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LATE TERTIARY AND QUATERNARY COASTAL LANDSCAPE DEVELOPMENT OF THE KROYA BEACH RIDGE AREA (SOUTH CENTRAL JAVA, INDONESIA)[1]

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ABSTRACT

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Topographical, lithological and paleo-pedological features enable the reconstruction of the Late Tertiary and Quaternary development of the Kroya coastal plain. Climatic changes and sea level fluctuations during the Pleistocene, and tectonic and volcanic activity which persisted up to the present, are the main factors that determine the current morphology of the area.

The coastal plain represents a horst-graben structure, both in an east-west as well as in a north-south direction. The central part is characterized by a Pleistocene beach ridge complex which is covered by younger volcanic ashes, and which is bordered to the east, north, and west by the lagoonal-fluvial sedimentation areas of the grabens. Only to the south there is an almost uninterrupted southward extending Holocene beach ridge system.

INTRODUCTION

This paper reports on the investigations that have been carried out within the framework of the NUFFIC[5]-sponsored Serayu Valley and Earth Sciences projects. The Serayu Valley Project is a cooperative project between the Gadjah Mada University in Yogyakarta (Indonesia) and the International Institute for Aerial Survey and Earth Sciences in Enschede, the University of Amsterdam and the Free University in Amsterdam (The Netherlands), while the Earth Sciences Project is a cooperation between the Gadjah Mada University and the Free University.

The aim of the research was to analyze the Late Tertiary and Quaternary geological, geomorphological and pedological development of the coastal plain area around Kroya which is located between the Serayu River and the Karangbolong Mountains (South Central Java, Indonesia; Fig. 1). To achieve this, topographical, sedimentological and (paleo) pedological data were gathered. Especially pedological data may supply information to identify periods of non-deposition that interrupted a sedimentary sequence (RUHE, 1965),and thus may indicate some of the ecological conditions of these periods of landscape stability (JUNGERIUS, 1976). Of course, the usage of paleopedological evidence to reconstruct past events that were related to climatic changes might be questionable, since it is based on a number of assumptions. Those assumptions are, that existing soils have formed under and are in equilibrium with presently existing environments, that buried soils do not undergo changes after burial, and that the soil morphology is specific for a simple genetic pathway. Since only some of the morphological features relate to specific genetic processes as well as to specific environments, discretion in the selection of such features is essential when interpretating soil profiles for the reconstruction of previous environments (PAWLUK, 1978).

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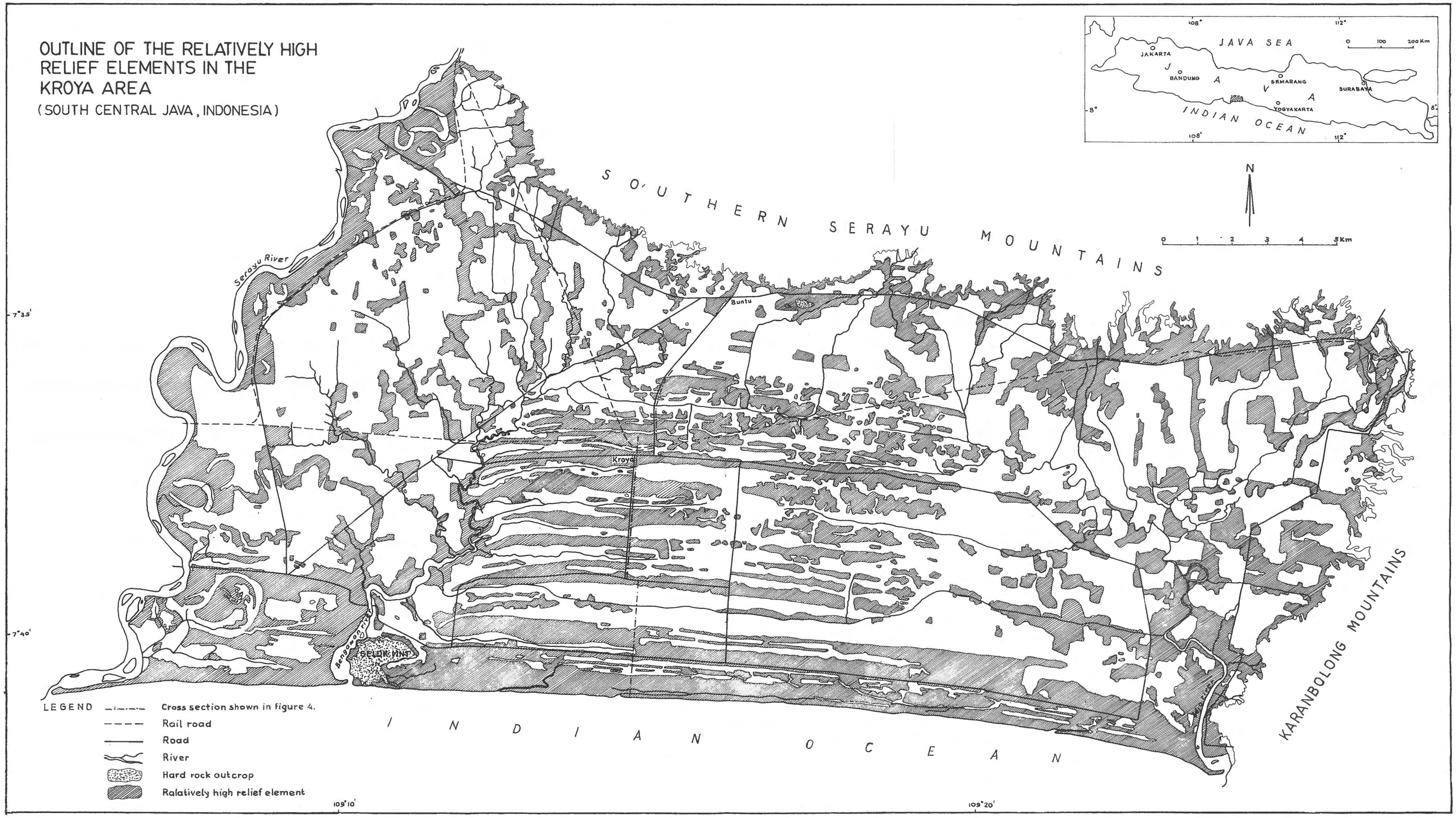

Fig. 1
Morphology of the Kroya region.

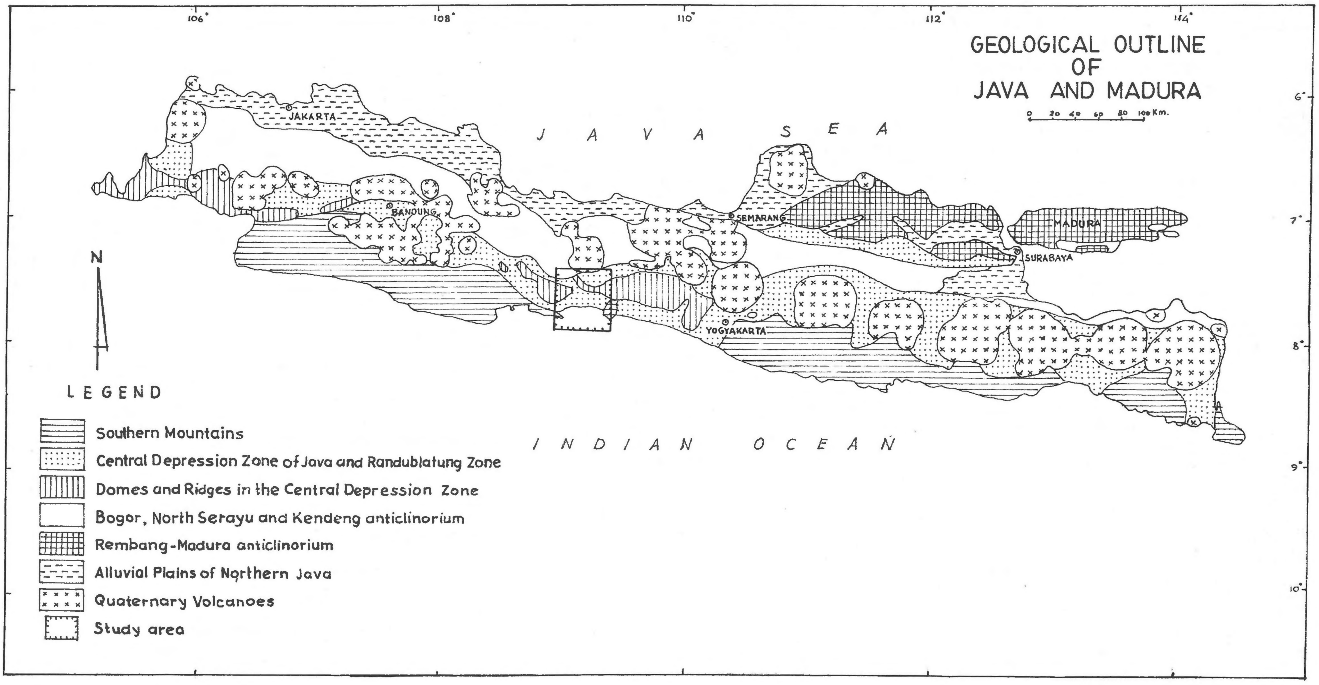

Fig. 2
The geology of Java and Madura (after van Bemmelen, 1949).

PROCEDURE

Field data were collected for one month, during the period November 1980 to January 1981. The field operations comprised several activities, all concentrated along an approximately north-south section through Kroya, perpendicular to the coast line:

(1) an eye levelling survey to estimate the relative height differences in the study area. Such detailed information was not available from topographic maps.

(2) manual and hydraulic-auger drilling to collect data on pedology and sedimentology.

(3) a geoelectrical survey to detect differences in lithology in the sub-soil. Analysis of the data revealed only differences in the ground water chemistry, however, and none in the lithology.

(4) sampling of soil material to analyze whether the soils represent equal or different stages of weathering and soil formation.

Intensive use was made of topographical maps (Revised edition by the U.S. Army Map Service, 1944, scale 1 : 50,000, No. 43/XLII – B and D, 44/XLI – C and D, and 44/XLII – A and B) and satellite images (scale 1 : 1,000,000., NASA-Landsat-E-30051-02085-6).

GEOLOGY

According to VAN BEMMELEN (1949) Java can be divided into several parallel, almost east-west stretching structural zones, of which an outline is given in figure 2. The area studied forms a part of the eastward extension of the 'Bandung Zone' which belongs to the 'Central Depression Zone of Java'. The Southern Serayu Mountains, together with the West Progo Hills in the east, belong to 'Domes and Ridges' unit, within the Central Depression Zone.

Together these two zones are the axial culmination of the Java geanticline. The 'Southern Mountains', south of the 'Central Depression Zone' are well preserved in East and West Java, but in Central Java they have disappeared almost completely.

The 'Southern Mountains', composed of Tertiary marine sediments and volcanoclastic deposits were domed up in the Late Miocene (SPEELMAN, 1979). During that time and also in the Early Pliocene, these mountains were tectonically broken down into different blocks, which slid down towards the Indian Ocean. This southward slumping explains the absence of the 'Southern Mountains' in Central Java, where the vertical displacement must have been more pronounced than in East and West Java. Only isolated remnants of these mountains crop out, i.e. Nusakambangan, Selok Hill and

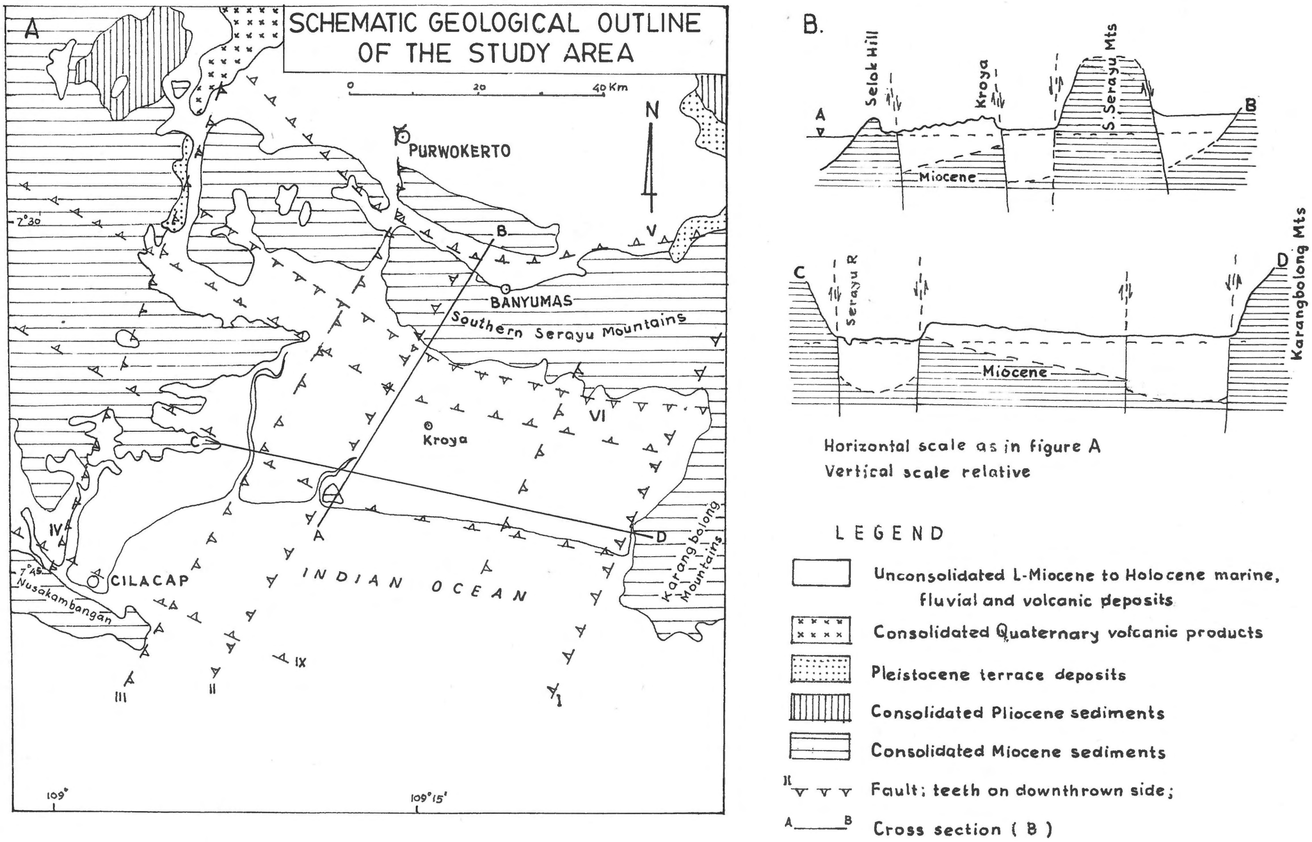

Fig. 3
Schematic geological outline of the study area (modified after Peta Geologi Jawa & Madura, Lembar Jawa – Tengah, scale 1: 500 000, Direktorat Geologi).

Karangbolong Mountains. According to BOLLIGER & DE RUITER (1974) the Karangbolong High (and also the Selok Hill) is similar to the West Progo Mountains, a relict of simple volcanic build-ups.

During Early Pliocene the Southern Serayu Mountains were arched up and this was accompanied by extensive volcanism. These mountains, like the 'Southern Mountains', are composed of an alternation of marine, predominantly marly sediments and volcanoclastic deposits. Because of the combined effects of gravity flow and surface erosion the Southern Serayu Mountains were already considerably levelled during this geanticlinal uplift (SPEELMAN, 1979).

The transition between the 'Central Depression Zone of Java' and the 'Southern Mountains' is formed by a system of longitudinal faults and flexures. The main direction of this system is approximately WNW-ESE. Perpendicular to these faults and flexures a set of parallel faults can be recognized that stretches NNE-SSW. Along these faults, the differential subsidence of the 'Southern Mountains', described above, has occurred. Faults representing both systems can be identified in the area investigated (Fig. 3).

Late Tertiary and Quaternary lagoonal fluvio-marine deposits, locally covered by Middle Pleistocene to Recent volcanic ashes determine the present landscape of the Kroya coastal plain.

GEOMORPHOLOGY

The research area is a relatively low-lying coastal plain, with a maximum elevation of about 17 m above mean sea level (amsl), where fluvial and marine/eolian deposits form the major relief elements. On the landward side the plain is bordered by the Southern Serayu Mountains, built up of mainly Miocene rocks. These are connected with the Karangbolong Mountains, marking the eastern boundary of the plain. The Indian Ocean and the Serayu River form the southern and western border respectively of the area studied.

Settlements are concentrated on the high relief elements, e.g. natural levees, point bar deposits and east-west stretching ridges. The relatively low-lying areas are intensively used for wet rice cultivation.

The south coast of the plain is formed by a smoothly curved

Table I
Mean annual meteorological data for the Kroya area (South Central-Java, Indonesia), after Isnugroho (1975).

Mean elevation (m)	Rainfall (mm)	Evaporation (mm)*	Temperature (°C)	Humidity (%)	Sunshine (%)	Windspeed (m/s)
10	2960	1650	26.5	84	55	1.4

*According to the Penman-Rijkoort method.

sandy beach ridge system, about 2 kilometres wide and up to 6 m high, only interrupted where the Bengawan and Idjo Rivers enter the Indian Ocean. The small isolated Selok Hill, east of the mouth of the Bengawan River, does not affect the existing coast line.

Numerous east-west stretching ridges can be distinguished inland, about 17 m high in the west. They gradually decrease in height towards the east, where they finally end. In the centre of this ridge system some of the ridges are interrupted. Furthermore the north-eastern part of this ridge system shows a more dissected character than the southwestern part. In the west the ridges suddenly bend to the south-east and end abruptly. Here they are bordered by the Old Serayu Deposits (VERSTAPPEN, 1978) in which former natural levees and point bars of the Serayu River have developed. The present Serayu River has built up a broad natural levee west of the Old Serayu Deposits.

Entering the coastal plain the Bengawan and Idjo Rivers and their tributaries suddenly start to meander at an imaginary east-west line, about 1 km north of Kroya. This probably is caused by a change in the transporting capacity of the rivers mentioned, e.g. a change in gradient (SCHUMM, 1977).

Comparison of 50 year old topographic maps and recently made aerial photographs revealed that at its outlet the Serayu River shifted its course from a westerly to an easterly direction. According to SOBUR (1981) this shift can be attributed to a minor change in the prevailing wind direction during approximately the last 30 years.

Between the Karangbolong Mountains and the broad ridge system, the Idjo River seems to be the only relief forming agent, creating natural levees.

Airborne ashes are widely distributed over the area; they are the result of increased volcanic activity from the Middle Pleistocene to the present (VAN BEMMELEN, 1949; VERSTAPPEN, 1974; VAN DER LINDEN, 1978a, 1978b; SPEELMAN, 1979). Throughout the area these deposits can be traced easily, and they form the top layer of the higher relief elements, e.g. of the ridges and natural levees. Only the beach ridge system which forms the present coast line does not possess such an ash cover.

CLIMATE

The area investigated is situated 7°40' south of the equator and consequently has a hot and humid climate with little annual variation in temperature and humidity. There are two main seasons: the wet, or north-west monsoon, and the dry, or south-east monsoon.

According to Köppen's classification, modified after SCHMIDT & FERGUSON (1952), the coastal plain is characterized by an Af-climate (continuously moist, having more than 60 mm of rainfall during the least rainy month). Average meteorological data for the area are given in Table 1.

RESULTS AND DISCUSSION

Already in 1929 'T HOEN considered the Kroya fluvial-marine-aeolian-coastal plain to be characterized by horst-graben structures. More recent literature also supported the hypothesis that the morphology of this area seems to have a tectonic rather than a marine sedimentary origin (FABER & KARMONO, 1976). SPEELMAN (1979) and VAN DER LINDEN (1978a) mention that three to four beach ridges close to the ocean are of marine-aeolian origin while ridges landinward are thought to represent anticlinal ridges, composed of folded Miocene marine rocks that are covered by volcanic ash.

As presented in figure 3, the Kroya coastal plain can be divided into three parts, from east to west: the Idjo graben, a central part, the Kroya horst, and the Serayu-Bengawan graben. Superimposed upon and perpendicular to this structure there is a second fault system accentuated by a graben in the north and a southeastward tilted halfgraben in the south. At the eastern boundary of the Serayu-Bengawan graben the direction of the second fault system changes from NW-SE into WNW-ESE. The study area thus, is composed of graben structures in the west, north and east, while the central part represents a slightly southeastward dipping horst. Figure 4 has been constructed from eye-levelling and drilling activities and shows the topography and lithology in a north-south section through the Kroya coastal plain (for location see figure 1). Based upon this cross-section and additional information from topographic maps, the area investigated can be divided into four zones.

1. *Holocene beach ridges.*

Along the coast there is a young beach ridge system, about 3 km wide in the west, that decreases in an easterly direction, and has equable elevations up to 6-7 m throughout the zone. Locally there are depressions that contain brackish water.

The ridges consist of coarse to medium grained sand of volcanic origin. Locally dunes are superimposed upon the ridges and dunes are still being formed in the southernmost part. Traces of soil formation can hardly be recognized in the south, but landinward the thickness of the solum increases to about 2 m. Figure 5 presents the texture of soil samples collected at sites indicated in figure 4 at a depth of approximately 1 m. The clay component, being negligable in the south, increases to a maximum of about 8% in the northern part of this zone. Because of the increasing width of this zone and the increase in grainsize of the beach material (SOBUR, 1981) when approaching the Serayu River, it can be concluded that the beach ridge material is largely derived from western sources, i.e. the Serayu and Bengawan Rivers. This zone stretches continuously from the Idjo River in the east to the Serayu River in the west, and is only interrupted by the mouth of the Bengawan River and by the Selok Hill. This small, isolated hill represents an intrusive body, located at the intersection of two faults, with an elevation of 124 m, and does not affect the existing coastline. Traces of wave action at the Selok Hill indicate marine erosional influences, and reveal that this hill can be considered to have been a former island or promontory. It is part of a range of smaller hills that parallel the coast and decrease in height toward the east. These hills form the upper part of a southeastern dipping block that belongs to the Kroya horst (Fig. 3). There is no field evidence that the formation of this beach ridge system was influenced by the presence of the Serayu-Bengawan and/or Idjo grabens.

North of the beach ridge system a maximally one km wide flat depression forms the boundary with the second zone. In this low-lying area, at about high water level, lagoonal-fluvial deposits can be recognized that contain sand, silt, clay, peat, and organic mud, completely reduced up to the surface. The depth of this deposit could not be established. Considering the absence of a Quaternary volcanic ash cover and the relatively shallow solum, this beach ridge system along the coast must be of Holocene age. Moreover, the equable height of the ridges indicates that they are unaffected by tectonic movements.

2. *The Pleistocene beach ridge complex.*

A ridge system with conspicuous differences in height and a width of about 6 km, forms the central part of the study area. Near Kroya, in the NW part, the ridges reach their maximum height (ca 17 m), and decrease in all directions; toward the south to 7 m, toward the east to 5 m, and toward the north to about 9 m. These high elevations coincide with the northernmost part of the central, southeastly dipping Kroya horst.

Both at the western and eastern sides of this ridge system, the ridges end abruptly at the boundaries of this tilted plain with the Serayu-Bengawan and Idjo grabens respectively.

On top of all the ridges airborne volcanic ash is deposited that varies in thickness from several decimetres up to ca. 7 m. According to figure 5 the major part of the material consists of clay (ca. 70 – 80%). Only the composition of sample 1 differs. Possibly some mixing has taken place with the underlying material. This volcanic ash originates from an increase in volcanic activity on Java, which started in the Middle Pleistocene and continued up to recent times (VERSTAPPEN, 1974; SPEELMAN, 1979; VAN DER LINDEN, 1978a, 1978b).

At the first ridge south of Kroya remnants of a buried andosol could be recognized within this deposit, at a depth of about 100 to 180 cm. According to MOHR ET AL (1972), who presented a soil sequence for varying altitudes for the western part of Central Java, andosols occur above 600 m elevation. Above this altitude the present climate, which is cooler and more humid than at the coastal areas, favours the formation of this soil type. The 15 m above mean sea level (amsl) elevation of the buried andosol south of Kroya indicates different climatic conditions at the coastal plain, and a stable phase in landscape development during the formation of this soil type. That such different climatic conditions did occur is demonstrated by the fact that during the Quaternary glacial periods New Guinea snowlines were 1000 to 1500 m lower than at present and this matches a 6 to 8°C lowering of temperature at the highlands (WEBSTER & STRETEN, 1978). Vegetation belts in New Guinea were at least 850 m lower during the last Glacial of the Pleistocene (WALKER, 1970), while the snowline at Mt. Kinabalu (Sabah) dropped 760 to 1070 m during the glacial

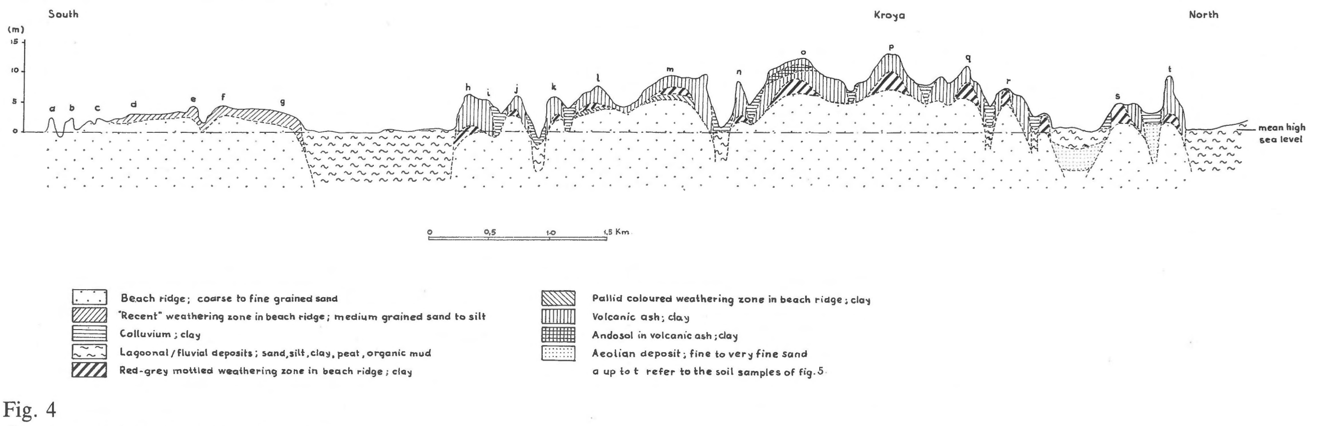

Fig. 4
Cross section of the Kroya beach ridge area.

periods (KOOPMANS & STAUFER, 1968). On average, the Indian Ocean was 1.9°C cooler in February and 1.7°C cooler in August during the last glacial maximum (PRELL ET AL, 1980). According to VERSTAPPEN (1980) the position of the Inter Tropical Convergence Zone (ITCZ) during the Quaternary Glacials had a more southerly position than at present. At Java's longitude the ITCZ nowadays stands at about 10-12°S and about 30°N during the northern winter and summer respectively. The maximum amount of precipitation occurs in the form of heavy showers at and near the ITCZ. Farther south the rainfall, though more continuous, is considerably less, and, similarly, north of the ITCZ rainfall is greatly reduced.

Consequently, high precipitation occurs over southern Indonesia if the ITCZ moves far south, whereas the highest precipitation values are recorded over northern Indonesia when the ITCZ remains farther north. Because of the latitudinal shift of the ITCZ in a southern direction during the glacial periods high amounts of rainfall possibly still could occur at the southernmost parts of Indonesia, e.g. the southern coast of Java, while the remaining northern area was characterized by a less humid climate. The latter corresponds with the considerably drier and somewhat cooler glacial climate in northern Australia and Indonesia as reported by WEBSTER & STRETEN (1978) and VERSTAPPEN (1974, 1980). The presence of a tropical rainforest and the undulating topography in the coastal area guaranteed a stable phase in landscape development during the development of the andosol.

At the ridges the boundary between the volcanic ash layer and the underlying material is formed by a red-grey mottled clay layer which in general increases up to 3 m in thickness in a northerly direction. Locally this layer is underlain by a pallid clay layer, about 0.5 m thick. Both clay layers still show a 'sandy texture' but the material can be rubbed easily to clay. The degree of weathering decreases downward and the material shades into scarcely weathered coarse to medium grained sand, sometimes containing small pebbles up to 1.0 cm diameter. Figure 5 clearly shows a decrease of the clay component (samples r and s) compared with the volcanic ash samples. The red-grey mottled and pallid clay layers are thought to represent remnants of an oxisol (formerly called laterite or latosol, depending on the presence of plinthite). The topographic position of these oxisol remnants indicates that the formation of this soiltype can be regarded as a residium and not as a precipitate; absolute impoverishment in silica and a residual enrichment in stable weathering products. Reference is made to VAN DER LINDEN (1978a, 1978b) for extensive data on physical and chemical properties of these clay layers. Similar observations about the occurence of oxisols are reported in MOHR ET AL (1972) and VERSTAPPEN (1974). ASHTON (1972) estimated these soils when they are formed 'in situ' to occupy about 6% of the total area of the Malay peninsula; EYLES (1968, 1969) mentioned that these oxisols are situated on old erosion surfaces, of Quaternary to Cretaceous age.

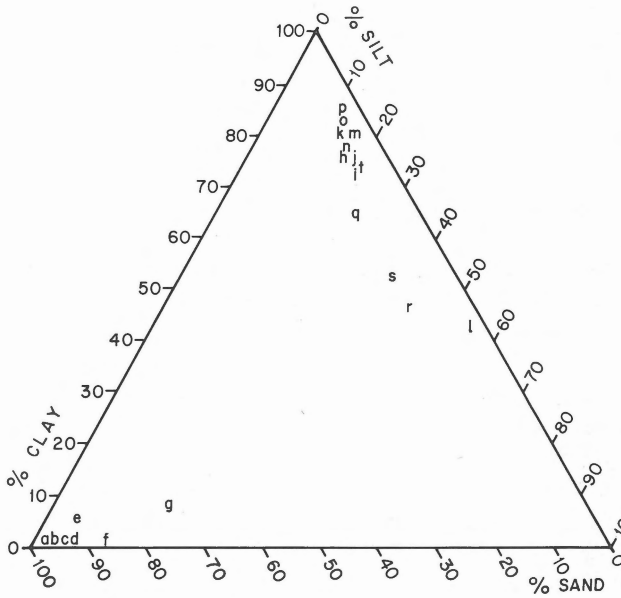

Fig. 5
Texture of the soil samples collected at the sites indicated in Fig. 4, at a depth of 1 m.

One of the most important factors in the formation of plinthite soils is a fluctuating groundwater table. Therefore all circumstances favouring such a fluctuation promote plinthite formations. These circumstances are a high temperature and an uneven distribution of the precipitation over the year (MOHR ER AL, 1972). The present climate of the coastal area lacks a pronounced seasonability which enables oxisol development. PRELL ET AL (1980) and VERSTAPPEN (1974, 1980) however, reported an increased seasonability of the climate during the Quaternary glacials, which together with the somewhat cooler, and humid conditions during those periods favoured the formation of an oxisol. Erosion was limited at the coastal plain of Kroya because of a dense vegetation cover over the undulating landscape.

Before the Quaternary increase in volcanic activity the upper part of the oxisol had been truncated up to the grey-red mottled clay layer. Whether this truncation may be attributed to the marked reduction in chemical weathering and the increase of physical disintegration of rocks during Quaternary glacials as reported by VAN ZUIDAM ET AL (1978) and VERSTAPPEN (1974, 1980), is doubtful. This unstable phase in landscape development brought about by the decrease in temperature, the reduction in rainfall, and the more pronounced seasonability, was restricted to the hilly and mountainous terrains of Australasia. Possible causes of truncation might be tectonic movements, marine invasions, or perhaps even the deposition of hot volcanic ashes that destroyed the vegetation cover. The ridges are separated from each other by depressions; two types have been distinguished:

- deep depressions at about 2-3 m amsl, with lagoonal-fluvial deposits;
- shallow depressions at 2.5 m amsl in the southern part of the

area increasing up to 7.5 m amsl going northward, with predominantly colluvial deposits.

The two deep depressions in the north contain layers of fine to very fine grained sand, which was possibly derived from the beach ridges and deposited after aeolian transport. In most shallow depressions coarse to medium grained sand similar to the subsoil of the ridges was encountered below the colluvial sediment.

The deep depressions probably represent permanent drainage lines, dating from the period of beach ridge formation. World-wide glacio-eustatic variations in sea level during and after the Pleistocene (VERSTAPPEN, 1974; BATCHELOR, 1979) caused the incision of relatively deep river valleys within the beach ridge system, that afterwards were filled in with lagoonal, fluvial and aeolian deposits. About 6,000 and 125,000 year B.P. sea levels stood between +2 and + 10 m higher than today. (BROECKER & VAN DONK, 1970; CHAPPELL, 1974). Material deposited in the deep depressions at those times has been removed, down to the present topographical situation.

In the centre of this zone the ridges are interrupted by a rather flat, relatively low-lying area (ca 6 m amsl). Only the most northern ridges and the most southern one are uninterrupted. Within this central area beach ridge material could be recognized in the subsoil in line with the ridges located east and west of this depression. Lagoonal-fluvial deposits cover the coarse to medium grained sand; locally, subaqueously deposited, airborne volcanic ash layers are intercalated.The thickness of this cover decreases in a northerly direction. Possibly before or during the formation of the southernmost ridge of this zone, a marine incursion caused the partial removal of landinward lying ridges. Afterwards, during Pleistocene and Holocene high sea levels, seawater entered the Kroya area from the west and the east through the valleys of the Serayu-Bengawan and Idjo Rivers, consequently leading to the deposition of lagoonal-fluvial material up to about 6 m amsl. The elevation is the maximum value for the Holocene rise in sea level and agrees with the data mentioned by TJIA (1970) and FAIRBRIDGE (1961), although local vertical tectonic movements of the Kroya plain cannot be excluded. The formation of the shallow depressions probably occurred simultaneously during periods of high sea level. Later they were filled with colluvial material from the surrounding beach ridges. The increase in elevation of these depressions northward may be attributed to tilting (about 10 to 15 degrees) of the central part of the Kroya plain after they were cut.

From figure 1 it is obvious that the southeastern part of this zone is more dissected than the northwestern part. Realizing that the southeastern part belongs to the lower portion of the southeasterly dipping block, indicated in figure 3, it will be clear that the topsoil of the ridges located here, is relatively moist. Due to the impermeability of the oxisol remnants to infiltrated rainwater, and to their high moisture content these clay layers served as excellent slip surfaces (decollements) for mass movement, which ultimately led to the dissected appearance. Based upon the topography and the presence of coarse to medium grained sand, similar to the present beach material, it seems justified to consider this zone to represent a beach ridge system that formed during the Pleistocene and that afterwards was covered by volcanic ash.

3. *The northern graben.*

This zone belongs to the approximately east-west stretching graben, south of Southern Serayu Mountains. It is a flat, slightly southward dipping low-lying area with minimal elevations of about 2 m amsl. Lagoonal-fluvial material has been deposited here. Influence of the Serayu-Bengawan and Idjo grabens within this zone could not be recognized. According to VERSTAPPEN (1978) some beach ridges are located within this sedimentation area, but next to natural levees and point bar deposits of some minor drainage lines, no other relief elements could be distinguished.

Especially the western part of this zone is ill-famed with respect to inundations during the wet season, which probably indicates on-going subsidence.

4. *The western and eastern grabens*

The topography of the western and eastern part of the study area is quite similar to that of zone 3. However, here only fluvial influences of the Serayu River (west) and the Idjo River (east) can be distinguished. As pointed out by VERSTAPPEN (1974) the eastern part of this zone is composed of Old Serayu Deposits which mark the easternmost position of the Serayu River. This former position probably dates from Pliocene-Early Quaternary (SPEELMAN, 1979). By that time the Serayu River followed the present course of the Tadjum River and entered the coastal plain from the west, causing a more eastern position of the Serayu River at the coastal plain. Due to the fault structure eastward extension of fluvial activity was limited by the Kroya horst. During the Quaternary, formation of the Slamet volcano forced the course of the Serayu River channel near Purwokerto southward and finally blocked it with volcanic products. The Serayu River thus, was forced to pass the Southern Serayu Mountains near Banyumas, the lowest part of the divide. Nowadays, the valley of the Tadjum River is still not proportional to its size.

CONCLUSIONS

The following sequence of geological, geomorphological and soil forming events can be established for the Late Tertiary and Quaternary development of the Kroya coastal plain:

– From the Eocene onwards into the Miocene marine and volcanic rocks were deposited upon a culmination of the pre-Tertiary metamorphic and igneous basement complex (VAN BEMMELEN, 1949).

– The Southern Mountains, including the Southern Serayu Mountains, were elevated during the Late-Miocene (SPEEL-

MAN, 1979). In that period and also in the Early-Pliocene, these mountains were tectonically broken down into different blocks that slid towards the Indian Ocean. The coastal plain of Kroya subsided and here material accumulated derived from the synorogenetic erosion of the Southern Mountains. This deposition continued up to present time in the Serayu-Bengawan and Idjo grabens.

– Glacio-eustatic rise in sea level since the Miocene (BATCHELOR, 1979) and the continuing overall uplift of the area (ENGELEN, 1973) favoured the development of beach ridges at the Kroya coastal plain during the Pleistocene. Their western aerial extension was limited by the Serayu River that entered the plain via the present Tadjum valley. It is probable that the course of this river was already determined and restricted by the Serayu-Bengawan graben. Whether the eastern aerial extension was hindered by the Idjo graben is not clear; in any case the Idjo River prohibited beach ridge formation up to the Karangbolong Mountains.

The beach ridges are separated from the Southern Serayu Mountains by a broad lagoonal-fluvial deposition area. Whether this depression was already present during the formation of the ridges or was formed afterwards by the development of a graben structure, is unknown.

– During or before the formation of the last beach ridge a marine invasion caused the partial removal of the landinward located ridges.

– During a (the) Pleistocene Glacial(s) the tropical climate with its marked alternation of wet and dry seasons, enabled the development of an oxisol at the beach ridges.

– After its genesis the oxisol was truncated generally up to the red-grey mottled and pallid clay layers. Futhermore, the glacial drop(s) in sea level caused a relatively deep incision of the drainage channels that separated the east-west stretching ridges.

– From the Middle Pleistocene up to the present strong volcanic activity covered the area under airborne ashes. Within this deposit a buried andosol indicates a soil forming phase that is characterized by a humid and slightly cooler climate than today, i.e. a climate that existed during the last glacial period of the Pleistocene (Weichselian). Due to alternating high and low Pleistocene sea levels, erosion and deposition succeeded each other in the depressions between the ridges.

– The high sea levels which occurred during the Pleistocene and Holocene (125,000 and 6,000 years B.P. respectively) resulted in the deposition of lagoonal-fluvial sediments in the deep depressions, and on the flat area situated in the centre of the ridge system, up to a present elevation of 6 m amsl. Due to local tectonic movements this elevation cannot be considered to be an absolute value.

The southeastern part of the ridges suffered serious erosion due to the higher moisture content of the soil that was caused by tilting during periods of high sea level and the susceptibility to mass movement of the soil. The formation of the shallow depressions probably also dates from those periods. The material that accumulated within these depressions was derived from the surrounding ridges mainly by slope failure.Tilting of the central part of the Kroya plain afterwards lifted the shallow depressions to higher levels and increasinly so in a northerly direction.

– The Holocene period is characterized by the formation of a beach ridge system along the coast. No anomalies in landscape development could be distinguished for that period. The material is mainly supplied by the Serayu and Bengawan Rivers.

Thanks to the flat to undulating topography of the Kroya coastal plain, which has elevations that do not differ greatly from that of the erosion base, there was no accelerated soil erosion in the area that can be ascribed to human activity during the last two centuries such as reported by VERSTAPPEN (1974, 1980) for other parts of Indonesia.

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