocrystalline. Clays 6, 7, 9, 10 and 11 gave mica reflections in the XRD spectra (chapter four). Clay 10 is the only one of these which is moderately micaceous in thin-section. It includes a few threads of "white mica".

Sponge spicule zones

Sponge spicules occur in relative abundance in two small zones. One lies close to the western edge of the basin. This zone includes clays 9 and 12. The other zone is represented by clay 10 at Nong Kham Din.

Plagioclase feldspar zone

Plagioclase feldspar is restricted to a small slightly elevated area which extends towards the northwest from the Phu Phan Range just north of Lake Kumpawaphi. This zone is about 10 km wide and stretches 25 km towards the basin interior. Ferruginous minerals are poorly represented. The plagioclase feldspar zone encloses Ban Na Di.

Ferruginous zone

Ferruginous minerals follow the above zoning pattern, but in reverse. They are poorly represented towards the centre of the basin and tend to be most numerous near its margins.

5.5 Paragenesis

An understanding of paragenetic processes which effected the present clay distributions is important to one of our primary objectives: the sourcing of prehistoric ceramic fabrics. Only a very brief outline is necessary.

It is likely that four principle geomorphological processes have been responsible for the present Sakon Nakhon Basin clay deposits. Epierogenetic uplift, tectonic folding and faulting, climatic change during the Pleistocene, and recent humid weathering conditions have combined to produce the present landscape. Each of these is interrelated.

The various quartz species, including cherts, are derived from weathered silica-cemented quartzarenite sandstones or orthoquartzites (i.e. unmetamorphosed quartz-cemented quartz arenites (Williams *et al.* 1982:559)). These reworked sediments are almost ubiquitous. Overgrowths are only absent in clay 8, which is located in a high portion of the basin. Polycrystalline quartz and chert both diminish in abundance with distance from outcrops of the Khorat Group. Igneous quartz can probably be sourced to the sandstone pebbles of the Phu Phan Formation. The lime-nodule conglomerates of the Khorat Group, plus allochemical constituents probably account for the calcareous minerals. The Phu Kradung Formation probably supplied the micas prominent in clays 2 and 3.

Thus three different sedimentary mineral groups are present:

1. allochemical: represented by spicules, phytoliths, diatoms and some calcite.

2. terrigenous: represented by reworked sediments, including weathered, chemically-cemented sandstones and igneous quartz.

3. orthochemical: represented by calcareous, and ferruginous minerals.

It is anticipated that the differentiation evident in Sakon Nakhon Basin clays will also prevail in the larger Khorat Basin. Given the broadscale regional lithofacies, however, many clays may be very similar to those set out above. Clay from the Chi Valley has been briefly examined for comparison. It also contains some reworked sedimentary minerals, but little chert or polycrystalline quartz. Spicules are well represented. Potassium feldspar and ferruginous precipitates are rare, and zircon and tourmaline very rare. Many quartz grains indicate severe stress.

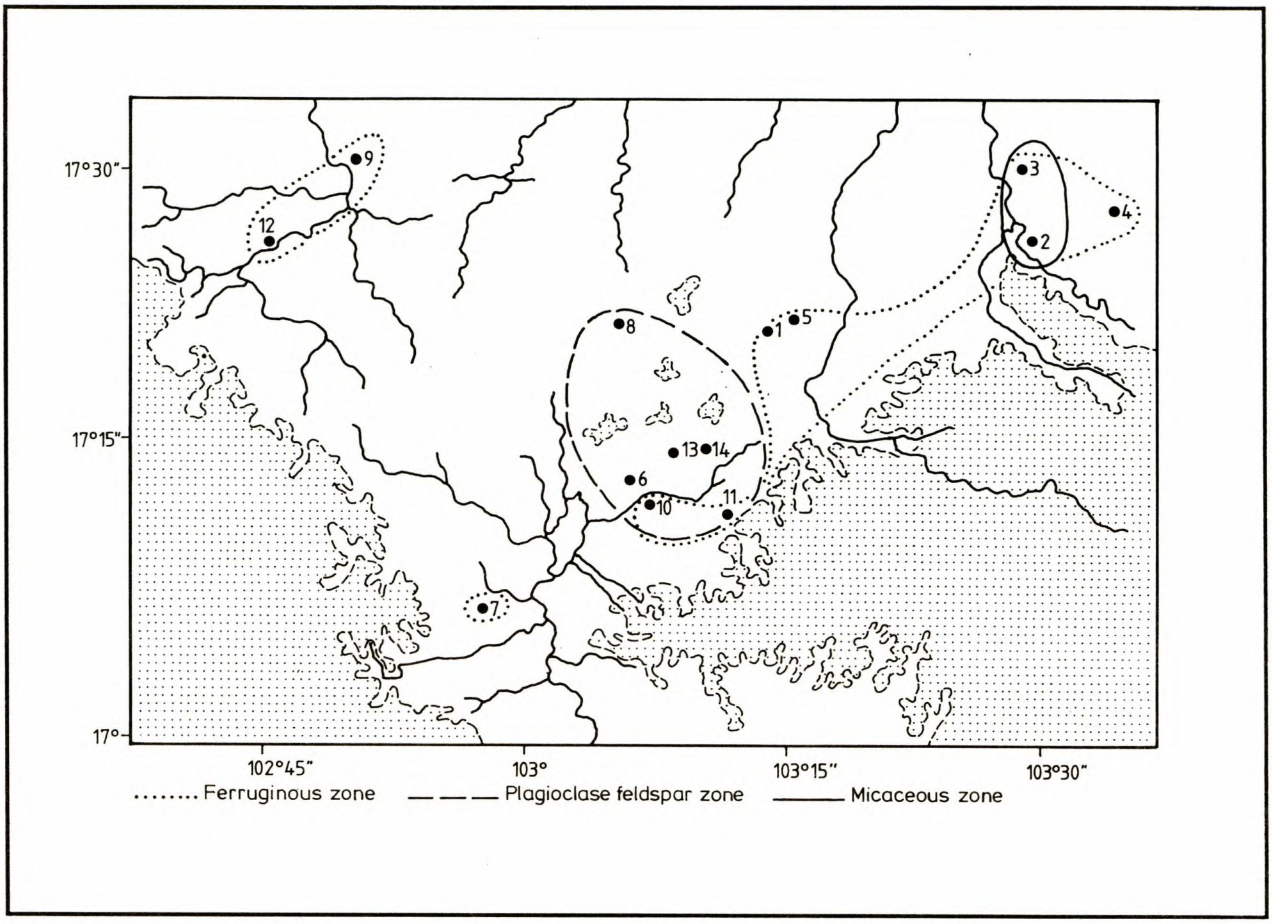

FIGURE 5.3: SAKON NAKHON BASIN MINERAL ZONES.

Chapter 6

The identification of production centres

"although technological and stylistic studies are closely interdependent, we cannot rate one as more important than the other, since they furnish different kinds of information".

Shepard (1942:232).

Consideration of Shepard's pioneer work in the Rio Grande will, in the first instance, provide a testable model for the present work. Her approach involved a petrographic analysis of ceramic fabrics and their comparison and quantification with pottery forms. Particular reference was made to tempers and surface treatments. She was able clearly to demonstrate intensive trade/exchange networks hitherto either unknown or the subject of conjecture. This enabled temporal changes to be understood in detail. As a result, substantial reformulation of the regional chronology was required. It had previously been erroneously based on changes in ceramic styles. In essence two important factors were considered in detail by Shepard:

(i) the various technologies involved were subjected to a fine-grained analysis. Thus changes in individual manufacturing traditions were detected and readily compared with other regionally-associated traditions.

(ii) the identification of pottery production centres.

Both of these factors are interrelated. They are important to an understanding of prehistoric ceramic cultures. Without this knowledge we may easily be deceived that the mere presence of pottery is consistent with its manufacture on site (Shepard 1942:177). Even large quantities of pottery cannot be taken as *prima facie* evidence for *in situ* production.

Production centres may be identified by defining the proportions of local against foreign material present in any site or ceramic district. Ceramically independent sites or districts should contain mainly local tempering material, and a small percentage of foreign material. Temper species may be defined by either mineralogical or technological criteria. An understanding of the magnitude of an indigenous industry provides insight into important cultural questions (Van der Leeuw 1981, Peacock 1982). It helps define the industry's production character and related technological complexity. These reflect sociological and economic influences. Many of these questions are interrelated with, and articulate, other cultural variables.