: RESEARCH PROGRAMME NO. 27

[redacted]VIRONMENTAL DATA (TREND)

ECOSYSTEM STUDY OF [redacted] DRY-EVERGREEN FOREST

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EARTH SCIENCES LABORATORY, U.S. ARMY NATICK LABORATORIES (NLABS)

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APPLIED SCIENTIFIC RESEARCH CORPORATION OF THAILAND

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DEPARTMENT OF METEOROLOGY, OFFICE OF THE PRIME MINISTER

NATIONAL STATISTICAL OFFICE, OFFICE OF THE PRIME MINISTER

ROYAL FOREST DEPARTMENT, MINISTRY OF AGRICULTURE

DEPARTMENT OF RICE, MINISTRY OF AGRICULTURE

DEPARTMENT OF LAND DEVELOPMENT, MINISTRY OF NATIONAL DEVELOPMENT

DEPARTMENT OF MINERAL RESOURCES, MINISTRY OF NATIONAL DEVELOPMENT

CHULALONGKORN UNIVERSITY

KASETSART UNIVERSITY

MILITARY RESEARCH AND DEVELOPMENT CENTER, MINISTRY OF DEFENCE

SEATO MEDICAL RESEARCH LABORATORY

RESEARCH PROJECT NO. 27/1

DESCRIPTION OF TROPICAL DRY-EVERGREEN FOREST ECOSYSTEM

REPORT NO. 8

A DEMONSTRATION OF LAND SYSTEM SURVEY TECHNIQUES AT SAKAERAT EXPERIMENTAL SITE

BY

H.A. HAANTJENS

P.C. HEYLIGERS

ASRCT, BANGKOK 1969

not for publication

COOPERATIVE RESEARCH PROGRAMME NO. 27

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CONTENTS

F O R E W O R D

The present report is concerned with a demonstration of land system survey techniques developed by the Division of Land Research, Commonwealth Scientific and Industrial Research Organization, Australia. This was based on the ASRCT Sakaerat Experiment Station and as it contributes to the description of the forest ecosystem under study at that site, it has been included under the present project reports. The authors visited Thailand under the auspices of the Colombo Plan.

ASRCT Cooperative Research Programme No. 27: Tropical Environmental data (TREND) - Ecosytem study of tropical dry-evergreen forest, is being conducted pursuant to ARPA Order 917 under the management of the Earth Sciences Laboratory, U.S. Army Natick Laboratory (NLABS), Natick, Massachusetts, U.S.A. Dr. Lester W. Trueblood is Director of the Earth Sciences Laboratory, Dr. Paul Dalrymple serves as Project Supervisor, Mr. George Rubin de la Borbolla as Project Manager, and Mr. Robert Fegley as Deputy Project Manager.

The research programme is being carried out by the Applied Scientific Research Corporation of Thailand through its Environmental and Ecological Research Institute in collaboration with other agencies of the Thai Government: The Department of Meteorology and the National Statistical Office (Office of the Prime Minister); The Royal Forest Department and the Department of Rice (Ministry of Agriculture); the Department of Land Development and the Department of Mineral Resources (Ministry of National Development); the Chulalongkorn University; the Kasetsart University; and the Military Research and Development Center (Ministry of Defence); and with the SEATO Medical Research Laboratory.

A DEMONSTRATION OF LAND SYSTEM SURVEY TECHNIQUES AT SAKAERAT EXPERIMENTAL SITE

By H.A. Haantjens* and P.C. Heyligers*

I. INTRODUCTION

After conducting a three-day seminar on integrated land resources surveys according to the land system method+, held at the Applied Scientific Research Cooperation of Thailand in March 1968, and attended by interested persons from various Thai Government agencies, the authors conducted a workshop with a group of five Thai participants, to demonstrate photo interpretation and field sampling techniques as used during similar work in the Territory of Papua and New Guinea. Two days were spent at ASRCT to carry out the preliminary mapping of "land system" and vegetation patterns on 1:40,000 aerial photographs for an area of about 1200 km^2, centered upon the Sakaerat experimental site, about 60 km SW. of Nakhon Ratchasima. During three days of field work soil and vegetation observations were made at 25 sites in most of the "land system" patterns, and some of the vegetation types recognized on the air photos. The authors then spent two days at ASRCT to carry out the final mapping and description of the "land system" patterns.

The boundaries of the patterns were transferred by eye from the aerial photographs onto a contoured 1:50,000 topographical map. This was converted into the accompanying map (Figure 1) at 1:250,000, the normal scale of working for this kind of reconnaissance survey, with the guidance of Col. Joe Castelli of the Resources Inventory Group at ASRCT. The aerial photographs with the photo interpretation boundaries of the "land system" patterns and vegetation types are on file in this group.

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+ See Haantjens (1963, 1965); Heyligers (1968).

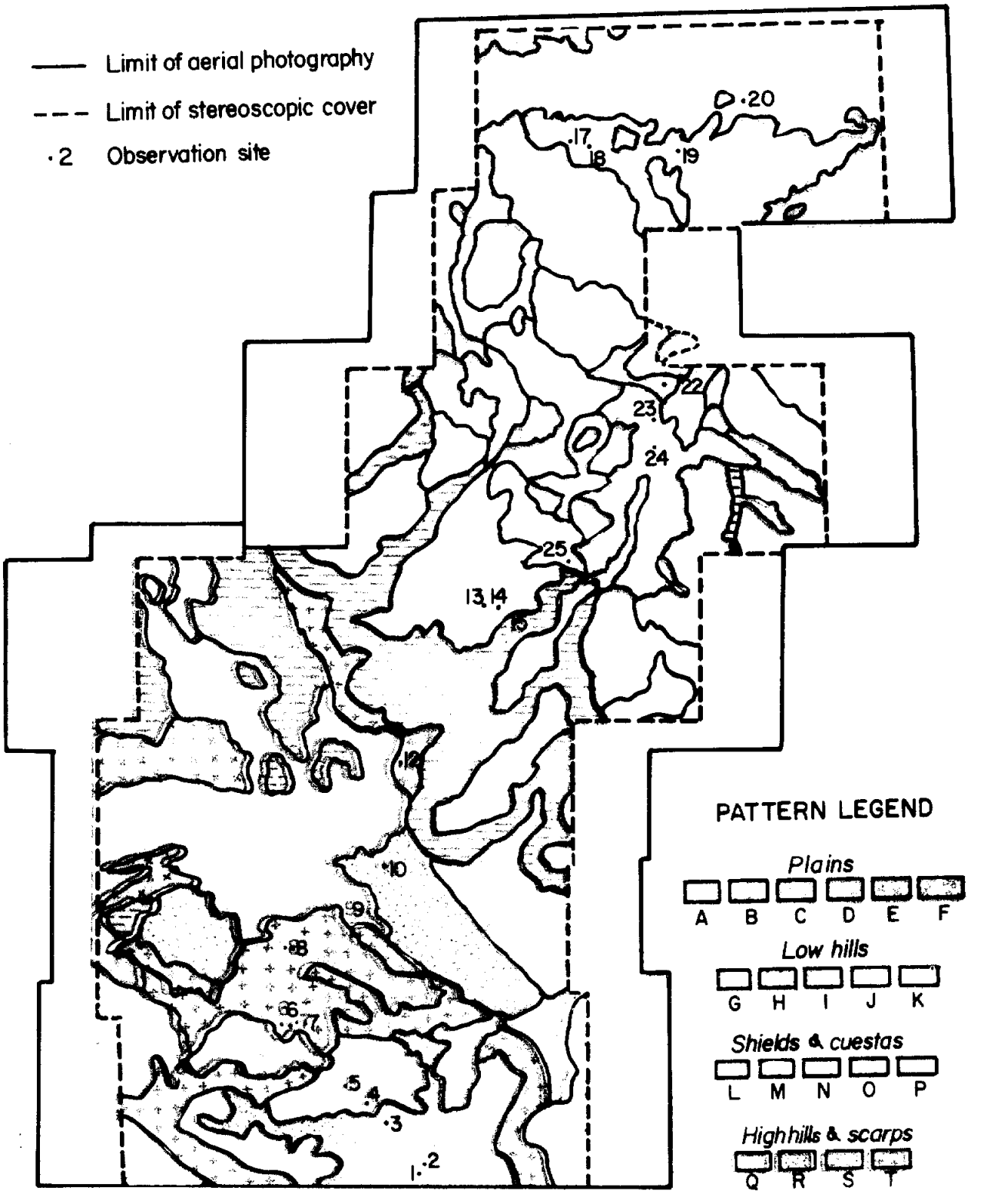


Figure 1. Land system survey, Sakaerat site. Scale 1 : 250 000.

II. DISCUSSION

(a) General

The term "land system" has been used between inverted commas, because of the very provisional nature of the workshop and field demonstration. Working conditions were unavoidably below normal for this kind of extensive reconnaissance survey. Under normal conditions more than two days would have been devoted to the preliminary photo interpretation. The number of observations is well below the normal average for an area of this size. Moreover, the observations could not be distributed to the best advantage, since access was restricted to a few all-weather roads in the area. Great changes in road alignment, and forest clearing after the air photos were taken fifteen years ago, made orientation on the photos very difficult in several cases. The two days available for final mapping and description fell far short of the time normally allowed for this work in similar surveys in New Guinea. The area was really too small for a proper application of the technique: the larger the area, the better the interrelationships between different landscapes can be interpreted. A final disadvantage was the lack of a geomorphologist in the group.

Whilst on the one hand these difficulties were aggravated by the lack of experience of the authors with the environment, which was new to them, the problems were on the other hand alleviated by the relative simplicity and clarity of the landscape photo patterns in parts of the area, and by the use that could be made of the high standard, contoured topographical maps of the area. Such maps would be of great help in any systematic integrated surveys in Thailand.

(b) The "land system" patterns

Twenty patterns were finally recognized and mapped. These are broadly grouped into plains, low hills, shields and cuestas, high hills, and scarps, and described in Section III and shown on the accompanying map (Figure 1). It is encouraging that, notwithstanding the difficulties outlined above, the field work generally confirmed the predictions made during the preliminary photo interpretation. Some guesses made, or doubts raised, about soil conditions in unsampled areas were confirmed

by subsequent checking against available soil data. Confidence was further strengthened by the fact that, wherever soils were observed, their nature was predictable from the characteristics of the photo pattern.

Due to the limitations listed above, the descriptions of the patterns had to be kept short and generalized. It was impossible to add information on land use and population, and on the assessment of land use capability. No systematic soil classification could be attempted in so short a time and with so few observations.

Nevertheless, as one practical result, the survey demonstrated the usefulness of the land system pattern approach for road construction. The maps show that a better alignment of Highway 23, now under construction by the U.S. Army, would have been achieved if it followed the major valley of Pattern S east of the present alignment, in order to traverse Patterns E and H in a straight line and descend to Pattern B along the eastern occurrence of Pattern Q. This would not only have shortened the route, but also reduced the need for cut and fill. Furthermore, if the plans to inundated Pattern B by damming the Huai Nam Khem just south of the area should eventuate, the proposed alignment would require only a short detour along the footslopes of Pattern T in the east, instead of the long detour to the west necessary with the present alignment.

The interrelationships between the twenty patterns are shown by their grouping and colouring into four main landscape types. The area as a whole lies on the SW. margin of the Khorat plateau. Its northern part clearly belongs to this plateau, but the central and southern sectors have been influenced by the development of a large anticlinal structure, the south-west limb of which is just represented on the map as an occurrence of Pattern P. This structure was most likely caused by the intrusion of igneous rocks, which are widely exposed along the eroded anticlinal axis. These earth movements appear to have truncated the NE. tending drainage system, since the small rivers in Pattern S appear to be clearly underfit with respect to the size of both their valleys, and their alluvial plains further north. Rock weathering is pronounced throughout the area, least on the capping sandstone, most on the igneous rocks and on the shaly beds intercalated with the

sandstone. The presence of little weathered colluvial mantles on steeper slopes suggests that the climate may have become drier, after a wetter period responsible for the deep and strong weathering.

(c) Vegetation mapping

Soil and vegetation observation were made at 25 sites in most of the "land system" patterns; some of the vegetation types are recognized on the air photos, from which a map of the vegetation types has been prepared (Figure 2).

III. DESCRIPTION OF "LAND SYSTEM" PATTERNS

(a) Plains (Patterns A-F)

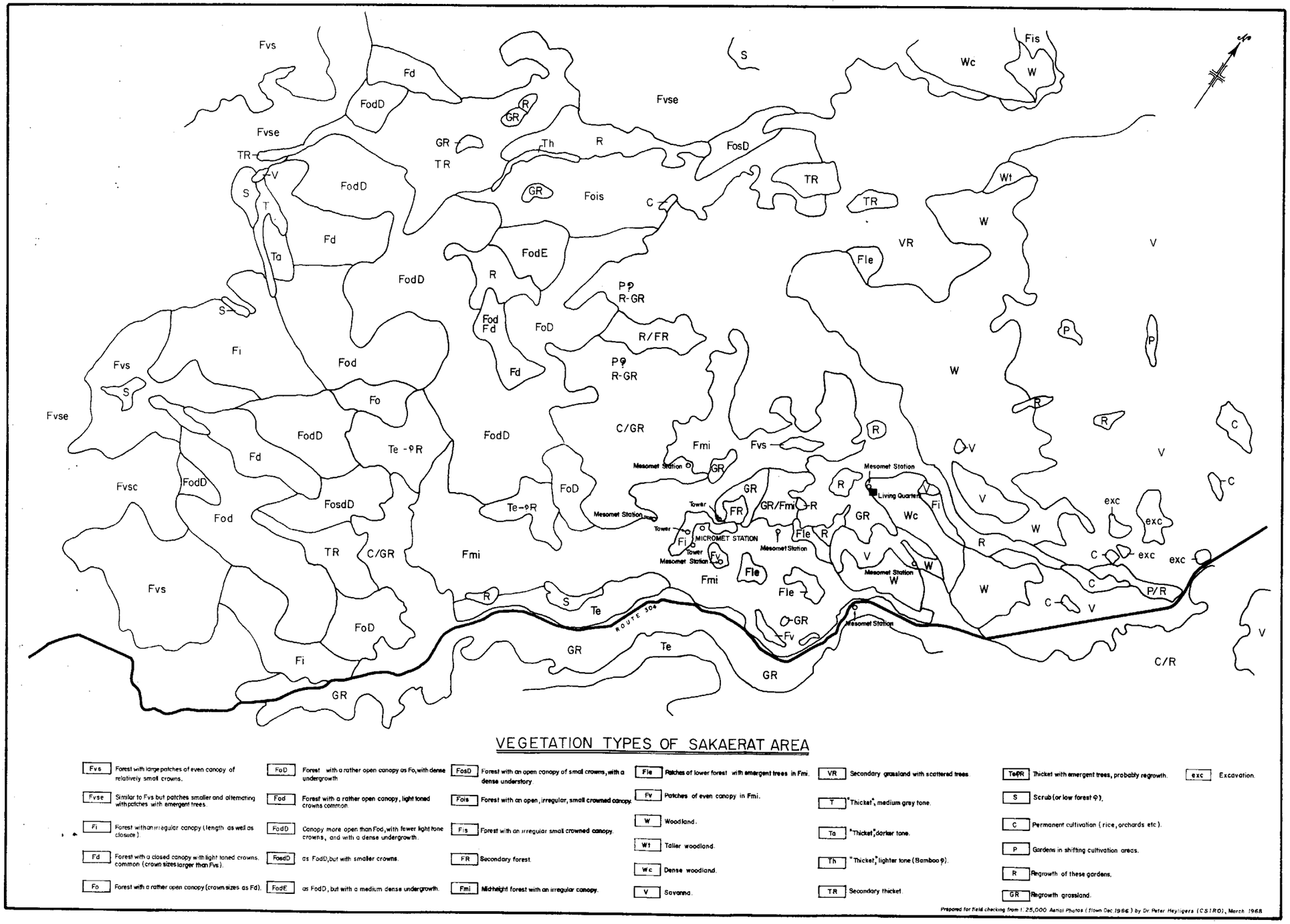
Pattern A

Land forms.—Level plains occupying a low position in the landscape. Levee tracts up to 400 m wide are separated from ½-2 m lower backplains in the wide plains in the north. Small meandering streams become indistinct and anabranching in the wide plains. Basin plains are inundated during the wet season, but some upper plain sectors in the north-west are probably flooded for only short periods.

Geology.—Recent alluvium, probably overlying weathered older alluvium which may possibly form the surface layer in the narrower plains in the east.

Soils.—Slightly developed, brownish, weakly acid soils, mainly clay and somewhat mottled on the backplains, mainly sandy loam to clay loam on levees. More developed, acid soils with texture contrast and mottled subsoils (cf. obs. 2 and 24) may possibly occur on older alluvium in the east, and slightly more developed brown alluvial soils on higher ground in the north-west.

Vegetation.—No natural vegetation remains. Backplains are used exclusively for rice cultivation; on the levee tracts other crops are grown, and villages occur.



VEGETATION TYPES OF SAKAERAT AREA

Fvs Forest with large patches of even canopy of relatively small crowns.	FoD Forest with a rather open canopy as Fo, with dense undergrowth.	FosD Forest with an open canopy of small crowns, with a dense understory.	Fle Patches of lower forest with emergent trees in Fmi.	VR Secondary grassland with scattered trees.	Te?R Thicket with emergent trees, probably regrowth.	exc Excavation.
Fvse Similar to Fvs but patches smaller and alternating with patches with emergent trees.	Fod Forest with a rather open canopy, light toned crowns common.	Fois Forest with an open, irregular, small crowned canopy.	Fv Patches of even canopy in Fmi.	T "Thicket", medium grey tone.	S Scrub (or low forest ?).
Fi Forest with an irregular canopy (length as well as closure).	FodD Canopy more open than Fod, with fewer light tone crowns, and with a dense undergrowth.	Fis Forest with an irregular small crowned canopy.	W Woodland.	Ta "Thicket", darker tone.	C Permanent cultivation (rice, orchards etc).
Fd Forest with a closed canopy with light toned crowns, common (crown sizes larger than Fvs).	FosdD as FodD, but with smaller crowns.	FR Secondary forest.	W1 Taller woodland.	Th "Thicket", lighter tone (Bamboo ?).	P Gardens in shifting cultivation areas.
Fo Forest with a rather open canopy (crown sizes as Fd).	FodE as FodD, but with a medium dense undergrowth.	Fmi Midheight forest with an irregular canopy.	Wc Dense woodland.	TR Secondary thicket.	R Regrowth of these gardens.
			V Savanna.		GR Regrowth grassland.

Prepared for field checking from 1:25,000 Aerial Photos (flown Dec 1966) by Dr. Peter Heyligers (CSIRO), March 1968

Figure 2. Vegetation types of Sakaerat area.

Pattern B

Land forms.—Mainly level plains forming a very gently undulating terrace surface, in which streams are 4 to 7 m incised. Wet and locally inundated during the rainy season. Near the foot of the surrounding hills the terraces merge into colluvial aprons and small fans, slightly dissected and with slopes of 2 to 6°. Narrow lower terraces, in places with marked irregular microrelief, border the major streams.

Geology.—Alluvium and fan deposits, probably of Sub-Recent to Pleistocene age. Minor Recent alluvium along major streams.

Soils.—A moderately to strongly developed strongly acid to acid (pH increases with depth) soil of brown sandy loam merging gradually into compact mottled clay was observed on the terrace surface; a strongly developed, strongly acid dark brown clay soil of clay loam merging gradually into mottled clay to heavy clay occurred on a marginal fan. Probably derived from igneous rock, this more friable soil has oxisolic characteristics. Slightly developed, weakly acid brown soils of mainly medium texture occur on the stratified young alluvium along rivers.

Vegetation.—Lower terraces are originally covered by a tall open forest (Fot) with a conspicuous undergrowth of Corypha palms. Over large areas this vegetation is cleared, except for the palms, and cultivated. Upper terraces and fans are covered with low forest (Fis, Fvl), in which Corypha palms are still present. These palms might indicate waterlogging or inundation for some length of time in the wet season.

Pattern C

Land forms.—Slightly but commonly closely dissected, very gently to gently sloping colluvial aprons at the foot of sandstone scarps; and almost level, very gently undulating plains along small streams, either merging down stream into Pattern A or forming relatively low-lying areas associated with Pattern F. The level plains may be partly flooded for short periods.

Geology.—Colluvium and alluvium, probably mostly of Sub-Recent to Pleistocene age.

Soils.—On colluvial aprons probably occur acid, sandy, and locally stony soils, probably mostly deep. On an alluvial plain a moderately developed, deep, acid soil was observed of brown fine sandy loam overlying very friable sandy clay loam, mottled with depth. Although this soil was remarkably moist at the end of the dry season, it is only imperfectly drained. Similar, but poorly drained soils with finer-textured subsoils can also be expected.

Vegetation.—Woodland covers most of this pattern; on level plains the Shorea type (Wt), on sloping ground types of a more mixed composition (W, WS). Clearings are extensive, some areas have regrowth with scattered trees (VR). The occurrence of Pattern C in the north-west between areas of Pattern N has a forest cover (Fos).

Pattern D

Land forms.—Slightly dissected colluvial aprons and fans at the foot of sandstone and igneous hills. Commonly slightly to markedly undulating surfaces with 2-6° slopes and relief up to 20 m.

Geology.—Colluvial and fan deposits, locally with sandstone boulders, and probably mainly of Pleistocene age.

Soils.—Probably mainly strongly developed, deep, strongly acid, rather friable brown over red brown soils with oxisolic characteristics, but a clay content gradually increasing with depth (e.g., sandy clay loam merging gradually into sandy heavy clay).

Vegetation.—Forest covers most of this pattern. Some types (FoD, Fos, FoEsd) are more luxuriant than others (Fcs, Fcis), which might express differences in rainfall due to position of the adjacent hills.

Pattern E

Land forms.—Gently and broadly undulating surface, very gently tilted to NE., and bounded in N. and E. by massive sandstone ridges, and in SW. by very low, NE. tilted ridges. Relief 10-20 m.

Geology.—Probably sandstone; possibly covered with thin or thick and possibly sandy alluvial material, and colluvial material near the bounding sandstone slopes.

Soils.—No data. Soils may be somewhat similar to those described for Pattern G, but more oxisolic soils as described for Pattern D may also occur.

Vegetation.—Forest types with an open canopy characterize this pattern: Fotd covers extensive valley flats, FoiE occurs on the dissected, sloping parts, and FoigD occupies the rest of the pattern.

Pattern F

Land forms.—Gently undulating plains with slopes up to 2°. Particularly along the edges occur very shallow, flat-floored, linear, branching drainage depressions, which are inundated in the wet season. Relief appears to be up to 10 m. There is mostly a very slight topographic break to the lower-lying Pattern A and a gradual transition to the higher Pattern L.

Geology.—Probably Pleistocene alluvium, mostly very sandy, but in many low-lying areas sandy clay to clay.

Soils.—Mostly weakly acid, brown to red brown (usually increasingly red with depth), sand to loamy sand overlie sandy clay loam at depth, or be as shallow as 60 cm and abruptly overlie mottled compact sandy heavy clay. The more clayey subsoils and sands above these are acid to strongly acid. Where Pattern F merges with Pattern A in the east, a strongly acid soil was found of dark brown loam merging into brown clay loam, overlying mottled very compact heavy clay. A soil observed in a flat drainage depression was a neutral to weakly acid, shallow sandy loam and loamy sand, separated from a sandy clay subsoil (alkaline with depth), by a very thin alluvial clay layer resulting from padi cultivation.

Vegetation.—Woodland is characteristic for this pattern (W, Wc, Ws, Wt), but it is extensively cut out (WR), or cleared in drainage depressions for padi cultivation. Extreme soil moisture conditions are expected to occur throughout the pattern.

(b) Low hills (Patterns G-K)

Pattern G

Land forms.—Very low hilly to rolling, locally undulating surfaces with a very slight NE. tilt, and a relief of 15 to 30 m. A few isolated small higher hills occur, mainly in the west. Whilst slopes are mainly gentle (2-8°), some short steeper slopes occur locally, partly forming NW.-SE. trending scarp-like features, separating different surface levels. There is an open pattern of small streams, and locally small shallow ponds occur in depressions.

Geology.—Mainly sandstone. One area in the south between Patterns J and T appears to be igneous rock, probably diorite.

Soils.—Soils on sandstone appear to range from deep, strongly acid, yellow brown sandy loam to loamy sand, merging at depth into slightly mottled sandy clay loam on crests, to acid sandy loam over sandy clay loam merging at shallow depth into weathered sandstone on lower slopes, where rock outcrop occurs in places. On igneous rock there is a similar soil pattern, but the soils are lighter brown, more mottled in the subsoil, not strongly acid, more clayey but with coarse-sand (coarse sandy loam to sandy clay loam topsoil over coarse sandy clay to clay subsoil). Similar but clearly colluvial soils with some boulders also occur on lower slopes.

Vegetation.—Thicket (Tr, Td, Tdg) covers most of the southern areas of this pattern; forests of medium or low height (Fcis, some Fois and Fisd) cover the northern part. These vegetation types could reflect low rainfall (rain shadow effects) and/or excessive drainage.

Pattern H

Land forms.—Short low hill ridges with a marked NW.-SE. trend in crests and valleys, and with an alternation of gentle (2-8°) and steep (17-25°) slopes. The steep slopes can be benched with much rock outcrop on the steepest sections. Few small streams. Relief 20-50 m, highest along the northern, western, and southern edges of the pattern, lowest in the east.

Geology.—Sandstone was observed and probably is the only major rock type.

Soils.—On gentle slopes and foot slopes soils are probably similar to those described for Pattern G but may be generally slightly redder. A soil observed on a steep slope had a thick, neutral to alkaline dark topsoil, merging into acid brown sandy clay loam over strongly acid red brown sandy clay. The upper horizons are obviously influenced by colluvial displacement, whilst the subsoil appears to be residual weathered material. This pattern as well as the strong pH gradient was also found on steep hill slopes in other patterns.

Vegetation.—Forest with an open canopy and with a medium dense undergrowth (FoEsd) covers the highest ridge which lies adjacent to Pattern J. The rest is covered with forest with a denser undergrowth: Foid mainly on the ridges and FoD on slopes and valleys. Steepest slopes are covered with a light-toned forest (Fish).

Pattern I

Land forms.—Short irregular low hill ridges with narrow rounded crests and strongly variable slopes, mostly between 8^{o} and 20^{o}, locally steeper on SW. facing short scarp-like slopes. Rock outcrop is probably common on steep slopes. Relief 30 to 60 m. There are slightly more small streams than in Patterns G and H. Pattern I is more irregular, has slightly higher relief and finer grain than Pattern H. It commonly has arbitrary gradual boundaries with Pattern G.

Geology.—No data. The hill pattern suggests that shale is at least a component of the rock sequence, although sandstone is probably the major rock type.

Soils.—No data. Soils are expected to be similar with respect to colluvial characteristics, acidity, and depth to those of Pattern H, but may be finer textured.

Vegetation.—Thicket (Td) and forest (fosD, Fcis) cover most of this pattern, probably indicating low rainfall and/or excessive drainage. In the west some areas seem to be bare or covered by herbaceous vegetation (H?).

Pattern J

Land forms.—Very low accordant convex hills with dense grain, forming a dissected weathered surface, slightly tilted to the east, and

gradually descending towards bounding scarp slopes of Pattern T. Rounded crests (0-8°) merge gradually into steep (17-25°) lower slopes. Very narrow valleys. Relief 15 to 30 m.

Geology.—Probably intermediate and basic igneous rock.

Soils.—Deep, acid, friable, red brown clay soils with thin, weakly acid, dark clay loam topsoils appear to be dominant. These oxisolic soils give way to paler soils in marginal areas with gentle slopes, as described for the igneous part of Pattern G.

Vegetation.—Almost exclusively covered by a type of forest, that comes closer to "tropical rain forest", than any other type in the area (FoEsd). This might indicate a relatively high rainfall and a favourable soil moisture regime.

Pattern K

Land forms.—Short low hill ridges of dense grain and with irregular, moderate to steep slopes, and a west-east directional trend. Relief 40 to 70 m, increasing to the east. The southern occurrence has particularly strong linear arrangement, broader crests and a relief up to 90 m. Rather many small streams occur.

Geology.—No data. Intermediate to basic igneous rocks are indicated by the intrusive dike - like structures in the south, by the sharp dissection, and by the W.-E. to SW.-NE. trend, which is opposed to the regional strike.

Soils.—No data. Soils may be expected to be roughly similar to those of Pattern G.

Vegetation.—The area with highest relief is covered by forest, with a scrub-like vegetation on lower slopes and valleys (Fis/S). The remainder is under thicket (T, Td).

(c) Shields and cuestas (Patterns L-P)

Pattern L

Land forms.—Gently and broadly convex surfaces (shields), 1/2-2 km wide and slightly tilted to NE., separated by rather straight, very narrow dissection valleys with very short, moderate to steep side slopes.

Shield slopes probably 1-5°. Relief 10-30 m. Common, rather parallel small streams. Very few shallow, narrow, flat-floored valleys.

Geology.—Sandstone.

Soils.—Observed was an acid light brown over strong brown sand with a slightly less acid, darker topsoil, and overlying hard sandstone at 65 cm. Deeper, redder, somewhat less sandy soils probably also occur.

Vegetation.—Mainly different types of woodland (W, Wc, Ws, Wcs, Wa; and Wt in valleys); forest (FosD) was only mapped in one area. Shallow soil depth, connected with extremes in soil moisture regime might be an explanation for the occurrence of woodland.

Pattern M

Land forms.—Essentially similar to those of Pattern L, since pattern distinction is mainly based on vegetation. Dissection valleys are closer spaced, slopes tend to be slightly steeper and relief slightly higher. Pattern M is commonly found at the top of escarpments, which is never the case with Pattern L.

Geology.—No data, presumably sandstone. This may be rather thin and overlying igneous rock in the most south-westerly occurrence.

Soils.—No data. Probably reddish, very to moderately sandy soils, acid to strongly acid, and mostly deep to moderately deep.

Vegetation.—Forest (FoEsd, FodD) covers most of this pattern, reflecting different conditions from Pattern L. Dissection slopes are covered with a forest of light tone (Fish). Only in the north-east some woodland is found, where this pattern grades in Pattern L.

Pattern N

Land forms.—Cuestas with very long gentle dipslopes bounded by very steep, slightly concave scarp slopes in the west and south. Scarps are 140 to 180 m high in the SW., decreasing gradually in height to N. and E. The southernmost occurrences of the pattern have only minor or no scarps, since the dipslopes merge with those of Pattern P. On the other hand, some buttes are included in Pattern P as erosional remnants of cuestas, and these consist largely of steep to very steep scarp slopes. Dipslope surfaces are gently to strongly undulating and partly

dissected by gullies and ravines 20-50 m deep, particularly on the lower slopes. At their base the dipslopes merge gradually with Pattern L.

Geology.—Sandstone. This could possibly contain local salt bodies, which may have caused the formation of a few karst-like dissection valleys and would explain the presence of saline subsoils in depressions of Pattern F.

Soil.—The only soil observed was from an area near to and transitional to Pattern P. It consists of thin, acid, strong brown sandy loam merging into strongly acid red brown clay loam and clayey gravel. The gravel consists of lateritized weathered sandstone. Large and small boulders and stones are abundant in, and in most places also on the soil, but some soil material may be present between these to depths of 1 to 2 m. The scarps consist mostly of rock outcrop and some stony scree material.

Vegetation.—Mainly woodland, often of the denser type (Wc, Wcs, Wca) and grading into open forest (Fovs). On escarpments a denser forest occurs with a very even canopy (Fv). On the south-western occurrences, forest (Fci) is found adjacent to the woodland, and these areas might be of particular interest for a study on the relationships between woodland and forest.

Pattern O

Land forms.—Dissected dipslopes with gently to moderately steep slopes, and dissected steep to very steep scarp slopes, facing W. to S. Together these elements form an intricate pattern of rugged low hills with a relief of 30 to 60 m, and with a rather gradual transition to Pattern I in the east.

Geology.—No data; presumably sandstone, dipping gently to NE.

Soils.—No data. Probably shallow and very shallow sandy, stony soils.

Vegetation.—Forest (Fcis).

Pattern P

Land forms.—Dissected dipslopes, rising gently from about 300 m in the NE. to 720 m on summits in the SW. Dissection also increases in this direction, and the land forms range from undulating to rolling

plateau-like surfaces with some linear flat-floored depressions, gentle slopes and a relief of 10 to 20 m, to hill ridges with moderate to steep slopes and a relief of 40 to 100 m.

Geology.—Mainly sandstone, generally gently dipping NE., but SW. in the extreme south-west corner of the area on the opposing flank of a large anticline. Shale fragments in the soils and weathered shale exposures in the associated Pattern S suggest the presence of some intercalated shaly beds. This weaker rock could have caused the stronger dissection and lack of prominent scarps in this pattern as compared with Pattern N.

Soils.—Three observations within a rather small area revealed essentially similar, strongly acid soils of dark (red) brown clay loam, 15 to 45 cm thick over red brown clay. Large amounts of lateritized weathered rock gravel occurred below 5 to 35 cm depth and the soils were too stony to be augered beyond 35 to 60 cm depth, although some soil material may be present to depths of 1 to 2 m. Surface stones and boulders are mostly rare to common, locally abundant.

Vegetation.—In the SW. mainly forest (FodD), towards the NE changing into smaller-crowned forest (FosdD) on slopes and ridges and thicket (T) on plateau-like surfaces, and into dense forest (Fci, Fcd) on the westernmost occurrences. In the extreme NE. several woodland types (W, Wc, Ws) are found, also patches of savannah which are probably largely secondary (V, Vg, VR). It is not unlikely that the SW.-NE, trend to poorer vegetation reflects a climatic gradient.

(d) High hills and scarps (Patterns Q-T)

Pattern Q

Land forms.—Strongly dissected irregular hill ridges, descending from higher plateau surfaces (in one area from lower scarp slopes) to the valley floor. The hills are strongly spurred, with local small slumps, uneven, narrow crests, and slopes generally ranging from 8-20°, but locally steeper. Some broad, rolling crestal surfaces occur on the upper slopes. Total relief is 160 to 280 m, whilst local relief is 30 to 100 m.

Geology.—Mainly intermediate to basic igneous rock, ranging from coarse-grained (probably diorite), to fine-grained (basalt-like). Quartzite was observed at one place, probably resulting from the contact between the intrusive and overlying sedimentary rocks. Rocks are deeply weathered with core stones particularly on lower slopes.

Soils.—Dark brown (red) coarse sandy clay loam to clay soils, with clay content increasing with depth, and merging into soft weathered rock at 60–70 cm, with hard weathered rock below 1 m or deeper. Whilst soil acidity increases from weakly acid to acid with depth, there can be a dark, stony, surficial colluvial mantle of alkaline reaction.

Vegetation.—Mainly forest with a moderately dense, irregular canopy, but of rather low height, especially on south facing slopes (Fis, other types: Fish, Fid, Foi). Adjacent to scarp slopes and plateau surfaces a mosaic of light toned scrub (Sh) and darker toned thicket (Ta) and forest (Fa) forms a conspicuous pattern on the air photos.

Pattern R

Land forms.—Strongly and finely dissected hill complex standing up to 300 m, above the surrounding plateau surface, and composed of radiating broad spurs with narrow, uneven crests, and finely spurred steep side slopes. Rolling to very low hilly broader crestal surfaces occur on the upper slopes. Local relief is 50 to 200 m. The pattern resembles that of Pattern Q, but occupies a contrasting position in the landscape.

Geology.—No data. Probably deeply weathered igneous rock.

Soils.—No data. Probably similar to the soils described for Pattern Q.

Vegetation.—Forest with an irregular canopy (Fi) is found on the higher parts; on the lower ridges mainly forest with an open canopy (FoEsd), with some thicket (Td), especially on the NE. side.

Pattern S

Land forms.—Major valleys and ridges cut into and from dissected cuestas, and associated with the dipslope surfaces of Pattern P. Relief increases from 50 m at the NE. extremities to 200 to 300 m in the SW.

Valley side slopes tend to be concave, with steep to very steep upper slopes and local precipitous scarps, and moderate to moderately steep but very irregular and dissected lower slopes. Valley floors are undulating to rolling and harbour small streams, mainly flowing to NE. The hill and mountain ridges occur, where the valleys widen to the SW., and appear to have smoother, moderately steep to steep slopes and rounded crests.

Geology.—Mainly sandstone with some intercalated beds of shale. Bouldery colluvial material covers the lower slopes, but becomes finer textured in the valley bottoms. Alluvium is virtually absent.

Soils.—No data. Probably brown and reddish, acid, deep, medium textured soils, locally with many large boulders, occur on lower slopes and valley bottoms. Upper valley slopes are predominantly rocky with some colluvial soil, increasing in quantity down slope. Soils of mountain slopes could be more residual, but are likely to be shallow and stony.

Vegetation.—In northern occurrences forest types with a closed canopy (Fcs, Fcis) are predominating. Towards the south forest types with an open canopy are more common (Fois, FoD, FosD) together with thicket (Td). Broader crests have small-crowned forest (Fs, Fsi).

Pattern T

Land forms.—Scarps along the margins of plateau surfaces and dissected dipslopes, mostly leading down to the low-lying alluvial basin of Pattern B and including a ravine cut into Pattern J. The scarp height is commonly 240-300 m, but up to 500 m in the SW. and down to 80 m at the head of the ravine. The upper rim is generally at 400 m, but at 800 m in the SW. The scarps are partly irregularly dissected and strongly spurred, with slightly concave slopes, very steep in the upper parts, steep in the lower parts. Partly they are little dissected and more clearly concave with precipitous upper slopes and steep lower slopes of a more colluvial nature. In the NE. the second type sharply overlies the first type.

Geology.—No data. The spurred scarps probably consist of more or less disintegrated igneous rock, the smooth scarps of more or less massive sandstone. Their distribution is generally in line with observations of these rocks nearby in other patterns, but complications may occur in one or two places.

Soils.—No data. The smooth scarps appear to consist largely of hard rock outcrop merging into bouldery scree material down slope. The spurred scarps probably have very shallow, undeveloped, and locally stony soils.

Vegetation.—Light-toned scrub in mosaic with darker-toned thicket and forest (Sh/Ta/Fa) is the dominant vegetation, with some other forest types (Fish, Fvl) in lowest parts. On the SW. scarp, however, forest with an open, irregular canopy (Foi) and thicket (T) are the prominent types, the forest mainly occurring as a horizontal band in thicket, and probably occurring on a different substratum.

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