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SOILS OF THE NAVRONGO-BAWKU AREA, UPPER REGION, GHANA

by

S. V. ADU
Senior Research Officer

KUMASI

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FOREWORD

The survey of the Navrongo-Bawku region has been conducted in pursuance of the policy of the Institute of taking an accurate inventory of the soil resources of the entire country as rapidly as possible. The demands of modern agricultural practice lean heavily on this and there is the great expectation that in future agriculturists and farm workers generally in this country would be able, with information available in this and other memoirs of this Institute, to match the land to the crops it can best support.

The Navrongo-Bawku Region, situated at the top right-hand corner of Ghana, is about 3,350 square miles in area. Because there was a full aerial-photo coverage the conventional method of soil survey developed in the country and adopted elsewhere in the tropics was discarded and a full advantage taken of those photographs. Considerable saving in time and money was the outcome. The method used has been described in earlier reports and the Institute is adequately equipped for this advanced technique.

In Ghana, soil series rarely cover a sufficient area in individual expanses to make it practicable to map them on any but very large scale maps. Soil associations only are therefore shown on the maps attached to this report but comprehensive descriptions of the soil series making up those associations and notes on their agricultural potentialities occur in the text.

Earlier workers in the region had warned on the seriousness of the damage being caused by land erosion. Indeed Dr. Adu has also cautioned about the widespread nature of such erosion and the need for adequate measures to combat any further deterioration. Some measures towards soil conservation have been adopted by resettling people within land-planning areas.

It is hoped that the findings of Dr. Adu will be found useful as pointing to other utilisable areas in a region engulfed in very serious erosion hazards.

KUMASI
October, 1969.

K. A. QUAGRAINE
Director

ACKNOWLEDGEMENTS

I wish to thank all my field staff (page 95) without whose help it would have been impossible to complete this assignment in good time. Particular thanks are due to Messrs. D. O. Tenadu, Senior Technical Assistant and J. O. Ansah, Scientific Assistant Grade I, for their invaluable help both in the field and in the photo-interpretation laboratory.

The soil samples were analysed by the Institute's laboratory staff and the final copies of maps and diagrams were reproduced by its cartographic staff. The assistance given by both sections is gratefully acknowledged.

Finally, I wish also to record my thanks for helpful criticisms and suggestions received from a number of specialist staff of the Soil Research Institute and for information received from various Agricultural Officers of the Ministry of Agriculture, stationed at one time or the other in various parts of the survey area.

S.V.A.

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HOW TO USE THIS REPORT

This is a reconnaissance soil survey report. The objectives of the survey were limited to taking an inventory of the soil resources of the region so as to discover and outline areas of soil suitable for more intensive agricultural development especially for crops, but also for grazing and forestry. Therefore, for special development projects covering a few square miles or less within the area and also for the successful planning of field management systems, more detailed soil reports and maps would necessarily be required, so that this report would serve only as a guide to such future surveys.

The soil map accompanying the report shows soil groups or associations; and the component soils in each association have been briefly described in the text. In many cases descriptions are accompanied by illustrative diagrams. Typical soil profile descriptions with analytical data are also given in the appendix at pages 59–89. Soil association numbers on the map correspond to those given in the text. Any one using the map and desiring to locate the soil series of a particular site may refer to the number on the site and follow this by reading through the descriptions of the various soil series under the association. The soil(s) at the site could then be easily identified from the descriptions.

The map showing soil quality groups is an interpretation of the soil map and has been included to give guidance on what agricultural and land-use possibilities exist in the area.

LOCATION OF THE NAVRONGO - BAWKU AREA

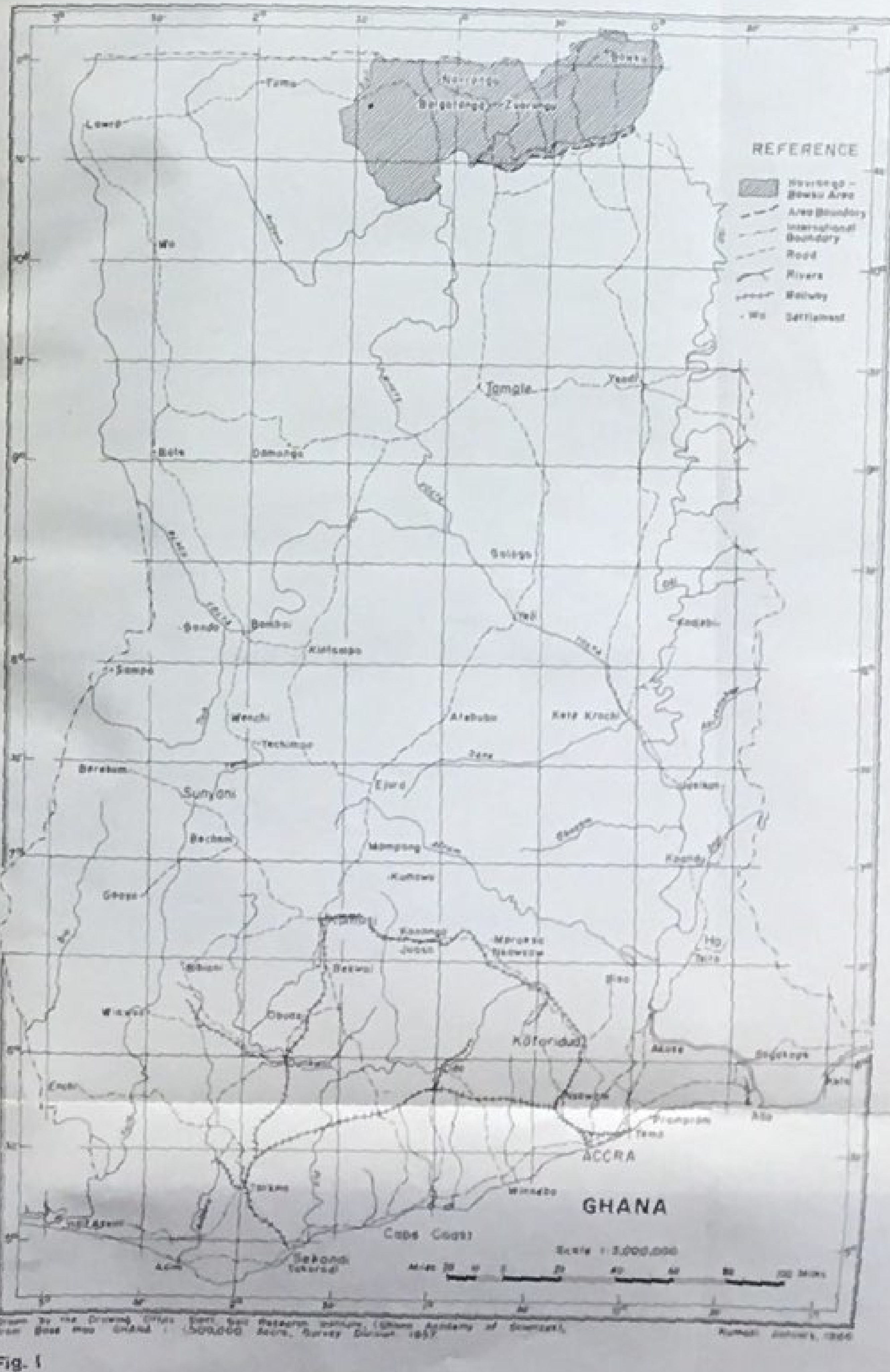

Fig. 1

SOILS OF THE NAVRONGO–BAWKU REGION

PART I

INTRODUCTION

1. DESCRIPTION OF AREA

The area comprises some 3,550 square miles in the extreme north-east corner of Ghana. It lies roughly between 10° 30′ and 11° North latitude and 0° and 1° 30′ West longitude. It is bounded on the north by Upper Volta, on the east by Togoland, on the west by the river Sisili and on the south by the Gambaga Scarp as far west as Karamenga. Between Karamenga and the Sisili, the White Volta and its tributary the Kulpawn delimit the remainder of the southern boundary (fig. 1).

2. PREVIOUS WORK

No formal soil survey of the area under consideration had been undertaken prior to the present work. Edmonds (1956) in the course of a geological survey produced a provisional soil map of the Bawku–Gambaga area. The map may be considered empirical as it merely indicates broad textural differences reflecting the types of parent rocks occurring in the area.

Between June and November, 1960, the writer carried out detailed soil surveys of three Agricultural Stations located in the area at Zuarungu, Manga-Bawku and Tono-Navrongo. These surveys are reported on in Soil and Land-Use Survey Technical Reports Nos. 54, 56 and 58 (Adu 1961, 1962 and 1963(*a*) respectively).

3. PURPOSE AND TIME OF SURVEY

The survey of the Navrongo–Bawku area was undertaken as part of a nation-wide soil survey to provide a basis for the best agricultural uses of the land. Field work was carried out between November, 1961 and May, 1962 by the writer and a team of assistants of varying ranks.

GENERAL ENVIRONMENTAL CONDITIONS

4. PHYSICAL FEATURES (Map 1)

The relief of the area is related to the geology. Along the frontier with Upper Volta, north of Bawku and Zebilla, lie a range of Birrimian greenstone hills rising in places to 1,500 feet above sea level. These hills turn south-west from the Red Volta, north of Nangodi to some miles south of the White Volta. South of Shiega and to the east of Tongo, the hills are isolated but of similar height as the ranges. To the east of the Red Volta, another range of hills trend south-west and these are also composed mainly of greenstones. The features of the hills vary from place to place but generally they have steep rocky slopes and narrow deeply incised valleys. Elsewhere, the Birrimian rocks which are mainly phyllites, quartz-sericite schists and greywackes are lowlying.

Areas occupied by granites are generally of low, gently rolling relief, 400–850 feet above sea level. Exceptions to these are the inselbergs near Kugri (1,218 ft.), Bongo (1,086 ft.), Tongo (1,091 ft.), Datoko (1,059 ft.) and Chana (1,200 ft.) which abruptly rise to heights 300–400 ft. above the surrounding lands.

These hills form outstanding features as they have steep craggy slopes. Low tabular hills (buttes) occur within the granites and are common in the area east of the Red Volta and in the south-west in the vicinity of Kanjarga and Fumbisi. A number of hillocks scattered throughout the area are quartz reefs.

Although the Voltaian rocks have, more or less, similar relief characteristics as those over granites and phyllites, their northern fringes are in places marked by small escarpments, examples of which can be seen near Zongoiri and Karamenga. These rise 100–150 feet above the White Volta.

The main scarp rises abruptly from an altitude of 600 feet to over 1,700 feet near the frontier with Togo. Thick accumulations of rock debris (talus) lie at the foot of this scarp and are traversed by fast flowing streams which have developed large outwash fans.

Sheet and gully erosion are widespread in the whole region, especially in the intensively farmed areas in the vicinity of Bawku, Pusiga, Bongo, Navrongo, Sandema, Wiaga and Kanjarga. In addition, stream bank erosion is prevalent along many of the major and minor streams of the area. Brammer (1956*b*) suggests that this is not due to a change of base level of the rivers but to a change in climate and/or vegetation cover which has resulted in increasing runoff.

The White Volta and the river Kulpawn have well developed old alluvial flats and levees (page 53). These are of variable width but near their confluence, stretches of up to 2 miles wide on either bank have been observed and mapped. Only a small bench terrace was encountered along the White Volta, between Uwasi and Pasinkpe (page 56).

The secondary streams have also developed old alluvial flats but these are less extensive than those bordering the White Volta and the Kulpawn.

The network of streamlets flow in wide shallow valleys and are subjected to annual flooding.

5. Drainage (Map 1)

The main rivers of the area are the White and Red Voltas in the east and the Sisili and the Kulpawn in the west. Excepting the Kulpawn which flows west to east to join the White Volta, all the other rivers flow north to south. The White Volta, however, turns sharply west at the point where it strikes the Gambaga scarp. It is fed by a number of secondary rivers which include the Nahau with its tributary the Kulupielugu in the north, the Tamne in the central area and the Morago in the south. In addition, the north to south flowing Biankuri flows along the Togo frontier to join the Morago at the foot of the scarp. Other important tributaries of the White Volta are the Atankwide, Yaratanga and Atamore which flow from N.E. to S.W., a direction stated to be controlled by the regional strike of the underlying Pre-cambrian geology (Murray 1960). There are also the north-south flowing Kuldaga-Kulubiliga group and the Tono-Kadembeli-Bukpeai group.

The Red Volta has no important tributaries throughout its course within the area but is fed by a number of short wet-season streams originating from the surrounding hills.

Two important tributary systems of the Sisili enter from the west but from the east, the only one of any importance is the north to south flowing Bonaponi river.

A network of small streams are connected to all the main tributary rivers. A number of these cascade down the scarp face into the Morago—White Volta system. Within the Voltaian shale and sandstone areas these streams are less numerous and their courses are often not so well defined as those developed over granites and Birrimian rocks.

All the small streams dry out early in the dry season but as regards the main rivers and the larger of the secondary ones, continuous surface flow ceases towards the end of the dry season and at such times a common feature is a series of disconnected pools separated by dry stretches of sand and rock.

During the rainy season all streams and rivers are liable to sudden fluctuations in water level, suggesting that there is considerable surface runoff within their catchments during heavy rainfall.

6. Climate*

The climate of the area, classified as Sudanese, is characterized by pronounced wet and dry seasons. The differing weather conditions prevailing are due to the influence of two oscillating air masses, the harmattan air mass which blows in a north-easterly direction across the area from the Sahara, reaching its maximum southward extent in January, and the monsoon air mass which passes over the area reaching its maximum northward extent in August. The harmattan air is warm, dry and dusty, whereas the monsoon air is warm, humid and wet.

The alternation of clear-cut wet and dry seasons have a direct effect on soil forming processes in the area. Although the prevailing climatic conditions permit accelerated chemical decomposition and deep weathering of rocks, the sudden and torrential rainfall following a prolonged dry season, during

*Most of the information presented in this section has been extracted from Walker (1962).

which the grass cover is burnt, induces top soil erosion which also leads to the irreversible hardening (laterisation) of the subsoil when exposed to the dry winds of the harmattan period.

Rainfall

The area has a single rainy season where the monthly totals increase gradually from March until a maximum is reached in August or September. Monthly totals then fall sharply. The average annual rainfall in inches shown in table 1 for Bawku (38.34), Zuarungu (40.85) and Navrongo (43.31) are consistent with conditions prevailing in the whole area. A careful study of the rainfall figures, however, shows that in most years, the Bawku area receives slightly less precipitation than the Navrongo, Zuarungu or the scarpland areas. Rainfall recorded at Gambaga, less than 3 miles south of the area, is 44.27 inches.

Very considerable variations exist between successive rainy seasons in time of onset, duration and amounts of precipitation. In years when the variations are wide off the mean, considerable disturbance to the food production cycle is experienced. A study of table 1 for Bawku, Zuarungu, Navrongo and Gambaga indicates what variations in monthly and annual rainfalls occur in the area. Yearly totals in inches range from 23.96 to 48.40 at Bawku, 30.88 to 45.76 at Zuarungu, 38.75 to 54.18 at Navrongo and 35.34 to 73.24 at Gambaga. Relative variability of rainfall calculated for the region is of the order of 12–14 per cent. It is therefore important when formulating land-use programmes for the area to make allowance for what variabilities in the rainfall from the mean and their frequency can be expected in order to avoid unnecessary losses.

For agricultural purposes the values of the average annual rainfall figures quoted are considerably lowered by high runoff during the rainy season and by high evapo-transpiration* especially during the harmattan weather.

In a sub-humid climate such as prevails in the region under consideration, crop raising depends on the reliability of the early rains. Table 2 gives percentage frequencies of monthly rainfall totals for Bawku, Zuarungu, Navrongo and Gambaga. If the monthly totals lying between 2.50 and 4.99 inches are considered as the lowest marginal range requirement for safe crop raising, the table indicates that April is more dependable than March and that adequate rainfall may generally be expected from May to September.

Walker states that rains seldom persist for more than 2–3 hours and those falling continuously for over 12 hours are very rare. In the dry months, rain may fall for less than 10 hours in a month and even in the wet season they do not exceed 30–40 hours in a month. Considerable variations in the intensity of falls have been recorded and rates of more than 8 inches per hour for short periods are not unusual.

Table 1

MONTHLY RAINFALL READINGS FROM 1949–60

BAWKU

Year	*Jan.*	*Feb.*	*March*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Total*
1949 ..	0.00	0.22	0.38	1.62	3.06	3.62	7.27	9.08	6.89	0.59	0.61	0.00	33.34
1950 ..	0.00	0.64	0.00	0.22	4.17	4.68	5.45	9.96	8.10	2.65	0.08	0.00	35.95
1951 ..	0.00	0.00	0.23	1.75	1.78	4.87	8.83	9.14	11.31	—	—	0.00	37.91
1952 ..	0.00	0.00	0.06	—	3.59	1.91	8.00	8.81	9.89	4.04	0.00	0.00	36.30
1953 ..	0.00	1.14	0.00	3.30	6.29	4.89	6.90	4.40	10.61	3.58	0.01	—	41.12
1954 ..	0.00	0.00	0.85	1.11	3.80	4.08	4.96	6.16	—	3.00	—	—	23.96
1955 ..	—	—	0.65	2.88	2.84	4.36	6.38	5.86	—	1.25	—	—	24.22
1956 ..	0.00	—	1.32	4.25	4.65	4.20	4.78	8.72	6.64	1.08	0.00	0.00	35.64
1957 ..	0.00	0.00	0.67	1.55	9.80	8.14	4.80	10.41	10.01	3.02	0.00	0.00	48.40
1958 ..	0.00	0.00	0.05	3.58	4.63	3.07	4.32	6.82	8.59	0.83	0.25	0.13	32.27
1959 ..	0.00	0.00	0.51	3.36	4.21	3.24	7.47	12.17	6.94	1.00	—	—	38.97
1960 ..	—	—	0.18	0.50	8.85	—	5.53	11.83	6.05	—	—	—	32.94
Average†	0.01	0.20	0.61	1.82	3.55	4.85	6.64	9.35	8.39	2.56	0.33	0.03	38.34

Evaporation from open water surface is stated to vary between 5½–6½ feet per annum (Walker 1962).

†Average figures are for Bawku (30 years), Zuarungu (40 years), Navrongo (25 years) and Gambaga (30 years). Obtained from; Ghana Meteorological Services Annual Summary of Observations in Ghana, 1960. "—" Denotes: no record, insufficient or unreliable record.

ZUARUNGU

Year	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1949 ..	0.00	0.00	0.00	2.50	5.52	5.10	6.43	8.60	4.47	2.03	0.13	0.00	34.78
1950 ..	0.00	1.10	0.00	0.10	2.03	5.51	7.16	9.46	8.11	3.29	0.00	0.00	35.75
1951 ..	0.00	0.00	1.08	0.26	4.97	3.88	7.19	11.26	8.60	7.77	0.75	0.00	44.76
1952 ..	0.00	0.00	0.22	1.44	4.11	4.43	7.19	11.79	10.37	3.69	0.00	0.00	43.24
1953 ..	0.00	0.18	0.00	1.74	4.15	7.94	10.79	6.93	12.74	1.29	0.00	0.00	45.76
1954 ..	0.00	2.95	0.43	1.09	—	3.44	4.65	10.86	6.44	3.39	2.10	0.00	35.35
1955 ..	0.00	0.28	0.27	—	3.94	2.11	—	9.72	13.85	3.50	0.00	0.00	33.67
1956 ..	0.00	0.47	0.88	—	4.65	—	3.75	12.36	7.79	—	0.00	0.98	30.88
1957 ..	0.05	0.00	0.20	0.86	7.68	6.06	3.97	9.72	10.10	3.16	0.00	0.00	41.80
1958 ..	0.00	0.00	0.00	3.56	8.89	3.32	1.81	6.32	5.91	1.95	1.27	0.00	33.03
1959 ..	0.10	0.00	0.88	0.53	3.69	5.53	—	12.88	8.43	0.64	—	0.00	32.68
1960 ..	0.00	—	0.34	2.20	5.27	—	—	11.50	11.96	4.46	0.00	0.03	35.76
Average†	0.06	0.17	0.64	1.86	4.29	5.67	6.76	9.73	8.64	2.55	0.43	0.05	40.85

NAVRONGO

Year	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1949 ..	0.00	0.00	0.01	2.02	4.51	5.85	7.11	10.03	9.22	—	—	—	38.75
1950 ..	0.00	—	0.00	0.81	4.59	6.17	9.55	11.64	13.22	1.73	0.47	0.00	54.18
1951 ..	0.00	TR	0.50	0.54	3.48	3.67	7.87	15.40	11.59	6.07	1.14	0.00	50.26
1952 ..	0.00	0.00	3.14	1.08	7.49	3.89	11.61	9.97	4.37	2.62	0.00	0.00	43.87
1953 ..	0.00	0.35	0.76	2.17	2.02	6.85	10.54	9.16	7.36	0.79	0.00	0.00	40.00
1954 ..	0.00	0.05	2.06	1.91	5.43	5.48	8.30	10.36	4.90	2.72	0.46	0.00	41.67
1955 ..	0.00	0.01	1.09	1.67	4.93	4.89	12.91	7.00	13.09	3.45	0.00	0.00	49.04
1956 ..	0.00	0.56	1.04	2.74	5.00	4.12	7.91	15.76	8.02	1.07	0.00	0.00	46.22
1957 ..	0.00	0.00	0.56	3.00	10.54	4.45	5.52	12.36	6.57	3.10	0.82	0.00	46.92
1958 ..	0.92	0.00	0.72	5.71	4.58	4.96	2.02	10.50	6.70	2.59	2.37	0.00	41.07
1959 ..	TR	0.00	1.05	0.51	7.64	2.75	6.33	15.28	6.86	0.14	TR	0.00	40.56
1960 ..	0.00	0.00	0.55	3.20	3.64	4.36	4.55	8.31	15.13	1.30	0.00	0.00	41.04
Average†	0.02	0.29	0.74	1.83	4.38	5.40	8.10	10.58	9.25	2.45	0.21	0.06	43.31

GAMBAGA

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1949 ..	0.00	0.00	0.04	1.60	3.74	3.86	6.67	12.18	8.52	2.29	0.41	0.00	39.31
1950 ..	0.00	0.54	0.00	1.46	3.53	4.94	5.40	8.42	10.58	3.50	1.02	0.00	39.39
1951 ..	0.00	0.07	1.40	0.46	4.07	3.34	5.64	10.93	14.52	4.62	0.00	0.00	45.05
1952 ..	—	0.00	0.03	2.06	5.19	4.37	8.43	6.94	16.45	2.10	0.03	0.01	45.61
1953 ..	0.00	2.59	0.05	0.91	4.00	8.82	11.83	9.30	9.21	5.07	0.20	0.00	51.98
1954 ..	—	0.05	2.10	—	1.80	3.42	4.00	10.59	5.86	5.77	1.75	0.00	35.34
1955 ..	0.00	0.70	0.61	1.73	4.51	5.08	12.24	6.62	12.01	3.57	0.00	0.00	47.07
1956 ..	0.00	0.58	1.90	—	3.37	2.79	3.95	11.44	9.77	1.72	0.22	0.23	35.97
1957 ..	0.00	—	0.69	2.01	14.33	—	4.82	10.93	10.88	5.88	1.81	—	51.35
1958 ..	0.05	—	0.07	4.83	6.73	3.80	2.85	9.45	6.70	0.70	1.90	0.05	37.13
1959 ..	0.05	0.05	2.05	4.70	1.99	1.46	7.36	10.22	7.61	1.40	—	—	36.89
1960 ..	—	—	4.93	—	5.89	10.16	18.99	11.72	21.55	—	—	—	73.24
Average†	0.05	0.22	0.68	2.67	4.13	5.35	6.93	10.18	9.76	3.64	0.52	0.14	44.27

†Average figures are for Bawku (30 years), Zuarungu (40 years), Navrongo (25 years), Gambaga (30 years). Obtained from Ghana Meteorological Service Annual Summary of Observations in Ghana 1960.

"—" Denotes, no record, insufficient or unreliable record.

TABLE 2

PERCENTAGE FREQUENCIES OF MONTHLY RAINFALL TOTALS

Bawku (32 Years)

Inches Rainfall	0.00	0.01 *to* 0.09	0.10 *to* 0.49	0.50 *to* 0.99	1.00 *to* 2.49	2.50 *to* 4.99	5.00 *to* 9.99	10.00 *to* 14.99	15.00 *to* 19.99	20.00 and *over*
January	94	3	3	—	—	—	—	—	—	—
February	63	25	6	6	—	—	—	—	—	—
March	—	—	—	—	—	22	73	5	—	—
April	—	—	9	13	47	31	—	—	—	—
May	—	—	—	3	19	62	16	—	—	—
June	—	—	—	—	9	54	37	—	—	—
July	—	—	—	—	—	31	63	6	—	—
August	—	—	—	—	—	3	62	32	3	—
September	—	—	—	—	—	3	78	19	—	—
October	3	—	—	9	31	48	9	—	—	—
November	52	9	13	13	13	—	—	—	—	—
December	87	—	13	—	—	—	—	—	—	—

Zuarungu (41 Years)

Inches Rainfall	0.00	0.01 *to* 0.09	0.10 *to* 0.49	0.50 *to* 0.99	1.00 *to* 2.49	2.50 *to* 4.99	5.00 *to* 9.99	10.00 *to* 14.99	15.00 *to* 19.99	20.00 and *over*
January	89	2	7	2	—	—	—	—	—	—
February	71	—	17	7	5	—	—	—	—	—
March	12	12	24	20	20	2	—	—	—	—
April	—	2	12	20	35	29	2	—	—	—
May	—	—	—	—	15	54	27	2	—	—
June	—	—	—	—	5	39	54	—	—	—
July	—	—	—	—	2	27	56	15	—	—
August	—	—	—	—	2	2	50	46	—	—
September	—	—	2	2	—	5	67	20	2	2
October	2	—	5	12	35	39	7	—	—	—
November	29	5	27	7	12	5	—	—	—	—
December	90	—	5	5	—	—	—	—	—	—

Navrongo (27 Years)

Inches Rainfall	0.00	0.01 *to* 0.09	0.10 *to* 0.49	0.50 *to* 0.99	1.00 *to* 2.49	2.50 *to* 4.99	5.00 *to* 9.99	10.00 *to* 14.99	15.00 *to* 19.99	20.00 and *over*
January	92	—	4	4	—	—	—	—	—	—
February	63	11	7	11	4	4	—	—	—	—
March	11	7	22	37	19	4	—	—	—	—
April	—	4	7	22	38	22	7	—	—	—
May	—	—	—	—	19	47	30	4	—	—
June	—	—	—	—	4	48	48	—	—	—
July	—	—	—	—	7	7	56	30	—	—
August	—	—	—	—	—	7	37	41	15	—
September	—	—	—	—	—	7	59	30	4	—
October	4	—	—	7	37	48	4	—	—	—
November	59	—	26	4	11	—	—	—	—	—
December	89	4	—	7	—	—	—	—	—	—

Gambaga (34 Years)

Inches Rainfall	0.00	0.01 *to* 0.09	0.10 *to* 0.49	0.50 *to* 0.99	1.00 *to* 2.49	2.50 *to* 4.99	5.00 *to* 9.99	10.00 *to* 14.99	15.00 *to* 19.99	20.00 and *over*
January	26	3	26	24	16	5	—	—	—	—
February	65	9	9	11	3	3	—	—	—	—
March	12	15	17	32	24	—	—	—	—	—
April	—	3	3	9	35	41	9	—	—	—
May	—	—	—	2	12	56	23	6	—	—
June	—	—	—	—	—	59	41	—	—	—
July	—	—	—	—	—	29	56	15	—	—
August	—	—	—	—	—	21	26	53	—	—
September	—	—	—	—	—	—	65	29	6	—
October	—	—	—	9	18	52	21	—	—	—
November	31	9	21	18	18	3	—	—	—	—
December	67	6	18	6	3	—	—	—	—	—

*Walter M.W. Dependability of rainfall in Ghana, Ghana Meteorological Department, Departmental Note No. 14, Accra, 1959.

TABLE 3

Station			*Jan.*	*Feb.*	*March*	*April*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Years*
Bawku (Zawse) 840′	MAXIMUM	Absolute	101	104	105	105	103	95.0	92.0	90.0	92.0	98.0	102	100	8
		Mean	95.6	98.9	100.6	99.0	95.2	88.6	86.4	84.2	86.6	92.7	96.7	95.0	
	MINIMUM	Mean	62.5	70.3	85.1	77.1	74.7	72.5	70.7	70.9	70.8	71.5	70.3	64.1	
		Absolute	55.0	63.0	68.0	70.0	67.0	68.0	66.0	67.0	67.0	66.0	62.0	57.0	
Zuarungu 700′	MAXIMUM	Absolute	100	104	105	105	102	94.0	91.0	90.0	93.0	97.0	99.0	99.0	8
		Mean	96.7	99.5	101.4	99.8	95.6	89.1	86.4	84.6	86.9	92.2	96.2	95.4	
	MINIMUM	Mean	68.7	71.4	76.7	75.6	95.4	72.6	71.4	71.2	70.8	71.2	70.4	67.3	
		Absolute	62.0	64.0	70.0	79.0	69.0	68.0	66.0	67.0	68.0	68.0	65.0	61.0	
Navrongo 665′	MAXIMUM	Absolute	101	104	106	106	103	97.0	93.0	90.0	92.0	97.0	100	99.0	12
		Mean	95.7	98.8	101.5	100.2	95.8	90.3	86.7	85.3	86.7	91.9	96.9	95.3	
	MINIMUM	Mean	67.0	72.1	76.1	78.2	76.7	73.6	72.9	71.9	71.6	71.7	68.8	66.0	
		Absolute	60.0	64.0	69.0	71.0	69.0	68.0	68.0	68.0	68.0	67.0	63.0	59.0	

Table 3: Mean and absolute maximum and minimum temperature (°F) for *Bawku*, *Zuarungu* and *Navrongo* meteorological stations to December, 1960. Compiled from Ghana monthly weather reports, Accra, Ghana Meteorological Services.

TABLE 4

Station	*Hour*	*Jan.*	*Feb.*	*March*	*April*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Years*
Bawku (Zawse) 840′	0900*	33	46	45	67	66	76	80	88	79	66	47	31	8
Zuarungu 700′	0900*	22	30	40	56	64	77	81	84	84	71	58	37	8
Navrongo 665′	0900	22	26	40	56	66	76	81	85	83	73	50	28	8
	1500	15	15	21	31	44	57	65	70	66	51	27	18	
	2100	26	26	33	48	62	76	84	88	88	78	52	33	

**Note.*—Data for 1500 and 2100 hours are not available for Bawku and Zuarungu.

Table 4: Mean Monthly Relative Humidity (per cent) at *Bawku*, *Zuarungu* and *Navrongo* meteorological stations to December, 1960. Compiled from Ghana monthly weather reports, Accra, Ghana Meteorological Services.

TABLE 5

Station		*Jan.*	*Feb.*	*March*	*April*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Annual Mean*
Bawku (Zawse) 840′	Hours	8.9	—	7.8	8.2	8.9	7.9	6.9	6.9	6.3	9.2	9.1	7.7	8.0
	Percentage of possible sunshine	77	—	64	67	70	58	54	56	52	77	78	68	65
Zuarungu 700′	Hours	8.2	—	8.5	—	9.0	7.9	6.5	6.0	6.1	8.9	9.2	8.4	7.9
	Percentage of possible sunshine	71	—	70	—	73	58	51	48	50	75	79	73	65
Navrongo 665′	Hours	8.3	9.9	8.8	8.2	9.0	8.1	7.1	6.7	6.4	9.0	9.7	8.8	8.3
	Percentage of possible sunshine	71	84	73	67	71	69	56	54	52	76	83	77	69

Table 5: Mean daily sunshine in hours for *Bawku, Zuarungu* and *Navrongo* meteorological stations for 1960. Compiled from Ghana monthly weather reports, Accra, Ghana Meteorological Services.

Most of the rain falls at night in April, May and October. From June to September rain is well distributed throughout the day with maxima centred just after dawn in June and dusk in July.

The onset of rainfall in March and April, and its termination in October are usually marked by violent linesqualls and thunderstorms which are caused by winds from between north-east and south-east and the monsoon rains with south-westerly winds.

Temperature

The mean annual temperatures given in table 3 are typical for the region and vary little from year to year. Average maximum temperatures are highest in March or April and lowest in August. The greatest individual temperatures may occur at any time just before the onset of the rains in March, April or even May. The highest temperature ever recorded in the region is 109°F at Navrongo. The difference between the greatest and least monthly mean values is about 20°F. The annual mean maximum temperature is about 94°F.

Average minimum temperatures are usually lowest in December and rarely in January. The highest average minimum temperatures may be recorded any time in March, April or May but most commonly in April. Absolute minimum temperatures usually occur in December, and rarely in January and are almost invariably associated with the presence of the harmattan.

The average diurnal range of temperature is greatest during the harmattan period in January and sometimes in December. The diurnal range is least in August.

In any day the lowest temperatures occur at sunrise. Temperatures rise sharply to their maximum at about 1500 G.M.T. Thereafter there is a fairly rapid fall during the remaining daylight hours and a relatively slower fall during the hours of darkness.

Humidity

As can be readily seen in table 4 relative humidity figures are usually high in the rainy season, in particular, from July to September, and low in the dry harmattan period, from December to March. Available data also indicate that the lowest diurnal humidity commonly occurs between noon and 1500 hours and the highest diurnal humidity occurs between midnight and 0600 hours. The data also indicate that humidity during the noon to 1500 hours period may be 20 to 30 per cent lower than the 0900 figure.

Winds

Wind speeds are generally less than 5 m.p.h. The speeds are least at night but may rise to 5 to 10 m.p.h. around 1200 hours. During the harmattan period, average wind speeds may increase to 9 m.p.h. as records at Navrongo show. High wind speeds of more than 50 m.p.h. occur as gusts, associated with either linesqualls or local thunderstorms. These are very infrequent and may occur about thrice a year.

The general wind direction is north-easterly between December and February, variable in February, March and September to November and south-south-westerly between April and August.

Calms are common at night, especially in September and November. In harmattan weather, however, they are less frequent.

Sunshine and visibility

Hours of sunshine in any day, vary according to how much rain, cloud or haze is present in the upper atmosphere. Table 5 gives the 1960 mean sunshine in hours and percentage sunshine for Bawku, Zuarungu and Navrongo. These indicate that sunshine is high in October to November and February to May and low throughout the rainy months, more particularly in September.

Visibility is generally good except during January and February when considerable reductions are experienced because of the harmattan haze.

7. Vegetation (Map 2)

The original vegetation, like the climate, is classified as Sudanese.* This consists of short deciduous trees often widely spaced and a ground flora composed of different species of grasses of varying height. Very little of the vegetation exist in its original form. Owing to long settlement, over population, annual and periodic fires, many areas now consist of degraded tree-savanna† with many of the trees fire resistant.

In its nearly natural form, such as may be seen in well-drained upland sites in forest reserves and little-inhabited areas, the commonest tree species include, *Anogeissus leiocarpus*, *Butyrospermum parkii*, *Detarium microcarpum* and *Parkia clappertoniana*. *Acacias* occur frequently and are usually found on heavy clay soils associated with old river alluvium, piedmont slopes and severely eroded sites where internal drainage is restricted.

In poorly drained situations, the commonest tree species include *Gardenia spp.*, *Pseudocedrela Kotschyi*, *Lannea spp.*, *Combretum spp.*, *Mitragyna inermis*, and a few stands of *Borassus aethiopum*.

Riverain woodland fringes attenuously the White and Red Voltas, the Sisili and a few of the minor streams. Usually, such woodland is associated with levee soils. *Khaya senegalensis* is a common tree of such woodland, besides being commonly used as avenue tree along the principal roads.

In all the very densely settled areas of the region, tree populations are sparse as a result of being felled for fuelwood, building and other domestic purposes. In such areas the few indigenous tree species left are mainly those of economic value and include *Ceiba pentandra*, *Butyrospermum*, *Parkia*, *Acacias*, *Anogeissus*, *Adansonia digitata* (baobab), *Tamarindus indica* and *Blighia sapida*.

In some forest reserves, land planning areas and in some towns and villages there are a few exotics planted to provide shade, amenity, fuelwood or timber. These include Neem, *Cassia mimosoides* and Teak.

The composition of grassland varies according to soil, situation and conditions of burning and grazing. Large areas of exposed land carry only a thin cover of *Heteropogon contortus*. *Imperata cylindrica* and *Pennisetum polystachyon* occur on arable soils. The latter is valued highly as a fodder grass. On waste or degraded land the common grasses include *Dactyloctenium aegyptium*, *Chloris spp.*, *Aristida kerstingii* and *Eragrostis spp.* In uncultivated areas, *Andropogon spp.* and *Cymbopogon giganteus* are common.

8. Land-Use (Map 2)

The soils of the area exert considerable influence on the pattern of land use. The best agricultural soils are those derived from granites, sandstones and greenstones (Group I soils)‡. These lands remain the most densely populated in the area and the pattern of farming is fixed (compound farming areas of map 2).$ Overcrowding and cultivation of these lands over a very long period without proper management practices have induced widespread erosion and loss of fertility of the upland soils.

The exceedingly stony but fertile greenstone hill-sides occurring around Tindongo, Zanlerigu, Nangodi and Sapeliga (Group I, sub-group Ic soils) have a special land-use feature. In cultivating these soils, the stones are shifted into contoured heaps against which the soil packs forming terraces.

The uncontrolled farming and overstocking, which lead to soil erosion and degradation of arable lands necessitated the introduction in some land planning areas of soil and water conservation measures to ensure that these good lands are not further damaged or dissipated but used to the full. These measures entailed the allocation of land to farming, grazing and forestry. In seriously eroded areas it includes the fencing off of gullied land. The prevention of soil erosion by construction of narrow-based contour bands is followed by other means such as stone checks and weirs. Water supplies for humans, livestock and crops are conserved and improved by the construction of dams.

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*Guinea savannah-woodland of Taylor (1952)

†Derived savannah-woodland of Taylor (1952)

‡*See* soil quality map (map 4) and pages 51-58.

$Agriculture and land-use systems are fully described in Lynn (1937), Smith (23) and Wills (1962).

Outcrops of sheet ironpan soils commonly developed over shales (Group I, sub-group Id soils) and elsewhere on low tabular hills or buttes (*see* pages 32 and 50) are seldom cultivated and consequently are uninhabited or sparsely peopled. Village communities are widely scattered and farmers practise extensive system of cultivation ('bush' farming areas of map 2).

Extensive lands (Group II, sub-group IIb soils) occurring along the major river valleys cannot at present be brought into full use owing to the incidence of *trypanosomiasis* and *onchocerciasis*. Where such lands have not been reserved for forestry purposes, they may be exploited for fuelwood and game or they may be visited for the purpose of collecting a variety of products which supplement diet in years of crop failures. Elsewhere stream valleys are seldom cultivated as the soils are heavy and difficult to work by means of ordinary hand cultivating implements.

Owing to the high elevation of the scarplands and some inselberg ranges (Group IV soils), their steep rocky slopes and their inaccessibility, cultivation is avoided and large areas of such lands have been appropriated for forest reserves.

Rough grazing is practised around all settlements and are confined to waste lands, those regenerating after farming and wet valley bottoms.

9. Agriculture

(a) Crop husbandry

The people in the area live by subsistence agriculture. There are two types of farms, the compound farm located around the house, and "bush" farms located some two to six miles away from the village (map 2).

On the compound farm the system is one of more or less permanent agriculture, fertility being maintained by the application of household refuse and livestock droppings. On "bush" farms no manure is applied to the land and the system is one of land rotation, fertility being restored by allowing the land to lie fallow for several years. As the compound area is usually not a viable unit for the whole household, most of the farm produce come from the "bush" farms but the compound farm is important in providing the early cereals. Mixed cropping is the rule on all farms although there are few exceptions.

The average size of a compound farm is about 2 acres. In the thickly populated settlements existing in the vicinities of Bawku, Navrongo, Bolgatanga, Zuarungu, Wiaga and Sandema the farms around the dispersed compound houses are contiguous owing to the heavy demand on land.

Land immediately around the house is normally fertile as a result of the dumping of household and farm refuse and is usually planted to horticultural crops mainly hibiscus, tobacco, gourds, melon, okro, tomatoes, pepper and sweet potatoes. Further away is another zone planted to early and late millet, guinea corn (sorghum), bambarra beans and cow peas. This second zone of land is intentionally fertilized with farmyard manure though often inadequately. The rest of the compound area, usually the largest, is not manured and is cropped to guinea corn and late millet. Groundnuts are sometimes planted or inter-planted over the whole compound area except those reserved for horticultural crops. All crops in the compound area are usually planted on prepared ridges.

The "bush" farms vary in size but are often about 3 acres in extent. The main bulk of the cereals are produced on these farms. Usually, the system of cropping is guinea corn and late millet mixed together, or both planted singly and often intercropped with groundnuts, bambarra beans or cow peas. Poorly drained soils in bush farm areas may be planted to a small plot of rice. Occasionally, early millet is grown first on the plot intended for rice and later interplanted with rice. On the "bush" farms, crops may be grown on ridges or on the flat.

In all areas planting usually begins after the first heavy rains and the crops are ready to be harvested early in the dry season.

Dry-season gardens are being encouraged and are commonly located away from the compound in valley bottoms or near wells, where sufficient water supplies are available. Tomatoes and onions are the main crops raised in these gardens, but lettuce, cabbage and other vegetables are also becoming popular.

(b) Animal husbandry

All livestock in the area are owned by the resident population and may be owned individually or by a family. Cattle are held either for security reasons, as a self-improving investment or for dowries. They are seldom slaughtered for the family's own consumption except on important ceremonial occasions. In difficult years, however, surpluses may be sold to itinerant buyers from Ashanti and further south.

The breed are mainly the small "shorthorn" and the N'dama. Compared with other cattle rearing areas of the country, the population is rather high, the density being more or less directly proportional to the human population.

Grazing lands are poor and are those obtainable under natural conditions. Where land has not been badly eroded or exhausted, there are usually sufficient grazing lands close at hand throughout the wet season. In the dry season, however, these are difficult to come by owing to drying, followed by burning so that pasture can only be reached some distance away from settlements.

The animals are usually kept inside a yard or room of the compound. Early in the morning, the children of the family drive the herds to grazing lands and water and bring them back to the house each evening. During the cropping season, the children see to it that the cattle are properly herded so as not to feed on or damage crops on farms. Attempts at organized grazing in fenced enclosures are being provided in some land planning areas. Within such areas, watering facilities for the livestock are provided by means of dams, wells and ponds.

Sheep and goats as well as fowls and guinea fowls are kept by a majority of householders. No special husbandry is practised and there are no forms of selective breeding. Like the cattle, the sheep and goats are kept in a room in the house but are released during the day and allowed free range (in the dry season) or tethered to uncultivated patches of grass near the farm (in the rains).

Donkeys and horses are common in some localities. The former usually serve as carrier animals and are bought and sold by onion and kola traders passing to and from neighbouring territories lying to the north. The latter are kept by chiefs and wealthy householders who keep them as a mark of authority and dignity.

All animals kept provide the bulk of the manure which is spread on the compound farm. Numerous herds of livestock—cattle, sheep and goats—are imported into Ghana through the area from neighbouring territories. These enter the area through the quarantine stations at Pusiga, Mogonori and Paga.

(c) Wildlife

The sparsely inhabited lands and uninhabited forest reserve areas found along the major rivers such as the Red and White Voltas, Morago, Sisili and on the scarp, harbour limited numbers of game, including primates and some carnivorous types. These animals provide a profitable trade for hunters who visit these areas to kill and prepare the carcases for sale in the larger centres.

10. Geology

The rocks of the area may be divided into three main groups, namely, Voltaian, Birrimian and granitic.

(a) Voltaian rocks

These sandstones and shales are confined to the southern part of the area where they lie uncomformably on the granitic and Birrimian rocks. Edmonds (1956) classifies these rocks into Upper Voltaian (V_3), Middle Voltaian (V_2) and Lower Voltaian (V_1). The succession from Upper Voltaian to Lower Voltaian can be followed down the scarp face.

Upper Voltaian (V_3).—This is subdivided into Upper massive sandstone (V_3b) and Lower thin-bedded sandstone (V_3a).

The V_3b beds consist of massive, medium-grained, cream, buff, or pink feldspathic sandstone, which show little variation throughout their extent in the main scarp. The lower thin-bedded sandstones (V_3a) are fine grained, micaceous, dirty-yellow in colour and iron oxide spotted. Variable amounts of siltstone, shale and mudstone are present within the group but usually only as thin partings.

Middle Voltaian (V_2).—This middle group consists mainly of shales, with characteristic greyish-green and purple colours. Lenses of fine-grained argillaceous sandstones, purple and chocolate coloured slaty-shale and thin limestone bands are often encountered within the series. They can be seen as thick bands in the scarp face but do outcrop in the extreme S.W. corner of the area in the neighbourhood of Kunkwa.

Lower Voltaian (V_1).—These lie at the base of the Voltaian system, below the shales and uncomformably above the granite and Birrimian rocks. They are generally fine, thin-bedded, feldspathic sandstone, often spotted with iron-oxide. Lenses of micaceous sandy shale, quartz grit and pebbly bands occur locally.

(b) Birrimian rocks

These rocks are associated with the granites. They are composed of steeply dipping metamorphosed sediments and volcanics.

Murray (1960) subdivides them into three: (*a*) a dominantly arenaceous series (*b*) a dominantly argillaceous series and (*c*) a dominantly volcanic group.

The arenaceous rocks consist of conglomerates, grits, arkoses, greywackes and quartz-sericite schists. Scattered outcrops of these rocks occur west of the Red Volta, in the Zuarungu and Navrongo districts.

The argillaceous rocks consist of phyllites, chlorite schists, biotite schists, greywackes and quartzites. Examples of these rocks can be seen north of Bawku and Zebilla, south of Sapeliga, around Nangodi, S.E. of Tongo and generally on lands surrounding the volcanic hills.

The volcanic group consists of greenstones, andesites, porphyries, actinolite schists, hornblende schists, amphibolites, tuffs and phyllites. These rocks occur as hill ranges, the best exposures being found north of Bawku and Zebilla and in the Nangodi and Tindogo hills.

(c) Granitic rocks

These rocks constitute the oldest of the three groups. Edmonds (1956) divided those in the Bawku area into *biotitic complex* (*G*1) and *hornblendic complex* (*G*2). The biotitic complex consists mainly of coarse and fine grained biotite granites, biotite granodiorites and gneisses. The predominant feldspars of the biotite granites are potash (microcline), whereas the biotite granodiorites contain mainly soda-oligoclase. Locally, biotite or feldspar may be preponderant in some rocks. The former examples are dark coloured granodiorites but the latter are pale granites (felsites). Rounded outcrops are frequently seen and these weather by exfoliation.

Within the hornblendic complex, Edmonds recognized hornblende granites, hornblende granodiorites and amphibolites. The granites and granodiorites are typically medium grained and the constituent feldspar is commonly pink coloured. Foliation is not prominent and the rocks not generally gneissic. The amphibolites are generally coarse grained and the content of feldspar variable.

Murray (1960) recognized the two granitic types in the Zuarungu area and describes them as granitic rocks associated with Birrimian. He mentions the granitic outcrops found near Pwalugu as containing in addition to biotite, variable proportions of muscovite.

Similar granitic type rocks as described by Edmonds and Murray occur in the Navrongo district, although outcrops of the hornblende group seem more common.

Associated with the granites are some major and minor intrusive rocks. The major intrusives are the *Bongo granites.* Murray mapped these granites in addition to the two granitic types already described. They are confined to a small area north of Bolgatanga and west from Bongo. They also form part of the Tongo hills. These granites are coloured pink, coarse grained and potassium rich. Hornblende and a little biotite are some of the constituent primary minerals but the Tongo hill examples have a higher proportion of quartz and plagioclase. The granite has a rectangular jointing and weathers into large upstanding masses and blocky perched boulders. The two hills near Bongo and the one near Tongo rise several hundred feet above the surrounding land and the sides are steep and craggy.

The minor intrusives frequently consist of quartz, quartz-feldspar, pegmatite and aplite. Less frequently are intrusions of basic rocks—quartz-dolerites and amphibolites.

11. Hydrology and Water Supply*

The water supply conditions are directly related to the underlying rocks. Areas occupied by Birrimian rocks have a high surface runoff so that surface flow of streams generally persist throughout the dry season. The rocks weather into clay and this combines with the relatively impermeable bedrock to give conditions favourable for surface water storage.

In the granitic areas, surface flow of streams cease during the dry season, but disconnected pools remain and shallow excavations yield water. Conditions are not so favourable for dam construction owing to the risk of water seepage, but wells sunk in valley and lower slope sites usually yield good supplies.

The Lower Voltaian (V_1) rocks composed generally of flat-lying, fine-grained sandstone and quartzites do not permit of free downward or lateral percolation within the bedrock. Surface supplies from boreholes therefore vary, but the chances are fair where the sandstone is sufficiently argillaceous. Topography and bedrock are not generally suitable for dams due to wide shallow valleys, permeable foundations and absence of good clay.

The Middle Voltaian (V_2) areas have a marked dry season shortage of surface water except in and near rivers. Groundwater occurs at generally shallow depths and deep wells would only give moderate yields. Owing to their impervious nature, the shales and mudstones are suitable for storage of surface water but good sites other than small shallow dams are difficult to find owing to wide shallow valleys (Junner and Hirst 1946).

The Upper Voltaian (V_3) areas are generally well-watered and natural surface supplies persist in many instances throughout, or well into, the dry season. The sandstone is of very uniform type, medium textured and over most of the area, of considerable thickness; thus groundwater prospects are excellent. The permeable nature of the rock and the absence of good clay, however, renders the V_3 areas unsuitable for dams or ponds.

At present the main sources of domestic water supply throughout the area are from rivers, springs, wells, boreholes, ponds and dams. Most rivers and springs dry up towards the end of the dry season and water is then scarce for those who depend on this source. At such times water may be obtained from shallow wells. The Water Supply Department has made excellent progress in the way of supplying water to many towns and villages by means of boreholes; and it is noteworthy that Bawku, Bolgatanga and Navrongo are supplied by pipe-lines leading from such bores.

Within the land-planning areas of Kusasi, Frafra, Navrongo and Wiaga, more than 150 dams have been constructed to provide water for humans, livestock and crops. Much still remains to be done to overcome dry season water shortage. The rainfall and water resources within the area are enough to support all life if properly developed, conserved and utilized.

*Mainly the findings of Edmunds (1956) and Murray (1960).

PART II

SOCIAL CONDITIONS

1. COMMUNICATIONS

The area is served by two main roads from the south. On the east the road from Yendi enters the area at Nakpanduri and continues northwards to Bawku and from there to the Republic of Togo and Upper Volta. On the west the trunk road from Tamale enters the area 4 miles south of Karamenga and continues northwards through Bolgatanga, Navrongo and Paga to Upper Volta. An alternative road to Togo and Upper Volta leads from Bolgatanga to Bawku, an important centre for trade with Upper Volta in livestock and other merchandise.

In addition to the trunk roads, there are several hundred miles of second and third class roads forming a fairly close network, especially in the more closely settled areas around Navrongo, Bolgatanga and Bawku. The second class road leading westwards from Navrongo to Wa is important as it is the only link road between the N.W. and the N.E. of Ghana.

Apart from the 20 miles of bitumenized surface on the Bolgatanga–Tamale route, all roads in the area are unsurfaced earth roads. The Central Government is responsible for the trunk roads which are always kept in a state of good repair although, occasional flooding during wet season storms may do considerable damage, causing blockage of sections of the roads. Most of the second and all the third class roads are maintained by Local Authorities and the Land Planning and Soil conservation services and are not kept in such good repair, so that many are impassable in wet season.

The trunk roads are generally carried over numerous streams and rivers which they traverse by means of bridges and culverts, but the minor roads usually cross many streams by means of drifts.

Head portage is still important. In all the settled areas, there is a close network of bush paths connecting village with village. Along these paths local produce are head loaded once or twice every week to rural and urban markets.

Transportation on the larger rivers is hampered by numerous rapids and absence of water of sufficient depth in the dry season. Along navigable stretches of the White Volta, itinerant fishermen—from Tongu district in Southern Ghana—fish from temporary camps along the banks.

During the last war an emergency landing strip was built near Navrongo for the purpose of freighting cargoes of slaughtered cattle (beef) on light aircrafts to troops stationed at Accra and Takoradi. The landing strip has been out of use since the war and is at present in a state of near disrepair.

2. TRIBES, POPULATION AND SETTLEMENTS

The people of the area are chiefly Mamprusi. They are divided into a number of tribes who differ in their customs and speak different dialects of Mole. In the more important market centres can be found immigrants from neighbouring territories, mainly Busangas and Moshis, and a number of traders from Southern Ghana and Nigeria.

The 1960 population census* recorded 468,638 people as living in the four existing local authority areas. These local authority administrative areas are Builsa (50,922), Kassena-Nankani (93,397), Frafra (150,028) and Kusasi (174,291). For comparison the 1948 population census figures were as follows: Builsa (51,215), Kassena-Nankani (91,051), Frafra (163,474) and Kusasi (147,448) giving an overall total of 453,188. Thus the 1960 figure shows an increase of 15,450 over that of 1948. The figure of 468,638 for 1960 may be considered as correct for the whole of the survey area which includes some virtually uninhabited local authority areas in the highlands of South Mamprusi.

*Population Census of Ghana, Vol. I, Accra, 1962.

The Frafra and eastern Navrongo areas remain the most densely peopled of all. Around Bongo and Sekoti densities of over 450 per square mile have been recorded and the figure is even higher around Sherigu and Manyoro near Navrongo.

Settlements are generally dispersed but localized. Tracts of uninhabited terrain, estimated to occupy about 45 per cent of the area exist, due to soil exhaustion and erosion in some areas and simulium fly infestation along the major river valleys.

Closer building around centres of importance have resulted in the formation of towns and compact villages such as Bawku, Pusiga, Bolgatanga, Navrongo and Sandema. Bolgatanga at present serves as the administrative headquarters for the Upper Region.

Owing to poverty arising from soil erosion and exhaustion and periodic famine, many of the young men, in particular, the Frafras, migrate from the districts to work for wages in the forested regions of Ashanti and southern Ghana, where there is a big demand for unskilled labour in the mines and in handling cocoa crop. These young men do not as a rule stay away from home for long at a time and usually return with a little money; but on their return do not take readily to farming again and represent a floating population. In recent years efforts have been made by the regional authorities to find useful employment for such people in various organizations such as United Ghana Farmers Council Co-operatives, State Farms Corporation, Workers Brigade and Young Farmers Settlement Farms.

Most people live in compound houses. Each compound is roughly elliptical in shape and consists of a number of round mud houses facing inwards; the whole is enclosed by a high mud wall. Roofs are made either flat, of beaten earth, or conical and thatched. A single narrow doorway gives entrance to the compound. The space inside is divided into compartments by low walls. In recent times mud-built rectangular houses commonly found in southern Ghana are on the increase and can be seen side by side with the compound houses within towns and villages.

3. Economic Resources and Trade

The economy of the area is tied up with products derived from agriculture. There are many signs that agriculture itself is now not being regarded mainly as a custom but a business. The chief products that enter into trade are grain, groundnuts and a certain number of livestock, principally fowls. Trade in shea nuts, tobacco and vegetables are also important.

There is at present no export trade in grain as quantities produced are locally consumed. Surplus guinea corn and millet, sometimes produced in the Kusasi districts, are normally sent to Bolgatanga where they are readily disposed of on the local market.

Rice cultivation has increased considerably in recent times. Cultivation is confined to wet clay valley bottoms where there are still large tracts of undeveloped land. The exact acreage under cultivation is not known as the bulk of the produce comes from peasant farmers' plots. The return to the rice farmer is good, but it would be even better if effective water control measures could be introduced into the farming system.

Groundnuts do well on the light sandy soils developed over granites and sandstones. It is largely a cash crop and a high proportion is sold to the south. The oil is a valuable source of revenue and is used extensively for cooking. To improve on the oil trade an oil expeller mill has recently been erected at Bawku so that surplus groundnuts can be processed here. It is hoped also to produce livestock feed as a by-product from the residue. Problems of suitable varieties of the crop and improved methods of cultivation have been resolved but more adequate returns to the farmer can be achieved if more satisfactory techniques of mechanizing production and harvesting as well as marketing can be worked out.

Shea nuts are bought and exported on a small scale by the Ghana Agricultural Produce Marketing Board. The quantity exported from the area has been on the increase since 1955. The commodity is exported either processed or unprocessed.

Vegetable cultivation in dry season gardens located away from the compound in valley bottoms is on the increase. Tomatoes and onions are produced for sale as cash crops and are exported south.

Tomatoes are the most important, and high yielding varieties with good quality fruit have been produced. Cultivation is dependent on availability of water, either permanent or in valleys below dams in Land-Planning areas. In the 1959–60 season alone, 362 tons were exported from this area. Given a sound marketing system and satisfactory packing and transportation, production can be greatly increased.

Demand for onions produced in the Bawku area is on the increase. It has a high cash value and being less perishable than tomatoes it is easily marketed.

Tobacco is an attractive cash crop in the Bolgatanga area. The Pioneer Tobacco Company produces the seedlings required by the farmers and all tobacco produced, suitable for manufacture, is purchased by the company. Considerable quantities of local tobacco are produced annually around compounds and on silty loams deposited on the banks of the larger rivers. The commodity has a high cash value on the local markets and elsewhere.

The increasing demand for meat in the larger towns and further south has stimulated considerable trade in fowls. Fowls and eggs are rarely eaten in the rural areas and are sold on the markets for consumption in towns.

Besides agricultural products, trade in basket and leather goods appears to be expanding. This trade is centred at Bolgatanga and caters for visitors and tourists. Its value is unknown at present as the business is mainly in the hands of middlemen.

The occurrence of minerals of economic importance is at present not fully known. Several years ago (1934–1939) gold deposits were worked from the mines near Nangodi. Building stones, some of high ornamental value, are stated to be available in large quantities, but these have rarely been used for this purpose (Murray 1960). Many of the stones would also supply good road metal. Road metal is at present quarried and crushed near Pwalugu.

Recent economic awakening amongst the people has stimulated a growing desire for imported commodities. The principal items of import are cotton piece goods, cycles and spare parts, drinks, canned fish and meat, sugar, salt and cigarretes. All these items are found in shops in the principal market centres at Bawku, Bolgatanga and Navrongo. A quantity of cement, corrugated roofing sheets and sawn timber are imported for use mainly on public buildings and works. Large quantities of kola-nuts are imported from the south.

4. Community Facilities

Missionary activity has been a strong factor in the development of education in the area. Schools are run either by the churches or by local authorities, but all receive government assistance.

Primary school education is common throughout the area and middle school education is available at many centres. Secondary school education is provided at the Government Secondary schools at Navrongo and Bawku and at the Catholic Mission (Notre Dame) Secondary School, Navrongo. The Catholic Mission also runs a Teacher Training College (St. John Busco Training College) at Navrongo in addition to the Government Training College at Pusiga. There is a Rural Rehabilitation Centre at Bolgatanga.

There are hospitals at Bawku, Bolgatanga and Navrongo and health centres at Binaba and Sandema. These are supplemented by several local dispensaries and special treatment centres.

Electricity for lighting and other domestic uses is available at Bolgatanga only, but the two hospitals at Bawku and Navrongo and some institutions and colleges maintain private generators.

There are Government Police Stations at Bolgatanga, Navrongo and Bawku and Customs Preventive Stations at Bawku and Paga. Bolgatanga, Navrongo and Bawku have full post and telegraph facilities; these are supplemented by postal agencies in some of the smaller towns. Telephone facilities are available at Bolgatanga and Navrongo but not at Bawku. All three towns have broadcast rediffusion stations.

Regular markets are held every three days or so at numerous centres throughout the area; the largest of these are held at Bawku, Navrongo, Bolgatanga, Fumbisi and Sandema.

Part III

SOILS

Method of survey employed

The method employed was a departure from the standard soil survey procedures used in the Soil and Land-Use Survey organization of this country and follows that described by Adu (6)* and Obeng *et al* (1962). The area has a complete air photo coverage (1960), the scale of photography being 1: 30,000. A number of these photographs were selected to represent the various physiographic regions known to be existing in the area. They were stereoscopically examined, analysed and interpreted in the laboratory after which they were taken to the field and the units delineated on them checked against the soils. The features distinguishing each soil were then established. Also, a careful study was carried out to determine how individual soil series are related to one another within the various soil associations being mapped, and how these are related to vegetation and land-use types. Profile pits were dug, sampled and sent to the laboratory for analysis.

On the basis of the preliminary survey involving a number of sample areas within each physiographic region, the remaining photographs of the entire project area were analysed and interpreted. Owing to its large extent, the area was divided up into sub-regions and each treated as an entity. Thus the survey area was completed in stages. Soil boundaries on the photographs were transferred to a base map (scale 1: 125,000) by means of aero-sketchmaster. The draft soil map compiled in this manner was finalized by a careful check along all the existing lines of communications—roads, paths, forest reserve boundaries, etc. The reliability of the final soil map (map 3), therefore, depends on the closeness of the communication network. For publication the final map was reduced to a scale of 1: 250,000. By using the above method the physical and cultural make-up of the whole terrain could be vividly observed and studied stereoscopically so that soil boundaries could generally be followed and accurately drawn. The map has therefore greater detail and greater accuracy than similar maps compiled by the conventional method of interpolating boundaries along traverses. The method has further advantages of being cheaper and speedier to use.

A number of physical and cultural elements were used in identifying and differentiating soils on the photographs. These included geology, physiography, relief and drainage and vegetation and land-use types. Whilst all were useful, the former two proved the most reliable.

As regards the geology of the area, little difficulty was encountered in delineating boundaries between granites, Birrimian greenstones, phyllites and schists and Voltaian shales and sandstones. It was not, however, easy to defferentiate on the photographs between the two granitic type rocks occurring in the area (i.e. the biotite-rich (G1) and the hornblende-rich (G2) examples). The land forms, drainage patterns, vegetation and land-use types are similar and to separate these and consequently map the soils occurring on them required greater field identification work. In fact, the two granitic types are so intermixed or occur in such gradations that the boundaries between soil associations developed on them are in a majority of cases not clearly defined. Such soil boundaries as shown on the map are therefore by no means fixed. The Bongo granite areas are exceptions which could readily be distinguished on the photographs by means of the characteristic way in which the rocks weather.

Characteristics of the soils of the area

The soils of the area have characteristics common to those occurring in the interior savanna zone of Ghana. When compared to soils of the forest zone however, they have less accumulation of organic matter—majority have less than 2 per cent—in the surface horizons owing to high temperatures resulting in a rapid rate of decomposition. The annual burning of the vegetation cover throughout the area also reduces the amount of organic matter available.

The soils developed over granites and sandstones have in the main light topsoils varying in texture from coarse sands to loams and heavier subsoils varying from coarse sandy loams to clays with variable amounts of gravel. Soils developed over basic rocks and most of those in valley bottoms have heavier topsoils and subsoils.

The soils have extreme moisture relationships. For about five months of the year, they receive a total rainfall of about 40 inches, whilst for the remaining seven months they dry almost completely. This alternation of wet and dry conditions, causes intense leaching of nutrients out of the topsoils and promotes the irreversible hardening of the subsoils leading to the development of iron-pan (laterite) and groundwater laterites in a good many of the soils encountered.

The soils have a lower nutrient status than forest soils. This and the unfavourable moisture regime and, in addition, the rainfall which is less reliable in occurrence make the potential productivity of the soils of the region as a whole, lower than in most forest soils. Phosphorus and nitrogen are especially deficient in almost all the soils encountered. This deficiency is, however, consistent with most soils occurring in the interior savanna zone of Ghana.

A majority of the soils occupy gently undulating to gently rolling topography yet are more vulnerable to erosion than those soils occurring on the more strongly rolling relief of forest regions in Ghana. Sheet and gully erosion are prevalent and it is believed that these were due, in the past, to a change in climate and/or vegetation cover which has resulted in increasing runoff. Currently, it is due to overgrazing, improper cultivation practices, periodic burning of the grass cover and lowering of organic matter content followed by torrential downpours on soils generally sandy by nature. Erosion is particularly evident and extensive along the lower slopes of both major and minor valley sides so that shallow, stony or rocky soils are common features at such sites.

Units of mapping employed

In a detailed soil survey, the usual mapping unit used is the *soil series*. Soil series are defined as soils with similar profile morphology derived from similar parent materials under similar conditions of climate, vegetation, relief and drainage. Under Ghanaian conditions soil series rarely cover a sufficient area in individual expanses to make it practical to map them on any but very large scale maps. Thus soil series maps are prepared for special development projects covering only a few square miles or less. On the very infrequent occasions where individual soil series are of sufficiently extensive occurrence to merit being shown separately on a small scale map, they are mapped as *soil consociations*.

For surveys of larger areas, soil series are combined into larger assemblages for mapping purposes. Such assemblages are known as *soil associations*. These form the main mapping units employed in the soil map (map 3) accompanying this report. The unit is defined as a group of series formed from related parent materials and possessing a similar profile morphology but differentiated by relief and drainage. Thus an association may comprise sedentary, colluvial and alluvial soils.

A less common mapping unit employed is the *soil complex*. This comprises a group of diverse series which are unrelated topographically but which occur in too close a pattern that it is impracticable to map separately due to the limitation of the map scale used in this report.

A soil phase is a minor subdivision of a soil series in which the profile has been modified by outside disturbance, e.g. cultivation or erosion.

In the following table the soil associations, consociations and complexes mapped and the component soil series and phases are given. For convenience and ease of reference each unit has been named after the most important soil(s) in the association.

NAVRONGO—BAWKU REGION: COMPONENT SOILS OF MAPPING UNITS

(*Major series in each group are italicized*)

I. Soils Developed over Granites

A. Soils derived from biotite granites (G1)

1. *Varempere association*
   - Wenchi series
   - Hilun series
   - *Varempere series*
   - *Tafali series*
   - Gulo series
   - Pusiga series
   - Pu series
   - *Berenyasi series*
   - *Kupela series*

B. Soils derived from hornblende granites (G2)

2. *Tanchera association*
   - *Tanchera series*
   - Puga series
   - Kolingu series
   - Kolingu series (stony sub-series)
   - *Kupela series*
   - Pusiga series
   - Gulo series
   - Pu series
   - *Berenyasi series*

C. Moderately eroded soils developed over hornblende and/or biotite granites (G1 and/or G2)

3. *Kolingu association*
   - *Kolingu series*
   - Kolingu series (stony sub-series)
   - *Puga series*
   - Tanchera series
   - Pusiga series
   - Pu series
   - *Berenyasi series*
   - *Kupela series*

D. Severely eroded soils developed over hornblende granites (G2)

4. *Pusiga association*
   - *Pusiga series*
   - *Pu series*
   - Kolingu series
   - Tanchera series
   - *Berenyasi series*
   - *Kupela series*

E. Granitic lithosols (G1 and G2)

5. *Chuchuliga association*
   - *Chuchuliga series*
   - Kolingu series
   - Pu series
   - Tanchera series
   - Pusiga series

F. Soils developed over ironpan-capped hills (G1 or G2)

6. *Wenchi consociation*

G. Soils developed over groundwater laterites (G1 or G2)

7. *Wenchi association*
   - *Wenchi series*
   - *Babile series*
   - *Tanchera series*
   - Pusiga series
   - Pu series
   - *Kupela series*
   - *Berenyasi*

H. Soils derived from local alluvium (G1 and G2)

8. *Berenyasi–Kupela association*
   - *Kupela series*
   - *Berenyasi series*
   - Dagare series
   - Pani series

I—Soils developed over Bongo granites (G2)
(Rich in hornblende and potash feldspar and with a high phosphate content)

9. *Bongo association*
   - *Bongo series*
   - *Vea series*
   - Yorogo series
   - *Yaratanga series*
   - *Akrubu series*
   - Zoko series
   - Tongo series

10. *Tongo association*
    - *Tongo series*
    - Bongo series

II. Soils Developed over Birrimian Rocks

(a) Soils derived from volcanic rocks—mainly greenstones, andesites, schists and amphibolites

11. Mogo consociation (lithosol)

12. *Nangodi association*
    - *Nangodi series*
    - Dorimon series
    - Yagha series
    - *Kalini series*

(b) Heavy clay piedmont slope soils derived from mixed volcanic rocks

13. *Yagha association*
    - *Yagha series*
    - Sapeliga series
    - *Kalini series*
    - Nangodi series

(c) Sandy clay soils derived from greywackes and quartz-sericite schists

14. *Bianya association*
    - *Bianya series*
    - *Bianya series (shallow)*
    - Nangodi series
    - Pale series

III. Soils Developed over Granite and Birimian Rocks

15. *Dorimon—Pu complex*

Kolingu series Pusiga series Pu series Berenyasi series Kupela series	developed over granites
Dorimon series Nangodi series Yagha series Kalini series	developed over Birrimian rocks

IV. Soils Developed over Voltaian Rocks

(a) Soils derived from Upper and Lower Voltaian sandstones (V_3 & V_1)

16. *Mimi association*
    - *Mimi series*
    - *Murugu series*
    - *Kintampo series*
    - Techiman series
    - *Wenchi series*
    - Nalerigu series
    - *Yaroyiri series*
    - *Bombi series*
    - Kunkwa series

17. *Kintampo association*
   - *Kintampo series*
   - Techiman series
   - Wenchi series
   - Mimi series
   - *Yaroyiri series*
   - *Bombi series*

18. *Wenchi consociation (bovals)*
19. *Bombi–Yaroyiri association (Local alluvium)*
   - *Bombi series*
   - *Yaroyiri series*
   - *Kunkwa series*

(*b*) *Soils derived from Voltaian shales* (V_2)
(*Mainly groundwater laterities*)

20. *Kpelesawgu association*
   - *Kpelesawgu series*
   - Sambu series
   - *Changnalili series*
   - *Volta series*
   - Lima series

21. *Volta–Lima association (Alluvium)*
   - *Volta series*
   - Lima series

(*c*) *Scarp slope soils*—(Derived from a mixture of sandstone and shale)

22. Kpea consociation (talus, mainly large boulders)
23. Klopu consociation (mixed colluvium of clay and rock boulders)

V. Soils Derived from recent and old Alluvian of mixed origin

(*a*) *Alluvial levees (recent)*

24. *Dagare association*
   - *Dagare series*
   - *Kunkwa series*
   - *Sirru series*

(*b*) *Flood plain alluvium (old)*

25. *Siare association*
   - *Siare series*
   - Pani series

(*c*) *Mixed recent and old alluvium*

26. *Siare–Dagare complex*
   - *Siare series*
   - Pani series
   - *Dagare series*
   - *Kunkwa series*
   - Sirru series

(*d*) *Terrace soils*

27. *Nterso–Zaw association*
   - *Nterso series*
   - Zaw series

28. *Sirru–Lapliki association*
   - Sirru series
   - Lapliki series

Complete descriptions of the associations and component soils listed above are given in the sections which follow. Attempts have also been made to give the agricultural characteristics of each series and an assessment of its agricultural value. Such assessments, it must be pointed out, are not entirely based on known or established productive capacities of the soils but on the evaluation of depth, drainage, texture, slope, permeability, water-holding capacity, base exchange capacity, organic matter content and the level, generally, of other nutrient reserves as obtained from analytical data. This information is supplemented by data gathered in conversations with other specialists and through observations on the performance of crops made during the course of the survey on farmers' fields, State Farms and on Agricultural Research Stations.

Table 6

SOILS OF THE NAVRONGO-BAWKU REGION

CLASSIFICATION

Series	*Ghana system*[1]	*C.C.T.A. system*[2]	*American system*[3]	*F.A.O.*[4]
Wenchi Varempere Tafali Puga Tanchera Kolingu Bongo Vea Techiman Mimi Murugu Hilun Nterso, Zaw	Savannah ochrosols.	Ferruginous tropical soils and Ferrisols.	Oxisols: (Idox).	Reddish brown lateritic soils.
Bianya Gulo Yorogo Nalerigu Kpelesawgu Changnalili	Ground water laterites.	Ferruginous tropical soils (leached), i.e. Intergrades between Ferruginous tropical soils with ironpan and hydromorphic soils.	Oxisols: (Aquox).	Ferruginous tropical soils. *N.B.*—Hydromorphic soils with concretions and pan is preferred
Pusiga Pu? Chuchuliga Tongo Zoko Mogo Nangodi Kintampo Kpea Gbeshie Klopu Wenchi Bongo	Lithosols	Raw mineral soil (rock and rock debris) and weakly developed soils (lithosols).	Entisols: (Ustents).	Rock and rock debris and Lithosols.

[1] Charter's interim scheme (Brammer 1956a).
[2] After J. D. Hoore (1963) Soil Map of Africa.
[3] U.S.D.A. 7th Approximation (1960).
[4] Soil Map of the World, FAO/UNESCO Project (1964).

Series	*Ghana system*[1]	*C.C.T.A. system*[2]	*American system*[3]	*F.A.O.*[4]
Yagha	Tropical Brown Earths.	Vertisols (lithomorphic).	Vertisols: (Aquerts) (Grummaquerts).	Vertisols
Pani Kalini	Tropical Black Earths.	Vertisols (topomorphic).		
Kupela (calc) Siare Lima	Savannah Grey Neutral Gleisols.			
Berenyasi Kupela Yaratanga Akrubu Pale Bombi Yaroyiri Volta	Savannah Grey Acid Gleisols.	Hydromorphic soils (mineral).	Entisols: (Ustents).	Alluvial soils
Dagare Sirru Kunkwa	Alluviosols	Weakly developed soils: Juvenile (riverine alluvium).	Entisols: (Psammustents).	

I. SOILS DEVELOPED OVER GRANITES

1. The Varempere Association

Soils in this association occupy approximately 280 square miles in an area confined to the south of Bawku and east of the White Volta. The association shows a definite relationship with the relief (fig. 2). On the uplands, red sedentary soils (*Varempere series*) occur. The subsoils of the series usually consist of plinthite: compact and indurated horizons containing variable quantities of iron concretions, quartz gravel and stones. The parent rocks from which the soils are derived—mainly biotite granites—weather to great depths and the sub-strata usually contain fine incompletely weathered black mica and feldspar. Frequently, eroded summit areas have iron concretions overlying massive indurated and ferruginized subsoils (*Hilun series*) or such areas may be capped by sheet ironpan (*Wenchi series*, page 32).

Soils on the middle slopes (*Tafali series*) have been developed from colluvium or hill wash. They are brownish or reddish yellow in colour and usually consist of several feet of coarse sandy loams underlain by quartz gravel and stones, iron concretions and/or seepage iron-pan.

Soils on lower slopes (*Gulo series*) are groundwater laterites. Normally, they consist of shallow pale-coloured loamy coarse sand (*colluvium*) overlying seepage ironpan or packed irregular-shaped iron concretions. Nearest to depressions, the top sandy layers of Gulo soils have sometimes been eroded away, exposing pan at the surface. Both the eroded and the normal soils are usually characterized by very short grass.

[1] Charter's interim scheme (Brammer) 1956a).
[2] After J. D. Hoore (1963) Soil Map of Africa.
[3] U.S.D.A. 7th Approximation (1960).
[4] Soil Map of the World, FAO/UNESCO Project (1964).

The association is made complete by grey poorly-drained alluvial clays (*Kupela series*) and sands (*Berenyasi series*). These soils are fully described under Kupela-Berenyasi association (*see* page 33).

Within the association valley sides are commonly severely eroded and give rise to Pusiga series (page 32) and *Pu series* (page 30).

Soils of the Varempere association were first described by Obeng (1963) in his report on the soils of the Seilo-Tuni Land Planning Area and in his account of the major soils of the Seilo-Tuni Land Planning Area (Obeng 1959).

Varempere series (*formerly Bawku series*).

The series occur on summit and upper slope sites where slope gradients average 2 per cent. It is a well drained soil generally having the following profile characteristics: The topsoil has often been disturbed by cultivation but shows a differentiation into an upper top soil consisting of 3–4 inches of light yellowish brown loamy coarse sand having a weak crumb structure and very slight humous staining over a lower topsoil which is also disturbed by cultivation and consisting of yellowish brown loamy coarse sand to the depth of 8–10 inches. This lower topsoil is less crumbly and much less humous. It is underlain by a reddish brown subsoil which varies in thickness from 2 to 3 feet. The horizon is coarse sandy loam in texture, weak medium blocky in structure and usually contains abundant fine quartz gravel. Iron concretions occasionally occur and may be frequent in some profiles. The lower part of the subsoil has usually developed into a plinthite which is indurated, massive, compacted and usually stained with manganese dioxide. Below the subsoil there is usually 3–4 feet of strongly weathered parent material, consisting of red and yellow or brown mottled coarse sandy, feldspathic and micaceous clay.

In some areas the series is concretionary or may even contain occasional small boulders of iron pan within 2 feet or so of the surface. Elsewhere they have been subjected to erosion.

Suitability for Agriculture

The soil has a good moisture-retaining capacity; although the topsoil may be droughty during dry spells, the subsoil will remain moist for long periods. Whereas moisture equivalent for the topsoils average 6.5 per cent, it is about 17 per cent in the subsoil and the corresponding clay fractions rise from about 8 per cent in the topsoils to about 32 per cent in the subsoils.*

The reaction of the series within the top and subsoils does not vary much, usually being slightly to moderately acid (pH 6.0–6.4). In the parent material, however, the reaction is neutral to slightly alkaline.

Analysis in the laboratory of complete profiles and composite topsoil samples show a total exchangeable base of the order of 2–4 m.e. per 100 gm in the topsoils increasing to about 6 m.e. within the subsoils and parent material. The low level of bases within the topsoil is due to a correspondingly low level of organic matter (less than 1.5 per cent). The higher base exchange capacity within the subsoil is due to the concentration of clay fraction in the horizon. Magnesium and potassium are present in very low quantities, these in no horizon exceed .8 m.e., but calcium increases from around 1.1 m.e. in the topsoil to about 3.5 m.e. in the subsoil. Both phosphorus and nitrogen levels are exceedingly low. Total phosphorus in the top layers lies around 45 p.p.m. This figure is more than doubled in the ferruginous subsoil layers suggesting a tie up of the element with iron. Nitrogen within the same horizons does not exceed .04 per cent.

* Data for chemical analysis are given with typical profile descriptions in the appendix, pages 59 to 89. Inherent fertility of Ghana soils may generally be categorized as follows: (Personal communication with Dr. A. S. de Endredy, soil analyst).

	Organic matter %	*Exchange cap. m.e./100g*	*Base Saturation %*	*Total phosphorus p.p.m*
1. Very low	Under .. 1	0–3	Under 20	Under 100
2. Low ..	.. 1	3–5	20–50	100–250
3. Medium ..	.. 1–4	5–10	50–80	250–500
4. High ..	.. over 4	over 10	over 80	over 500

VAREMPERE ASSOCIATION—IDEALIZED SECTION AND SOIL PROFILE DIAGRAMS

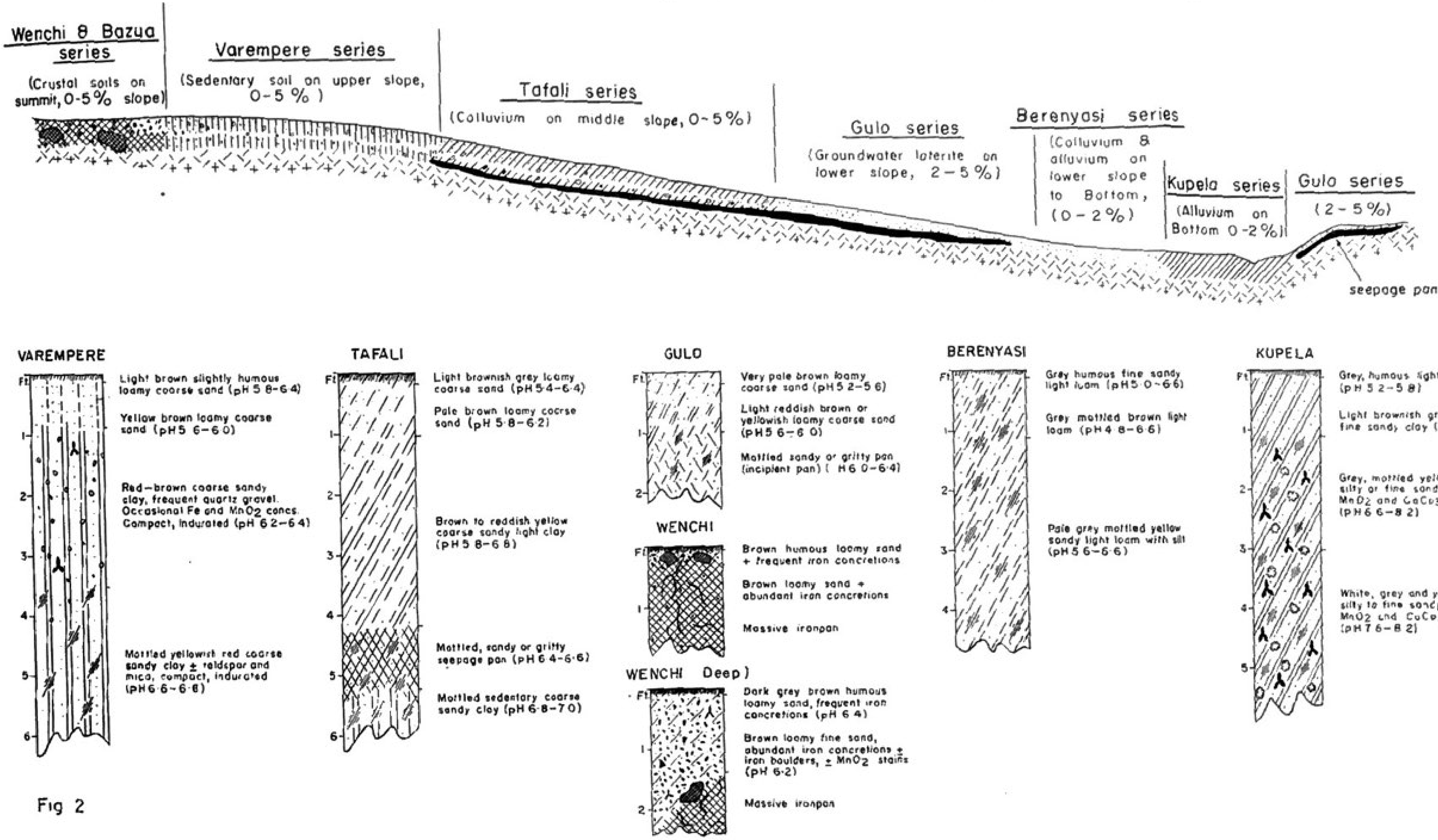


Fig 2

As the soil is deep, well drained, easily tilled and offers freedom of root development, it is suitable for almost all the traditional crops commonly grown in the region: millet, guinea corn, maize, groundnuts, bambarra beans, cowpeas and tobacco which is grown as an additional cash crop. The productivity of the soil is easily improved by the application of fertilizers. Good responses to the application of superphosphate and kraal manure have been reported by Djokoto and Stephens (1961) from fertilizer trials conducted on Varempere soils at Manga Agricultural Research sub-station. Most of the crops also responded well to the application of sulphate of ammonia.

The concretionary variants are also fit for cropping but hand or bullock plough cultivation is recommended. Compared to the normal Varempere soils, they are more freely-draining and consequently less retentive of moisture within surface horizons.

Hilun series

The series occur in similar situations as Varempere soils. They have simple profiles consisting of about 18–24 inches of abundant irregular-shaped iron concretions in a sandy loam matrix and overlying massive iron-pan or plinthite.

Hilun soils are almost sterile, rather unfit for cultivation and are generally avoided by local farmers in preference to Varempere soils.

Tafali series

The series is developed in local colluvium. It occurs at a lower site than Varempere series, on slope gradients approximating 2 per cent.

Usually the topsoils have been disturbed by cultivation. When seen in section, about 3 inches of very pale brown to light brownish grey loamy coarse sand with very faint humous staining is underlain to the depth of 6–12 inches by pale brown to brown less humous loamy coarse sand. Both these layers have developed a weak crumb structure and overlie 3–4 feet of light brown to reddish yellow coarse sandy loam to coarse sandy clay. Below 4 feet the horizon is mottled and commonly consists of sand grains, gravel and iron concretions weakly cemented by iron to form a weak seepage iron pan (plinthite)

In the eroded phase of the series this last horizon may be encountered at 2–3 feet from the surface. Also, seepage iron-pan is not always present but may be replaced by a thin stone-line separating the colluvial material from the underlying mottled weathered substratum.

Suitability for Agriculture

Compared to Varempere series, Tafali soils are more sandy and more porous and consequently have a slightly lower moisture-retaining capacity. External drainage is slow and it is moderately well drained internally for the first 3–4 feet. Imperfect drainage occurs below 4 feet at the stone-line or where seepage iron-pan has developed. The soil has no physical disadvantages: owing to the absence of stones or iron-pan it is easy to cultivate and offers a good growing medium for both root and tree crops. It is, however, easily eroded and it is important that adequate erosion control measures are taken during cultivation to counteract this hazard.

The reaction of the series lies around pH 6.3 throughout the profile, i.e. it is slightly acid. Organic matter supply is very low and base exchange capacity is also very low throughout the profile being less than 3m.e/100 gm in all horizons. Calcium, magnesium and potassium levels are throughout, lower than in Varempere series as the soil is more thoroughly leached and more weathered. Within the top layers, both total phosphorus (72 p.p.m) and nitrogen (.05 per cent) contents are also very low.

Like Varempere series the productivity of the soil is easily improved by the application of farmyard manure and mineral fertilizers, especially nitrogen and phosphate.

Gulo series

The usual degree of slope associated with this soil is 2 per cent. It occurs below Tafali series but above the poorly-drained soils of the valleys. The series is commonly seen on the flanks of streams and depressions where underground water derived from lateral seepage is concentrated. Drainage is imperfect and different stages of groundwater laterite development are seen.

The topsoil consists of 3 inches, more or less, of very pale brown loamy coarse sand underlain by 6 inches or so of brown or light yellowish brown loamy coarse sand. The horizon below is usually indurated or forming an incipient pan. It consists of reddish yellow, yellow and grey mottled coarse sandy loam or coarse sandy clay containing frequent fine quartz gravel, frequent irregular-shaped iron concretions and stains of manganese dioxide. The soil is compacted *in situ* but crumbles fairly easily when a lump is pressed between the fingers. Mottling increases with depth. *Aristida, Eragrostis,* and *Loudetia* spp. are common grasses associated with the series.

The *eroded phase* of Gulo series occurs nearest to the edge of streams and depressions than the normal series. The former can be easily differentiated from the latter by its shallower depth—less than 12 inches—to a more hardened seepage iron-pan. The transition from topsoil to pan layer is usually very sharply defined and occasionally pan may be exposed at the surface. Generally the profile consists of brown or yellow brown loamy sand—3–6 inches thick—overlying light yellowish brown, red and grey mottled seepage pan. Like Gulo series, manganese dioxide staining is frequent and *Aristida, Eragrostis* and *Loudetia* spp. grow profusely on the soil.

Suitability for Agriculture

Analytical data of composite topsoil samples appear to correlate well with *Varempere* and *Tafali* series discussed above, but conceals the fact that at relatively shallow depths incipient pan has often developed and that the high base exchange capacity is due to the concentration of clay fractions in the pan layer. Reaction is moderately acid (pH 5.6 to pH 5.8) in the topsoils becoming slightly acid pH 6.0–pH 6.4) in the indurated horizons below. Owing to the extreme moisture relationships which is either too droughty or too wet, plus the presence of incipient pan at very shallow depths, the soil is not really considered suitable for cultivation.

2. The Tanchera Association

Soils in this association are derived from hornblende granite. They occupy about 640 square miles and are distributed throughout the area. In the past, they were probably the predominating soils of the area but now show in many areas the effects of moderate to very severe erosion (*see* Kolingu and Pusiga associations, page 31).

A catena relationship exists between soils and relief (Fig. 3). Generally, on the upper slopes there are moderately well drained soils (*Puga series*) developed in situ. These soils have shallow, pale sandy topsoils underlain by a subsoil consisting of quartz stones, gravels and iron concretions. These in turn overlie heavy, massive, mottled clay.

Soils on the middle slopes comprise *Tanchera series*. These are imperfectly drained soils which consist of 2–3 feet of pale gritty sandy loam usually underlain by packed iron concretions or seepage iron-pan. These usually overlie decomposed granite.

The soils of the lower slopes (*Pu series*) are somewhat poorly drained, eroded lithosols which usually expose partly weathered rock at or near the surface of the ground.

Other constituent but less important soils of the association are Kolingu, Pusiga and Gulo series (pages 31, 32 & 27). Like the soils of the Varempere association, Kupela and Berenyasi series (pages 33 and 34) complete the association.

Puga series

The series occurs on summit and upper slope sites where slope gradients are 2 per cent or less.

The general appearance of the series, when seen in section, shows a differentiation into a topsoil, subsoil and weathered substratum. The topsoil consists of a foot, more or less, of light yellowish brown coarse sandy loam or loamy coarse sand containing occasional to very frequent fine quartz gravel. The horizon is porous and has a weakly developed subangular blocky structure except for the topmost few inches which is usually crumbly and slightly humous stained.

TANCHERA ASSOCIATION — IDEALIZED SECTION AND SOIL PROFILE DIAGRAMS

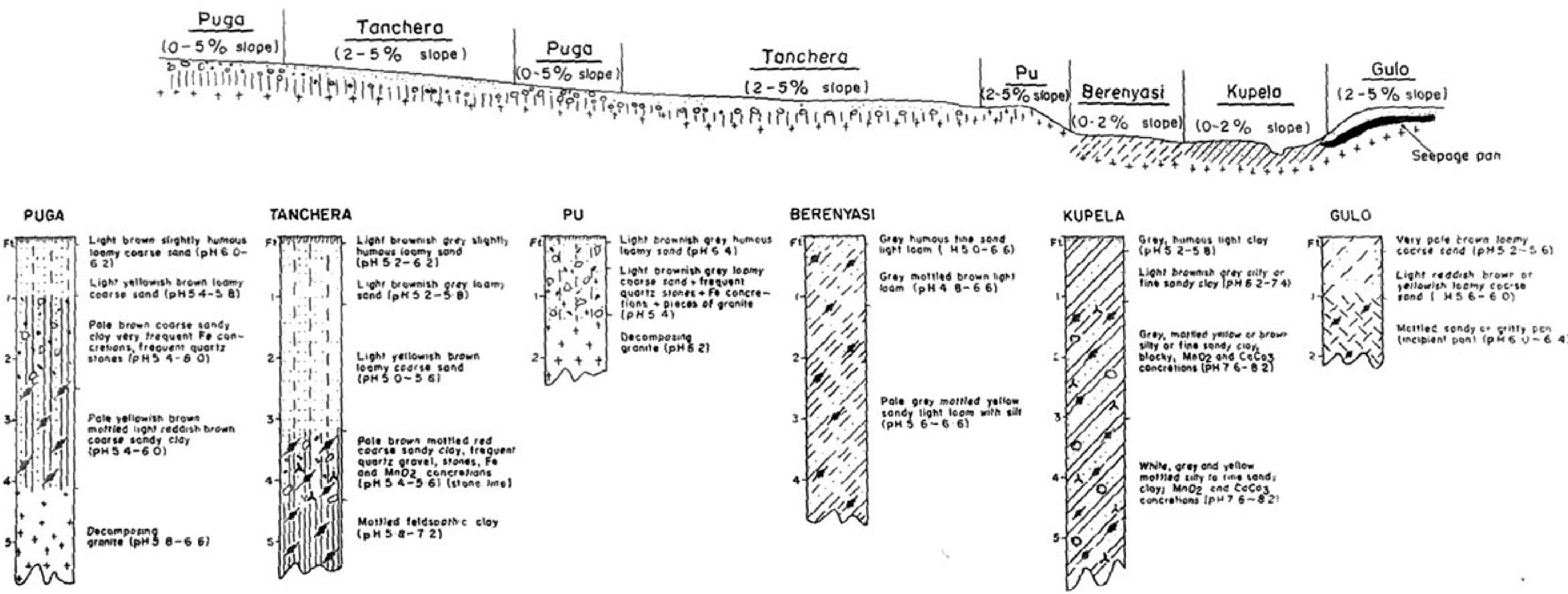


Fig. 3

The subsoil, which extends downwards from 12–26 inches, has very frequent to abundant irregular iron concretions, occasional to frequent quartz stones, fine and medium quartz gravel, and frequent manganese dioxide concretions or staining, all in a matrix of pale brown to light reddish brown coarse sandy clay. The layer has a weak fine granular structure which sometimes dries up hard and cemented.

The transition from subsoil to weathered substratum is usually sharply defined. The upper part of the weathered substratum, from about 26–36 inches, is pale yellowish brown mottled light reddish brown coarse sandy heavy clay in which there are frequent particles of feldspar. On exposure and drying, large prisms are developed. The lower portion of the weathered substratum consists of decomposing hornblende granite which is usually hard and massive.

A very coarse gritty subseries of Puga soils has been identified in some limited areas. These are not unlike Babile series first mapped and reported on during the soil survey of Babile Agricultural Station (Brammer 1956*c*.)

Suitability for Agriculture

The series has a low capacity for retaining moisture. Owing to the sandy nature of the topsoil and the gravelly nature of the subsoil, internal drainage is rapid to the clayey decomposed rock.

The top soil and subsoil, therefore, dry out quickly during dry spells. It is moderately well drained internally and external drainage is good.

The loose, porous, sandy top soil is easily cultivated, but is susceptible to severe erosion. Cultivation should therefore be carried out with great care. Analytical data of the series indicate generally low nutrient reserves as these soils are very thoroughly leached. Like Varempere soils, base exchange capacity within cultivated layers is between 2–3 m.e./100 gm., 50 per cent of the bases present being calcium and the rest mainly magnesium and potassium. Nitrogen present is very low indeed and total phosphorus lies within the range 60–80 p.p.m. Owing to its shallowness, greater rooting depth might be provided by growing of crops on ridges or mounds; in fact, bullock ploughing rather than mechanical tillage is recommended for the soil. Erosion must be reduced by contour ploughing, strip cropping and keeping of a close cover. Farmyard manure, compost or fertilizers should be utilized to maintain fertility and increase moisture-holding capacity. The soil may be developed for grazing or put under tree crops or forest.

Tanchera series

Soils in this series occur on slopes with gradients of 2–3 per cent. They occupy sites varying from lower slopes to middle slopes and, occasionally, on upper slopes. Within the association the series occurs in a spotty manner.

The soil section consists of 2–3 inches of light brownish grey, slightly humous and crumbly loamy sand, underlain by 2–3½ feet of loose light yellowish brown loamy coarse sand or coarse sandy loam which has developed a weak crumbly structure. Below 3½ feet a stone-line or gravel horizon is encountered. This commonly consists of pale brown mottled with red, coarse sandy clay or loam containing frequent fine quartz gravels, occasional quartz stones and usually fine iron and manganese concretions or staining. Below the stone-line, rotten clayey feldspathic granite is encountered. Upon exposure and drying the last two horizons crack widely forming large prismatic blocks.

The origin of the top sandy layer is at present not clearly understood. It is thought, however, to be derived partly from direct weathering of the underlying rock and from local wash.

In the Lawra-Wa area, soils equivalent to Tanchera series are shallow, orange-brown, moderately well drained gritty to sandy clays with mottlings occurring below 2 feet from the surface (*Na series*). These are probably eroded Tanchera soils.

Suitability for Agriculture

The soil is loose, porous, coarse textured and easy to cultivate; however, it is also easily eroded and poorly supplied with nutrients. The sandy top layers are moderately acid, base saturation being 65 per cent more or less. Total cation exchange capacity is 1–2 m.e/100 gm throughout the profile, the figures being considerably lower than those obtained for Varempere series (2–6 m.e). Organic matter level usually averages 0.5 per cent in the top layers but falls sharply in the subsoil layers. Nitrogen content is almost negligible and total phosphorus is about 50 p.p.m.

The series has a low capacity to retain moisture: due to the sandy nature, drainage is somewhat excessive to the decomposed rock and it dries out rapidly during periodic lulls in the rains with adverse effects on crop growth. External drainage is slow.

Being physically a good arable soil, it must be protected against erosion by an adequate soil conserving rotation farming, including contouring, strip cropping and provision of enough ground cover. The tilth and moisture-holding capacity of the soil must be improved by the provision and maintenance of a high content of organic matter. Fertility must be raised by the application of nitrogen, phosphorus and potassium; nutrient losses through leaching must be minimized and burning of grass must be limited or controlled.

The series may be cultivated to almost all the main cash crops grown in the locality, namely millet, guinea corn, maize, groundnuts, bambarra beans, cowpeas and tobacco.

Under present soil management systems in the area, the productive capacity of Tanchera series is limited since the soil has very low base exchange capacity. Crop yield data on treated soils indicate a doubling in yields when farmyard manure is applied at the rate of 4 tons per acre. At higher rates of application there are no further significant increase in yields. The trials by Djokoto and Stephens (1961) on Tanchera soils at Zuarungu Agricultural Station (now State Farm) proved that the serious deficiency in phosphorus could be corrected by the application of super-phosphate and kraal manure together, the manure improving both the phosphate content and the physical properties of the soil.

Pu series

The usual degree of slope associated with this soil is 2 per cent. It occurs near stream and valley edges, usually below Tanchera series but above the poorly drained soils of the bottoms.

The soil is severely eroded so that weathered or partially weathered rock is always exposed at the surface of the ground. It is common in occurrence and widely distributed in the Navrongo–Bawku Region.

Pu soils are lithosols. Usually, they consist of about 6 inches of light brownish grey loamy coarse sand containing frequent medium quartz gravel, iron concretions and pieces of rock brash which overlie highly feldspathic, clayey, incompletely weathered rock.

In some areas the top gravelly layer may be absent so that only rotten rock is exposed, whilst in others, feldspar fragments are present in only very small quantities for the first 18 inches or so. Calcium carbonate concretions have been encountered in occasional profiles and these probably originate from more basic intrusions.

Suitability for Agriculture

In its present physical state, the soil is not considered satisfactory for raising crops. Where the rock is thoroughly weathered, friable and soft it may be utilized for limited hand cultivation or for the production of tree crops. Nutrient reserves are within easy reach of plant roots and the moderate high fertility suggested by the analytical data (page 65) is attributable to the presence of fresh incompletely decomposed rock minerals occurring within a foot or so of the profile. Such nutrient elements are probably not in a readily available form for the use of plants.

Although the soil may be under water in the wet season, it is not retentive of moisture; rain water percolates easily through the thin gravelly layer to the partially weathered rock below and does not penetrate far beyond this. It would be necessary, therefore, when cultivating the soil to improve on the tilth so as to increase its water-holding capacity.

3. THE KOLINGU ASSOCIATION

The component soils of this association are Kolingu, Tanchera, Puga, Pusiga and Pu. Of these Kolingu series is the most widespread being distributed throughout the area. It is a moderately eroded shallow soil* occurring on middle to upper slope sites.

Areas they occupy are frequently broken by rock outcrops and this is especially so west of the area between Ketiu and the river Sisili. In many other areas the soil is easily distinguished by the presence of quartz gravel and stones which frequently litter the ground surface.

Like the Varempere and Tanchera associations, Kupela and Berenyasi soils (pages 33 and 34) complete the association. An aggregate total area of approximately 870 square miles were mapped.

Kolingu series

Two forms of Kolingu series were identified, the normal series and the stony sub-series.

The normal series occurs on slopes having gradients of 2 to 3 per cent. When seen in section, it consists of about 8 inches of pale brown loamy coarse sand containing very frequent fine quartz gravel and, usually, near the lower limit of the horizon, quartz stones and iron concretions which are often brought up to the surface during cultivation. The layer below is thin—6 inches approximately—and transitional to weathered bedrock. It consists of very pale brown coarse sandy clay usually containing very frequent quartz gravel and occasional stones. Frequent iron and manganese concretions and frequent pieces of decomposed granite are included in this layer. From 12 to 24 inches below ground, a coarse sandy clay layer containing frequent to abundant quartz gravel, iron and manganese concretions or stains is encountered; this layer is pale or yellow brown in colour and usually mottled white, red or yellow. It is underlain by decomposed, often manganese-stained, granite.

Variations within the series are those of depth to rotten rock which is usually not more than 24 inches and the absence of iron concretions and stones in some profiles.

The profile of the stony subseries is packed full of angular quartz and/or pegmatite stones and gravels from the surface. The stony character is due to the presence, locally, of quartz or pegmatite veins in the soil. The subseries is not important areally, but typical examples can be seen in the neighbourhood of Chuchuliga and Chana.

Suitability for Agriculture

Kolingu series is not retentive of moisture: rain water percolates easily through the thin gravelly top layer to the slowly permeable clayey decomposing rock below and then moves laterally downslope to valley bottoms. In the dry season, most plants suffer as these soils are droughty.

Kolingu soils may be cultivated but with great care. In order to reduce the risk of erosion and to conserve moisture, contour ploughing, strip cropping and keeping of close cover crop are recommended. Farmyard manure, compost or fertilizers should also be utilized to maintain fertility.

The sub-series of Kolingu is too stony, too shallow and too droughty to be of any significant agricultural value. It is best left uncultivated but relegated to permanent grass for rough grazing.

4. THE PUSIGA ASSOCIATION

The soils in this association are located in three major areas, namely, around Pusiga, north of Bawku and Kulungugu and around Kanjarga in the S.W. Small areas have also been mapped surrounding Kugri hill, Navrongo and Wiaga village. The areas they occupy total about 170 square miles. The main upland soil of the association is Pusiga series but such areas also have Puga and Tanchera soils. On the slopes the series include Kolingu and Pu (pages 31 and 30), and in the valley bottoms Berenyasi and Kupela (pages 34 and 33). Usually the association is characterized by frequent stands of *Acasia spp.*

*The series is probably an eroded shallow phase of Tanchera soils but rather common and widespread to warrant a series name. Kolingu soils were first identified and mapped within the Seilo-Tuni Land Planning Area. *See* Obeng 1963.

Pusiga series

Pusiga soils occur on summit and upper slope sites in low-lying areas where the relief has been subdued by erosion and denudation over a very long period of time. They are lithosols which generally consist of 2–3 inches of slightly nutty, pale brown, coarse sandy loam, containing frequent medium quartz gravel, over 6 inches or less of yellowish brown coarse sandy clay with frequent fragments of decomposed granite. This last layer is transitional to hard and massive partially weathered rock.

The series does not vary much from place to place. In some examples, however, frequent quartz stones may be incorporated in the top weathered horizons or may even occur as gravel or stone pavements on the ground surface. The area surrounding Kugri hill has frequent stones of hard iron-coated sandstone lying about the ground surface. The origin of the sandstone is not at present known but they do not appear to have had any influence on the character of the soils.

Suitability for Agriculture

Pusiga soils have generally lost their organic top soil layers. Although the exposed subsoil has abundant reserves of rock mineral elements these are incompletely weathered and in forms that are probably not readily available to plants. Moreover, the heavy textured nature of the soil induces rapid surface runoff of water in wet periods. They are also easily puddled. On the other hand the soil dries hard and massive, cracking into large prismatic blocks as they are exposed to the sun.

At present limited hand cultivation is practised on these soils but as they are difficult to protect against erosion it is recommended that they should be taken out of cultivation.

5. The Chuchuliga Association

These are areas occupied by more or less bare granitic inselberg ranges, inselbergs and outcrops. They do not include similar areas developed over Bongo granites (*see* Tongo association, page 37). They are lithosols showing no particular profile development and having little agricultural value. Pressure of population has compelled people to cultivate small but frequently occurring pockets of Kolingu, Tanchera, Pusiga and Pu series which are component soils of the association. All the areas occupied by the association total approximately 60 square miles.

6. The Wenchi Consociation

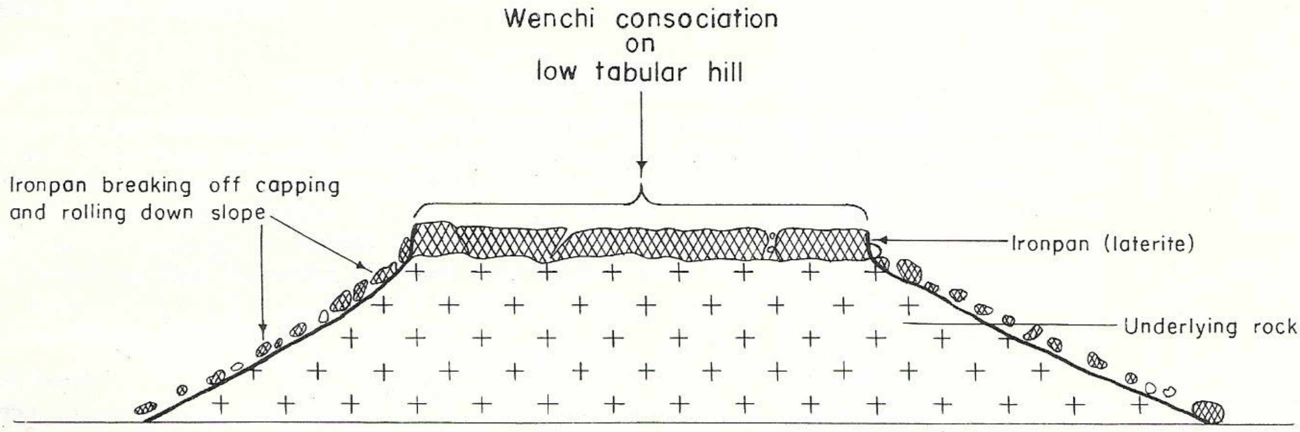
Wenchi consociation is a crustal soil occurring on summits of small, isolated tabular hills (buttes) which rise approximately 40 feet above the surrounding topography. Several examples encountered within the area occur between 5–20 feet above the present land surface and these are degraded remnants of the former. The parent material of Wenchi series consists of sheet iron-pan (laterite) which appears to be a relict of a peneplain mantle probably belonging to the mid-Tertiary age.*

A normal profile is characterized by the presence of ironpan within 12 inches of the surface. The iron-pan cap itself is about 5–10 feet thick and overlies mottled highly indurated weathered rock. Quite frequently, the iron-pan is exposed but not continuous as it may be fissured into large cubic blocks which fall off the rim of the hills and accumulate on the slopes (*see* fig. 4). The vegetation is often scanty, consisting mainly of short grasses and low shrubs.

Suitability for Agriculture

Wenchi soils have physical limitations for cropping and are best left under grass for rough grazing. They have extreme water supply relationships, being very droughty in dry weather and being temporarily flooded or waterlogged in heavy rainstorms. The areas they occupy are sometimes suitable as building sites and the pan can in suitable examples be quarried for the construction of buildings.

* Nearly all the papers dealing with the age of laterite assign it to the Tertiary (Miocene and Pliocene). *See* "Geographical Review" page 415 for a comprehensive list. This date also correlates with King's African surface.



IDEALIZED SECTION ILLUSTRATING WENCHI CONSOCIATION

Fig. 4

7. The Wenchi Association

The summit and slope soils included in this association are Wenchi, Puga, Tanchera, Pusiga and Pu series (pages 28, 29, 32, and 30). In the valley bottoms Berenyasi (page 34) and Kupela soils are common (page 33). The upland soils do not conform to any recognizable catenary arrangement, but whilst Wenchi and Puga soils are both widely and, more or less, equally distributed, Tanchera series occur in a spotty manner.

Wenchi soils are characterized by the presence of iron-pan at less than 12 inches from the surface. Although pedologically similar to Wenchi series described earlier (page 32), they are younger (probably late Tertiary) and generally occur on lower-lying undulating land. The association occupies about 60 square miles.

Suitability for Agriculture

As a whole the association is poor for agricultural development due to low nutrient reserves and, especially to the presence of iron-pan which is frequently exposed. The loose, thin, sandy surface layers of Wenchi and Puga soils may be hand cultivated but it is advisable to prepare ridges or mounds in order to obtain greater rooting depth. Such a measure will improve drainage, check erosion and help to conserve moisture. Limited areas of Tanchera soils within the association are, of course, good arable lands but occasionally have iron-pan outcrops and would also be more suited to bullock ploughing or hand cultivation.

8. The Berenyasi—Kupela Association

Berenyasi and Kupela soils are local alluvia derived from granites other than those of the Bongo suite. They occur near and along the bottoms of all the numerous minor valleys and are usually of variable extent, ranging in width from a few feet to more than 100 yards so that the sum total of the areas they occupy is considerable. The soil map accompanying this report shows only those areas which could conveniently be mapped on the scale employed. Usually Berenyasi series occur at the base of slopes and flank both sides of Kupela series at the valley bottom (*see* Figs. 2 and 3). Along larger streams—e.g. the Tamne river—the association includes small areas of Pani and Dagare series the (pages 50 and 48).

Kupela series

This poorly drained alluvium occurs on nearly level land where slope gradients are 1 per cent or less. It generally, consists of about 3 inches of grey humous silty fine sandy clay with hard crumb structure, underlain by about 9 inches of light brownish grey silty to fine sandy clay. The subsoil consists of grey, mottled yellow or brown silty or fine sandy clay, sticky when wet but cracking widely into large blocks on drying. Occasionally included in the subsoil are fine manganese dioxide and calcium carbonate concretions. In some profiles the texture tends to lighten below 3 feet of the surface, whilst in others the subsoil overlies weathered rock.

Suitability for Agriculture

Both external and internal drainage conditions are slow; the soil is seasonally waterlogged but dries out during the ary season.

The series often supports medium to tall grass. Though not so difficult to work by hand or mechanical implements, it is seldom cultivated except for occasional rice or for dry-season rough-grazing.

It is slightly to moderately acid in the surface horizons, becoming neutral to moderately alkaline below. In profiles which have calcium carbonate accumulations, the reaction may be pH 8.5 or higher. Base exchange capacity is fairly high (5–10 m.e/100 gm or more in the top and subsoil layers) and calcium in particular is in good supply. Organic matter content of about 2.5 per cent within the first foot of the profile is moderately high and comparatively better than most soils associated with the series. This remark applies to the level of total phosphorus which lies within the range 200–300 p.p.m. The content of nitrogen, however, is very low. The percentage of soluble salts (sodium) in some instances, is more than .15 and this could be injurious to many crops unless irrigated or periodically flushed with water to remove salts. The high sodium content accompanied by an increase of calcium and magnesium is indicative of fluctuating water-table conditions of the series.

Water control measures, including the construction of dams, ponds, drains, ditches and bunds are to be provided when cultivating Kupela soils. Water stored behind dams and in ponds may be utilized to irrigate the soil for the production of rice, sugar-cane, pasture and for dry-season vegetable farming. The fertility of the soil may be maintained and improved by the application, especially, of nitrogenous and phosphatic fertilizers and by the addition of farmyard manure (organic matter). Such organic manure will also preserve and improve soil structure and prevent the soil from puddling. The soil should not be worked when too wet or too dry.

Berenyasi series

The series occurs on low somewhat poorly drained sites where slope gradients are usually 1–2 per cent.

Generally, it is more sandy than Kupela series. The first foot of the profile consists of grey strongly mottled brown loam with medium hard crumbs, underlain by approximately 3 feet of whitish grey mottled reddish yellow fine sandy loam to loamy fine sand. Locally, there may be layers of clay in the profile.

It appears, in some profiles, that the top few inches have been derived in part from local hill wash.

Suitability for Agriculture

The series is more acid than Kupela soils. Top soils are strongly acid (pH 5.1), and subsoils very strongly acid (pH 4.85). Both have base saturation generally below 50%. In some profiles however, horizons below the subsoils are less acid. Like Kupela series, organic matter status is moderately high (2.4 per cent) and total exchangeable bases is correspondingly fair (2–4–m.e/100 gm). Below the top soil, however, both organic matter content and base exchange capacity progressively decrease down the profile. The main effect of leaching is on potash; calcium and magnesium being present in moderate quantities. Compared to Kupela soils, total phosphorus is very low (about 50–100 p.p.m) being about 50 per cent less than that normally present in Kupela soils. Nitrogen and probably phosphorus would therefore be required to raise and maintain fertility.

Berenyasi soils are liable to seasonal waterlogging or flooding for varying periods, but generally become thoroughly dry during the dry season. In fact, it dries more rapidly than Kupela soils which have clay surface horizons. The soil is easily cultivated by either machines or by hand and is considered suitable for millet, guinea corn, maize, groundnuts, bambarra beans, cowpeas and tobacco. In years of exceptionally high rainfall, however, the water-table may rise too high for the satisfactory growth of crops requiring better soil drainage. It is even possible that with adequate water control measures the soils would produce well, mangoes, citrus, bananas, pawpaw, guava, kapok and a variety of vegetables.

As the soil is erodible, contour ploughing, strip cropping, rotation farming, cover crops and the incorporation of organic matter to the soil during cultivation are recommended.

9. The Bongo Association

The Bongo group of soils are developed over Bongo granites. These granites are confined to a small area north of Bolgatanga and west from Bongo. They also form part of the Tongo hills. In the Bongo-Bolgatanga area, they are characterized by numerous groves of Baobab trees. The association occupies nearly 55 square miles.

The parent materials of Bongo soils have, from early times, been known to be very productive; a fact perhaps attributable to the high potash and phosphate contents of the parent rock. On these soils human population densities are high, being more than 450 persons per square mile in some localities.

Owing to a very long period of intensive farming accompanied by mismanagement of the land, soil exhaustion and erosion are prevalent in many areas. Over wide expanses very severe erosion has resulted in the formation of lithosols.

IDEALIZED SECTION AND PROFILE DIAGRAMS ILLUSTRATING SOILS OF THE TONGO AND BONGO ASSOCIATIONS

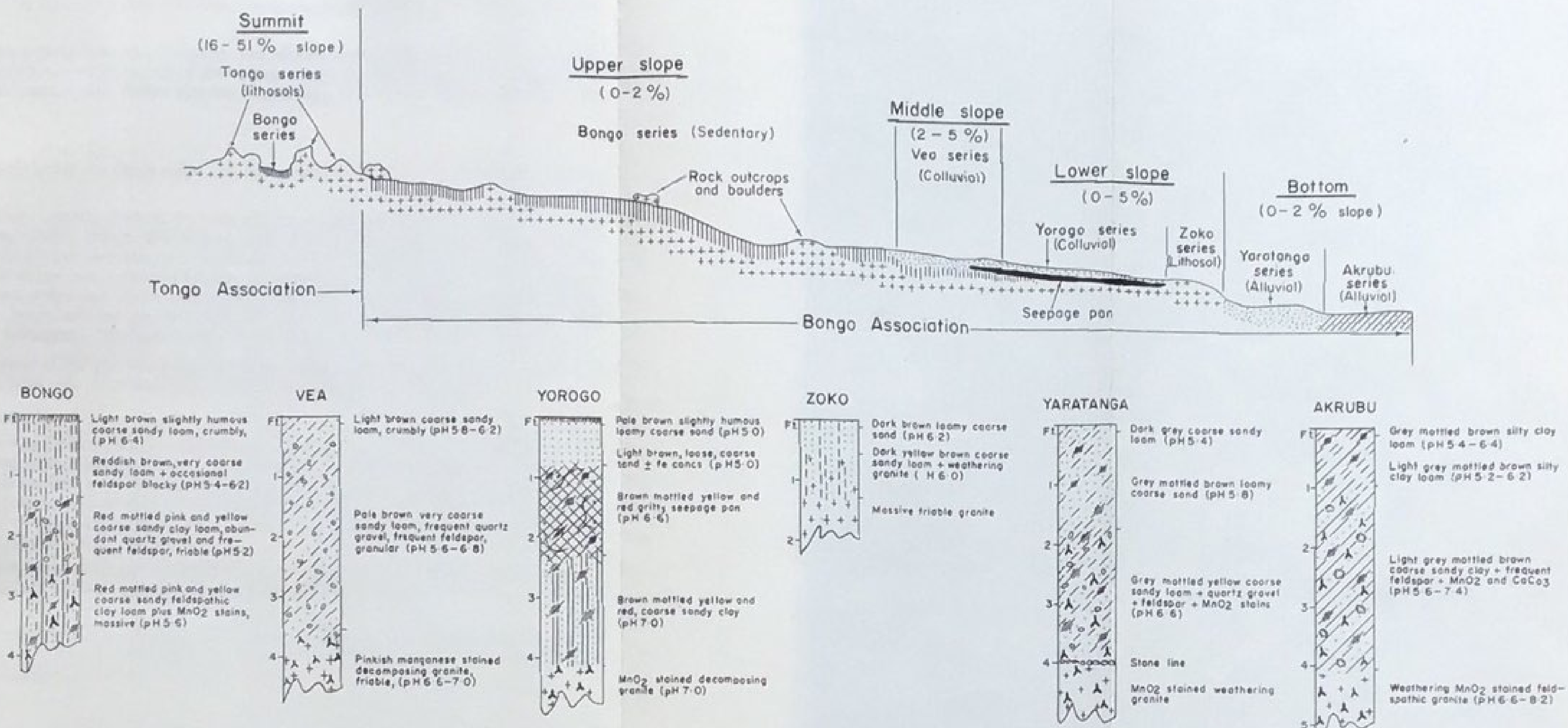


Fig. 5

On summit and upper slope sites, the commonest soils are *Tongo* and *Bongo series*. The former are lithosols, consisting primarily of rock outcrops which do not usually occupy large areas (page 37). The latter are moderately well drained coarse textured soils occupying larger tracts of land on middle and upper slopes and less frequently on summits.

Lower slope soils comprise *Yorogo* and *Zoko series*. Yorogo soils are groundwater laterites consisting of shallow pale coloured very coarse sands (colluvial), overlying gritty seepage iron-pan. Zoko series are poorly-drained, eroded, lithosols occurring near valley edges and usually exposing partly weathered rock on ground-surface.

On the upper part of drainage grooves are found moderately deep, brown, very coarse sandy loams (*Vea series*).

Soils of the valley bottoms comprise *Yaratanga* and *Akrubu series*. Both are poorly drained soils, but whereas the former is composed mainly of grey coarse sands, the latter is made up of grey coarse sandy clays. Idealized section with profile diagrams illustrating soils of the Bongo association are shown in Fig. 5.

Bongo series

Bongo soils usually occur on upper slope and flat summit sites where slope gradients do not exceed 2 per cent.

Generally the profile consists of about 3 inches of very slightly humous-stained, crumbly, coarse sandy loam overlying reddish brown, fine blocky, very coarse sandy loam containing occasional incompletely weathered feldspar particles to a depth of about 12–18 inches. The horizon below extends to a depth of about 30 inches and consists of friable, red, mottled pink and yellow, coarse sandy clay loam containing abundant fine and coarse quartz gravel and frequent incompletely weathered pieces of feldspar. It grades below into red, mottled pink and yellow, coarse sandy clay loam of partially decomposed granite. Commonly, this layer is massive and stained black with manganese dioxide.

In the shallow phase of the series incompletely weathered primary minerals occur abundantly in the surface horizons. Such soils occur near rock outcrops and on severely eroded sites.

Suitability for Agriculture

Bongo soils are well drained, friable, porous and possess good tilth; consequently they have good water-holding capacity. Top horizons are near neutral in reaction (pH 6.2–pH 6.4) but lower layers are slightly to moderately acid (pH 5.4–pH 5.6). They are inherently fertile but for the most part farmed more or less continuously so that they are lacking in organic matter and nitrogen. The soil is rich in phosphate, however, but it is unknown how much of this is available to plants. Base exchange capacity is reasonably high (3–8 m.e/100 gm soil).

The present low fertility can easily be improved by the application of organic and nitrogenous fertilizers which are in short supply. Organic manure would also improve structure and increase water holding capacity.

Owing to frequent granite outcrops, hand and bullock plough cultivation are recommended on these soils. On all Bongo soils, and particularly on the shallow examples, greater rooting depth might be provided by growing crops on ridges or mounds.

Vea series

These soils occur as small isolated patches on the upper parts of drainage grooves and on slopes varying between 2–3 per cent. Generally, they have profiles which consist of 3–4 feet of pale brown to brown granular very coarse sandy loam with frequent fine and coarse quartz gravel and frequent particles of feldspar. This transported material grades below into pinkish, manganese-stained, friable, weathered granite.

In most profiles examined, humous colouration is noticeably absent from surface horizons. In a few others, the series may be poorly to imperfectly drained below 4 feet.

Suitability for Agriculture

Vea soils are more light-textured and more porous than Bongo series, consequently they have a slightly lower moisture and nutrient retaining capacity. They are moderately well drained, but somewhat poorly drained at about five feet or more. They have few physical disadvantages, so that they are easily tilled and offer freedom of root development. The soils may be developed together with Bongo series as they do not usually occupy large enough tracts of land.

The series have slightly acid to near-neutral reaction throughout the profile (pH 6.2–pH 6.6), Organic matter supply is very low and so is base exchange capacity (4-5 me/100gm). Like Bongo series. phosphate mineral—available phosphate is probably very small—is in good supply but nitrogen content is very low. The latter two elements will be required in addition to organic manure in order to raise the productivity of these soils.

Yorogo series

The usual degree of slope on which these soils are found is about 2 per cent. They occur at lower levels than Bongo and Vea series but above the poorly drained soils of the valleys (Fig. 5). Commonly they are seen near to the edges of streams and depressions where water derived from lateral seepage is concentrated. Drainage is imperfect and different stages of groundwater development are seen.

When seen in section the profile consists of about 3 inches of very pale brown, slightly humous, loamy coarse sand, overlying, light brown, loose, coarse sand to the depth of 9 inches. These layers may contain occasional to frequent iron concretions and overlie brown, mottled yellow and red, gritty, seepage pan to 2–2½ feet. The pan is followed below by brown, mottled yellow and red, coarse sandy clay loam which grades at about 4–5 feet into manganese-stained decomposing granite. Transitions to horizons above and below the pan layer are usually sharply defined.

Suitability for Agriculture

Analytical data on the series show generally low nutrient reserves, especially in nitrogen and organic matter. Acidity decreases with depth (pH 5.0–pH 7.0) whilst base saturation has an opposite trend, i.e. from about 50 per cent in the surface horizons to over 90 per cent in lower horizons. The soil is subject to extreme wet and dry conditions; this and the presence of seepage pan at very shallow depths make the series unfavourable for cropping.

Zoko series

The series commonly occurs on stream and valley edges usually in a higher position than Yaratanga series described below; but at a lower level than Yorogo series described above (Fig. 5). The slopes on which it is seen vary between 2–3 per cent. It is a poorly drained severely eroded soil (lithosol) pedologically similar to Pu series (page 30). Like Pu series, weathered rock is always exposed at ground surface.

Zoko series consists of about 4 inches of slightly crumbly dark brown loamy coarse sand with occasional quartz gravel and fragments of feldspar, over 3–4 inches of dark yellowish brown coarse sandy loam containing pieces of partially weathered Bongo granite. This layer grades into massive friable rock.

Suitability for Agriculture

Zoko soils generally have little or no organic matter. Although nutrient reserves are within easy reach of plant roots as is shown by the relatively fairly high values of phosphorus, calcium and potassium, they are probably not in a readily available form. The series is poor to imperfectly drained and has a rapid surface run off. It dries out deeply, however, in the dry season.

At present limited hand cultivation is practised on them but it is recommended that they be taken out of cultivation owing to difficulty in protecting them against erosion.

Yaratanga series

These poorly drained coarse sandy alluvia occur quite extensively on lower slope to bottom sites on slopes usually not greater than 1.5 per cent.

Yaratanga soils generally consist of about 1–2 feet of grey, mottled brown slightly humous, loamy coarse sand, overlying to a depth of 5 feet, more or less, light grey, mottled pale yellow, loamy coarse sand with quartz gravel, abundant feldspar particles, and occasional black stains of manganese dioxide. The substratum consists of manganese-stained weathered granite which is in some profiles separated from the horizon above by a gravel or stone-line.

Commonly, some profiles are more sandy throughout but others may be stratified with layers (lenses) of coarse sandy clay of variable thickness.

Suitability for Agriculture

The series is poorly drained and liable to be waterlogged or flooded in wet periods. It is, however, not as retentive of moisture as its associate, Akrubu series, described below, so that it is droughty early in the dry season. The topsoils are strongly acid (pH 5.2–pH5.4) and the subsoils slightly acid to near neutral (pH 6.4–pH 6.6). Organic matter content is low and the soil is generally poor in nutrients. Base exchange capacity is also low but slightly better than Bongo, Vea or Yorogo series. The soil is suitable for dry season vegetable growing and also for the cultivation of rice and sugar-cane but water control measures would be required in addition to the application of nitrogen and phosphatic fertilizers.

Akrubu series

This poorly drained valley bottom soil found on nearly level land is developed in mixed alluvium of clay and coarse sand.

The profile consists of a thin top layer (0–3 inches) of grey silty clay loam mottled brown with rust, underlain by light grey, mottled yellow, silty clay loam with fine quartz gravel to a depth of 12 inches or less. The subsoil consists of 4 feet or more of light or olive grey mottled brown coarse sandy clay containing frequent feldspar particles. In some profiles occasional manganese dioxide and calcium carbonate concretions are included in the horizon and become frequent with depth. It dries hard, cracking widely into blocks. Below the subsoil lies weathered highly feldspathic manganese dioxide-stained granite. In some examples, however, the subsoil is underlain by coarse loamy sand.

Suitability for Agriculture

The series is liable to seasonal waterlogging or flooding for varying periods, but generally becomes thoroughly dry during the dry season. It can be cultivated either by hand or using mechanized methods.

It is slightly to moderately acid near the surface but gradually becomes slightly to moderately alkaline towards subsoil and rotten rock layers. Generally, the soil is much better provided with nutrients than the associated Yaratanga soils and also the adjoining upland soils. Total exchangeable bases is moderately high and the levels of calcium, potassium and magnesium are all satisfactory. Total phosphorus supply is also moderately high and it is likely that a fair fraction of this is available to plants.

The soil would be suitable for dry season vegetable growing and for swamp rice cultivation but rrigation water would be required to supplement the natural rainfall. To improve on the tilth and ertility organic manure, phosphorus and nitrogen fertilizers would be required during cultivation.

10. The Tongo Association

These areas—approximately 10 square miles—are occupied by Bongo granite outcrops, inselbergs and inselberg ranges (Fig. 5). They are lithosols showing no definite horizon differentiation and having, for the most part, no vegetative cover. Usually, however, numerous groves of baobab trees occur amongst the outcrops in cracks and gullies, where there is sufficient unconsolidated material for the roots to establish themselves. Want of arable land compel local inhabitants to cultivate small but frequently occurring pockets of Bongo series (page 35) which occur as component soils of the association.

II—SOILS DEVELOPED OVER BIRRIMIAN ROCKS

11. The Mogo Consociation

Mogo series are lithosols developed over volcanic rocks, mainly Birrimian greenstones, andesites, schists and amphibolites. They occur on steep upper slopes (16 per cent and over) and rounded summits of hill ranges which rise 800–1,000 feet or more above sea level, i.e. 300–400 feet above the surrounding lands (Fig. 6). The consociation occupies an aggregate total area of a little over 30 square miles, most of them found on the hills seen north of Bawku and Zebilla and around Nangodi. These soils are young and therefore show no horizon differentiation. They are too shallow to support any trees but a thin cover of grass usually occurs on the windswept slopes. The steep slopes and the almost bare hard surface rock induce very rapid surface runoff resulting in drought, so that these soils have little agricultural value or potentiality except perhaps for poor rough hill grazing.

12. The Nangodi Association

Soils in this association are derived from similar rocks as those of Mogo consociation described above. They occur at the foot slopes of hill ranges at a lower level than Mogo series (Fig. 6). Over 150 square miles of the soils were mapped in the same localities where Mogo soils are found.

Component soils of the association are Nangodi, Dorimon, Yagha, and Kalini series. *Nangodi series* are brashy lithosols formed partly from the disintegration of the underlying rock. *Dorimon* soils are more mature soils occurring patchily within the Nangodi areas. They consist of reddish brown silty clay containing frequent polished ferruginized brash and overlying at some depth in the profile mottled silty clay. Lower slope colluvium (*Yagha series*) consists of moderately deep greyish yellow silty clays with lime concretions at depth. At the bottoms of depressions, very dark grey to black alluvial clays (*Kalini series*) are found.

Nangodi series

Nangodi soils generally occur on strong slopes (9-12 per cent). They consist of abundant greenstone brash with some quartz stones in a matrix of brown to reddish brown silty clay. The brash increase in size with depth and overlie weathering greenstone at 2–3 feet. In some examples, the profile contains abundant spheroidal weathering greenstones of variable dimensions.

Suitability for Agriculture

The parent rocks of Nangodi soils are inherently fertile. Although very stony, they are intensively farmed almost continuously. Root penetration is fairly easy because of the steep angle of dip of the schistose cleavage planes of the underlying rocks. The traditional crops grown on these soils are guinea corn, millet and groundnuts. Brammer (1955) also reports of similar soils being cropped successfully to cotton in Upper Volta. In cultivating them, the stones are shifted into contoured heaps against which the soil packs forming terracettes. This practice provides greater rooting depth for crops and reduces surface run-off as well as helping to conserve moisture. Total cation exchangeable capacity is high and so are base saturation and total phosphorus. From the analytical data it appears that nitrogen, organic matter and dry season drought are the main limitations of the series.

Dorimon series

This soil occurs on upper-slope and summit sites in areas predominantly occupied by Nangodi series. The section consists of 2–3 inches of dark brown humous and crumbly fine sandy loam overlying 12–18 inches of porous and slightly firm layer, containing frequent to abundant irregular-shaped ferruginized rock brash and iron concretions in a matrix of reddish brown silty clay loam. It grades below into an indurated yellowish red, mottled yellow silty clay containing frequent rock brash and quartz stones. The layer just described overlies at depth grey and red mottled silty clay which shows stains of manganese dioxide and occasional pieces of incompletely weathered greenstones.

In some profiles iron-pan boulders are included in the subsoil or may lie near the surface.

Dorimon soils were first encountered within the Seilo–Tuni Land Planning area (Obeng 1963).

IDEALIZED SECTION AND PROFILE DIAGRAMS ILLUSTRATING SOILS DEVELOPED OVER BIRRIMIAN ROCKS MOGO CONSOCIATION AND NANGODI AND YAGHA ASSOCIATIONS

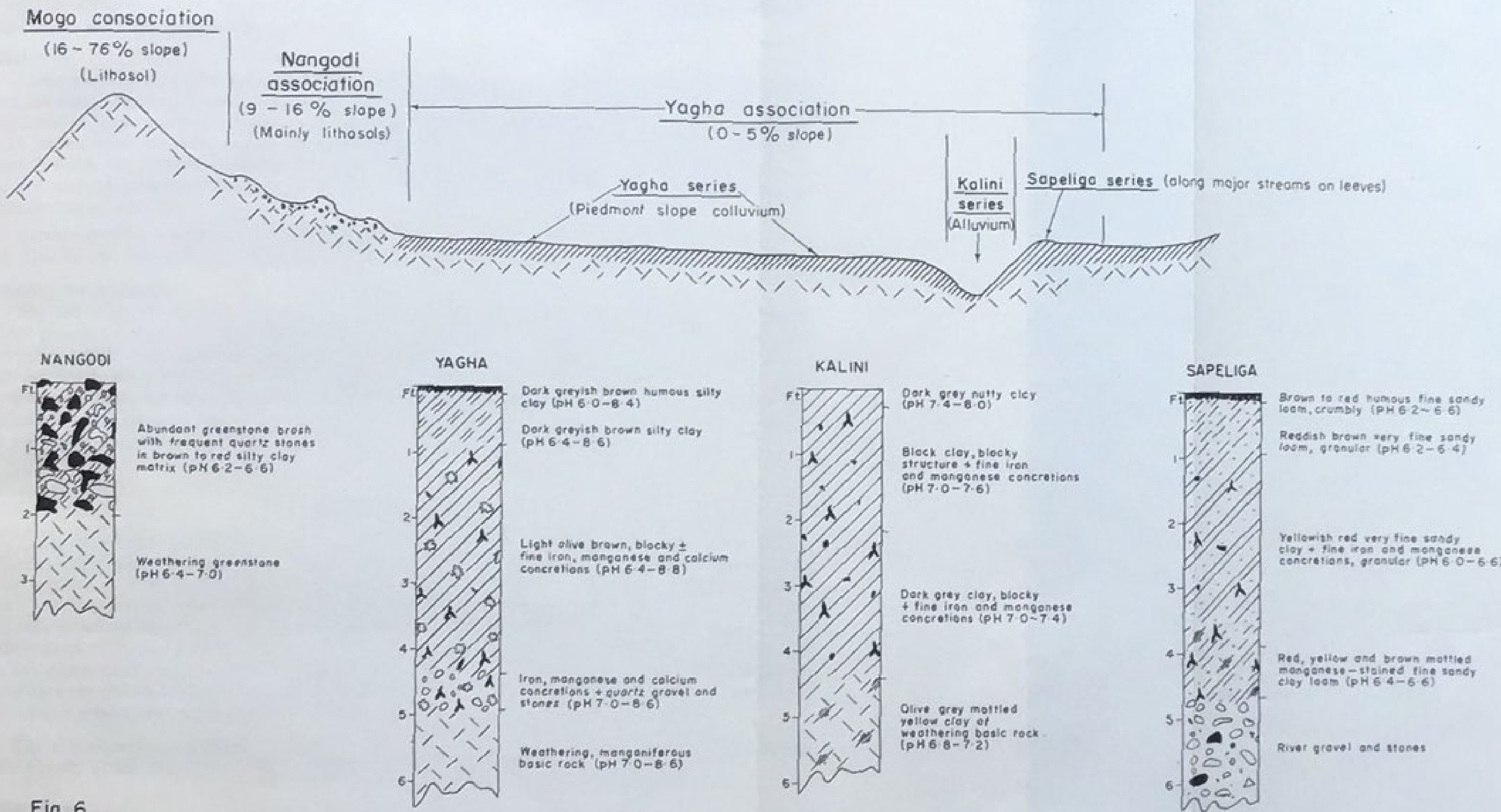


Fig. 6

Suitability for Agriculture

Analytical data for Dorimon soils (page 89) show a rather low fertility. Phosphorus and nitrogen are particularly deficient. Top soils are generally slightly acid; lower horizons are rather less acid and reaction values lie around pH 6.0. Tillage of the soil is easy if no iron-pan boulders are included in the surface layers. They are well drained but moisture relationships are poor as surface runoff during rains are high. Top soils tend to be droughty and subsoils have poor retentive properties owing to the presence of ferruginized brash and the formation of indurated layers.

Yagha series

This is a piedmont slope colluvium consisting of dark greyish brown very fine sandy clay underlain by light olive brown cloddy, plastic clay containing lime concretions at depth. The series is more fully described under Yagha association (*see* below).

Kalini series

These soils occur at the bottoms of depressions on slope gradients not exceeding 1.5 per cent. They are alluvial in origin and comprise an upper top soil of very dark grey nutty clay, 3–4 inches thick, over a lower top soil consisting of black clay with medium blocky structure to the depth of 18–24 inches. Both top soils contain occasional fine polished iron and manganese concretions. From below 2–4 feet, the horizon consists of dark grey subangular blocky clay, also containing occasional fine iron and manganese concretions. It usually overlies olive grey mottled yellow and brown clay of decomposing greenstone.

In some profiles a layer of iron and manganese concretions with some quartz gravel and stones may separate the decomposing sedentary rock from the overburden of transported material.

Suitability for Agriculture

The soil is poorly drained; on the other hand, it dries hard and compact showing wide cracks on the ground surface. It is little farmed at present except for an occasional dry-season vegetable garden for which supplementary water is normally obtained from dams, ponds and wells. It has a high nutrient-holding capacity and well supplied with calcium and magnesium (*see* page 77). Total phosphorus is high, but the proportions available to plants are not yet known. With adequate water control and usage measures and proper tillage, including the provision of organic manure and nitrogen, the soil can be cropped almost continuously and high yields can be expected.

13. The Yagha Association

The principal soil, occupying more than 60 per cent of the association, is *Yagha series*. It is a piedmont slope colluvium occurring, usually, below soils of the Nangodi association (Fig. 6). The series consists of dark greyish brown very fine sandy clay underlain by light olive brown cloddy, plastic clay containing lime concretions at depth. Commonly, small outcrops of greenstone are encountered within the Yagha tract. Around such outcrops are found *Nangodi series* (page 38) and shallow phase of Yagha. *Sapeliga series* is a mature levee soil occurring along the major streams traversing this association and comprises yellowish red, manganese spotted, sandy clay loam sometimes overlying river gravel at depth. Soils of small valley bottoms comprise very dark grey to black silty clays (*Kalini series*) more fully described above.

The soils occupy an aggregate total area of just over 80 square miles and are especially developed in the vicinity of the hills lying north of Bawku and Zebilla and those around Nangodi.

Yagha series

The series occurs on long piedmont slopes with gradients usually less than 2 per cent. It is developed in colluvial material derived from up-slope Nangodi soils.

Generally, the series comprises 0–3 inches of dark greyish brown humous silty clay, nutty or medium blocky in structure, over dark greyish brown silty clay, medium subangular blocky structured to a depth of 10 inches or less. The parent material is usually 4–5 feet or more thick and consists of light olive brown clay, plastic when moist but cloddy and cracking into large blocks on drying. Usually it has occasional fine rust coloured mottlings and fine iron and manganese dioxide concretions. Frequent calcium carbonate concretions may also occur at the base of this layer. The transported parent material overlies sedentary, weathering, manganiferous basic rock (greenstone). Usually the transported and sedentary materials are separated by a layer of iron, manganese and calcium concretions with some quartz gravel and stones.

The shallow phase of the series is closely similar to that just described, but weathering rock is usually encountered within 18–24 inches of the surface.

Where Yagha soils come into contact with those of granitic origins the admixture of sand tends to lighten the texture.

In some localities frequent quartz stones litter the land surface and are not usually incorporated deeply in the surface layers. The origin of these stones is not clearly known but it is likely that they have rolled down from steep higher slopes to accumulate on the very gentle slopes of Yagha series.

Yagha soils crack widely from the surface when dry and often develop holes approximately one foot wide and deep at irregular intervals. They also appear to have self-mulching properties.

Suitability for Agriculture

The series is imperfectly drained internally. Externally, drainage is very slow. These conditions prevail because of heavy textures and very gentle slopes. The heavy texture makes the series difficult to work especially with hand cultivating implements. It is therefore little farmed at present although the nutrient status is high (*see* page 78). The presence of montmorillonitic clay minerals give the series its characteristic structure and texture; it also ensures a high base exchange capacity, as well as an exceptional water-retaining capacity, though some of this water is not available to plants during the early part of the dry season. Base status is high and the soil is well supplied with calcium and magnesium. Usually, reaction values show a near-neutral to slightly alkaline soil.

Where not badly broken by rock outcrops (Nangodi series), it appears suitable for development with the aid of heavy machinery and might become highly productive provided supplementary water is available in addition to organic manure and artificial fertilizers, especially nitrogen.

Sapeliga series

The series occurs patchily and attenuously on the banks of the major streams traversing the association. It appears to be an old river levee now rarely inundated by river floods.

It has a simple profile; the upper top soil consists of 2–3 inches of brown to red very fine sandy loam, crumbly and slightly humous, overlying a lower top soil comprising reddish brown coarse granular very fine sandy loam which seldom go deeper than 8–11 inches below ground. The parent material usually reaches the depth of 3–5 feet and is free from gravel and stones. It consists of yellowish red, very fine sandy clay, containing fine iron and manganese concretions and having medium subangular blocky structure and grading below into red, yellow and brown mottled manganese-stained fine sandy clay loam. At 6–8 feet, river gravel and stones, mainly greenstones and quartz, are encountered.

Suitability for Agriculture

The series is moderately well drained except in the zone of fluctuating water table at 3–9 feet or more. It has favourable physical properties for tillage, since the soil is easily worked by hand implements and is free of stones. It is, however, poor in nutrients (*see* page 79) and if cultivated, complete fertilizer applications would be required. The main disadvantage of the series is severe dry-season drought, its scattered distribution and small extent in any one area.

14. The Bianya Association

Soils in this association are derived from grey-wackes and quartz-sericite schists. They are comparable to soils of the Yagha association but are slightly more sandy and consequently lighter textured. Areas totalling more than 140 square miles were mapped, all lying west of the Red Volta, near Nangodi, south of Bolgatanga, east of Bongo and north of Navrongo. Elsewhere they have been encountered in the Lawra–Wa area. (*See* Obeng 1963).

The major soils of the association comprise *Bianya series:* a light grey silty or fine sandy clay colluvium, overlying quartz gravel and stones or weathering rock at 2½–4½ feet in the profile. The series as described occupies about 30 per cent of the association. Commonly small areas of rock outcrops give rise to *Nangodi series* (page 38) and shallow phase of Bianya.

Within the association fairly extensive tracts of eroded valley sides often expose on the ground surface frequent stones of quartz, quartzites and rock brash. Soils of the valley bottoms are poorly developed and consist of moderately deep grey mottled brown silty clays (*Pale series*).

Bianya series

The series occurs on nearly level to gently undulating land where slope gradients rarely exceed 2.5 per cent. It is derived from wash from up-slope. The soil is easily identified by the frequent Acasia trees which it commonly supports and by earth-worm casts at the surface.

When seen in section, it consists of about a foot or less of light grey fine sandy clay having a thin (0–3") crumbly and slightly humic surface horizon, over light grey medium blocky fine sandy or silty clay which extends downwards to 30–36 inches. The horizon is mottled brown and yellow, the mottling increasingly becoming frequent towards bed rock. The layer just described is separated from a sedentary manganese-stained weathering clay below, by approximately a foot of iron and manganese concretions with some quartz gravel and stones.

The shallow phase of the series has weathering rock occurring within 12–24 inches of the surface and North of Paga the parent rocks of these soils are underlain by granites.

Suitability for Agriculture

Nutrient status of the series appears slightly inferior to Yagha series although other agricultural properties appear closely similar. The deep Bianya soils, however, are more frequently interrupted by outcrops of Nangodi soils and the shallow and eroded phases of Bianya series so that the association appears somewhat less attractive than Yagha association.

III—SOILS DEVELOPED OVER GRANITIC AND BIRRIMIAN ROCKS

15. The Dorimon—Pu Complex

Soils forming this complex include those listed under Kolingu and Nangodi associations. Kolingu association—granitic—includes Kolingu, Pusiga, Puga, Pu, Tanchera, Berenyasi and Kupela and those comprising Nangodi association—Birrimian—are Dorimon, Nangodi, Yagha and Kalini series. All the soils named have been fully described above under their respective associations (pages 31 and 38). The two soil groups are pedologically unrelated but occur so close to each other that it was not practicable to map each association separately due to the limitation of the map scale used in this report.

The total area mapped, and located a few miles S.W. of Bawku, is approximately 20 square miles.

Suitability for Agriculture

The agricultural values of individual soil series included in the complex have been dealt with elsewhere. For future development, the area occupied by this complex has to be treated together. The area is particularly depleted and not, in many respects, unlike the severely eroded Pusiga association soils found near Bawku. Taken as a whole, it is poor for arable agriculture and can at present only be relegated to poor rough grazing or reafforestation (fuelwood plantation); but this can succeed only when the prevailing severe erosion and severe gullying in the area have been arrested.

IV—SOILS DEVELOPED OVER VOLTAIAN ROCKS

(a) Soils derived from Upper and Lower Voltaian sandstones
(V_3 and V_1)

16. The Mimi Association

Soils in this association form part of the extensively farmed Upper Voltaian (V_3) sandstone area which lies a few miles south from the edge of the scarp. Equivalent and outwardly similar soils are developed over the lower Voltaian (V_1) sandstone areas lying north of the scarp but separated from the former by an altitude difference of from 200–400 feet. Approximately 124 square miles of the association occur in the area, the major portion of it lying E–W from the Togo frontier to the vicinity of Karamenga. They occur again S.W. of the area at Wiase.

The major soil of the association (*Mimi series*) consists of 4 feet or more of reddish coloured piedmont drift soil lying below either very shallow rocky lithosols (*Kintampo series*, page 43), iron-pan (*Wenchi*) soils (page 32) or ferruginous brash *Techiman series* (page 44). Downslope of Mimi series, the soil, (*Murugu series*) consists of mottled yellow-brown sandy clay overlying a ferruginous layer. Along the valley slopes, seepage iron-pan soils (*Nalerigu series*) usually overlie hard sandstone. Nearest to the steep valley sides, sheet and river erosion have often exposed hard sandstone rocks which are pedologically not unlike Kintampo series.

Within the V_3 areas alluvial soils are very poorly developed and occur in a spotty manner owing to marked steepening of valley slopes. Where slopes are less steep, mottled grey loamy sands (*Yaroyiri series*, page 45) occur in the valley bottoms. Within the V_1 areas, however, the topography is less undulating and valleys are broader, so that besides Yaroyiri series mottled grey alluvial clays (*Bombi series*, page 44) are common. In all areas, deep, yellow-brown, sandy, alluvial levees (*Kunkwa series*, page 45) occur along the larger streams. The last three named soils are fully described below, under Yaroyiri association. More detailed accounts of the soils of the Mimi association are also to be found in the report on the Soils of Mimima State Farm (Adu 1963*b*).

Idealized section and profile diagrams, illustrating the soils of this association are given in Fig. 7.

Mimi series

The series is common, and from the agricultural point of view, very important. It occurs as a piedmont drift colluvium usually at a lower level than Kintampo, Wenchi or Techiman soils (Fig. 7).

The normal profile consists of a foot or less of grey-brown crumbly, porous, loamy fine sand, grading into 4 feet or more of uniform, friable, red, firm, porous sandy clay loam. Rock brash or iron concretions are typically absent but may occur at a lower depth as a stone line or seepage pan fragments overlying bed rock. Occasionally, very deep profiles show slight mottlings below 5 or 6 feet.

Some profiles have loamy sandy textures throughout and reflect slight differences in the texture of the parent rock.

Suitability for Agriculture

The soil is deep, well drained, easily tilled and offers freedom of root development. It tends to be droughty, however, owing to water losses, through evaporation and rapid surface runoff during rainstorms. The poor nature of the parent rock has conferred on the soil low nutrient reserves. Organic matter, concentrated in the first few inches of the profile, is generally low—less than 1.5 per cent—and decreases sharply with depth. Base exchange capacity is moderate throughout the profile, being in the order of 3–7 m.e/100 gm soil. Other nutrients are also in poor supply and nitrogen and phosphorus are particularly deficient. Free iron oxide increases with depth: a trend suggesting a tie-up of the element with phosphorus. Surface horizons are near-neutral in reaction but lower horizon are slightly to moderately acid (i.e. pH 5.0–5.2).

The soil is intensively farmed in the locality and is admirably suited to the production of yams, guinea corn, millet and tobacco. Productivity from the soil can be considerably increased by the provision of organic matter, cover crops and artificial fertilizers, particularly nitrogen and phosphorus.

Djokoto and Stephens (1961) have confirmed in their long-term fertilizer experiments, on similar soils at Tamale and Damango, that the main requirements of these soils when cultivating cereals are, nitrogen and phosphorus applied when the pH is high or raised by the addition of lime. For the growth of yams, they recommend organic treatments in the presence of lime and potassium but for groundnuts lime and potassium treatments only.

IDEALIZED SECTION AND PROFILE DIAGRAMS ILLUSTRATING SOILS OF THE MIMI ASSOCIATION

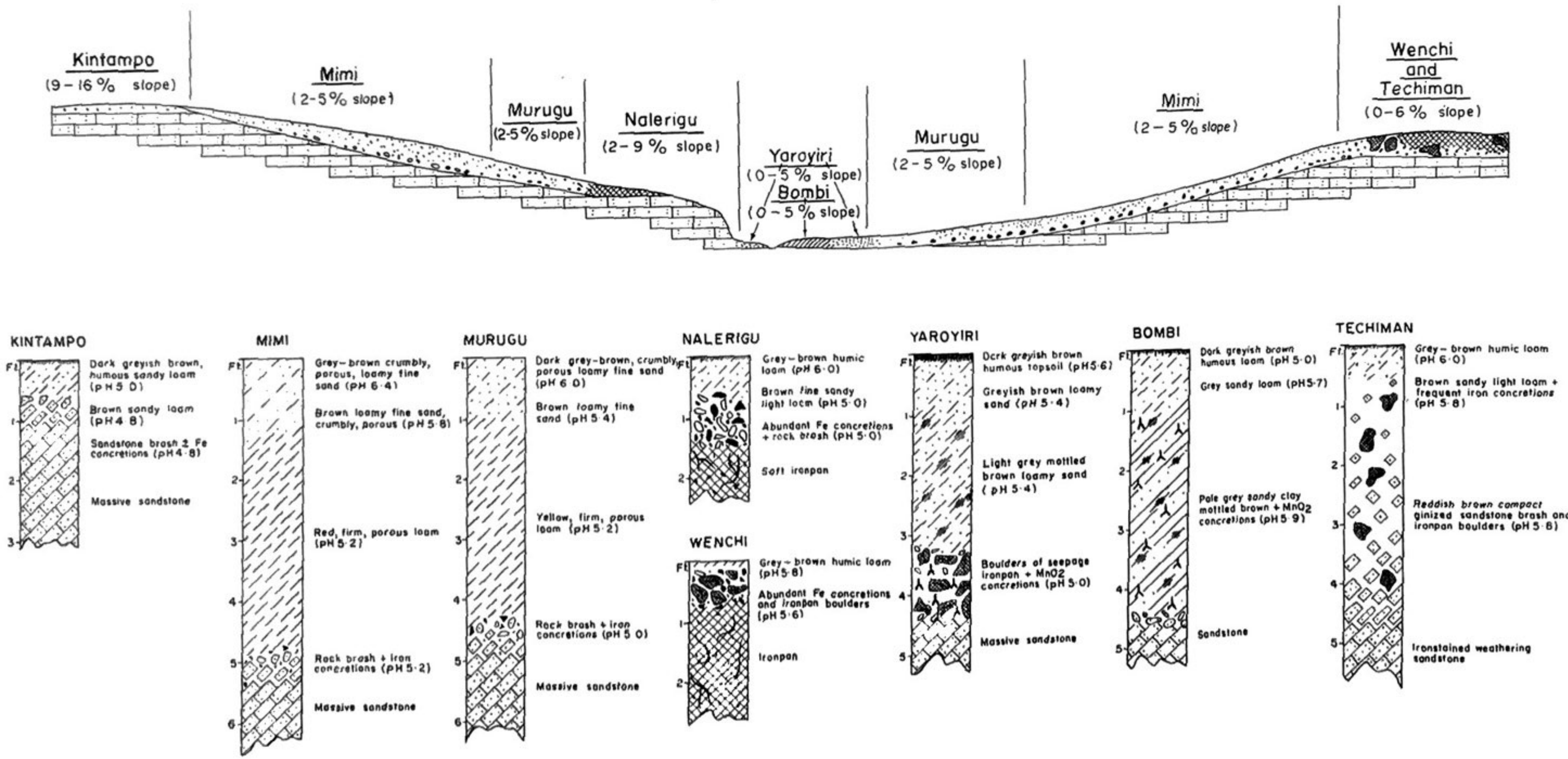


Fig. 7

Murugu series

The series usually occurs as a narrow band downslope of Mimi series from which it has been derived partly as slopewash (Fig. 7).

There are no essential differences between Murugu and Mimi series except for a brown colour which replaces the red colour of Mimi series. The difference in colour is attributable to slightly less perfect drainage. When seen in section, the profile consists of a crumbly, loamy fine sand, 9–10 inches in thickness, over 2–3 feet or more of yellow, occasionally mottled orange to brown, friable, firm, porous sandy loam to medium sandy clay. The layer just described passes below into rock brash or iron concretions. Like the Mimi soils some profiles have loamy sandy textures throughout.

Suitability for Agriculture

The soil is moderately well drained, deep, concretion-free and porous. It can be tilled easily both by hand and by machines. Although susceptible to drought through water losses by evaporation and surface runoff during rainstorms, subsoil layers retain some moisture throughout the dry season.

Nutrient reserves are generally poor as organic matter is less than 1.5 per cent throughout and both nitrogen and phosphorus levels low. Top soil reaction is near neutral but lower horizons have values which lie around pH 5.5. Base exchange capacity of around 4 m.e/100 gm within the humic top layers is only slightly better than Mimi series.

Murugu soils are ideal for the cultivation of yams, guinea corn, millet and tobacco. Like Mimi series, the level of fertility can be raised by the application of organic and mineral fertilizers to the soil during cropping; especially essential are nitrogen and phosphorus. As the soil is even more susceptible to erosion than Mimi series it would be necessary to introduce anti-erosion devices.

Nalerigu series

Nalerigu soils are groundwater laterites which occur downslope of Murugu series. The normal profile consists of 0–9 inches of brownish fine sandy loam, humous-stained for the first few inches at the top, overlying frequent to abundant irregular-shaped iron concretions which give place at about 18 inches to a soft or hard seepage pan layer.

Suitability for Agriculture

The soil is moderately acid throughout the profile and is fundamentally poor in nutrients. It is liable to be waterlogged to the surface at the height of the rains but dries out speedily early in the dry season. The presence of iron concretions and pan near the surface of the ground provide adverse conditions both for mechanized tillage and root growth. Very little farming is practised on this soil.

17. The Kintampo Association

This association of approximately 220 square miles has been mapped on the V_1 sandstone areas lying north of the scarp. The principal soils in the group—perhaps occupying about 80 per cent—are *Kintampo* and *Techiman* series, but there are also limited areas of *Wenchi*, *Mimi* and *Murugu* soils (pages 32, 42 and 43). Soils occurring in the valleys comprise *Yaroyiri* and *Bombi* series described below (pages 45 and 44).

Kintampo series

The series occurs mainly on eroded uplands and commonly along eroded valley slopes. The profile of the series normally consists of about 2 inches of a slightly humous top soil, overlying 8–10 inches of brown fine sandy heavy loam which contains pieces of ferruginized rock brash. Frequent large pieces of sandstone usually separate the top soil layer from massive rock.

Suitability for Agriculture

Because of the shallow accumulation of weathered material, the soil is droughty and poorly provided with nutrients to be of any important agricultural value. They may be developed for townships or best left under tree savanna.

Techiman series

The series occurs extensively on upper slope and summit sites where slope gradients vary between 2–6 per cent. The profile consists of crumbly, brown, loamy sand top soil, 8–12 inches in thickness with a slightly humic thin surface horizon, over reddish brown, very compact, abundant ferruginized sandstone brash which pass downwards at about 4–5 feet into ironstained weathering sandstone.

In many profiles a semi-indurated iron-pan is developed on top of the sandstone. Usually, also, the ferruginized brash layer is contained in a sandy loam matrix; but in some examples such fine earth material is virtually absent. The profile usually includes iron-pan boulders or may have sheet iron-pan at depth, so that the soil is differentiated from Wenchi series by having at the surface more than 12 nches of iron concretions and brash.

Suitability for Agriculture

The soil is permeable throughout, despite the compactness. External drainage is rapid and internal drainage somewhat excessive so that it dries up speedily early in the dry season.

The presence of concretions and brash in the surface horizons and the likelihood of encountering iron-pan boulders near the surface of the ground, provide adverse conditions both for mechanized tillage and root growth. Careless cultivation methods would promote top soil erosion which would lead to the irreversible hardening of the exposed compact ferruginized brash layer to form iron-pan.

Crops recommended for cultivation on this soil are guinea corn, millet, groundnuts, tobacco, pepper, okro, beans and, generally, shallow-rooted crops. The soil is suitable for only limited hand or bullock plough cultivation.

17*a*. The Kintampo Consociation

These are areas of mainly V_3 sandstone outcrops occurring on the scarp summit and forming the drainage divide between the S.E. of the survey area and the Nasia basin. Kintampo series is a lithosol with characteristics similar to that described above (page 43) but many areas expose bare rock outcrops. There is a thin vegetative cover of short grasses and shrubs with stunted trees growing in cracks and gullies where there is sufficient unconsolidated material for the roots to establish themselves. The soils have little agricultural value and have been appropriated for watershed forest reserve. They occupy about 44 square miles.

18. The Wenchi Consociation

These soils are, more or less, similar to the Wenchi soils described earlier (page 32). In this consociation, however, they occur on low-lying land and as usual, comprise small areas of exposed sheet iron-pan (bovals) generally bare of vegetation. The soils are of no agricultural value.

19. The Bombi-Yaroyiri Association

The soils in this association are local alluvia derived from sandstone. Extensive areas occur in the valley of the Morago river as well as in some of the smaller valleys leading away from its right bank.

They comprise deep, grey, mottled brown, sandy clay (*Bombi series*), usually flanked on either side by deep, greyish mottled brown, loamy sands (*Yaroyiri series*). Where undisturbed, these soils support riverain woodland. On the banks of the Morago, however, deep coarse sandy levees (*Kunkwa series*), occur patchily and are characterized by open tall grassland areas within the riverain woodland. The association occupies approximately 20 square miles.

Bombi series

This is a poorly drained soil, developed in transported alluvial parent material. It comprises a foot or less of crumbly, grey, leached, sandy loam with a dark humus staining, over 4 feet or more of pale grey, sandy clay, mottled yellow or brown. Black stains of manganese dioxide occur below 2 feet or so from the surface and medium blocks are also developed in the profile. The horizon may pass below 4 feet or more into a layer of abundant flat pieces of sandstone, partially cemented by iron and manganese.

Most examples of the series contain considerable proportions of silt throughout the profile, but like most alluvial soils, the silt or even sand may be present as definite horizons in the profile.

Suitability for Agriculture

The series is poorly drained and seasonally flooded or waterlogged. However, it retains considerable subsoil moisture throughout the dry season. It is free from stones and coarse gravel, so that it is easily tilled but this is better carried out not when too wet or too dry. In this connection, it would be necessary to introduce water control measures. Under undisturbed riverain woodland, organic matter in the surface layer is high (6 per cent) but falls below 1 per cent within the subsoil layers. Surface horizons are strongly acid (pH 5.2–5.4) and lower horizons are moderately acid (pH 5.6–6.0). Base saturation lies between 40–70 per cent. Total exchangeable bases is rather high (18 m.e/100 gm) in the humic surface layers and moderate (5–10 m.e/100gm) in the subsoils. Most of the bases are taken up by calcium and magnesium but manganese, potassium and sodium are each less than 1 per cent Total phosphorus content of from 279–485 p.p.m. in the surface horizons is moderate.

The soil is suitable for paddy rice, sugar-cane, tobacco and dry season vegetable growing.

Yaroyiri series

The series is a sandy alluvium occurring in association with Bombi series. A typical profile consists of 10 inches of crumbly, loose, fine sand, light brownish grey in colour and slightly humous in the top 2 inches, over, from 10 to 54 inches, light grey strongly mottled brown and yellow loamy fine sand which is loose, porous and crumbly. Below 54 inches, grey strongly mottled orange sandy loam or clay horizons are encountered. In some examples the last horizon may include boulders of soft seepage iron-pan and frequent manganese dioxide concretions at depth.

Suitability for Agriculture

Yaroyiri soils are permeable but subject to seasonal waterlogging. Because of the sandy character, they are easily drained and dry thoroughly early in the dry season although some profiles may retain considerable subsoil moisture at such periods. Like the Bombi series they are moderately acid but acidity decreases towards bedrock. Nutrients appear concentrated within the first few inches of the profile. Base saturation is on the whole moderate. Total exchangeable capacity is low throughout, the value being less than 5 m.e/100 gm soil. Organic matter level is considerably lower than Bombi soils and so is the nitrogen content.

Owing to poor water-holding properties, the series is not as ideal for paddy rice cultivation as Bombi series. With adequate dry season water supply, sugar-cane, tobacco and vegetables are recommended for growth on this soil.

Kunkwa series

This river levee occurs patchily along the major streams of the association. Typical examples consist of very dark greyish brown humous loose fine sand, about 3 inches in thickness, over a less humous loose fine sandy layer extending downwards to a depth of about 18 inches. The remainder of the profile consists of yellow-brown, brown or reddish yellow loose fine sand, 6 feet or more deep and mottled at depth.

Suitability for Agriculture

The soil is highly permeable and has very little capacity to retain moisture. It is therefore droughty so that crops grown on it need to be supplemented by irrigation. The series is thoroughly leached and consequently very poor in nutrients, although the humic top foot or so may hold some meagre nutrient reserves. The top soil reaction is slightly acid but acidity becomes increasingly high with depth.

The soil may be cultivated to tobacco and vegetables.

(*b*) *Soils derived from Voltaian shales* (V_2)

20. The Kpelesawgu Association

Soils in this association occupy approximately 16 square miles in the S.W. part of the area. They form a small portion of groundwater laterite soils which probably occupy very nearly 50 per cent of the interior savanna zone of Ghana and over one quarter of the whole country.

Soils included in the association conform to the following drainage catena: The upland soils (*Sambu series*) comprise shallow, concretionary soils with frequent ironpan boulders occurring on and throughout the profile. Middle and lower slope soils (*Kpelesawgu series*) comprise imperfectly drained yellow-brown, porous, very fine sandy top soil, usually less than a foot thick, overlying ferruginous gravelly clay or hard ironpan. On lower slope to bottom sites, the soils (*Changnalili series*) consist of grey and brown mottled sandy clay or loamy sand containing massive ironstone at relatively shallow depth. *Lima-Volta* soils of the wet bottom lands are developed from transported alluvium. They consist of deep, grey and brown mottled clays or sandy silt and are more fully described below under Lima-Volta association (page 74).

Kpelesawgu association soils were first studied and reported on by the writer (Adu 1957) during a soil survey of the Agricultural Research Institute Substation at Nyankpala (*see* S.L.U.S. Technical Report No. 28).

Sambu series

The series occupies a low summit area surrounding Uwasi village. It is characterized by shale brash in a matrix of reddish brown silty clay loam to more than 12 inches. Frequent boulders of broken iron-pan are usually present and may also be encountered as a continuous hard substratum. The series may be differentiated from Wenchi series by having at the surface more than 12 inches of iron concretions and brash.

Suitability for Agriculture

The soil is at present cultivated to shallow-rooted crops such as guinea corn, millet, groundnuts, tobacco, pepper, okro and beans. Only limited hand or bullock plough cultivation is possible as the presence of concretions and brash in the surface horizons and the likelihood of encountering iron-pan boulders near the surface provide adverse conditions for mechanized tillage.

The soil is permeable throughout and has good drainage both externally and internally. It, however, dries up speedily in the dry season.

Kpelesawgu series

This typical groundwater laterite is by far the commonest of the association. It occurs on very gentle slope gradients usually below Samba series but above Changnalili soils. Below an inch or two of humus-stained top layer the profile consists of a foot, more or less, of porous, greyish yellow, silty or fine sandy loam, having a weakly developed subangular blocky structure, over, from 12–48 inches, very frequent to abundant iron concretions and ferruginized brash of varying sizes, in a pale greyish brown mottled orange silty clay loam matrix. This concretionary layer is massive and on exposure dries up hard and cemented to form pan. It overlies, abruptly, grey and brown mottled clay which within a few inches grades into hard shale or mudstone, manganese-stained along the partings.

The top sandy silt horizon has largely been derived from hillwash. It is, however, non-existent or nearly so in many eroded or disturbed sites.

Suitability for Agriculture

Kpelesawgu soils are imperfectly drained. They are liable to be waterlogged to the surface at the height of the rains, thus restricting root development. On the other hand, they dry out rapidly after the end of the rains and become droughty. These soils have reaction profiles in which the surface layers are near-neutral and lower horizons moderately to very acid. Organic matter contents are generally very low, few exceeding 1.5 per cent in the surface. Available phosphorus is very low, as considerable amounts of this are fixed by the iron in the subsoil. Nitrogen contents are low, and supplies of other nutrients are low because of the low retentivity of soil minerals within root-range.

There is little farming of these soils in the area and elsewhere in the country. Yam and cereals are grown in some localities but appearances suggest low yields as these tend to be drowned out. Attempts at improving drainage by open ditches or subsoil drains tend to increase the irreversible induration of the subsoil to iron-pan.

Other major obstacles to development, besides poor moisture relationships, are the shallow depth of the top soils and their erodibility. Where top soils are deep enough for cultivation to be safely practised, it would be desirable to add farmyard manure in large quantities, of say 4 tons per acre, to the soil in order to help reduce runoff, raise moisture-holding capacity and maintain and build up fertility.

Mechanical cultivation is generally not advisable on these soils because of the presence of boulders which occasionally lie near the surface.

It is difficult to envisage a high rate of productivity being achieved from these soils. They seem best adapted to the production of grass pasture and some early crops. However, the fact that they occur very extensively in Ghana makes it imperative that serious attention be paid to the study of the problems these soils present and to device techniques which might circumvent them and permit increased productivity.

Changnalili series

The series is also a groundwater laterite which occurs on valley edges downslope of Kpelesawgu series. They are yellow-grey mottled brown in colour and have crumbly, porous, silty or very fine sandy top soils, 6–12 inches thick, over massive, compact and manganiferous iron-pan which often extends downwards from 12 to 30 inches or more. Layers below the pan comprise frequent iron and manganese concretions in a matrix of grey and yellow mottled silty clay which pass downwards into manganese-stained decomposing shale or mudstone.

Quite often, erosion exposes the massive iron-pan layer at the surface.

Suitability for Agriculture

Changnalili soils are unsuitable for arable agriculture as they are saturated with water during the wet season and are exceedingly droughty during the dry season. They are also too shallow and too stony and support poor pasture which is available for grazing during the early part of the wet season and early part of the following dry season only.

21. The Volta—Lima Association

These flat valley-bottom soils occur over Voltaian shale and mudstone areas. They commonly occupy narrow as well as very broad intermittent streamways and the sum total of the areas they occupy is far more than the 15 square miles mapped on the accompanying map. Characteristically, they support tree-less tall swamp grass.

Volta series has a rather simple profile which consists of about 6 inches of pale grey, porous, silty or very fine sandy loam with a thin dark slightly humous surface layer, over 4–6 feet or more of grey and orange mottled porous very fine sandy or silty clay.

The morphology of Lima series is similar. It is however differentiated from Volta soils by being lighter textured—sandy rather than silty top soils—and perhaps being better supplied with calcium and manganese at depth. It also shows indications of excess sodium content. Both soils commonly show 'gilgai' micro-relief in areas of excessive wetness.

Suitability for Agriculture

These valley bottom soils are rarely used although they have the greatest potential for intensive agricultural development within the V_2 shale formations of this area and elsewhere. They are comparatively better supplied with nutrients than the associated Kpelesawgu soils. Moreover they have greater value due to their depth and particularly their occurrence on relatively flat land in sites where conditions are suitable for mechanized tillage and where there are possibilities of effecting water control.

These bottomlands are liable to seasonal waterlogging or flooding for varying periods, but generally become thoroughly dry during the dry season.

At present some areas are used for dry-season rough grazing but they appear to provide excellent opportunities for large-scale swamp rice cultivation and dry-season vegetable growing. Rice cultivation is not generally worthwhile if the crop has to rely on the irregular natural rainfall and runoff. It is essential if satisfactory yields are to be achieved to provide for complete water control structures and to improve and maintain the fertility of the soils by the regular use of artificial and organic fertilizers.

(c) Scarp slope soils: derived from a mixture of sandstone and shale

22. The Kpea Consociation

These are scree soils (lithosols) comprising sandstone boulders of varying sizes with some shale debris. They break off the edge of the scarp and accumulate on middle slopes. Rockfall adds to them from time to time and there is a very slow gravitational creep downslope*. The soils occur along the entire length of the scarp from the Togoland frontier to within 12 miles east of Karamenga.

Kpea soils are of no arable agricultural significance. They support a thin grass cover with scattered stunted trees in which game roam freely. Sections of the area these soils occupy have been appropriated for watershed forest reserves.

23. The Klopu Consociation

These are piedmont drifts and outwash fan soils originating from the disintegration of boulders of Kpea consociation. They comprise frequent to abundant medium and small pieces of sandstone and shale in a sandy loam matrix. They occupy the footslopes and the entire length of the scarp to near Karamenga.

The vegetative cover is more luxuriant than on Kpea soils as they have better moisture conserving properties. However, like Kpea soils, they have little agricultural value, although sections of the areas they occupy have been reserved for watershed protection.

V—SOILS DERIVED FROM RECENT AND OLD ALLUVIA OF MIXED ORIGIN

(a) Soils developed from recent alluvial levees

24. The Dagare Association

Soils of this association occur irregularly along the high banks of the White Volta and the Kulpawn rivers. They comprise deep, yellow-brown, loose sands (*Kunkwa series*, page 45) next to and above the river bed, and grey mottled yellow-brown, porous, silty loams (*Dagare series*) a little away from the river bed but usually at a slightly lower level than Kunkwa series. Occasionally included in the association are pockets of deep, greyish yellow, heavy calcareous, clays (*Siare series*, page 49) and well drained old levees consisting of brown (*Lapliki series*) or reddish brown (*Sirru series*) coarse or fine sandy loam. The soils of Dagare association normally support riverain woodland.

Idealized section and profile diagrams illustrating soils developed along the Volta and Kulpawn flood plains is shown in Fig. 8.

Dagare series

Dagare soils occur irregularly on the high banks or levees of the major rivers of the area. They are alluvial soils formed by the periodic deposition of silt and clay when these rivers overflow their banks.

*In wet seasons, avalanche debris from this creep frequently cause partial obstructions on sections of the pass northwards from Nakpanduri to Bawku. On the road itself subsidence due to creep is a common feature.

A typical profile comprises a dark brown, humous, woodland top soil underlain by porous and friable silty clay loam, 4–5 feet or more deep. Below this depth, the profile consists of several feet of sandy clay loam. A fluctuating water table is usually encountered below the depth of 4–5 feet. Commonly, the profile is stratified with layers (lenses) of coarse sand of varying thickness.

Colours of various layers of each profile depend on age and drainage conditions at the site and on the quantities of organic matter and other minerals in suspension at the time of deposition. Generally, however, they are in various shades of grey with slight brown mottlings in the subsoil layers.

Suitability for Agriculture

The series is seldom flooded, except where a river has low banks or in years of exceptionally high rainfall. It is relatively fertile and easy to work being neither too heavy nor too light. It has also a good capacity to retain moisture.

Under normal woodland conditions, the organic matter content in the surface layers is moderate, being generally more than 3 per cent. Profile reaction is slightly to moderately acid and base saturation is generally above 80 per cent. Total exchangeable bases are high in the surface horizons being in the order of 20–30 m.e/100 gm. soil, and the principal bases mainly calcium and magnesium. Phosphorus content is also moderately high and considerable proportions appear available to plants. Nitrogen supply is low.

These soils are eminently suitable for intensive cultivation of tobacco for which there is a high cash value. They would also produce well, a variety of vegetables. The main disadvantages are their irregular distribution and small total extent in any particular area. Dry season drought is also common but is at present overcome by hand irrigating with river water.

As these soils do not often form viable units they can be developed together with Dagare and Kunkwa series.

(b) Soils developed from old flood plain alluvium

25. THE SIARE ASSOCIATION

This association occurs extensively along the old flood plains of the White Volta and the Kulpawn rivers. The tract varies in width from almost nil in some localities to as much as 2 miles on either bank of the rivers: near the confluence of the Volta and the Kulpawn rivers the tract is about 4 miles wide.

The major soil of the association (*Siare series*) comprises very deep, olive brown, silty and slightly to moderately calcareous clay, plastic and massive when wet but rather hard and firm when dry and often cracking into medium and large angular blocks. Within the Siare tracts are small areas—usually the sites of silted and abandoned ox bows—of deep, very dark grey to black silty clay soils which are also massive when wet, but crack into wide blocks on drying: these constitute *Pani series* (*Fig.* 8). Old abandoned levees usually carry Dagare and Kunkwa soils (*see* pages 48 and 45).

Soils of Siare association are generally devoid of large trees but usually carry *Acasia sp.* with pockets of sedges and other grasses where Pani, Dagare and Kunkwa soils occur.

Siare series

Siare soils occur on almost level land. Below 2 inches of a dark greyish brown slightly humous clay, the profile consists of about 2–3 feet of olive brown silty clay overlying brown, yellow and grey mottled silty clay to 6 feet or more. The whole profile has a very hard medium angular blocky structure when dry, but is massive, sticky and plastic when wet. Lime and manganese concretions usually occur below a depth of 2–3 feet. On the surface, wide cracks which develop into subsidence hollows are common.

In shallow examples, the alluvial parent material passes below into partially rotten rock but the two may be separated by a thin stone line.

Suitability for Agriculture

Siare soils are little used partly because of the incidence of *onchocerciasis* (river blindness) and partly because of the difficulty of working these soils by ordinary peasant methods.

Like the soils of the Volta—Lima association (*see* page 47) they provide a valuable reserve of agricultural land suitable for development by modern techniques. They are moderately provided with nutrients especially calcium and magnesium. Base exchange capacity varies between 16–24 m.e/100 gm. soil. This value is well above most soils of the area. The series is slightly to moderately alkaline at depth but may be slightly acid in reaction near the surface. The soil is low in organic matter as well as nitrogen.

Drainage is somewhat poor and runoff is slow. Actual flood by the river overtopping its banks is rare but extensive areas become waterlogged or flooded by water seeping from adjoining upland areas and being unable to drain into the river because of the levee. Successful development will therefore involve expensive capital works for drainage and water control, but crop returns—under efficient management—would be likely to make such investment economic. These soils would be suitable for extensive mechanized farming of maize, guinea-corn, millet, rice, sugar-cane and vegetables

Pani series

Pani series are very poorly drained alluvia which occur patchily within Siare areas. They are usually confined to broad depressions which lie between sandy levees of the river and adjoining uplands. Commonly, also, they occur in silted and abandoned ox bows where sites are nearly level and slope gradients less than 1 per cent.

The top soil of Pani series, generally, consists of about 3 inches of very dark grey, humous, silty clay having hard crumb structure, underlain by dark grey, silty heavy clay extending downwards to the depth of 18 inches. This horizon usually contains frequent stains of rust along root channels, is massive when wet and cracks into 5-sided blocks on drying. The subsoil extending to a depth of approximately 4 feet, consists of dark grey, strongly mottled brown, silty clay, also massive when wet but cracking into very large blocks on drying. A water-table occurs below 4 feet and the horizons encountered usually consist of grey or light greyish brown sandy loam or loamy sands.

Suitability for Agriculture

Runoff is very slow and internal drainage very poor. The soil is seasonally flooded and remains waterlogged for the first few weeks of the dry season.

The soil is slightly to moderately acid in the surface horizons, becoming neutral to alkaline at depth. Base exchange capacity throughout the rooting zone is even higher than the associated Siare soils. Calcium, magnesium and potassium levels are satisfactory and phosphorus supply is moderate. Tall grasses and sedges which often grow profusely on these soils decay and subsequently get incorporated in the top soil so that the content of organic matter in the first few inches of the profile is high but medium in the subsurface horizons. Organic matter so accumulated is available for only the first two years or so of cultivation and would need to be replenished by the addition of organic manure. These soils do not form viable units and can be developed together with Siare series. In fact, future development should be on the same lines as those recommended for Volta—Lima (page 47) and Siare soils.

(*c*) *Soils developed from mixed recent and old alluvia*

26. The Siare-Dagare Complex

Soils forming this complex occur extensively along the alluvial tracts of the major tributary rivers of the White Volta and the Kulpawn. They are, more or less, confined to the area lying west from the Red Volta, and comprise all the soils in groups 24 and 25 above, namely, Kunkwa, Dagare, Sirru, Siare and Pani series. The two soil groups occur in such a manner that it is impossible to separate them on any but a semi-detailed or detailed survey. The alluvial tracts rarely exceed 0.5 mile in width but the sum total of all these flats—approximately 90 square miles—is considerable.

The soils have similar agricultural properties as those described for the respective soils above.

(*d*) *Terrace soils*

27. THE NTERSO-ZAW ASSOCIATION

This small area of 0.6 square mile is a remnant of an old river terrace. The soils occur more extensively further downstream and can be seen bordering the White Volta at Daboya and at Yapei. The area mapped would therefore appear to be near the northern limit of these high (bench) terrace soils along the Volta within Ghana.

Two soils series comprise the association. *Nterso series* occurs about 100 feet above the river on a flat to very gently undulating land. It consists of 4–5 inches of brown sandy loam overlying to a depth of 18 inches reddish brown loam with iron concretions and gravel. Below 18 inches an often indurated layer consisting of abundant pebbles in a matrix of reddish brown clay is encountered. In very mature profiles, this last layer maybe in the form of a conglomerate iron-pan. The associated soil (*Zaw series*) is similar but brown in colour. It occurs on the edge of the terrace and at a lower level than Nterso series so that the surface layers include wash from higher ground. Elsewhere, the series is severely eroded or highly dissected exposing the underlying rock (clay shale) at about 4–5 feet.

Both soils have tillage problems due to the presence of pebbles at or near the surface, subsoil induration and dissection of the land. They may be left under grass for rough grazing.

28. THE SIRRU-LAPLIKI ASSOCIATION

Soils in this association are formed on terraces intermediate in height between the present-day floodplains and sloughs (i.e. Siare, Dagare and Volta-Lima associations) and the high (bench) terrace soils of the Nterso-Zaw association. They occur distributed in the south-western part of the area around Giadema and Uwasi along the White Volta, the Kulpawn and the Sisili rivers. These soils are of alluvial origin and were deposited as levees. With a renewed downward erosion cycle of the rivers, better drainage conditions have prevailed under which red and brown loams have developed.

Characteristically, *Sirru series* is moderately to well drained and has about 3 inches of brown, crumbly, humous loamy fine sand, underlain to a depth of approximately 12 inches, by dark reddish brown loamy fine sand with weak crumb structure. The last layer overlies at variable depth, usually about 4–5 feet, red or yellow red sandy loam or clay loam, which grades down into mottled red coarse sandy clay.

Lapliki series is the lower slope associate of Sirru series and is differentiated from it by being less well drained. It has a top soil of grey brown to light grey loamy fine sand, slightly humic, and usually less than a foot thick. This grades into brownish yellow compact loam for about a foot and in turn overlies several feet of yellowish brown, mottled red sandy clay loam or sandy clay.

Both Sirru and Lapliki soils may develop vesicular, manganese-stained ferruginous subsoils.

Suitability for Agriculture

Sirru and Lapliki soils have near-neutral top layers but become slightly to moderately acid with depth. They have no physical disadvantages and offer good media for root crops. Though low in fertility they should be responsive to applications of artificial fertilizers. They are capable of being tilled with machines and developed in association with the poorly drained soils of the floodplains in a form of mixed arable farming, a wide range of local crops, and such cash crops as groundnuts and tobacco can be raised.

PART IV
RECOMMENDATIONS AND CONCLUSIONS

Soil Quality Classes

Arising from the discussions of the various soil groups in the preceding section, it is now possible to make, briefly, some observations, recommendations and conclusions.

The soils of the area have been arranged into four groups with sub-groups according to soil quality* in order to provide a helpful guide for land-use purposes (*see* table below and map 4). There are also brief notes on recommended practices to be adopted on each class and on suitability of use. These recommendations are not absolute and are to be regarded as approximations since the assessment of quality and suitability of use is not entirely based on known or established productive capacities of the soils but on the evaluation of soil characteristics such as depth, drainage, texture, slope, permeability, water-holding capacity, organic matter content and the level, generally, of other nutrient reserves as obtained from analytical data. This information is supplemented by data gathered in conversations with other specialists and through observations on the performance of crops made during the course of the survey on farmers' fields, State Farms and Agricultural Research Stations. By suitable management practices it is possible to raise some of the lower classes into higher categories.

The quality groups shown result from the regrouping of the various soil associations, etc. on the basis of the zonal upland or lowland soils of each association. Thus a group, considered to be the best for arable agriculture, naturally, includes minor areas—generally not exceeding 30 per cent—of soil which belong to some other groups of relatively inferior properties.

The main soil quality groups referred to above are:

Group I Developed arable soils
Group II Undeveloped arable soils
Group III Degraded arable soils, and
Group IV Non-arable soils.

Group I—Developed arable soils

Sub-group Ia

These are very good soils. They are moderately deep and usually occur on undulating land (2–3 per cent). They are generally well drained sandy loams with moderately good water-holding capacity, although they suffer from seasonal drought. They have moderately permeable subsoils. These soils have low to moderate inherent fertility but are responsive to manurial treatments, especially superphosphate, nitrogen and kraal manure. Mechanical tillage is easy but it is important that they are protected against erosion by adequate soil conserving rotation farming, contouring, strip cropping and provision of ground cover. Burning of grass should be discouraged or controlled.

The soils are suitable for cereals (millet, sorghum, maize), beans, nuts and oilseeds (groundnuts, bambarra beans, cowpeas), tobacco and *hibiscus sp.* (kenaf). They can also be utilized for improved and controlled grazing. The soils falling into this sub-group are the Varempere, Tanchera, Mimi and Sirru-Lapliki associations.

Sub-group Ib

These are moderately eroded but good soils occurring on undulating land (2–3 per cent). They are shallow, fairly gravelly or stony in parts, have low water-holding capacity and suffer from dry-season drought. The subsoils are slowly permeable. They have low to moderate fertility but can be improved by the addition of mineral and organic fertilizers, which besides increasing and maintaining fertility would improve moisture holding capacity. They have occasional to frequent rock outcrops locally so that some tracts are not really suitable for mechanized cultivation. Bullock plough cultivation is, however, recommended.

Owing to shallowness, greater rooting depth might be provided by growing crops on ridges or mounds. Further erosion should be checked by bunding, contour ploughing, strip cropping and

* Soil quality is an attribute of a soil that cannot be seen or measured directly from soil alone but which is inferred from soil characteristics and soil behaviour under defined conditions. Fertility, productivity and erodibility are examples of soil qualities (in contrast to soil characteristics).

See page 767 of SOIL, the 1957 year-book of Agriculture, USDA.

the keeping of a close ground cover. Like sub-group I*a* soils, grass burning should be discouraged or controlled. All the crops recommended for cultivation on sub-group I*a* soils may be successfully grown here but yields cannot be expected to be as high unless, of course, the management practices recommended are fully implemented. Soils falling into this sub-group are Bongo and Kolingu associations.

The Bongo soils have, from early times, been known to be very productive, a fact perhaps attributable to the high potash and phosphate contents of the parent rock. On these soils human population densities are very high, being more than 450 persons per square mile in some localities. The present low fertility is the result of a long period of intensive farming accompanied by mismanagement of the soils.

Sub-group Ic

These soils of moderately high fertility generally occur on strong slopes (9–12 per cent) in rolling topography where there are severe erosion hazards. They are very shallow, very stony and/or bouldery. Surface runoff is very high so that moisture is not readily available to plants.

The soils are unfit for mechanized or bullock plough cultivation but hand cultivation is practicable. The parent rocks of the soils are rich in bases so that they have a high inherent fertility.

Despite the very stony character they are intensively and continuously cultivated to cereals, groundnuts, beans and tobacco. Under normal conditions yields are satisfactory.

In cultivating these soils the local people shift the stones into contoured heaps against which the soil packs forming terracettes. This practice is commendable as it provides greater rooting depth for crops, reduces surface runoff and helps to conserve much needed moisture.

Apart from stoniness and steep slopes, nitrogen, organic matter and dry-season drought are other limitations of the soils in this sub-group.

Sub-group Id

These are poor arable soils occurring on undulating land (2–3 per cent). They are shallow, concretionary, gravelly or stony soils which have very low water-holding capacity, very low inherent fertility and very severe erosion hazard. They are imperfectly drained owing to very slowly permeable subsoils. They suffer from drought as well as seasonal waterlogging and flooding. Very limited mechanical tillage is possible on these soils owing to the risk of damage to implements but bullock plough and hand cultivation are possible and are recommended.

Like the sub-group I*b* soils greater rooting depth might be provided by growing crops on ridges or mounds. Further erosion should be checked by bunding, contour ploughing, strip cropping and the keeping of a close ground cover. All the crops listed under sub-group I*a* soils are at present grown on these soils but crop appearances are poor and yields are not expected to be high even with adequate fertilizer treatments.

The soils falling into this sub-group are the Wenchi, Kintampo Nterso-Zaw and Kpelesawgu associations. The last-named association occupies approximately 16 square miles of the area and has special problems which have already been discussed (*see* page 46). It forms a very small portion of groundwater laterite soils which probably occupy very nearly 50 per cent of the interior savannah zone of Ghana and over a quarter of the whole country.

It is difficult to envisage a high rate of productivity being achieved from these Kpelesawgu soils. They seem best adapted to the production of grass pasture and some early crops. However, the fact that they occur very extensively in Ghana makes it imperative that serious attention be paid to the study of the problems these soils present and to devise techniques which might circumvent them and permit increased productivity.

Group II—Undeveloped arable soils

Sub-group IIa

These are good arable soils. They are moderately deep to deep and occur on nearly level land (1–2 per cent). Internal drainage is imperfect owing to very heavy textures. The soils in this sub-group—mainly the Yagha soil association—have montmorillonitic clay mineral. This gives the soils their characteristic physical properties so that on wetting they increase in volume by 40–50 per cent becoming plastic and impervious. They are droughty in the dry season when they become hard and compact showing wide surface cracks. The soils have generally moderately high inherent fertility and lime concretions usually occur at depth.

The soils are little-farmed at present, partly because of the difficulty of working them by ordinary peasant cultivating implements and partly because of their difficult moisture relationships.

They require skilled management in the use of heavy cultivating machinery, irrigation and/or drainage and the use of suitable fertilizers to keep them in a stable, friable tilth. They could then be cropped continuously with rice and sugar-cane in particular, as well as cereals and vegetables.

These soils may locally be broken by rock outcrops (Nangodi series) and this is one main limitation to their development by heavy machinery.

Sub-group IIb

These are good but little-farmed soils. They are deep to very deep and occur on nearly level to level (2 per cent or less) alluvial land. They are poorly drained, have moderately heavy textures and good water-retaining capacity. They are seasonally flooded or waterlogged but dry out hard, showing surface cracks during the dry season. They may be locally lime-rich or sodium saturated, but generally have fair inherent fertility.

These soils are unfarmed partly because of the incidence of *onchocerciasis* (river blindness) and partly because of the difficulty of working them by ordinary peasant cultivating implements. Small areas, mainly Kupela-Berenyasi association soils, occurring near settlements are at present utilized for dry-season rough grazing, vegetable growing and a little swamp rice cultivation, but rice cultivation which has to rely on the irregular natural rainfall and runoff is not for commercial purposes worthwhile.

The larger flats of the Volta-Lima and Siare associations provide a valuable reserve of agricultural land suitable for intensive development by modern techniques. They are comparatively better supplied with nutrients than all the associated upland soils. Moreover, they have greater value due to their depth and particularly their occurrence on relatively flat land and in sites where conditions are suitable for mechanized tillage and where there are possibilities of effecting water control. Successful development will therefore involve expensive capital works, but crop returns—under efficient management—would be likely to make such investment economic.

These soils would be suitable for the intensive mechanized farming of rice, other cereals, sugar-cane and vegetables. Finally, agronomic investigations would be required to determine whether salts present, locally, in some of these soils are liable to interfere with cropping.

Group III—Degraded arable soils

These very poor, very shallow, severely eroded or gullied land occur on undulating topography (2–3 per cent). The exposed subsoils are very heavy textured resulting in rapid surface runoff. Infiltration rate is very low but water retention is high. The soils are easily puddled when wet and on drying become hard showing surface cracks. Organic matter reserves are almost completely depleted and although nutrients from decomposed rocks are abundant and close to the surface, they are perhaps not in readily utilizable forms by plants so that the soils are generally of low fertility.

The soils have at present very limited use, the crops grown being mainly cereals which do not produce well. They also serve as very poor rough grazing lands as they support a few thorny shrubs scattered over a thin cover of grass. As they are at present difficult to protect against erosion it is recommended that they are taken out of cultivation.

Research into improved grazing possibilities on these soils and their utilization for tree crops such as silk cotton, teak, *Anogeissus* and fuelwood production may be undertaken so that these soils are not further dissipated but conserved.

Group IV—Non-arable soils

These are non-agricultural lands. They are either very severely eroded, very shallow, very stony or very rocky. A majority of them occur on rocky hill ranges and on very steep rocky slopes where there is a very rapid surface runoff under conditions with very low waterholding capacity and very slowly permeable subsoils. Generally the soils have very low fertility.

Some areas—especially the scarplands—have been appropriated for forestry and watershed protection purposes but others could be developed into recreation and wildlife reservation areas. Suitable rocks from these areas could also be more fully exploited for road metal, building and ornamental stones.

Conclusion

This area of approximately 3,550 square miles at present supports a population of nearly ½ million (1960 census). This is very unevenly distributed: tracts of almost uninhabited terrain are estimated to occupy about 45 per cent and of the remainder, densities vary from a few persons per square mile in some areas to over 450 in some parts of the Frafra District.

This density of population led to intensive farming and over-stocking of the good lands with consequent gradual elimination in many localities of the traditional land rotation cultivation system which enabled fallow land to regain its fertility. Soils became exhausted, crop yields declined and soil erosion caused increasing serious and long-term damage to much of the land.

Several workers in this area have remarked on the serious damage caused to land by erosion. Although this is a matter of considerable national concern, it is the opinion of the writer that much of these remarks verge on exaggeration. Even in those areas where the damage is considered to be serious (c.f. Pusiga association of soils) page 31 (and degraded arable soils) page 54 and along many valley slopes) there are on the whole little spectacular gully erosion as is common in many other parts of Africa and elsewhere in the world. There is no cause, however, to be complacent about the situation. The need now is to prevent further deterioration of the land.

In order to relieve population pressure on these lands and to rehabilitate the soils, the Gonja Development Scheme was originally conceived as a pilot scheme for mechanized production of groundnuts and other food crops on the thinly peopled deep, red, V_3 sandstone soils, using settlers from some of the over-populated parts of the Frafra District. The scheme fell through, mainly for social reasons, and little relief was achieved.

The plan now is the resettlement of people within land-planning areas in the region itself. To date, excellent and important conservation measures have already been undertaken in some of these land-planning areas (e.g. Kusasi District) where the land is protected from erosion by planting watershed forest reserves (also to provide poles and fuelwood), erecting contour banks on slopes, constructing dams for water storage and the utilization of stored water for dry-season vegetable growing and fish farming.

Undoubtedly, water for dry-season use is the main requirement of the area. As stated earlier in this report, the rainfall and water resources within the region are adequate to support humans, livestock and crops but need to be properly developed, conserved and utilized.

Plans for large-scale irrigation should commence with soils of the alluvial bottoms and flats. These sites offer the greatest possibilities for irrigation development at the present time (*see* Group II, sub-group IIb) for the main reason that control of irrigation water would not involve expensive capital expenditure as it would on a majority of upland soils where water would need to be lifted several feet above eroded valley slopes in order to reach more productive soils.

To date, conservation measures have suffered from lack of fundamental environmental data, so that designs and layouts adopted have necessarily been empirical and arbitrary later requiring modifications as experience is gained.

What has so far been achieved need to be put on a better basis by scientifically laid down plans which will lead to the introduction of improved farming and grassland management on a more intensive basis than already exist. This work is now being undertaken in specially selected areas by Soil Conservation, Dams and Irrigation Unit of the Ministry of Agriculture in conjuction with a team of experts provided by the United Nations Special Fund.

Improved farming will involve educating the local farmer in all aspects of soil conservation and improvement, including the proper use of organic manure and artificial fertilizers. The effect of manure on yields are seen to be great and it is desirable if not imperative that more attention should be paid to fertility.

Finally, there should be a long-term plan for road building and improvement in order to promote productivity in the area.

Table 7

SOIL QUALITY CLASSES AND SUITABILITY OF USE

(AN APPROXIMATION)

Sub-group	*Soil Quality*	*Recommended Practices*	*Suitability of use—Actual and Potential*
I*a* (Very Good)	Moderately deep; undulating (2–3 per cent); well drained; sandy loams; moderate water-holding capacity; dry-season drought; moderately permeable subsoils; low to moderate inherent fertility; easy mechanical tillage.	Protection against erosion by contour ploughing, strip cropping, rotation farming and provision of ground cover; control of grass burning. Soils require superphosphate, nitrogen and kraal manure.	Dry-land cultivation of cereals (millet, guinea corn, maize) beans, nuts and oilseeds; tobacco; hibiscus sp. (kenaaf).
I*b* (Good)	Moderately eroded; undulating (2–3 per cent); well drained; sandy loams; shallow; gravelly or stony; low water-holding capacity; dry season drought; slowly permeable subsoils; low to moderate fertility; occasional to frequent rock out-crops; limited mechanical cultivation.	Provision of rooting depth by planting on ridges or mounds, checking of erosion by contour ploughing, strip cropping and keeping of ground cover; control of grass burning; application of mineral and organic fertilizers to increase and maintain fertility and help conserve moisture.	Dry-land cultivation of cereals (millet, guinea corn, maize); beans, nuts and oilseeds; tobacco; hibiscus sp. (kenaaf).
I*c* (Moderately Good)	Very shallow, very stony and/or bouldery soils; strong slopes (9–12 per cent); strong undulations; high surface runoff; severe erosion hazard; very low water holding capacity; dry-season drought; unfit for mechanical or bullock plough cultivation; moderately high inherent fertility.	Provision of soil depth and increase of moisture-retaining properties by the preparation of contoured terraces; hand cultivation only practicable; provision of nitrogenous fertilizers and organic matter.	Dryland cultivation of cereals; beans, nuts and oilseeds; tobacco; cotton.
I*d* (Poor)	Shallow; concretionary; gravelly or stony; undulating (2–3 per cent); very low inherent fertility; very severe erosion hazard; imperfect drainage; very slowly permeable subsoils; dry-season drought; seasonal flooding or waterlogging; very limited mechanical tillage.	Provision of rooting depth and checking of erosion as in 1*b*. above; provision of drainage for removal of excess water; increase of moisture-holding capacity;	Dryland improved grazing and some early crops.

Group I: Developed arable soils.

Sub-group	Soil Quality	Recommended Practice	Suitability of use—Actual and Potential
II*a* (Good)	Moderately deep to deep soils; moderately high fertility; nearly level land (1–2%); imperfect; internal drainage. Montmorillonitic clay soils; plastic and impervious when wet; droughty, hard and compact in dry-season showing surface cracks; lime concs. occur at depth; easy mechanical tillage at right moisture content.	Levelling; provision of water for irrigation; use of suitable fertilizers to achieve a stable and friable tilth; drainage in wet season; reduction per unit production by use of machinery; no burning but discing in of vegetation.	Intensive mechanized irrigation farming of rice, sugar-cane, other cereals and vegetables.
II*b* (Good)	Very deep soils occurring on nearly level or level alluvial flats (2% or less); poorly drained; moderately heavy texture; good water-holding capacity; seasonally flooded or waterlogged; hard when dry showing surface cracks; locally lime or sodium; saturated; fair inherent fertility; slight erosion hazard; easy mechanical tillage.	Removal of excess surface water by provision of water control structures; drains, levees, bunds, ditches, dams or ponds and levelling. Utilization of stored water for dry-season irrigation. Maintenance or improvement of fertility by the addition of commercial fertilizers supplemented by organic manure. Increase in moisture-holding capacity and infiltration rate of soil. Reduction per unit production by the use of machinery. No burning but discing in of vegetation; removal of salts where present.	Intensive mechanized irrigation farming of cereals, especially rice; sugar-cane, vegetables, tobacco, orchard crops, pawpaw, guava, can also be grown. Irrigated improved pasture.
III (Very poor)	Very shallow; severely eroded or gullied; undulating (2–3%); very heavy textured; rapid surface runoff; very low infiltration capacity; puddling when wet; hard when dry showing surface cracks; depleted organic matter; very low fertility.	Limitation or discontinuation of cropping. Introduction of soil conservation measures.	Research into improved grazing possibilities. Utilization for tree crops, e.g. silk cotton, teak, *Anogeissus;* fuelwood production.
IV (Non-agricultural)	Very severely eroded, very shallow, very stony or very rocky. Includes hill ranges and very steep rocky, scarp slopes; very rapid surface runoff; very low water holding properties; very slowly permeable subsoils; infertile.	—	Recreation, forestry, watershed protection and wildlife preservation. Exploitation of suitable rocks for road metal, building and ornamental stones.

GROUP II — Undeveloped arable soils
GROUP III — Degraded arable soils
GROUP IV — Non-arable soils

APPENDIX

N.B.—1. pH figures given with profile descriptions were determined by colorimetric method in the field.
2. pH figures given in tables were determined by the glass electrode pH meter.
3. Some horizons described in the field as concretionary to various degrees may not show any coarse material in the analysis, because the concretions of lower impact strength may have been crushed during the preparation of the soil sample for analysis.

Varempere series
Parent material: Granite (G1)
Profile No.: NBR 27, Lab. No. B 1443
Location: Manga-Bawku Agricultural Station Detailed Soil Survey, Traverse 3, chain 16.
Site: Upper slope, 2 per cent
Vegetation: Short grass savannah, mainly *Heteropogon contortus.*

A_{11} 0–4 *inches* Light yellowish brown (10YR 6/4), slightly humous, loamy coarse sand, rare fine quartz gravel, porous, crumbly, pH 5.8.

A_{12} 4–10 *inches* Very pale brown (10YR 7/4), loamy coarse and, very frequent fine quartz gravel, rare fine iron concretions, porous, slightly crumbly, pH 5.6.

B_1 10–15 *inches* Reddish brown (2.5YR 5/4), coarse sandy loam, abundant fine quartz gravel, rare fine iron concretions, porous, slightly crumbly, pH 5.6.

B_{21} 15–25 *inches* Light red (2.5YR 5/4), coarse sandy clay loam, abundant fine quartz gravel, rare iron concretions, firm, coarse granular, porous, compact, indurated, pH 6.0.

B_{22}cnt 25–31 *inches* Yellowish red (5YR 4/6) mottled yellow (10YR 7/6), coarse sandy clay, very abundant fine and coarse quartz gravel and rare quartz stones; frequent irregular-shaped iron concretions, firm, compact, indurated, coarse granular, porous, pH 6.2.

B_{23}cnt 31–45 *inches* Yellowish red (5YR 4/6) mottled with yellow (10YR 7/6) and very pale brown (10YR 7/4), coarse sandy clay, very abundant fine and coarse quartz gravel, very frequent irregular-shaped iron and manganese concretions, very frequent feldspar particles, blocky, porous, indurated, firm, pH 6.4.

B_3 45–60 *inches* Reddish yellow (5YR 6/6), very pale brown (10YR 7/3) and yellow (10YR 8/6) mottled coarse sandy clay, very abundant fine quartz gravel, frequent irregular-shaped iron and manganese concretions, very frequent particles of feldspar, massive, indurated, blocky, porous, firm, pH 6.6.

C_1 60–70 *inches* Yellowish red (5YR 5/6) mottled with yellow (10YR 7/3) and very pale brown (10YR 8/7) coarse sandy clay, very abundant fine quartz gravel, frequent irregular iron and manganese concretions, frequent particles of feldspar, frequent flakes of biotite, massive when wet, indurated and blocky when dry, pH 6.6.

C_2 70–81 *inches* Reddish yellow (5YR 6/6) and very pale brown (10YR 7/4) mottled coarse sandy loam, frequent patches of rotten granite, massive weak irregular blocks, pH 6.8.

C_3 81–93 *inches* Soft weathered granite, massive.

LABORATORY ANALYSIS OF VAREMPERA SERIES DESCRIBED AT PAGE 64

Depth inches	*Horizon*	*% Part. Size >2mm*	*Particle size distribution— International Pipette and hexametaphosphate (mm.) (%)*				*Moisture Equiv.*	*Organic Matter*		*pH*	*Exchangeable complex m.e./100gm.*									*% Free Fe_2O_3*	*Phosphorus p.p.m.*	
			C. sand 2–.2	*Fine sand* .2–.02	*Silt.* .02–.002	*Clay* < .002		*%C.* *(n)*	*C/N* *(k)*		*T(CEC)* *(b)*	*Ca*	*Mg*	*Mn*	*K*	*Na*	*S* *(TEB)*	*% Base sat.*			*Total*	*Acid Soluble*
0–4	A_{11}	—	58.7	33.3	4.5	3.5	5.3	.46	12	6.5	1.96	1.14	.38	.07	.16	.06	1.81	92		.41	42	4
4–10	A_{12}	—	72.7	16.1	5.0	6.0	6.9	.35	13	6.3	2.22	1.26	.44	.06	.07	.06	1.89	85		.66	46	3
10–15	B_1	—	54.2	25.7	7.0	13.1	8.0	.25	10	6.4	2.85	1.59	.60	.06	.07	.06	2.38	84		1.04	55	3
15–25	B_{21}	—	47.4	18.0	7.6	27.0	13.1	.28	10	6.1	4.60	2.49	.82	.05	.11	.06	3.53	77		2.20	86	
25–31	B_{22}cnt	18.0	37.6	16.3	10.8	35.3	17.0	.21	8.4	6.0	6.40	3.49	1.16	.03	.18	.07	4.93	77		3.80	102	
31–45	B_{23}cnt	15.6	38.8	16.1	10.8	34.3	16.8	.14	7.4	6.1										3.42	76	
45–60	B_3	11.0	34.5	22.2	12.8	30.5				6.4										3.19		
60–70	C_1	33.9	29.8	21.6	11.7	36.9				6.9										2.80		
70–81	C_2	12.6	37.8	20.7	11.8	29.7				6.9										2.58		
81–93	C_3	—								7.2										1.59		

(*n*) Wakley-Black, (*k*) Kjeldahl method, (*b*) NH_4^+ saturation and direct distillation of NH_3.

Hilum series ..

Parent material	Granite (G I)
Profile No.	NBR 82, Lab. No. B2002
Location	Near Mile post 5, Bawku-Yendi road
Site	Flat summit, less than .5 per cent
Vegetation	Savannah regrowth after cultivation

Ap 0–3 *inches* .. Abundant irregular-shaped iron concretions, occasional quartz gravel and occasional quartz stones, in a matrix of dark brown (7.5YR 4/2) slightly humous sandy loam. Plentiful fine roots, weak fine crumbs, porous, friable, pH 6.2.

B_{11}cn 3–9 *inches* .. Abundant small and large irregular-shaped iron concretions, rare quartz gravel in a matrix of reddish brown (5YR 4/3) sandy loam, few fine roots, porous, friable, pH 6.2.

B_{12}cn 9–17 *inches* Abundant iron concretions, rare quartz gravel in a matrix of light reddish brown (5YR 6/3), sandy loam, weak granular, porous, friable, pH 6.8.

B_{21}t 17–33 *inches* Light red (2.5YR 6/6) slightly mottled brownish yellow (10YR 6/6) sandy clay loam, slightly indurated, frequent iron concretions, rare quartz gravel, weak granular, slightly firm, pH 6.8.

B_{22}t 33–48 *inches* Red (2.5YR 4/6) and yellow (10YR 7/6) mottled, clay loam, slightly indurated, frequent iron concretions, frequent fine quartz gravel, rare manganese concretions, and stains; weak fine and medium subangular blocks firm, pH 5.8.

B_{23}t 48–57 *inches* Abundant sub-angular quartz stones and gravel and rare iron concretions in yellowish red (5YR 5/6) and yellowish brown (10YR 5/4) mottled clay loam matrix, massive, very firm, pH 5.6.

C_1 57–72 *inches* Red (2.5YR 4/6) and light yellowish brown (10YR 6/4) mottled, clay loam indurated, rare iron concretions, rare fine quartz gravel, frequent traces of parent rock, strong medium and coarse subangular blocky, very firm, pH 5.6.

C_2 72–84 *inches* Red (2.5YR 5/6), yellow (5Y 8/6) and white (7.5YR 8/10) mottled, clay loam of decomposed granite, rare iron concretions, strong medium and coarse subangular blocky, very firm, pH 5.6.

Depth inches	*Horizon*	*% Part. Size* >2mm	*Particle size distribution —International Pipette & hexametaphosphate (mm.)* *C. Sand* 2–.2	*Fine sand* .2–.02	*Silt.* .02–.002	*Clay* <.002	*Moisture Equiv.*	*Organic Matter % C (n)*	*C/N(k)*	*pH*	*T (CEC) (b)*	*Exchangeable complex m.e./100gm.* *Ca*	*Mg*	*Mn*	*K*	*Na*	*S (TEB)*	*% Base Sat.*	*% Free* Fe_2O_3	*phosphorus p.p.m.* *Total*	*Acid Soluble*
0–3	AP	7.1	55.2	29.5	5.6	9.7		0.60	15	6.2	4.42	2.15	.56	.09	.07	.07	2.85	65	1.95	194	2
3–9	B_{11}	21.0	46.5	32.6	7.2	13.7		0.36	12	6.3	3.53	1.84	.61	.07	.06	.05	2.56	73	1.97	153	2
9–17	B_{12}	21.6	44.3	20.3	10.7	24.4		0.26	13	6.2	3.69	1.68	.66	.05	.06	.07	2.47	67	3.92	157	2
17–33	B_{21}t	21.1	15.1	13.3	16.9	54.7		0.20	12	6.2	6.37	2.79	1.18	.02	.08	.10	4.18	66	6.14	151	
33–48	B_{22}t	—	12.2	11.9	19.5	56.4		0.12	8.6	5.7	6.36	2.71	1.18	.04	.08	.14	4.11	65	5.39	132	
48–57	B_{23}t	63.4	20.7	9.2	15.7	54.4		0.10	7.1	5.3	6.29	2.41	1.06	.04	.16	.21	3.84	61		109	
57–72	C_1	—	19.6	12.9	24.9	42.6		0.04	5.0	5.3	5.70	2.33	1.17	.02	.09	.09	3.68	65		84	
72–84	C_2	—	16.1	10.1	19.9	53.9		0.08	6.7	5.3	5.82	2.39	1.02	.05	.08	.10	3.61	62		94	

(*n*) Wakely—Black, (*k*) Kjeldahl method,[4] (*b*) NH + saturation and direct distillation of NH_3.

Tafali series

Parent material:	Colluvium derived from G1 granite
Profile No.:	NBR 28, Lab. No. B 1444
Location:	Manga—Bawku Agric. Station Detailed Soil Survey, between traverses 9 and 10, chain 8.
Site:	Middle gentle slope, 2 per cent
Vegetation:	Short grass; *Heteropogon contortus*
A_{11} 0–3 *inches*	Light brownish grey (10YR 6/8), humous, loamy fine sand, occasional fine quartz gravel, rare iron concretions, weak crumbs, porous, pH 6.0.
A_{12} 3–6 *inches*	Pale brown (10YR 6/3), loamy coarse sand, very frequent fine quartz gravel, rare iron concretions, weak crumbs, porous, pH 6.0.
A_{13} 6–12 *inches*	Light yellowish brown (7.5YR 6/4), loamy coarse sand, very frequent fine quartz gravel, rare iron concretions, weak blocky, pH 5.8.
A_{14} 12–20 *inches*	Light brown (7.5YR 6/4), loamy coarse sand, very frequent fine quartz gravel, rare iron concretions, firm, weak blocky breaking into weak granular. pH 6.4.
B_{21} 20–31 *inches*	Reddish yellow (7.5YR 7/6), coarse sandy loam, very frequent fine quartz gravel, rare manganese and iron concretions, slightly compact, weak blocky breaking into weak granular, firm, pH 6.0.
B_{22} 31–40 *inches*	Reddish yellow (7.5YR 7/6), and red (2.5YR 4/6) mottled, coarse sandy loam, very frequent fine quartz gravel, frequent manganese and iron concretions, weak blocky, compact, firm, pH 6.0.
B_{23} m 40–51 *inches*	Red (2.5YR 4/6), and pale yellow (2.5YR 8/2) mottled coarse sandy loam, abundant fine quartz gravel, very abundant irregular iron and manganese concretions massive, compact, indurated, pH 6.4.
B_{24} m 51 + *inches*	Seepage iron-pan, cemented, massive, breaks into medium irregular blocks.

Depth inches	*Horizon*	*Mois-ture Equiv.*	*% Part. Size >2mm*	*Organic matter %*				*pH*	*Exchangeable complex m.e/100 gm.*									*Phosphorus p.p.m.*	
				C (n)	*N (k)*	*C/N*	*O.M. Cx1.72*		*T (CEC) (b)*	*Ca*	*Mg*	*Mn*	*K*	*Na*	*S (TEB)*	*% Base Sat.*	*% Free Fe_2O_3*	*Total*	*Acid Soluble*
0–3	A_{11}	9.95	—	.68	.045	15	1.17	6.3	2.90	1.64	.62	.08	.10	.04	2.48	86		73	2
3–6	A_{12}	7.55	—	.40	.025	16	.69	6.1	2.48	1.36	.48	.07	.04	.03	1.93	80		72	1
6–12	A_{13}	6.15	—	.23	.016	14	.40	6.3	1.81	1.10	.39	.06	.03	.02	1.60	89		72	1
12–20	A_{14}	7.20	—	.14	.011	13	.24	6.4	1.86	1.13	.40	.05	.04	.04	1.66	89		60	
20–31	B_{21}	10.45	—	.14				6.2	2.23	1.39	.46	.04	.04	.03	1.96	88		66	
31–40	B_{22}	11.00		.13				6.2										63	
40–51	B_{23}m							6.4											
51+	B_{24}m							6.5											

(*n*) Wakley-Black, (*k*) Kjeldahl method (*b*) NH_4^+ saturation and direct distillation of NH_3

Puga series

Parent material	..	Granite (G2)
Profile No.	..	NBR 44, Lab. No. B1438.
Location ..	..	Tono—Navrongo State Farm Detailed Soil Survey, Traverse 5 B, chain 44.
Site ..	..	Upper slope, 2.5 per cent.
Vegetation ..	..	Short grass.

A_{11} 0–3 *inches* .. Pale brown (10YR 6/3), slightly humous, loamy fine sand, rare fine quartz gravel, rare irregular fine iron concretions, few fine roots, crumbly, porous, pH 6.2.

A_{12} 3–8 *inches* .. Pale brown (10YR 6/3), loamy fine sand, rare fine quartz gravel, rare irregular iron concretions, crumbly, porous, pH 5.8.

A_{13} 8–12 *inches* .. Very pale brown (10 YR 7/4), loamy sand, occasional, irregular iron concretions, frequent fine quartz gravel, crumbly, porous, pH 5.6.

B_2cn 12–26 *inches* Very pale brown (10 YR 7/3), mottled red (2.5 YR 5/6), sandy loam matrix, very abundant irregular iron concretions stained with manganese dioxide, occasional subangular quartz stones, weakly cemented, pH 5.6.

B_3 26–36 *inches* Pale yellow (10YR 8/4) mottled reddish yellow (7.5 YR. 6/6) and light red (2.5 YR. 6/6), coarse sandy clay matrix, very abundant iron concretions, frequent manganese concretions, occasional quartz stones, occasional patches of weathered granite, weakly cemented, pH 5.2.

C_1 36–48 *inches* Pale yellow (2.5YR 8/4) mottled brown (7.5 YR 5/4) and yellowish red (5YR 5/6), heavy clay, frequent (patches of weathered granite), prismatic, firm, pH 5.2.

C_2 48–56 *inches* Decomposing granite, massive, hard, pH 5.8.

Depth inches	*Horizon*	*Moisture Equiv.*	*% Part. Size >2mm*	*Organic matter %*					*Exchangeable complex m.e/100 gm.*									*Phosphorus p.p.m.*	
				C (n)	*N (k)*	*C/N*	*O.M. Cx1. 72*	*pH*	*T (CEC) (b)*	*Ca*	*Mg*	*Mn*	*K*	*Na*	*S (TEB)*	*% Base Sat.*	*% Free Fe_2O_3*	*Total*	*Acid Soluble*
0–3	A_{11}	5.50	—	.39	.031	13	.67	6.5	2.34	1.26	.46	.05	.19	.07	2.03	87		62	1
3–8	A_{12}	7.15	—	.29	.025	12	.50	6.5	2.81	1.45	.73	.04	.08	.09	2.39	85		70	1
8–12	A_{13}	8.45	—	.22	.023	9.6	.38	6.2	3.27	1.81	.69	.04	.08	.06	2.68	82		85	1
12–26	B_2cn	17.15	73.0	.18	.024	7.5	.31	6.2	7.29	4.07	1.45	.07	.14	.13	5.86	80		119	
26–36	B_3	24.65	67.4	.18	.026	6.9	.31	5.4	13.92	8.25	2.47	.07	.22	.28	11.29	81		104	
36–48	C_1		—	.18			.31	4.8										78	
48–56	C_2		—					5.6											

(*n*) Wakley-Black, (*k*) Kjeldahl method, (*b*) NH_4^+ saturation and direct distillation of NH_3.

Tanchera series

Parent material:	Granite (G2)
Profile No.:	NBR 47, Lab. No.B 1439
Location:	Tono-Navrongo State Farm Detailed Soil Survey. Traverse 21, chain 8.
Site:	Upper Slope 2.5 per cent.
Vegetation:	Short grass

A_{11} 0–3 *inches* — Light brownish grey (10YR 6/2), slightly humous, loamy sand, plentiful fine roots, crumbly, porous, pH 6.2.

A_{12} 3–8 *inches* — Light brownish grey (10YR 6/2), loamy sand, very rare fine quartz gravel, plentiful fine roots, structureless, porous, pH 5.8.

A_{13} 8–16 *inches* — Light yellowish brown (10YR 6/4), loamy, sand, occasional fine quartz gravel, rare irregular iron concretions, very few fine roots, structureless, porous, pH 5.2.

A_{14} 16–30 *inches* — Very pale brown (10YR 8/4) mottled reddish yellow (5YR 6/6), loamy coarse sand, occasional fine quartz gravel, rare irregular iron concretions, structureless, porous, pH 5.2.

B_2 30–42 *inches* — Light grey (10YR 7/2) mottled reddish yellow (5YR 6/6), coarse sandy light loam, frequent fine quartz gravel, rare irregular iron concretions, structureless, porous, pH 5.2.

B_3 42–45 *inches* — Light grey (2.5 YR 7/2) mottled reddish yellow (5YR 6/6), coarse sandy clay, very frequent fine and coarse quartz gravel, frequent small and medium angular and sub-angular quartz stones, occasional irregular iron concretions, weak blocky structure, pH 5.4.

C 45–53 *inches* — Light grey (2.5YR 7/2) mottled light reddish brown (7.5YR 5/6) clay, frequent fine quartz gravel, occasional manganese concretions, very frequent pieces of decomposed granite, massive, pH 5.4.

CR 53–61 *inches* — Decomposing granite, massive, hard, pH 5.8.

				Organic matter %					*Exchangeable complex m.e/100 gm.*									*Phosphorus p.p.m.*	
Depth inches	*Horizon*	*Moisture Equiv.*	*% Part. Size >2mm*	*C (n)*	*N (k)*	*C/N*	*O.M. Cx1.72*	*pH*	*T (CEC) (b)*	*Ca*	*Mg*	*Mn*	*K*	*Na*	*S(TEB)*	*% Base Sat.*	*Free Fe_2O_3*	*Total*	*Acid Soluble*
0– 3	A_{11}	5.85	—	.64	.041	16	1.10	6.4	3.01	1.99	.60	.07	.10	.05	2.81	93	—	62	3
3– 8	A_{12}	5.20	—	.35	.032	12	.60	6.0	2.24	1.49	.61	.06	.06	.04	2.26	10	—	52	2
8–16	A_{13}	7.05	—	.23	.023	10	.40	5.9	2.61	1.20	.64	.03	.04	.05	1.96	75	.17	62	3
16–30	A_{14}	7.35	—	.12	.016	7.5	.21	5.9	2.66	1.45	.48	.03	.06	.08	2.10	79	.24	40	
30–42	B_2	10.80	—	.10	.015	6.7	.17	5.8	4.66	2.52	.75	.03	.01	.13	3.53	76	.39	71	
42–45	B_3		44.3	.15			.26	5.4									.67		
45–53	C							5.4									.37		
53–61	CR							6.0											

(*n*) Wakley-Black, (*k*) Kjeldahl method, (*b*) NH_4^+ Saturation and direct distillation of NH_3.

Pu series

Parent material ..	Granite (G1 or G2)
Profile No. ..	NBR 128, Lab. No. 2020
Location	Tono-Navrongo State Farm Detailed Soil Survey, Traverse 15, chain 4.
Site	Lower slope, 2 per cent
Vegetation	Short grass.

A_1 0–3 *inches* — Light brownish grey (2.5Y 6/2), humous, loamy sand, frequent fine and coarse quartz gravel, occasional angular quartz stones, occasional feldspar, plentiful fine roots, crumbly, pH 6.4.

AC 3–11 *inches* — Pale brown (10YR 6/3), slightly humous, sandy loam, very frequent fine and coarse quartz gravel, very frequent large pieces of decomposing biotite granite, plentiful fine roots, firm, pH 5.4.

C_1 11–21 *inches* — Pale brown (10YR 6/3), sandy loam of decomposing biotite granite, occasional fine quartz gravel, friable, pH 5.8.
C_2 21–28 *inches* — Light brownish grey (2.5Y 6/2), decomposing biotite, granite, massive, firm, pH 5.8.
C_3 28–39 *inches* — Light brownish grey (2.5YR 6/2), mottled yellow (10YR 8/6) decomposing biotite granite, massive, firm, pH 6.2.
C_4 39–43 *inches* — Decomposing biotite granite.

Depth inches	Horizon	Moisture Equiv.	%Part. Size >2mm	Organic matter % C (n)	N (k)	C/N	O.M. Cx1.72	pH	T(CEC) (b)	Exchangeable complex m.e/100 gm. Ca	Mg	Mn	K	Na	S(TEB)	% Base Sat.	% Free Fe_2O_3	Phosphorus p.p.m Total	Acid Soluble
0.3	A_1		—	.18	.115	16	.31	7.2	13.82	10.83	4.01	.07	.82	.17	15.90	115		452	136
3–11	AC		1.8	.95	.076	13	1.63	6.6	14.22	10.10	3.12	.05	.56	.21	14.04	99		335	51
11–21	C_1		2.2	.49	.042	12	.84	6.5	16.56	12.16	4.50	.05	.28	.23	17.22	104		198	24
21–28	C_2		—	.22	.023	9.6	.38	6.3	18.63	14.36	5.05	.09	.22	.39	20.11	108		293	
28–39	C_3		—	.08	.008	10	.14	6.5	15.05	14.42	4.59	.06	.16	.36	19.59	130		744	

(*n*) Wakley-Black, (*k*) Kjeldahl method, (*b*) NH_4^+ Saturation and direct distillation of NH_3.

Kolingu series

Parent material:	*Granite* (*G1 or G2*)
Profile No.:	NBR 15
Location:	Zuarungu Agricultural Station Detailed Soil Survey. Between traverses 17 and 18, chain 8.
Site:	Middle slope, 3 per cent.
Vegetation	Short grass.

Ap 0–3 *inches* — Pale brown (10YR 6/3), loamy coarse sand, very frequent fine quartz gravel, occasional small and large angular quartz stones, occasional fine iron concretions, weak crumbs, pH 5.6.

A_2 3–8 inches — Light yellow-brown (10YR 6/4), coarse sandy loam very frequent fine quartz gravel, frequent small and large angular and subangular. quartz stones and gravel, frequent small iron concretions, pH 5.6.

AC 8–14 *inches* — Brown (7.5YR 5/4), coarse sandy clay, very frequent fine quartz gravel, occasional iron and manganese concretion, frequent pieces of decomposing rock, slightly porous, slightly firm, pH 5.6.

C_1 14–27 — Yellowish brown (2.5YR 8/2), coarse sandy clay, frequent patches of white decomposing feldspar, occasional manganese staining, pH 5.8.

C_2 27+ — Clayey rotten rock, prismatic.

Pusiga series

Parent material:	..	Granite (mainly G2)
Profile No.:	..	NBR 97, Lab. No. B2019
Location ..	..	½ mile S.E. of Pusiga near road to Training college
Site: ..	..	Upper slope, 4 per cent
Vegetation:	..	Short grass savanna

A_1 0–3 *inches* Light olive brown (2.5YR 5/4), slightly humous, loamy coarse sand, few fine roots, frequent fine and coarse quartz gravel, rare iron concretions, slightly crumbly, porous, pH 6.4.

AC 3–7 *inches* Yellowish brown (10YR 5/4), coarse sandy loam, very few fine roots, frequent fine and coarse quartz gravel, occasional pieces of decomposing rock, occasional quartz gravel and stones, coarse granular, hard, porous, pH 6.6.

C_1 7–20 *inches* Decomposed sandy clay granite, strong, medium subangular blocks.

C_2 20–32 *inches* Partially decomposed granite with clay patches, massive, hard.

C_3 32–40 *inches* Hard, massive, decomposing granite.

Depth inches	*Horizon*	*Moisture Equiv.*	*%Part. Size >2mm*	*Organic matter %*				*pH*	*Exchangeable complex m.e/100 gm.*							*% Base Sat.*	*% Free Fe_2O_3*	*Phosphorus p.p.m.*	
				C (n)	*N (k)*	*C/N*	*O.M. Cx1. 72*		*T (CEC) (b)*	*Ca*	*Mg*	*Mn*	*K*	*Na*	*S(TEB)*			*Total*	*Acid Soluble*
0– 3	A_1		—	.45	.039	12	.77	6.9	4.61	2.86	1.13	.08	.16	.08	4.31	94		319	63
3– 7	AC		—	.47	.044	11	.81	6.6	2.81	5.29	2.19	.04	.12	.15	7.79	277		240	10
7–20	C_1		—	.12	.014	8.6	.21	6.8	9.30	6.02	2.50	.05	.13	.23	8.93	96		638	94
20–32	C_2		—	.04	.006	6.7	.07	7.0	10.12	6.92	3.25	.02	.13	.28	10.60	105		821	
32–40	C_3		—	.03	.006	5.0	.05	7.2	11.18	7.78	3.84	.05	.13	.34	12.14	109		2012	

(*n*) Wakley-Black, (*k*) Kjeldahl method, (*b*) NH_4^+ saturation and direct distillation of NH_3.

Kupela series

Parent material .. Local alluvium derived from G_1 or G_2 granite.

Profile No .. .. NBR 31, Lab. No. B1445

Location .. .. Manga–Bawku Agricultural Station Detailed Soil Survey. Traverse 9, chain 60.

Site .. .. Bottom, very gentle slope, less than 2 per cent

Vegetation .. Swamp grass (*Vetiveria nigritana* & *Seteria anceps*)

A_{11} 0–3 *inches* .. Grey (10YR 6/1), humous, silty fine sandy loam, very rare fine quartz gravel, frequent rusty root channels, hard crumbs, pH 5.2.

A_{12} 3–8 *inches* .. Grey (10YR 5/1), silty fine sandy clay, very rare fine quartz gravel, occasional rusty root channels, hard crumbs, pH 6.2.

A_3 8–15 *inches* .. Light grey (10YR 7/1) mottled yellowish brown (10YR 5/4), silty fine sandy clay, rare fine quartz gravel, rare rusty root channels, occasional manganese stains, blocky, pH 7.4.

B_{11} 15–25 *inches* .. White (10YR 8/1) mottled brownish yellow (10YR 6/6), silty fine sandy clay, occasional manganese stains, frequent fine quartz gravel, massive when wet, weak blocky when dry, pH 7.2.

B_{12} 25–35 *inches* White (10YR 8/1) mottled brownish yellow (10YR 6/6), silty fine sandy loam, occasional manganese stains, very frequent fine quartz gravel, massive when wet, weak blocky when dry, pH 7.2.

B_{21} 35–43 *inches* White (10YR 8/2) mottled yellow (10YR 7/6), silty fine sandy loam, occasional manganese stains, very frequent fine quartz gravel, massive and wet, pH 6.8.

$B_{22}t$ 43–53 *inches* White (10YR 8/1) mottled brownish yellow (10YR 6/6), silty fine sandy clay, occasional manganese stains, very frequent fine quartz gravel, massive and wet, pH 7.2.

$B_{23}t$ 53–56 *inches* White (10YR 8/1) mottled yellowish brown (10YR 5/6) silty fine sandy clay, very frequent fine quartz gravel, occasional manganese stains, massive and wet, pH 7.2.

				Organic matter %					*Exchangeable complex m.e./100 gm*									*Phosphorus p.p.m.*	
Depth inches	*Horizon*	*Moisture Equiv.*	*%Part. Size* > *2mm*	*C(n)*	*N(k)*	*C/N*	*O.M. Cx1.72*	*pH*	*T(CEC) (b)*	*Ca*	*Mg*	*Mn*	*K*	*Na*	*S(TEB)*	*%Base Sat.*	*%Free* Fe_2O_3	*Total*	*Acid Soluble*
0–3	A_{11}	26.45	—	2.73	.187	15	4.70	5.2	13.00	4.47	2.36	.38	.17	.81	8.19	63		280	8
3–8	A_{12}	23.50	—	.77	.057	14	1.32	7.1	9.25	4.61	2.07	.15	.09	1.48	8.40	91		128	4
8–15	A_3	14.90	—	.23	.017	14	.40	8.6	6.87	4.85	2.38	.04	.11	.95	8.33	121		61	4
15–25	B_{11}	16.10	—	.11	.015	7.3	.19	8.2	5.57	3.09	2.27	.03	.08	.24	5.71	103		49	
25–35	B_{12}	13.70	—	.06	.010	6.0	.10	8.1	2.96	1.53	1.52	.02	.05	.08	3.23	109		38	
35–43	B_{21}			.08	.008	10	.14	8.0											
43–53	$B_{22}t$							7.6											
53–56	$B_{23}t$							7.6											

(*n*) Wakley-Black, (*k*) Kjeldahl method, (*b*) NH_4^+ saturation and direct distillation of NH_3

Berenyasi series

Parent material .. Local alluvium derived from G_1 or G_2 granite

Profile No. .. NBR 57, Lab. No. B 1446

Location .. .. Manga—Bawku Agriculture Station Detailed Soil Survey, Traverse 11, chain 52.

Site .. .. Lower slope of gentle slope, 1–2 per cent

Vegetation .. .. Swamp grass (*Vetiveria nigritana* and *Seteria anceps*)

A_{11} 0–3 *inches* .. Grey (10 YR 6/1) mottled with strong brown (7.5 YR 5/6), humous, silty fine sandy light loam, crumbly, pH 5.0.

A_{12} 3–7 *inches* .. Light grey (10 YR 7/1) mottled strong brown (7.5 YR 5/8), slightly humous, silty fine sandy loam, occasional fine quartz gravel, crumbly, pH 5.0.

B_1 7–15 *inches* .. Grey (10 YR 6/1) and yellowish red (5 YR 5/6) mottled silty loamy sand, frequent fine quartz gravel, granular, pH 5.0.

B_{21} 15–29 *inches* .. White (5 YR 8/1) and yellow (10 YR 7/6) mottled silty loamy sand, frequent fine quartz gravel, granular, pH 4.8.

B_{22} 29–43 *inches* .. White (10 YR 8/2), reddish yellow (7.5 YR 6/2) and strong brown (7.5 YR 5/6) mottled silty loamy sand frequent fine quartz gravel, wet, sticky, massive, pH 5.6.

B_{23} 43–58 *inches* .. White (10 YR 8/2) mottled reddish yellow (7.5 YR 7/6), silty loamy sand, occasional fine quartz gravel, sticky, massive, pH 5.6.

B_{24} 58–69 *inches* .. White (10 YR 8/2), brownish yellow (7.5 YR 6/8) and very pale brown (10 YR 7/4) mottled, coarse sandy clay loam, frequent fine quartz gravel, wet, sticky, massive, pH 6.2.

Depth inches	*Horizon*	*Moisture Equiv.*	*% Part. Size* ≥ *2mm*	*% Organic matter* C (n)	N (k)	C/N	*O.M. Cx1.72*	*pH*	*T (CEC) (b)*	*Exchangeable complex m. e/100 gm* Ca	Mg	Mn	K	Na	S(TEB)	*% Base Sat.*	*% Free* Fe_2O_3	*Phosphorus %* Total	Acid Soluble
0–3	A_{11}	16.35	—	1.40	.094	15	2.41	5.2	5.93	1.54	.74	.08	.09	.11	2.56	43		132	3
3–7	A_{12}	10.40	—	.46	.032	14	.79	4.9	3.37	.94	.49	.06	.03	.07	1.59	47		52	2
7–15	B_1	12.65	—	.37	.026	14	.64	4.9	3.59	1.07	.57	.09	.05	.07	1.85	52		45	1
15–29	B_{21}	11.50	—	.19	.019	10	.33	4.9	2.54	.99	.54	.04	.05	.06	8.65	65		38	
29–43	B_{22}	12.85	—	.17	.015	11	.29	5.5	2.59	1.26	.62	.04	.09	.06	2.07	80		38	
43–58	B_{23}			.06			.10	6.0											
58–69	B_{24}							5.5											

(*n*) Wakley-Black, (*k*) Kjeldahl method, (*b*) NH_4^+ saturation and direct distillation of NH_3

Bongo series

Parent material	..	Bongo granite
Profile No.	..	NBR 116, Lab. No. B2029
Location ..	..	2½ miles on Bolgatanga–Bongo Road
Site ..	..	Flat summit, less than 1 per cent
Vegetation	..	Cropped farm land, guinea corn

Ap 0–3 *inches* — Reddish brown (5YR 4/4), slightly humous, loamy coarse sand, occasional iron concretions, occasional feldspar particles, few fine roots, weak granular, porous, loose, pH 6.4.

A_{12} 3–8 *inches* — Reddish brown (2.5YR 4/4), coarse sandy loam, occasional particles of feldspar, rare iron concretions, occasional traces of decomposing rock, very few fine roots, weak medium subangular blocks, porous, firm, pH 6.2

AC 8–16 *inches* — Red (2.5YR 4/6), coarse sandy loam, frequent traces of decomposing rock, frequent quartz gravel, frequent feldspar particles, very few fine roots, weak medium subangular blocks, porous, firm, pH 5.4.

C_1 16–28 *inches* — Red (2.5YR 4/6) mottled pink (5YR 8/3) sandy clay loam, abundant fine and coarse quartz gravel, abundant traces of decomposing feldspar, rare manganese dioxide stains, weak medium subangular blocks, porous, firm, pH 5.4.

C_2 28–42 *inches* — Red (2.5YR 4/6) mottled pink (5YR 8/4) and yellow, (10YR 8/6) sandy clay loam of decomposed granite rare manganese stains, strong medium and coarse subangular and angular blocks, porous and very firm, pH 5.2.

C_3 42–54 *inches* — Red (2.5YR 4/6) mottled pink (5YR 8/6) and yellow (10YR 8/6) sandy clay loam of decomposed granite rare manganese dioxide stains, strong medium and coarse subangular and angular blocks, porous and very firm, pH 5.2.

C_4 54–63 *inches* — Yellow (2.5YR 7/6) mottled red (2.5YR 4/8) and pale yellow (5YR 8/3) sandy clay of decomposed Bongo granite (pH 5.6).

Depth inches	Horizon	% Part. Size >2mm	Particle size distribution —International Pipette and hexametaphosphate (mm.) (%) C. sand Sand 2–.2	Fine sand .2–.02	Silt .02–.002	Clay <.002	moisture Equiv.	Organic matter % C (n)	C/N (k)	pH	Exchangeable complex m.e./100gm. T (CE) (b)	Ca	Mg	Mn	K	Na	S (TEB)	% Base Sat.	% Fe_2O_3 Free	phosphorus p.p.m. Total	Acid Soluble
0–3	Ap	—	42.0	42.8	8.1	7.1		.31	1.1	5.9	2.78	1.14	.37	.08	.07	.06	1.72	62		122	2
3–8	A_{12}	—	40.5	33.6	7.1	18.8		.26	1.0	5.6	4.65	2.67	.71	.05	.08	.06	3.57	77		150	<1
8–16	AC	—	41.5	32.1	8.1	18.3		.17	8.1	5.4	4.45	1.26	.56	.05	.07	.06	2.00	45		139	1
16–28	C_1	—	27.2	24.6	11.3	36.9		.08	5.7	5.2	7.61	1.72	.61	.05	.26	.16	2.80	37		184	
28–42	C_2	—	29.1	22.3	13.8	34.8		.05	4.2	5.2	7.97	4.46	.88	.04	.41	.28	6.08	76		163	
42–54	C_3	—	30.3	18.8	16.0	35.6		.05	4.5	5.2	12.69	6.25	2.10	.06	.42	.54	9.37	74		154	
54–63	C_4	—	29.8	23.7	19.3	27.2		.03	5.0	5.5	21.23	12.41	3.07	.07	.06	.05	15.68	74		201	

(*n*) Wakley-Black, (*k*) Kjeldahl method, (*b*) NH_4^+ saturation and direct distillation of NH_3

Vea series

Parent material .. .. Colluvium derived from Bongo granite

Profile No. .. .. NBR 122, Lab. No. B2031

Location .. .. 6 miles on Bolgatanga—Bongo Road

Site .. .. .. Middle to Upper slope of drainage grooves, 2–3 per cent

Vegetation .. .. Cropped farm land, guinea corn

Ap 0–3 *inches* .. .. Brown (5 YR 5/4) loamy coarse sand, occasional pieces of feldspar, frequent quartz gravel, very weak crumbs, loose, porous, pH 6.2.

A_{12} 3–9 *inches* .. Reddish brown (5 YR 4/3) coarse sandy loam, frequent quartz gravel, occasional pieces of feldspar, very weak granules, loose, porous, pH 6.0.

B_{21} 9–18 *inches* .. Reddish brown (5 YR 4/3) coarse sandy loam, rare iron concretions, abundant quartz gravel, rare iron coated manganese dioxide concretions, occasional feldspar particles, weak, medium subangular blocks, porous, slightly firm pH 6.0.

B_{22} 18–34 *inches* Yellowish red (5 YR 4/6) coarse sandy loam, rare iron concretions, abundant quartz gravel, occasional feldspar particles, rare manganese concretions, weak medium blocks, porous, slightly firm, pH 6.6.

B_3 34–53 *inches* .. Reddish brown (2.5 YR 4/4), coarse sandy loam, containing patches of partially weathered pinkish granite, occasional stains of manganese, weak medium subangular blocky, porous, slightly firm, (pH 6.6.).

C 53–60 *inches* .. Olive (5 YR 5/4) mottled pink (5 YR 7/3) coarse sandy clay with patches of manganese stained partially disintergrated Bongo granite, massive, firm (pH 6.6).

Depth inches	*Horizon*	*Moisture Equiv.*	*% Part. Size* ⋝*2mm*	*% Organic matter* *C (n)*	*N (k)*	*C/N*	*O.M. Cx1. 72*	*pH*	*T (CEC) (b)*	*Exchangeable complex m.e/100 gm.* *Ca*	*Mg*	*Mn*	*K*	*Na*	*S (TEB)*	*% Base Sat.*	*% Free* Fe_2O_3	*Phosphorus p.p.m.* *Total*	*Acid Soluble*
0–3	Ap		—	.25	.021	12	.43	5.8	5.55	2.82	1.20	.10	.08	.09	4.29	77		301	
3–9	A_{12}		—	.27	.021	13	.46	6.1	4.01	1.91	.73	.08	.09	.06	2.87	72		226	1
9–18	B_{21}		—	.18	.017	11	.31	6.1	4.83	2.36	1.13	.08	.07	.06	3.70	77		297	3
18–34	B_{22}		—	.15	.014	11	.26	6.4	5.30	2.80	1.24	.07	.07	.06	4.25	80		328	
34–53	B_3		—	.15	.011	14	.26	6.8	5.15	3.26	1.62	.05	.10	.02	5.05	98		309	
53–60	C		—	.06	.006	10	.10	6.5	16.25	10.14	6.10	.05	.15	.21	16.65	103		1941	

(*n*) Wakley-Black, (*k*) Kjeldahl method, (*b*) NH_4+ sauration and direct distillation of NH_3

Yorogo series

Parent material .. Bongo granite

Profile No. .. NBR. 118, Lab. No. B2030

Location .. 4⅜ miles on Bolgatanga–Bongo Road

Site .. Lower slope of a gentle slope, 1–2 per cent

Vegetation .. Cropped farm land (Harvested)

Ap 0–3 *inches* .. Very pale brown (10YR 7/3) loamy coarse sand, frequent quartz gravel, occasional small quartz stones, occasional iron concretions, few fine roots, weak crumbs, porous and hard (pH 5.0).

A_{12} 3–9 *inches* .. Light brown (7.5YR 6/4) loamy coarse sand, frequent quartz gravel, occasional iron concretions, occasional small quartz stones, few fine roots, weak crumbs, hard, pH 5.0.

B_{21}m 9–26 *inches* .. Very pale brown (10YR 7/3) mottled yellow (10YR 7/6) and yellowish red (5YR 4/6) seepage pan, occasional small angular quartz stones, very few fine roots, massive, very hard, porous, pH 6.6.

B_{22}m 26–44 *inches* Very pale brown (10YR 8/4) mottled yellow (10YR 7/6) and reddish brown (2.5YR 4/4) sandy clay loam, abundant fine and coarse quartz gravel, occasional manganese concretions, few fine roots, indurated, massive, slightly porous, very hard, pH 7.0.

B_3 44–58 *inches* .. Abundant fine and coarse quartz gravel, frequent particles of decomposing granite all in a matrix of reddish yellow (7.5YR 7/6) mottled red (10YR 4/6) and yellow (2.5YR 8/4) sandy clay loam, weak induration, fine and medium subangular and angular blocks, porous, firm, pH 7.0.

C_1 58–73 *inches* .. Reddish yellow (7.5YR 7/6) mottled pale yellow (2.5YR 8/4) and red (2.5YR 5/6) sandy clay loam of decomposed feldspathic granite, fine and medium subangular and angular blocks, porous, firm, pH 7.0.

C_2 73–82 *inches* .. Decomposing Bongo granite.

			%	*Organic matter %*						*Exchangeable complex m.e/100 gm.*								..	*Phosphorus p.p.m.*	
Depth inches	*Horizon*	*Moisture Equiv.*	*Part. Size* >2mm	*C (n)*	*N (k)*	*C/N*	*O.M. Cx1.72*	*pH*	*T (CEC) (b)*	*Ca*	*Mg*	*Mn*	*K*	*Na*	*S(TEB)*	*%Base Sat.*	*%Free* Fe_2O_3		*Total*	*Acid Soluble*
0–3	Ap		—	.22	.022	10	.38	5.5	1.92	.56	.23	.07	.06	.05	.97	51			86	1
3–9	A_{12}		—	.20	.019	11	.34	5.4	2.70	.49	.21	.09	.05	.06	.90	33			82	1
9–26	B_{21}m		—	.14	.018	7.8	.24	6.0	5.86	2.79	.89	.03	.13	.11	3.95	67			95	<1
26–44	B_{22}m		—	.07	.011	6.4	.12	6.6	5.18	3.13	1.29	.03	.16	.10	4.71	91			77	
44–58	B_3		—	.08	.011	7.3	.14	6.7	8.62	5.43	2.06	.04	.20	.15	7.88	91			80	
58–73	C_1		—	.06	.012	5.0	.10	6.5	12.91	8.08	2.28	.07	.28	.22	11.93	92			87	
73–82	C_2		—	.04	.006	6.7	.07	5.6	13.98	8.48	4.05	.08	.36	.36	13.28	95			147	

(*n*) Wakley-Black, (*k*) Kjeldahl method, (*b*) NH_4+ saturation and direct distillation of NH

6A

Zoko series

Parent material	..	Bongo granite
Profile No. ..	..	NBR 119, Lab. No. B2023
Location ..	..	7/8 miles on Bolgatanga–Bongo Road
Site	..	Lower slope.
Vegetation ..	..	Cropped farm land (Harvested)
Ap 0–4 *inches*	..	Pale brown (10YR 6/3) slightly humous, loamy coarse sand, abundant fine and coarse quartz gravel, frequent feldspar particles, weak crumbs, porous, loose, pH 6.2.
C_1 4–9 *inches* ..	..	Yellowish brown (10YR 5/6) sandy loam of weathered granite, massive, porous and hard, pH 6.0.
C_2 9–15 *inches*	..	Decomposed granite, massive, very hard.
C_3 15–24 *inches*	..	Partially disintegrated Bongo granite.

			%	*Organic matter %*						*Exchangeable complex m.e/100 gm*								*Phosphorus p.p.m.*	
Depth inches	*Horizon*	*Moisture Equiv.*	*Part. Size* ⋝ *2mm*	*C (n)*	*N (k)*	*C/N*	*O.N. Cx1.72*	*pH*	*T (CEC) (b)*	*Ca*	*Mg*	*Mn*	*K*	*Na*	*S(TEB)*	*%Base Sat.*	*%Free* Fe_2O_3	*Total*	*Acid Soluble*
0–4	Ap		5.5	.41	.035	12	.71	6.6	4.69	2.28	.92	.04	.11	.05	3.40	73		241	9
4–9	C_1		12.7	.31	.034	9.1	.53	6.0	11.85	6.82	3.14	.04	.10	.12	10.22	86		495	18
9–15	C_2		12.3	.06	.012	5.0	.10	6.5	13.22	9.09	3.99	.02	.09	.16	13.35	101		2,996	101
15–24	C_3		20.3	.03	.005	6.0	.05	6.8	15.35	11.54	5.14	.02	.09	.27	17.06	111		5,576	

(*n*) Wakley-Black, (*k*) Kjeldahl method, (*b*) NH_4^+ saturation and direct distillation of NH_3

Yaratanga series

Parent material .. Local alluvium derived from Bongo granite
Profile No. .. NBR 137, Lab. No. B2024
Location .. .. Near Moroko stream at Vea-Village
Site .. .. Lower slope to Bottom, less than 1 per cent
Vegetation .. Cropped farm land (harvested)

Ap 0–2 *inches* Grey (10YR 6/1) mottled brownish yellow (10YR 6/8), humous coarse sandy loam, occasional fine quartz gravel, few fine roots, occasional rusty root channels, weak fine crumbs, porous and loose, pH 5.4.

A_{12} 2–10 *inches* Grey (10YR 6/1) mottled yellowish brown (10YR 5/6) coarse sandy loam, very few fine root, occasional rusty root channels, occasional fine quartz gravel, rare iron concretions, weak, fine, subangular blocks, porous and firm, pH 5.8.

A_{13} 10–23 *inches* Light grey (10YR 7/1) mottled yellowish brown (10YR 5/4) coarse sandy loam, very few fine roots, frequent fine quartz gravel, rare iron concretions, weak, fine subangular blocks, porous and firm, pH 6.6.

B_{21} 23–42 *inches* White (10YR 8/1) and brownish yellow (10YR 6/8) mottled, coarse sand, frequent fine quartz gravel, rare iron concretions, frequent feldspar particles, massive, porous loose, pH 6.6.

B_{22} 42–62 *inches* Yellowish brown (10YR 5/6) and white (10YR 8/2) mottled coarse sand, frequent quartz gravel, occasional iron concretions, very rare angular quartz stones, frequent feldspar particles, massive, porous, loose, pH 6.6.

B_3 62–78 *inches* .. Light yellowish brown (10YR 6/4) coarse sand, very frequent fine quartz gravel, abundant feldspar particles and gravel, rare traces of Bongo granite, occasional angular and subangular, small quartz stones occasional iron concretions, massive, porous, loose, pH 6.8.

C_1 78–88 *inches* .. Grey (10YR 6/1) mottled reddish yellow (7.5YR 6/8), coarse sandy loam, frequent patches of decomposing Bongo granite, massive, hard, pH 6.6.

C_2 88–90 *inches*.. Decomposing Bongo granite.

Depth inches	*Horizon*	*Moisture Equiv.*	*%Part. Size >2mm*	*Organic matter%*				*pH*	*Exchangeable complex m.e/100 gm*								*%Free Fe_2O_3*	*Phosphorus p.p.m.*	
				C (n)	*N (k)*	*C/N*	*O.M. Cx1.72*		*T (CEC) (b)*	*Ca*	*Mg*	*Mn*	*K*	*Na*	*S(TEB)*	*%Base Sat.*		*Total*	*Acid Soluble*
0–2	Ap		—	1.30	.091	14	2.24	5.4	7.01	2.92	.58	.03	.35	.20	4.08	58		148	4
2–10	A_{12}		—	.43	.048	9.0	.74	6.3	6.56	4.21	1.21	.01	.12	.12	5.67	86		134	1
10–23	A_{13}		—	.20	.016	13	.34	6.9	4.03	2.79	.90	.01	.10	.15	3.95	98		70	1
23–42	B_{21}		5.0	.06	.007	8.6	.10	6.9	1.89	1.29	.50	$<$.001	.07	.08	1.94	103		66	
42–62	B_{22}		5.0	.04	.005	8.0	.07	7.0	1.28	1.01	.50	$<$.001	.06	.04	1.61	126		40	
62–78	B_3		9.5	.04	.005	8.0	.07	6.8	2.97	2.03	.71	.003	.09	.08	2.91	98		133	
78–88	C_1		—	.06	.011	5.5	.10	6.4	12.45	5.86	2.77	.03	.16	.23	8.55	69		30	
88–90	C_2		13.7	.03	.008	3.8	.05	6.3		8.44	3.19	.02	.20	.30	12.15	85			

(*n*) Wakley-Black, (*k*) Kjeldahl method, (*b*) NH_4^+ saturatillation of NH_3

Akrubu series

Parent materials .. Local alluvium derived from Bongo granite

Profile No. .. NBR 117, Lab. No. B 2022

Location .. .. 1½ miles on Bolgatanga—Bongo Road

Site .. .. Bottom, less than 1 per cent

Vegetation .. Short grass regrowth after cultivation

Ap 0–2½ *inches* Light grey (5Y 7/0) slightly humous, silty clay loam, plentiful fine roots, occasional rusty root channels, strong medium and coarse subangular blocks, very hard, slightly porous, pH 5.4.

A_{12} 2½–7 *inches* Light grey (5Y 7/10) mottled yellow (2.5Y 7/6), silty clay loam, rare fine quartz gravel, plentiful fine roots, occasional rusty root channels, strong medium and coarse angular and subangular blocks, very hard, slightly porous, pH 5.0.

A_{13} 7–13 *inches* Light grey (5Y 7/2) mottled yellow (2.5Y 7/6), silty clay loam, frequent fine quartz gravel, occasional fine iron concretions, few fine roots, strong medium and coarse angular and subangular blocks, very hard, slightly porous, pH 5.0.

B_{21} 13–24 *inches* Light grey (5Y 7/0) mottled yellow (2.5YR 7/6) sandy clay, frequent fine quartz gravel, rare iron concretions, very few fine roots, medium and coarse angular and subangular blocks, very hard, slightly porous, pH 5.6.

B_{22} 24–38 *inches* .. Light grey (2.5YR 7/2) mottled yellowish brown (10YR 5/6) coarse sandy loam, rare iron concretions, occasional manganese stains, frequent feldspar particles, very few fine roots, medium and coarse angular and subangular blocks, very hard, slightly porous, pH 6.0.

B_{23} 38–50 *inches* .. Pale brown (10YR 6/3) mottled brownish yellow (10YR 6/6) and light grey (5Y 7/2) coarse sandy loam, frequent feldspar particles, occasional manganese concretions, very few fine roots, medium and coarse angular blocks, very firm, porous, pH 6.4.

C_1 50–60 *inches* .. Brownish yellow (10YR 6/6) mottled grey (2.5Y 6/0) and white (5Y 8/0) coarse sandy loam, frequent manganese stains, frequent traces of decomposing granite, firm, massive, porous, pH 6.6.

C_2 60–66 *inches* .. Manganese dioxide stained clayey decomposing Bongo granite massive, firm, pH 6.6.

				Organic matter %						*Exchangeable complex m.e/100 gm*									*Phosphorus p.p.m.*	
Depth inches	*Horizon*	*Moisture Equiv.*	*% Part. Size >2mm*	*C (n)*	*N (k)*	*C/N*	*O.M. Cx1 72*	*pH*	*T (GEC) (b)*	*Ca*	*Mg*	*Mn*	*K*	*Na*	*S (TEB)*	*% Base Sat.*	*% Free Fe_2O_3*	*Total*	*Acid Soluble*
0–2½	Ap		—	2.23	.171	13	4.01	4.92	11.94	2.45	1.26	.09	.18	.36	4.34	36		397	10
2½–7	A_{12}		—	1.04	.079	13	1.79	5.05	10.80	3.24	1.11	.07	.10	.22	4.74	44		221	4
7–13	A_{13}		—	.58	.041	14	1.00	5.54	9.12	4.59	1.71	.03	.09	.22	6.64	73		204	2
13–24	B_{21}		7.0	.25	.024	10	.43	6.04	6.54	3.50	1.51	.01	.07	.12	5.21	80		167	
24–38	B_{22}		11.1	.12	.019	6.3	.21	6.24	6.01	3.22	1.31	.01	.07	.11	4.72	79		167	
38–50	B_{23}		16.7	.08	.012	6.7	.14	6.51	3.73	2.08	1.91	.01	.08	.09	4.17	112		138	
50–60	C_1		13.7	.08	.014	6.4	.14	6.34	11.39	6.60	2.91	.03	.17	.22	9.93	87		318	
60–66	C_2		25.1	.03	.007	4.3	.05	6.21	20.09	14.62	6.17	.03	.23	.41	21.46	107		561	

(*n*) Wakley-Black, (*k*) Kjeldahl method, (*b*) NH_4^+ saturation and direct distillation of NH_3

Nangodi series

Parent material .. Birrimian greenstones and schists

Profile No. .. .. NBR 135, Lab. No. B 2025

Location .. .. 11½ miles on Bolgatanga–Bawku Road

Site .. .. .. Upper slope, steeply sloping, 10 per cent

Vegetation .. .. Cultivated land

Ap 0–3 *inches* .. .. Reddish brown (5YR 4/4), silty clay, occasional quartz gravel and small stones, very frequent rock brash, few fine roots, weak fine crumbs, porous, loose, grades below into (pH 6.4).

AC 3–8 *inches* .. Reddish brown (2.5YR 4/4), silty clay, abundant brash of decomposing rock, weak fine crumbs, firm, grades below into (pH 6.4).

C_1 8–21 *inches* .. Very abundant small, medium and large stones and boulders of decomposing greenstone in a matrix of reddish brown (2.5YR 4/4) silty clay, weak fine subangular blocks, very firm, pH 6.6.

C_2 21–32 *inches* .. Very abundant stones and boulders of decomposing greenstones in a matrix of yellowish red (2.5YR 4/6) silty clay, weak fine subangular blocks, very firm, pH 6.6.

C_3 32–36 *inches* .. Decomposing greenstone massive, very firm.

				Organic matter %					*Exchangeable complex m.e/100 gm*										*Phosphorus p.p.m.*	
Depth inches	*Horizon*	*Moisture Equiv.*	*%Part. Size >2mm*	*C (n)*	*N (k)*	*C/N*	*O.M. Cx1.72*	*pH*	*T(CEC) (b)*	*Ca*	*Mg*	*Mn*	*K*	*Na*	*S(TEB)*	*%Base Sat.*	*%Free Fe_2O_3*		*Total*	*Acid Soluble*
0–3	Ap		—	1.81	.131	14	3.11	6.6	33.91	15.66	9.32	.01	.14	.16	25.29	75			419	3
3–8	AC		—	.93	.075	12	1.60	6.4	21.88	16.63	9.74	.05	.07	1.00	27.49	126			298	2
8–21	C_1		—	.53	.047	11	.91	6.4	23.79	17.71	10.40	.02	.06	.29	28.48	120			340	2
21–32	C_2		—	.54	.047	12	.93	6.1	29.86	21.32	12.33	.02	.06	.03	34.03	114			370	
32–36	C_3		—	.27	.031	8.7	.46	6.5	26.70	21.53	12.53	.02	.07	.38	34.53	129			241	

(*n*) Wakley-Black, (*k*) Kjeldahl method, (*b*) NH_4^+ saturation and direct distillation of NH_3

Gbeshie series

Parent material ..	Birrimian
Profile No. ..	NBR 113, Lab. No. B 2001
Location	Mile 41, Bolgatanga–Bawku Road
Site	Middle slope, 1½ per cent
Vegetation	Short grass savanna regrowth after cultivation

Ap 0–3 *inches* — Dark brown (7.5YR 4/4), humous, fine sandy loam, rare manganese concretions, occasional quartz gravel, frequent irregular-shaped small and large iron concretions, very few fine roots, crumbly, porous, slightly firm, pH 6.0.

C_1 3–9 *inches* — Abundant ferruginized greenstone brash, frequent iron concretions, occasional manganese concretions and occasional quartz gravel all in reddish brown (5YR 4/4) silty clay loam matrix, crumbly, porous, slightly firm, pH 6.4.

C_2 9–18 *inches* — Abundant ferruginized rock brash, occasional iron and manganese concretions, occasional quartz gravel all in a matrix of reddish brown (5YR 5/4) mottled brownish yellow (10YR 6/6) silty clay, indurated and porous, pH 6.0.

C_3 18–31 *inches* .. Yellowish red (5YR 4/6), mottled pale yellow (2.5Y 8/4) silty clay, rare quartz gravel, very frequent ferruginized rock brash, occasional iron and manganese concretions, indurated, massive, pH 6.4.

C_4 31–44 *inches* .. Red (2.5YR 4/6), mottled yellow (10YR 8/6) silty clay, occasional ferruginized rock brash, occasional iron concretions, rare quartz gravel, rare manganese concretions, weakly cemented, massive, pH 6.2.

C_5 44–62 *inches* .. Light grey (2.5YR 7/2) mottled red (2.5YR 4/6) and strong brown (7.5YR 5/8) silty clay, rare ferruginized rock brash, rare iron concretions, frequent small pieces of greenstone, strong coarse angular and subangular blocks, weakly cemented, firm, pH 6.2.

				Organic matter %						*Exchangeable complex m.e/100 gm.*									*Phosphorus p.p.m.*	
Depth inches	*Horizon*	*Moisture Equiv.*	*%Part. Size >2mm*	*C (n)*	*N (k)*	*C/N*	*O.M. Cx1.72*	*pH*	*T (CEC) (b)*	*Ca*	*Mg*	*Mn*	*K*	*Na*	*S (TEB)*	*% Base Sat.*	*%Free Fe_2O_3*	*Total*	*Acid Soluble*
0–3	Ap		37	.58	.046	13	1.00	6.4	4.62	2.37	.91	.13	.10	.08	3.46	75		127	1
3–9	C_1		26.6	.37	.034	11	.64	6.2	6.52	2.83	1.33	.07	.14	.08	4.38	67		135	1
9–18	C_2		45.2	.27	.029	9.3	.36	5.8	8.14	3.05	1.77	.07	.21	.11	5.14	63		144	<1
18–31	C_3		30.5	.13	.020	6.5	.22	6.0	8.17	3.52	1.66	.05	.24	.14	5.56	68		118	
31–44	C_4		—	.14	.020	7.0	.24	5.9	8.15	3.12	1.86	.07	.21	.15	5.34	66		85	
44–62	C_5		—	.11	.014	7.9	.19	5.6	8.75	3.08	2.17	.06	.20	.19	5.64	65		80	

(*n*) Wakley-Black, (*k*) Kjeldahl method, (*b*) NH_4^+ saturation and direct distillation of NH_3

Kalini series

Parent material ..	Local alluvium derived from Birrimian rocks
Profile No. ..	NBR 115, Lab. No. B2006
Location ..	3 miles on Zebila–Upper Volta Road
Site ..	Bottom, 1½ per cent slope
Vegetation ..	Cultivated land

Ap 0–3 *inches* .. Very dark grey (10YR 3/1), humous, clay, rare quartz gravel, rare angular quartz stones, occasional polished iron concretions, rare rock brash, abundant fine roots, weak, fine and medium angular and subangular blocks, porous, firm, pH 7.8.

A_{12} 3–8 *inches* .. Black (5Y 2/1), clay, rare quartz gravel, occasional fine iron concretions, occasional ferruginized brash, rare manganese concretions, plentiful fine roots, weak fine and medium angular and subangular blocks, porous, firm, pH 7.2.

A_{13} 8–15 *inches* .. Black (5Y 2/1), clay, rare quartz gravel, rare manganese concretions, occasional iron concretions, rare ferruginized brash, few fine roots, strong medium and coarse angular and subangular blocks, porous, very firm, pH 7.0.

B_{21} 15–24 *inches* .. Olive (5YR 4/3) mottled light olive brown (2.5Y 5/4) clay, frequent iron concretions, rare ferruginized brash, very few fine roots, strong medium and coarse angular and subangular blocks, porous, very firm, pH 7.0.

B_{22} 24–32 *inches* .. Very dark greyish brown (2.5Y 3/2), mottled brownish yellow (10YR 6/6) sandy clay, occasional quartz stones and gravel, very frequent iron concretions, rare ferruginized brash, occasional manganese concretions, very few fine roots, strong medium and coarse angular and subangular blocks, porous, very firm, pH 7.0.

B_{23} 32–43 *inches* .. Olive grey (5Y 4/2) mottled yellowish brown (10YR 5/6) sandy clay, occasional quartz gravel, rare quartz stones, frequent iron concretions, frequent manganese concretions, strong medium and coarse angular and subangular blocks, porous, very firm, pH 7.0.

B_3 *Cn* 43–51 *inches* .. Grey (5Y 5/1) mottled yellowish brown (10YR 5/6) sandy clay loam, abundant fine and coarse quartz gravel, occasional iron concretions, abundant manganese concretions, occasional traces of decomposing rock, strong medium and coarse angular and subangular blocks, porous, firm, pH 7.0.

C_1 51–60 *inches* .. Pale olive (5Y 6/3) mottled brownish yellow (10YR 6/6) silty clay, very rare quartz gravel occasional manganese concretions, frequent traces of decomposing rock, strong, medium and coarse angular and subangular blocks, porous, firm, pH 7.0.

C_2 60–64 *inches* .. Decomposing greenstone, pH 6.8.

				Organic matter %						*Exchangeable complex m.e/100 gm*									*Phosphorus p.p.m.*	
Depth inches	*Horizon*	*Moisture Equiv.*	*% Part. Size* ⊾*2mm*	*C (n)*	*N (k)*	*C/N*	*O.M. Cln .72*	*pH*	*T (CEC) (b)*	*Ca*	*Mg*	*Mn*	*K*	*Na*	*S (TEB)*	*% Base Sat.*	*% Free* Fe_2O_3	*Total*	*Acid Soluble*
0–3	Ap		12.1	2.66	.187	14	4.18	7.8	70.68	42.21	13.24	⊾.005	.29	1.03	56.77	80		233	5
3–8	A_{12}		10.9	1.22	.091	13	2.10	7.4	39.72	29.70	11.76	.03	.18	.73	42.37	107		124	2
8–15	A_{13}		5.4	0.82	.046	18	1.41	7.1	38.44	27.02	11.67	.02	.17	.53	39.44	103		101	3
15–24	B_{21}		9.1	0.26	.018	14	.45	7.4	17.84	11.95	6.25	.01	.11	.32	18.63	104		62	
24–32	B_{22}		41.5	0.48	.030	16	.83	7.2	25.44	16.65	8.13	.01	.16	.46	25.40	109		116	
32–43	B_{23}		14.8	0.18	.014	13	.31	7.4	15.23	9.81	5.16	.01	.10	.28	15.35	101		52	
43–51	B_3Cn		19.1	0.17	.012	14	.29	6.4	19.58	12.45	6.89	.01	.10	.32	19.76	101		38	
51–60	C_1		-	0.07	.008	8.8	.12	7.5	17.94	12.17	6.59	.01	.09	.27	19.12	101			
60–64	C_2		—	0.04	.006	6.7	.07	7.8	10.06	7.93	5.93	.01	.05	.18	12.09	120			

(*n*) Wakley-Black, (*k*) Kjeldahl method, (*b*) NH_4^+ saturation and direct distillation of NH_3

Yagha series

Parent material ..	Piedmont slope colluvium derived from Birrimian rocks.
Profile No. ..	NBR 107, Lab No. B2003
Location	2¼ miles south of Sapeliga on road to Bawku
Site	Lower slope, 1½ per cent
Vegetation	Short grass savannah

A_{11} 0–3 *inches* — Dark greyish brown (2.5YR 4/2), humous, clay, frequent fine polished iron concretions, occasional manganese concretions, rare fine quartz gravel, few fine roots, fine and medium subangular blocks, porous, hard, pH 6.0.

A_{12} 3–10 *inches* — Dark greyish brown (2.5YR4/2), slightly humous, clay occasional fine quartz gravel, occasional fine polished iron and manganese concretions, plentiful fine roots, fine, medium and subangular blocks, porous, hard, pH.6.4.

B_{21} 10–22 *inches* — Dark greyish brown (2.5YR 4/2), clay, frequent fine quartz gravel, frequent iron and manganese concretions, few fine roots, strong medium, coarse and very coarse angular and subangular blocks, slightly porous, very hard, pH 6.4.

B_{22} 22–35 *inches* — Olive brown (2.5YR4/4) clay, frequent iron and manganese concretions, occasional fine quartz gravel, very few fine roots, rare calcium concretions; strong medium, and very coarse angular and subangular blocks, slightly porous, very hard, pH 6.8.

B_{23}ca 35–52 *inches* — Light olive brown (2.5YR5/4), clay frequent polished iron and manganese concretions, rare calcium concretions, very few fine roots; strong medium, coarse and very coarse angular and subangular blocks, slightly porous, very firm, pH 6.6.

B_{24}ca 52–66 *inches* — Light olive brown (2.5YR 5/6), frequent manganese concretions, occasional polished iron concretions, occasional calcium concretions; strong, medium coarse and very coarse angular and subangular blocks; slightly porous, very firm, pH 7.0.

B_{25}ca 66–77 *inches* — Light olive brown (2.5YR 5/6) mottled dark reddish grey (2.5Y 4/0) and yellow brown (10YR 5/6) clay; frequent manganese and calcium concretions, occasional polished iron concretions; strong medium, coarse and very coarse angular and subangular blocks, slightly porous, very firm, pH 7.4.

		Particle size distribution— International Pipette and hexa-metaphosphate (mm.) (%)						Organic Matter %				Exchangeable complex m.e./100gm.									Phosphorus p.p.m.	
Depth inches	*Hori-zon*	*% Part. ⩾2mm*	*C. sand 2–.2*	*Fine sand .2–.02*	*Silt .02–.002*	*Clay ⩽.002*	*Mois-ture Equiv.*	*C (n)*	*C/N (k)*	*pH*	*T(CE) (d)*	*Ca*	*Mg*	*Mn*	*K*	*Na*	*S(TEB)*	*%Base Sat.*	*%Free Fe_2O_3*	*Total*	*Acid Soluble*
0–3	A_{11}	—	15.8	37.5	17.2	29.5		.75	15	6.1	20.98	13.46	5.25	.09	.18	.18	19.07	91	4.37	137	⩽1
3–10	A_{12}	—	14.2	32.1	18.8	34.9		.57	15	5.8	24.03	14.29	5.29	.09	.17	.24	19.99	83	4.80	116	⩽1
10–22	B_{21}	—	10.5	27.6	19.9	42.0		.53	18	5.6	26.98	16.24	5.82	.06	.21	.30	22.57	84	5.65	102	⩽1
22–35	B_{22}	—	9.9	27.2	19.5	43.4		32	15	5.5	27.90	17.94	6.16	.03	.26	.34	24.70	89	5.75	90	
35–52	B_{23}ca	—	7.5	25.7	20.8	46.0		.26	17	6.0	30.90	21.09	6.96	.01	.26	.35	28.58	93	5.96	69	
52–66	B_{24}ca	—	5.2	26.6	20.4	47.8		.18	12	6.9	34.13	24.43	7.62	.01	.27	.41	32.73	96	6.28	60	
66–77	B_{25}ca	—	10.7	26.9	18.6	43.8		.09	10	7.6	32.16	24.38	7.70	.01	.19	.40	32.67	102	6.42	57	

(*n*) Wakley-Black, (*k*) Kjeldahl method, (*b*) NH_4^+ saturation and direct distillation of NH_3

Sapeliga series

Parent material .. Levee loam associated with Birrimian rocks.

Profile No. .. NBR 105, Lab. No. B2021

Location .. .. $1\frac{3}{4}$ miles south of Sapeliga on road to Bawku

Site .. .. .. On river levee

Vegetation .. .. Short grass savanna.

A_{11} 0–2 *inches* Brown (7.5YR 5/4), sandy loam, frequent iron concretions, frequent fine quartz gravel, very rare subangular quartz stones, plentiful fine roots, moderately weak, fine and medium crumbs, porous, slightly firm, pH 6.6.

A_{12} 2–8 *inches* Brown (7.5YR 5/4) sandy loam, occasional fine iron concretions, occasional fine quartz gravel, rare manganese concretions, few fine roots, moderately weak, fine and medium crumbs, porous, slightly firm, pH 6.4.

B_{21} 8–17 *inches* Yellowish red (5YR 5/6), sandy clay loam, occasional fine iron concretions, occasional fine quartz gravel, occasional manganese concretions, fine and medium subangular and angular blocks, porous, slightly compact, firm, pH 6.2.

B_{22}t 17–27 *inches* Yellowish red (5YR 5/6), sandy clay, occasional iron concretions, rare fine quartz gravel, frequent manganese concretions; fine and medium subangular and angular blocks, porous, slightly compact, firm, pH 6.0.

B_{23}t 27–40 *inches* .. Yellowish red (5YR 4/8) weakly mottled strong brown (7.5YR 5/8) sandy clay; rare iron concretions, very frequent manganese concretions, fine and medium subangular and angular blocks, porous, firm, pH 6.2.

B_{24} 40–60 *inches* .. Strong brown (7.5YR 5/6) mottled brownish yellow (10YR 6/6) and red (2.5YR 5/8) sandy clay loam, frequent soft manganese concretions and stains, fine and medium subangular and angular blocks, porous slightly firm, pH, 6.4.

B_{25} 60–72 *inches* .. Yellowish brown (10YR 5/6) mottled light yellowish brown (2.5YR 6/4) and yellowish red (5YR 5/8) sandy clay loam, occasional soft manganese concretions, very frequent manganese stains, occasional particles of feldspar, weak medium, subangular and angular blocks, porous and slightly firm, pH 6.6.

				Organic matter %					Exchangeable complex m.e/100 gm.										Phosphorus p.p.m.	
Depth inches	*Hori-zon*	*Mois-ture Equiv.*	*% Part. Size >2mm*	*C(n)*	*N(k)*	*C/N*	*O.M. Cx1.72*	*pH*	*T(CEC (b)*	*Ca*	*Mg*	*Mn*	*K*	*Na*	*S(TEB)*	*%Base Sat.*	*% Free Fe_2O_3*	*Total*	*Acid Soluble*
0–2	A_{11}		.13	.37	.029	13	.64	6.9	4.95	2.81	1.54	.18	.16	.09	4.78	97		124	4
2–8	A_{12}		—	.34	.030	11	.58	6.5	7.71	4.58	1.76	.17	.09	.12	6.72	87		110	3
8–17	B_{21}		—	.26	.026	10	.45	6.4	9.57	5.12	2.52	.15	.13	.15	8.07	84		86	1
17–27	B_{22}t		–	.23	.027	8.5	.40	6.1	12.27	6.49	3.24	.13	.18	.25	10.29	84		63	
27–40	B_{23}t		–	.17	.022	7.7	.29	6.3	13.73	7.80	3.77	.08	.22	.41	12.28	89		38	
40–60	B_{24}		–	.11	.018	6.1	.19	6.5	12.68	7.65	3.92	.07	.21	.43	12.28	97		20	
60–72	B_{25}		–	.06	.011	5.5	.10	6.7	12.98	7.68	4.19	.05	.17	.35	12.44	96		12	

(*n*) Wakley-Black, (*k*) Kjeldahl method, (*b*) NH_4+ saturation and direct distillation of NH_3

Bianya series

Parent material	..	Greywackes and quartz sericite schists
Profile No. ..	..	NBR 130, Lab. No. B 2000
Location ..	..	¾ mile east of Nangodi—Sekoti road
Site	..	Middle slope, 2.5 per cent
Vegetation ..	..	Short grass savanna

A_1 0–3 *inches* — Light brownish grey (2.5YR 6/2), slightly humous, very fine sandy loam, rare fine quartz gravel, rare iron concretions, plentiful fine roots, strong medium subangular blocks, slightly porous, very hard, pH 6.8.

B_1 3–9 *inches* — Light grey (10YR 7/2), silty clay loam, rare fine quartz gravel, rare iron concretions, few fine roots, strong medium and coarse angular and subangular blocks, slightly porous, very hard, pH 6.0.

B_{21} 9–22 *inches* — Light grey (10YR 7/2) mottled brownish yellow (10YR 6/6) silty clay, occasional fine quartz gravel, occasional iron and manganese concretions, very few fine roots, strong medium and coarse angular and subangular blocks, slightly porous, very hard, pH 5.4.

B_{22}t 22–34 *inches* — Light grey (5Y 6/3) mottled light olive brown (2.5Y 5/6) and olive yellow (2.5Y 6/6) silty clay, occasional iron and manganese concretions, very few roots, fine and medium subangular blocks, slightly porous, hard, pH 6.4.

B_{23}cnt 34–44 *inches* .. Brownish yellow (1) YR 6/6) mottled pale olive (5Y 6/4) silty clay, frequent fine coarse quartz gravel, very frequent iron and manganese concretions, occasional quartz stones, very few roots, fine subangular blocks, porous, very hard, pH 6.8.

B_{24} 44–56 *inches* .. Pale olive (5Y 6/3) mottled yellow (10YR 7/6) silty clay, frequent iron and manganese concretions, occasional fine and coarse quartz gravel, medium and coarse angular and subangular blocks, slightly porous, hard, pH 6.8.

B_3 56–60 *inches* .. Pale yellow (5Y 7/3) mottled yellow (10YR 7/6 silty clay, frequent angular and subangular quartz stones, occasional decomposing pieces of quartz sericite schist, massive, porous, hard, pH 7.0.

C 60–66 *inches* .. Decomposing quartz sericite schist, massive, hard, pH 7.2.

				Organic matter %						Exchangeable complex m.e/100 gm								Phosphorus p.p.m	
Depth inches	*Horizon*	*Moisture Equiv.*	*%Part. Size >2 mm*	*C (n)*	*N(k)*	*C/N*	*O.M. Cx1. 72*	*pH*	*T (CEC) (b)*	*Ca*	*Mg*	*Mn*	*K*	*Na*	*S (TEB)*	*%Base Sat.*	*%Free Fe_2O_3*	*Total*	*Acid Soluble*
0–3	A_1	—	—	.79	.040	20	1.36	6.1	12.81	8.39	2.32	.09	.11	.34	11.16	87	6.29	113	3
3–9	B_1	—	—	.43	.035	12	.74	5.6	11.99	7.37	1.96	.10	.10	.34	9.77	82	6.82	101	1
9–22	B_{21}	—	—	.31	.038	8.2	.53	5.2	13.47	7.94	2.27	.07	.14	.37	10.72	80	7.04	88	1
22–34	B_{22}t		—	.40	.035	11	.69	5.9	17.57	11.72	3.36	.13	.16	.39	15.63	89	7.37	94	
34–44	B_{23} cnt		29.6	.13	.019	6.8	.22	6.6	20.92	13.31	4.56	.04	.17	.76	18.80	90	7.57	110	
44–56	B_{24}		—	.13	.018	7.2	.22	6.8	24.85	16.36	5.92	.02	.17	.80	23.25	94	8.21	53	
56–60	B_3		72.7	.09	.016	5.6	.15	6.5	22.86	14.90	5.45	.02	.17	.75	21.27	93	9.06	49	
60–66	C			.04	.012	3.3	.07	6.8	25.54	19.32	6.05	.02	.12	.72	26.21	103		39	

(*n*) Wakley-Black, (*k*) Kjeldahl method, (*b*) NH_4^+ saturation and direct distillation of NH_3

Mimi series

Parent material ..	.. Piedmont slope soil derived from V_1 or V_3 sandstone
Profile No. ..	.. NBR 101, Lab. No. B 2028
Location ..	.. 3 miles south of Zongoiri on road to White Volta
Site	.. Upper slope 2–3 per cent
Vegetation ..	.. Tall grass savanna (forest reserve)

A_{11} 0–3 *inches*	Dark brown (7.5YR 4/4), humous, loamy fine sand, plentiful fine roots, weak crumbs, porous, pH 6.4.
A_{12} 3–11 *inches*	Yellowish red (5YR 5/6), loamy fine sand, plentiful fine roots, weak crumbs, porous, soft, pH 5.6.
B_{21}t 11–27 *inches*	Red (2.5YR 5/8), sandy clay, occasional small polished iron concretions, few fine roots, strong medium angular and subangular blocks, porous, hard, pH 5.4.
B_{22}t 27–47 *inches*	Red (2.5YR 4/8), sandy clay, few fine roots, medium and coarse angular and subangular blocks, porous, firm, pH 5.4.
B_{23}t 47–68 *inches*	Red (2.5YR 4/6,) sandy clay, few fine roots, medium and coarse angular and subangular blocks, porous, firm, pH 5.4.
B_{24}t 68–80 *inches*	Red (2.5YR 4/6) weakly mottled light yellowish brown (10 YR 6/4) sandy clay, rare iron concretions, very few fine roots, medium and coarse angular and subangular blocks, porous, firm, pH 5.2.

		Particle size distribution —International Pipette and hexametaphosphate (mm.) (%)						Organic Matter%			Exchangeable complex m.e./100gm.									phosphorus p.p.m.	
Depth inches	Horizon	% Part. Size >2mm	C. Sand 2–.2	Fine Sand .2–.02	Silt .02–.002	Clay <.002	Moisture Equiv.	(C(n)	C/N(k)	pH	T(CE) (b)	Ca	Mg	Mn	K	Na	S(TEB)	% Base Sat.	% Free Fe_2O_3	Total	Acid Soluble
0–3	A_{11}	—	43.2	47.7	4.0	5.1				7.0	3.65	2.12	h83	.12	.09	.09	3.25	89		68	2
3–11	A_{12}	—	46.7	41.6	4.5	7.1		.31	11	6.2	2.56	.75	.69	.16	.06	.06	1.72	67		45	<1
11–27	B_{21}t	—	24.3	29.0	6.2	40.6		.32	11	5.1	6.80	1.49	1.24	.04	.08	.07	2.92	43		130	<1
27–47	B_{22}t	—	22.7	33.1	6.6	37.7		.12	6.7	5.6	5.98	1.68	1.36	.01	.09	.12	3.26	55		118	
47–68	B_{23}t	—	25.7	32.0	6.6	35.6		.11	7.9	5.4	5.22	1.10	1.53	<.005	.09	.08	2.80	54		109	
68–80	B_{24}t	—	20.9	37.8	5.0	36.3		.10	7.1	5.3	5.01	.44	1.12	<.005	.08	.07	1.71	34		93	

(*n*) Wakley-Black, (*k*) Kjeldahl method, (*b*) NH_4^+ saturation and direct distillation of NH_3

Murugu series

Parent material .. .. Colluvium derived from V_1 or V_3 sandstones.
Profile No. .. .. NBR 95, Lab. No. B 2027
Location .. .. About 3½ miles from Shishie on road to Sinibaga
Site .. .. .. Middle slope, 2.5 per cent
Vegetation .. .. Short grass savannah

A_{11} 0 – 3 *inches* — Brown (10YR 5/3), humous, loamy fine sand, few fine roots, rare small iron concretions, crumbly, loose, porous, pH 6.6.

A_{12} 3 – 7½ *inches* — Brown (7.5YR 5/0), loamy fine sand, occasional small iron concretions, few fine roots, fine subangular blocks, porous, slightly firm, pH 6.2.

B_{21} 7½–15 *inches* — Reddish yellow (5YR 6/6), fine sandy loam, few fine roots, occasional iron concretions, fine subangular blocks, porous, slightly firm, pH 6.0.

B_{22} 15 –25 *inches* — Yellowish red (5YR 5/8), fine sandy loam, few fine roots, occasional iron concretions, coarse angular and subangular blocks, firm, porous, pH 6.0.

B_{23} 25 –42 *inches* — Yellowish red (5YR 4/8), fine sandy loam, few fine roots, occasional iron concretions, coarse angular and subangular blocks, porous, firm, pH 6.4.

$B_{24}t$ 42–55 *inches* — Yellowish red (5YR 5/8) sandy clay loam, very few fine roots, occasional iron concretions, occasional ferruginized sandstone brash, porous, very firm, indurated, pH 5.8.

$B_{25}mt$ 55–68 *inches* — Yellowish red (5YR 5/8) mottled reddish yellow (7.5YR–7/6) sandy clay loam, occasional sandstone brash, occasional iron concretions, occasional ferruginized sandstone brash, indurated, very few roots, porous, very firm, pH 5.6.

$B_{26}t$ 68–81 *inches* — Yellowish red (5YR 5/8) mottled yellow (10YR 7/6) and pale yellow (2.5Y 8/4) sandy clay loam, frequent sandstone brash, occasional iron concretions, weakly indurated, porous, very firm, pH 5.4.

				Organic matter%					*Exchangeable complex m.e/100 gm*										*Phosphorus p.p.m*	
Depth inches	*Horizon*	*Moisture Equiv.*	*%Part. Size >2mm*	*C (n)*	*N (k)*	*C/N*	*O.M Cx1.72*	*pH*	*T (CEC) (b)*	*Ca*	*Mg*	*Mn*	*K*	*Na*	*S(TEB)*	*%Base Sat.*	*%Free Fe_2O_3*		*Total*	*Acid Soluble*
0–3	A_{11}		—	.70	.040	18	1.20	6.6	4.41	2.56	.77	.24	.15	.08	3.80	86			37	2
3–7½	A_{12}		—	.58	.038	15	1.00	6.5	4.41	2.24	.76	.35	.08	.06	3.49	79			93	1
7½–15	B_{21}		—	.32	.024	13	.55	6.3	2.98	1.26	.60	.31	.06	.05	2.28	77			71	1
15–25	B_{22}		—	.19	.019	10	.33	6.4	3.52	.87	1.05	.21	.09	.13	2.35	67			68	
25–42	B_{23}		—	.15	.017	8.8	.26	6.4	3.84	.91	1.44	.13	.14	.14	2.76	72			99	
42–55	$B_{24}t$		—	.12	.018	6.7	.21	5.5	4.53	1.01	1.13	.14	.23	.14	2.65	59			104	
55–68	$B_{25}mt$		—	.13	.022	5.9	.22	5.3	5.94	1.32	1.35	.13	.36	.17	3.33	56			132	
68–81	$B_{26}t$		—	.12	.023	5.2	.21	5.3	6.17	1.33	1.39	.09	.33	.19	3.33	54			123	

(*n*) Wakley-Black, (*k*) Kjeldahl method, (*b*) NH_4^+ saturation and direct distillation of NH_3

Bombi series

Parent material .. River alluvium associated with V_1 or V_3 sandstone

Profile No. .. NBR 91. Lab. No. B 2017

Location .. .. About 3 miles from Shishie on road to Sinibaga

Site .. .. Bottom, 2 per cent

Vegetation .. Cultivated land

A_{11} 0–2½ *inches* — Very dark greyish brown (2.5Y 3/2) speckled olive yellow (2.5Y 6/6) slightly humous, silty clay loam, few fine roots, porous, hard crumbs, pH 5.2.

A_{12} 2½–8 *inches* — Light olive grey (5Y 6/2) mottled yellowish brown (10YR 5/6) silty clay, few fine roots, medium blocks, porous, pH 5.2.

A_{13} 8–19 *inches* — Very dark greyish brown (2.5Y 3/2) mottled dark brown (10YR 4/3) silty loam, few fine roots, weak medium blocks, porous, sticky, pH 5.6.

B_{21} 19–34 *inches* — Dark greyish brown (10YR 4/2) silty loam, rare brown soft iron concretions, few fine roots, sticky, massive, wet, pH 5.4.

B_{22} 34–45 *inches* — Dark brown (10YR 4/3), mottled light grey (5Y 7/2) silty loam, rare soft iron concretions, very few fine roots, massive, wet sticky, pH 5.4.

B_{23} 45–53 *inches* — Yellowish brown (10YR 5/4) fine sandy loam, frequent soft iron concretions, wet, water-table occurs here, slightly sticky, pH 5.6.

$B_{24}t$ 53–63 *inches* — Yellowish brown (10YR 5/2) mottled strong brown (7.5YR 5/6) silty clay, rare manganese stains, massive, firm, pH 5.8.

$B_{25}t$ 63–74 *inches* — Light brownish grey (10YR 6/2) mottled strong brown (7.5YR 5/8) and white (2.5Y 8/0) silty clay, rare manganese stains, massive, firm, pH 6.0.

Depth inches	Hori-zon	Mois-ture Equiv.	% Part. Size >2mm	*Organic matter %*				pH	*Exchangeable complex m.e/100 gm*							% Base Sat.	% Free Fe_2O_3	*Phosphorus p.p.m.*	
				C(n)	N(k)	C/N	O.M. Cx1 72		T(CEC) (b)	(Ca	Mg	Mn	K	Na	S(TEB)			Total	Acid Soluble
0–2½	A_{11}		—	3.43	.230	15	5.89	5.1	19.56	8.27	1.66	.89	.33	.30	11.45	59		485	7
2½–8	A_{12}		—	1.45	.093	16	2.59	5.1	15.88	4.85	1.54	.46	.13	.12	7.10	45		279	2
8–19	A_{13}		—	.77	.049	16	1.32	5.7	9.50	4.03	1.26	.39	.07	.10	5.85	62		187	2
19–34	B_{21}		—	.41	.029	14	.70	5.6	6.70	2.04	1.06	.16	.06	.09	3.41	51		136	
34–45	B_{22}		—	.22	.018	12	.37	5.6	5.06	1.07	.82	.14	.06	.11	2.20	44		78	
45–53	B_{23}		—	.14	.014	10	.14	5.9	3.74	.58	.74	.07	.02	.15	1.56	42		120	
53–63	Bt_{24}		—	.25	.026	9.6	.43	5.5	11.26	3.13	2.84	.06	.13	.78	6.94	62		108	
63–74	$B_{25}t$		—	.23	.019	12	.39	6.0	9.89	3.29	2.69	.07	.11	.72	6.88	70		79	

(*n*) Wakley-Black, (*k*) Kjeldahl method, (*b*) NH_4^+ saturation and direct distillation of NH_3

Yaroyiri series

Parent material .. River alluvium associated with V_1 or V_3 sandstone
Profile No. .. NBR 92, Lab. No. B 1018
Location .. .. mile post 98 on Bawku–Yendi Road
Site .. .. Lower slope, 1.5 per cent
Vegetation .. .. Swamp grass

A_{11} 0–2 *inches* — Greyish brown (10YR 5/2), slightly humous, fine sand, plentiful fine roots, weak crumbs, loose, porous, pH 5.8.

A_{12} 2–9 *inches* — Light brownish grey (10YR 6/2), fine sand, few fine roots, structureless, loose, porous, pH 5.4.

B_{11} 9–18 *inches* — Very pale brown (10YR 7/3), fine sand, very few fine roots, rare black stains of manganese, weak fine and medium crumbs, porous, loose, pH 5.4.

B_{12} 18–26 *inches* — Very pale brown (10YR 8/3) mottled strong brown (7.5YR 5/8) fine sand, very few fine roots, rare black, stains of manganese, weak fine and medium crumbs, porous, loose, pH 6.6.

B_{21} 26–38 *inches* — Very pale brown (10YR 8/3) mottled yellowish brown (10YR 5/8) loamy fine sand, rare iron concretions, rare manganese stains, medium and coarse subangular blocks, firm, pH 6.6.

B_{22} 38–56 *inches* — Very pale brown (10YR 7/4) mottled yellow (10YR 7/6) fine sandy loam, rare iron concretions, medium, and coarse subangular blocks, very firm, pH 7.2.

$B_{23}t$ 56–67 *inches* — Light grey (10YR 7/2) mottled yellowish brown (10YR 5/4) sandy clay loam, rare iron concretions, frequent manganese stains, strong medium and coarse subangular blocks, firm, pH 7.0.

$B_{24}t$ 67–74 *inches* — Grey (10YR 6/1) mottled strong brown (7.5YR 5/8) sandy clay, frequent manganese stains, fine and medium subangular blocks, firm, pH 7.0.

				Organic matter %					*Exchangeable complex m.e/100 gm*									*Phosphorus p.p.m.*	
Depth inches	*Horizon*	*Moisture Equiv.*	*% Part. Size >2mm*	*C (n)*	*N(k)*	*C/N*	*O.M. Cx1 72*	*pH*	*T(CEC) (b)*	*Ca*	*Mg*	*Mn*	*K*	*Na*	*S(TEB)*	*% Base Sat.*	*% Free Fe_2O_3*	*Total*	*Acid Soluble*
0–2	A_{11}		—	.57	.040	14	.98	6.1	5.08	1.85	.44	.16	.11	.09	2.65	52		69	5
2–9	A_{12}		—	.32	.028	11	.55	5.9	3.91	1.31	.44	.11	.05	.04	1.95	50		55	2
9–18	B_{11}		—	.11	.017	6.5	.19	6.5	2.50	1.02	.53	.02	.05	.04	1.66	66		47	3
18–26	B_{12}		—	.04	.007	5.7	.07	7.1	1.34	.51	.19	.01	.02	.04	.77	58		23	
26–38	B_{21}		—	.06	.012	5.0	.10	7.2	3.52	.81	.90	.01	.01	1.03	2.85	81		36	
38–56	B_{22}		—	.06	.010	6.0	.10	7.9	4.59	1.26	.88	.03	.11	1.21	3.49	76		36	
56–67	$B_{23}t$		—	.12	.014	8.6	.20	7.6	9.83	3.12	2.18	.07	.15	3.29	8.81	90		31	
67–74	$B_{24}t$		—	.09	.012	7.5	.15	7.3										48	

(*n*) Wakley-Black, (*k*) Kjeldahl method, (*b*) NH_4^+ saturation and direct distillation of NH_3

Dagare series

Parent material	River alluvium (levee) derived from mixed rocks
Profile No.	NBR 85, Lab. No. 2005
Location	Just east of White Volta bridge on Bawku–Bolgatanga road.
Site	On river levee
Vegetation:	Riverain woodland.
A_{11} 0–4 *inches*	Light brownish grey (2.5Y 6/2), humous, silty loam, few fine roots, crumbly, porous, pH 5.8.
A_{12} 4–13 *inches*	Pale brown (10YR 6/3), silty loam, few fine roots, fine and medium subangular blocks, porous, pH 6.8.
B_{21} 13–27 *inches*	Dark grey (10YR 4/1), silty clay loam, few fine roots, fine and medium sub angular blocks, porous, slightly firm, pH 6.6.
B_{22} 27–40 *inches*	Pale brown (10YR 6/3), weakly mottled dark greyish brown (10YR 4/4), silty clay loam, very few fine roots, friable, massive, pH 6.2.
B_{23} 40–55 *inches*	Brown (10YR 5/3) mottled dark reddish brown (5YR 3/4) sandy clay loam, very few fine roots, massive, friable, pH 6.0.
B_{24} 55–69 *inches*	Dark greyish brown (10YR 4/2), sandy clay loam, very-few fine roots, massive, wet, pH 5.6.
$B_{25}t$ 69–78 *inches*	Pale brown (10YR 6/3), sandy clay loam, frequent manganese stains, very few fine roots, massive, wet, pH 5.6.

			Particle size distribution— International pipette and hexametaphosphate %(mm.)					*Organic Matter %*				*Exchangeable complex m.e/100 gm.*								*Phosphorus p.p.m.*	
Depth inches	*Horizon*	*% Part. size* $\geq$ *2mm*	*C. sand 2–.2*	*Fine sand 2–.02*	*Silt .02–.002*	*Clay* $\leq$ *.002*	*Moisture Equiv.*	*%C (n)*	*C/N (k)*	*pH*	*T (CEC) (b)*	*Ca*	*Mg*	*Mn*	*K*	*Na*	*S(TEB)*	*%Base Sat.*	*%Free* Fe_2O_3	*Total*	*Acid Soluble*
0–4	A_{11}	—	0.3	45.1	26.8	27.9		1.16	13	6.0	20.57	12.08	5.77	.46	.37	.26	18.48	90		382	22
4–13	A_{12}	—	0.1	49.5	23.1	27.3		0.98	14	6.7	22.33	14.92	4.18	.16	.27	.25	19.12	88		355	26
13–27	B_{21}	—	0.3	15.6	45.0	39.1		1.09	14	6.3	30.00	18.73	6.75	.28	.37	.27	26.12	87		505	26
27–40	B_{22}	—	0.1	59.0	17.6	23.1		0.33	12	6.3	14.81	9.04	4.26	.16	.20	.20	13.70	93		246	
40–55	B_{23}	—	0.1	69.0	12.9	18.0		0.27	14	6.3	12.09	6.55	3.70	.16	.15	.24	10.64	88		241	
55–69	B_{24}	—	0.2	76.9	8.6	14.3		0.15	10	5.8	9.35	4.50	2.47	.12	.12	.18	7.27	78		181	
69–78	$B_{25}t$	—	0.1	46.2	25.6	28.2		0.32	11	5.6	18.05	8.77	5.30	.20	.24	.55	14.86	82		318	

(*n*) Wakley-Black, (*k*) Kjeldahl method, (*b*) NH_4^+ saturation and direct distillation of NH_3

Sirru series

Parent material ..	Levee sandy loam derived from mixed rocks
Profile No. ..	NBR 142, Lab. No. B 2026
Location: ..	Near mile 12 on Bolgatanga—Navrongo road
Site ..	On old river levee
Vegetation ..	Short grass savannah

A_{11} 0–3 *inches* .. Dark brown (10YR 4/3), loamy fine sand, few fine roots, slightly crumbly, porous, loose, pH 6.6.

A_{12} 3–7 *inches* Reddish brown (5 YR 4/4), loamy fine sand, few fine roots, rare quartz gravel, weak crumbs, porous, loose, pH 6.6.

B_{21} 7–12 *inches* Yellowish red (5YR 4/6), sandy clay loam, very few roots, rare fine quartz gravel, fine and medium subangular blocks, porous, firm, pH 6.6.

B_{22} 12–25 *inches* Yellowish red (5YR 4/8), sandy clay loam, rare fine quartz gravel, rare very fine polished iron concretions, very few roots, strong fine medium and coarse subangular blocks, porous, very firm, pH6.4.

B_{23} 25–43 *inches* Strong brown (7.5YR 5/6) sandy clay loam, rare fine quartz gravel, very few roots, strong fine, medium and coarse subangular blocks, porous, very firm, pH 6.6.

C_1 43–62 *inches* .. Brownish Yellow (10YR 6/4), loamy fine sand, rare fine quartz gravel, very few roots, strong fine medium and coarse subangular blocks, porous, very firm, pH 6.4.

C_2 62–76 *inches* .. Yellow (10YR 7/6), loamy fine sand, very few fine roots, rare quartz gravel, fine and medium crumbs, porous, pH 6.0.

C_3 76–87 *inches* .. Yellow (10YR 7/6) fine sand, rare iron and manganese concretions, occasional fine and coarse quartz gravel, very few fine roots, weak crumbs, porous, loose, pH 6.2.

C_4 87–104 *inches* .. Very pale brown (10YR 7/4) sand, occasional quartz gravel, occasional small subangular quartz stones, rare iron concretions, single grained, porous, loose, pH 6.8.

Depth inches	Horison	Moisture Equiv.	% Part. Size > 2mm	Organic matters %				pH	Exchangeable complex m.e/100 gm								% Free Fe_2O_3	Phosphorus p.p.m	
				C(n)	N(k)	C/N	O.M. Cx1.72		T (CEC) (b)	Ca	Mg	Mn	K	Na	S (TEB)	% Base Sat.		Total	Acid Soluble
0–3	A_1		—	.38	.035	11	.65	6.6	3.77	2.10	1.13	.03	.23	.13	3.62	96		73	4
3–7	A_{21}		—	.35	.029	12	.60	6.3	4.42	2.14	1.47	.04	.12	.05	3.82	86		106	2
7–12	B_{21}		—	.29	.031	9.4	.50	6.3	5.49	2.56	1.46	.06	.09	.07	4.24	77		90	1
12–25	B_{22}		—	.26	.029	9.0	.45	6.1	8.78	3.81	1.25	.06	.13	.13	6.38	73		99	
25–43	B_{23}		—	.10	.015	6.7	.17	6.2	6.48	3.00	1.63	.05	.13	.11	4.92	76		43	
43–62	C_1		—	.05	.008	6.3	.09	6.3	4.96	2.50	1.32	.05	.09	.07	4.03	81		27	
62–76	C_2		—	.03	.007	4.3	.05	6.4	3.53	1.75	1.01	.05	.09	.09	2.99	85		20	
76–87	C_3		—	.03	.005	6.0	.05	6.5	2.83	1.86	.84	.02	.06	.10	2.38	84		14	
78–104	C_4		—	.01	.004		.02	6.9	1.98	.98	.44	.01	.03	.09	1.55	78		17	

(*n*) Wakley-Black, (*k*) Kjeldahl method, (*b*) NH_4^+ saturation and direct distillation of NH_3

Siare series

Parent material .. River alluvium derived from mixed rocks

Profile No. .. .. NBR 86, Lab. No. B2004

Location .. .. 2 chains north of Bolgatanga– Bawku road at mile 36½

Site .. .. .. Nearly flat

Vegetation .. .. Accasia and short grass

A_{11} 0–2 *inches* .. Dark greyish brown (2.5 YR4/2), slightly humous; clay, occasional manganese concretions, plentiful fine roots, medium and coarse angular and subangular blocks, slightly porous, very hard, pH 6.6.

A_{12} 2–9 *inches* .. Olive brown (2.5 YR 4/4) clay, occasional manganese concretions, few fine roots, medium and coarse angular and subangular blocks, slightly porous, very hard, pH 6.6.

B_{22} 9–20 *inches* .. Olive brown (2.5 Y 4/4), clay, frequent manganese concretions, few fine roots, medium and coarse angular and subangular blocks, slightly porous, hard, pH 6.8.

B_{23} 20–33 *inches* .. Light olive brown (2.5 YR 5/4), clay, frequent small manganese concretions, few fine roots, medium and coarse angular and subangular blocks, slightly porous, hard, pH 7.4.

B_{24} 33–46 *inches* Yellowish brown (10 YR 5/6) mottled grey (10 YR 6/1) clay, occasional manganese stains, rare small calcium concretions, few small roots, very few fine roots, medium and coarse angular and subangular blocks, slightly porous, very hard, pH 8.2.

B_{25}t 46–60 *inches* Yellowish brown (10 YR 5/6) mottled grey (10 YR 6/1) clay, occasional manganese stains, rare small calcium concretions, few small roots, very few fine roots, medium and coarse angular and subangular blocks, slightly porous, very hard, pH 8.2.

B_{26}ca 60–74 *inches* Yellowish brown (10 YR 5/6) mottled grey (10 YR 6/1) clay, frequent soft manganese concretions, rare calcium concretions, very few fine roots, medium and coarse angular and subangular blocks, slightly porous, very hard, pH 8.0.

			Particle size distribution— International pipette and hexametaphosphate (mm.) %					*Organic Matter %*			*Exchangeable complex m.e/100gm*										*phosphorus p.p.m.*	
Depth inches	*Horizon*	*% Part. Size > 2mm*	*C.Sand 2–.2*	*Fine .2–.02*	*Silt .02–.002*	*Clay < .002*	*Moisture Equiv.*	*C(n)*	*C/N (k)*	*pH*	*T(CE) (b)*	*Ca*	*Mg*	*Mn*	*K*	*Na*	*S (TEB)*	*% Base Sat.*	*% Free Fe_2O_3*	*Total*	*Acid Soluble*
0–2	A_{11}	—	2.7	47.2	18.8	3.3		.51	13	6.6	16.59	8.13	5.88	.05	.40	.50	14.91	90		166	5
2–9	A_{12}	—	2.8	30.3	20.7	46.2		.50	17	6.4	23.25	12.27	7.20	.07	.46	1.04	20.97	90		147	1
9–20	B_{22}	—	3.0	30.3	19.6	47.1		.42	14	6.6	23.25	12.40	7.25	.04	.53	.81	20.99	90		133	1
20–33	B_{23}	—	1.2	30.1	20.1	48.6		.31	16	7.7	24.22	13.41	8.12	.16	.64	1.10	23.27	96		144	
33–46	B_{24}	—	0.4	30.8	20.1	48.7		.12	12	7.8	23.03	14.37	7.86	< 005	.59	1.38	24.20	58		184	
46–60	B_{25}t	—	0.2	28.4	21.7	49.8		.10	10	7.7	24.98	14.57	7.97	.01	.50	1.56	24.60	99		229	
60–74	B_{26}ca	—	0.1	30.1	21.6	48.2		.11	11	7.5	24.52	13.36	8.02	< 005	.50	23.61	23.61	96		225	

(*n*) Wakley-Black, (*k*) Kjeldabl method (*b*) NH_4^+ saturation and direct distillation of NH_3

Pani series

Parent material .. Alluvium derived from mixed rocks
Profile No. .. NBR 48, Lab. No. B 1440
Location .. Tono State Farm Detailed Soil Survey, traverse 4A, chain 15
Site .. Bottom/Flat, less than 5 per cent
Vegetation .. Swamp grass regrowth after cultivation

Ap 0–3 *inches* — Very dark grey (10YR 3/1), humous, silty clay, plentiful fine roots, occasional rusty root channels, strong coarse subangular blocky, very plastic and massive when wet, pH 6.0.

A_{11} 3–6 *inches* — Dark grey (10YR 4/1) faintly mottled dark brown (7.5YR 4/4), humous, silty clay, few fine roots, occasional rusty root channels, strong coarse subangular blocky, very plastic and massive when wet, pH 5.6.

A_{12} 6–18 *inches* — Dark grey (10YR 4/1) faintly mottled brown (10YR 5/3), silty clay, occasional fine roots, large blocky, very plastic and massive when wet, pH 5.6.

$B_{21}t$ 18–33 *inches* — Grey (10YR 5/1) faintly mottled pale brown (10YR 6/3) silty clay, large blocky, very plastic and massive when wet, pH 6.6.

$B_{22}t$ 33–43 *inches* — Dark grey (10YR 4/1) mottled yellow brown (10YR 5/6), silty clay, medium blocky, very plastic and massive when wet, pH 7.6.

B_{23} 43–54 *inches* — Light yellowish brown (10YR 6/4) mottled grey (10YR 5/1), fine sandy loam, occasional soft manganese concretions; weak, fine subangular blocky, plastic, pH 7.2.

B_{24} 54–60 *inches* — Light yellowish brown (10YR 6/4) loamy sand, very rare fine quartz gravel, rare manganese concretions, structureless, loose, pH 6.8.

				Organic matter %						*Exchangeable complex m.e/100 gm*										*Phosphorus p.p.m.*	
Depth inches	*Horizon*	*Moisture Equiv.*	*%Part. Size >2mm*	*C (n)*	*N(k)*	*C/N*	*O.M. Cx1.72*	*pH*	*T(CEC) (b)*	*Ca*	*Mg*	*Mn*	*K*	*Na*	*S(TEB)*	*%Base Sat.*	*% Free Fe_2O_3*	*Total*	*Acid Soluble*
0–3	Ap	38.65	—	3.92	.271	14	6.74	6.0	28.09	9.70	4.68	.40	.63	.54	15.95	57		281	8
3–6	A_{11}	34.30	—	1.61	.107	15	2.77	5.5	26.61	11.95	6.08	.41	.43	.72	19.59	74		422	9
6–18	A_{12}	32.95	—	1.13	.069	16	1.95	5.6	27.01	14.50	6.92	.19	.40	1.01	23.02	85		418	9
18–33	$B_{21}t$		—	.86	.056	15	1.48	6.7	25.97	17.01	6.78	.03	.40	1.03	25.25	100		278	
33–43	$B_{22}t$		—	.47	.041	11	.85	7.5	25.31	18.33	5.79	.02	.35	1.03	25.52	101		148	
43–54	B_{23}		—					7.2	10.86	7.86	3.51	.02	.16	.57	12.12	112		105	
54–60	B_{24}		—					6.9	4.57	2.99	1.45	.06	.13	.23	4.86	106			

(*n*) Wakley-Black, (*k*) Kjeldahl method, (*b*) NH_4^+ saturation and direct distillation of NH_3.

Dorimon series

Parent material .. Birrimian

Profile No. .. NBR 113 Lab. No. B 2001

Location .. Mile 41, Bolgatanga–Bawku Road

Site .. Middle slope, 1½ per cent

Vegetation .. Short grass savanna regrowth after cultivation

Ap 0–3 *inches* .. Dark brown (7.5YR 4/4), humous, fine loam, rare manganese concretions, occasional quartz gravel, frequent irreguar-shaped small and large iron concretions, very few fine roots, crumbly, porous, slightly firm, pH 6.0.

A_3 3–9 *inches* .. Abundant ferruginized greenstone brash, frequent iron concretions, occasional manganese concretions and occasional quartz gravel all in reddish brown (5YR 4/4) silty clay loam matrix, crumbly, porous, slightly firm, pH 6.4.

B_{21}cn 9–18 *inches* .. Abundant ferruginized rock brash, occasional iron and manganese concretions, occasional quartz gravel all in a matrix of reddish brown (5YR 5/4) mottled brownish yellow (10YR 6/6) silty clay, indurated and porous, pH 6.0.

B_{22}tm 18–31 *inches* Yellowish red (5YR 4/6), mottled pale yellow (2.5Y 8/4) silty clay, rare quartz gravel, very frequent ferruginized rock brash, occasional iron and manganese concretions, indurated massive, pH 6.4.

B_{23}t 31–44 *inches* Red (2.5YR 4/6) mottled yellow (10YR 8/6) silty clay occasional ferruginized rock brash, occasional iron concretions, rare quartz gravel, rare manganese concretions, weakly cemented, massive, pH 6.2.

B_3 44–62 *inches* Light grey (2.5YR 7/2) mottled red (2.5YR 4/6) and strong brown (7.5YR 5/8) silty clay, rare ferruginized rock brash, rare iron concretions, frequent small pieces of greenstone, strong coarse angular and subangular blocks weakly cemented, firm, pH 6.2.

				Organic matter					*Exhangeable complex m.e/100 gm.*								*% Free Fe_2O_3*	*Phosphorus p.p.m.*	
Depth inches	*Horizon*	*Moisture Equiv.*	*Part. Size >2mm*	*C (n)*	*N(k)*	*C/N*	*O.M. Cx1.72*	*pH*	*T (CEC) (b)*	*Ca*	*Mg*	*Mn*	*K*	*Na*	*S(TEB)*	*% Base Sat.*		*Total*	*Acid Soluble*
0–3	Ap		37	.58	.046	13	1.00	6.4	6.62	2.37	.91	.13	.10	.08	3.46	75		127	1
3–9	A_3		26.6	.37	.034	11	.64	6.2	6.52	2.83	1.33	.07	.14	.08	4.38	67		135	1
9–18	B_{21}cn		45.2	.27	.029	9.3	.36	5.8	8.14	3.05	1.77	.07	.21	.11	5.14	63		144	1
18–31	B_{22}tm		30.5	.13	.020	6.5	.22	6.0	8.17	3.52	1.66	.05	.24	.14	5.56	68		118	
31–44	B_{23}t		—	.14	.020	7.0	.24	5.9	8.15	3.12	1.86	.07	.21	.15	5.34	66		85	
44–62	B_3		—	.11	.014	7.9	.19	5.6	8.75	3.08	2.17	.06	.20	.19	5.64	65		80	

(*n*) Wakley-Black, (*k*) Kjeldahl method, (*b*) NH_4^+ saturation ana direct distillation of NH_3

GLOSSARY OF SPECIAL TERMS*

A-horison ..	.. *See* horizon, soil.
Acid soil ..	.. *See* Reaction, soil.
Alkaline soil	.. *See* Reaction, soil
Alluvium ..	.. Fine material such as sand, clay or other sediments deposited on land by stream.
Arable land	.. Land that in its present condition is physically capable, without further substantial improvement, of producing crops requiring tillage.
B-horizon ..	.. *See* horizon, soil.
Base saturation	.. Metallic cation saturation.
Bedrock ..	.. The solid rock beneath the soils and other unconsolidated natural formations.
C-horizon ..	.. *See* horizon, soil.
Calcareous ..	.. A soil containing enough calcium carbonate (lime) to effervesce (fizz like soda water) visibly to the naked eye when treated with dilute hydrochloric acid. The presence of free calcium carbonate gives this soil alkaline reaction.
Catena ..	.. A sequence of different soils usually from similar parent material but varying with relief and drainage.
Clay	.. The small mineral soil grains, less than 0.002 mm (0.000079 inch) in diameter.
Colluvium ..	.. Heterogeneous deposits of rock fragments and soil material accumulated at the base of slopes through the influence of gravity, including creep and local wash.
Concretions	.. Local concentrations of certain chemical compounds, such as calcium carbonate or compounds of iron, that form hard grains or nodules of mixed composition and of various sizes, shapes and colours.
Consistence, soil	.. A measure of the property of a soil to adhere or cohere or to resist deformation or rupture. Consistence of a soil is described when wet, moist or dry by such terms as loose; hard; friable; firm; sticky; plastic; soft; compact.
Drainage basin	.. Area drained by a river and its tributaries.
Erosion, gully	.. Erosion that cuts deep channels (gullies) into land.
Erosion, sheet	.. The gradual, uniform removal of surface soil by water.
Exchange capacity ..	Milliequivalent of ions that can be absorbed by 100 gm. soil at a specific pH (soil reaction).
Friable ..	.. Easily crumbled in the fingers.
Groundwater laterite	Soil with a high water-table and a coarsely mottled ferruginous subsoil which either is hard or will harden on exposure.
Gravel ..	.. Soil particles between 20 and 2 mm in diameter.
Hardpan ..	.. An indurated (hardened) or cemented soil horizon. The soil may be of any texture, but is compacted or cemented together by iron oxide, silica, calcium carbonate or other substances.
Horizon, soil	.. A layer of soil approximately parallel to the soil surface, with characteristics produced by soil-forming processes. Soil horizons are designated as A, B, C and R.
	A-horizon refers to the uppermost layers of a soil profile where accumulation of organic matter and eluviation commonly occur.

*Taken mostly from Glossary of special terms in *Soil and Men* (1938) and *Multilingual Vocabulary of Soil Science* (1961).

B-horizon is that part of the soil profile below the A horizon; usually illuvial, i.e. it has received material in solution or suspension from the upper part of the soil.

C-horizon is the zone of weathered rock material little affected by biological soil forming processes.

R-horizon is unweathered rock below C-horizon.

Humus .. .. The well-decomposed, more or less, stable part of the organic matter in the soil.

Impeded drainage .. Condition in which downward movement of gravitational water is impeded.

Indurated .. .. Very strongly cemented; brittle; does not soften under prolonged wetting; bieaks only with a sharp blow with a hammer.

Ironpan .. .. Layer cemented with iron oxides.

Laterite .. .. A red subsoil which hardens permanently on exposure or has already hardened under natural conditions.

Leaching .. .. Removal of materials in solution.

Levee .. .. The natural bank of a river formed during flooding by the deposition of silt. When the flood subsides, the silt remains, and the levee is thus the highest portion of the flood-plain of a river.

Lime .. .. Strictly, calcium oxide; but in the commonly used agricultural sense, calcium carbonate and calcium hydroxide.

Lithosol .. .. Soil consisting of nearly unweathered rock fragments A C profile usually shallow and without horizon development.

Loam .. .. Soil having clay and coarser particles in proportions which usually form a permeable, friable, mixture.

Mottled (mottling) .. Irregularly marked with spots of different colours.

Neutral soil .. (*See* Reaction, soil).

Parent material .. The unconsolidated mass of geologic material from which the soil profile develops.

Permeability .. Readiness with which air or water can pass through soil.

Plastic .. .. Capable of being moulded without breaking.

Porosity, soil .. The degree to which the soil mass is permeated with pores or cavities.

Profile, soil .. .. A vertical section of the soil showing sequence of horizons from surface to parent material.

R-horizon .. .. *See* horizon.

Reaction, soil .. The degree of acidity or alkalinity of the soil mass, generally expressed mathe matically as the pH value. A pH value of 7 indicates precise neutrality; higher values, alkalinity; and lower values, acidity. The degree of acidity or alkalinity is expressed in words and pH values as follows:

Extremely acid	Below 4.5
Very Strongly acid	4.5–5.0
Strongly acid	5.1–5.5
Medium or moderately acid	5.6–6.0
Slightly acid	6.1–6.5
Neutral	6.6–7.3
Mildly or slightly alkaline	7.4–7.8

	Moderately alkaline	7.9–8.4
	Strongly alkaline	8.5–9.0
	Very strongly alkaline	9.1 or higher.

Sand .. .. Small rock or mineral fragments from 2–0.02 mm.

Seepage pan .. Groundwater laterite formed as a result of the slow oozing out of groundwater charged with iron, aluminium and other compounds on to the earth's surface.

Silt .. .. .. Small mineral soil grains, the particles of which range in diameter from .02–.002 mm.

Skeletal soil .. *See* lithosol.

Soil association ..
complex ..
consociation ..
phase .. ..
series .. ..
} *See* page 20.

Structure, soil .. Arrangement of primary soil particles in aggregates. Structure is described by such terms as "prismatic, subangular blocky, columnar, crumb, granular, blocky and single grain".

Subsoil .. .. Part of a soil between the layer normally used in tillage and the depth to which most plant roots grow.

Surface soil .. A general term applied to the upper layer of the soil. This may be either to plough depth or the A-horizon if it extends below plough depth (*see* also top soil).

Talus .. .. Detritus accumulated at foot of a steep slope.

Texture, soil .. Relative proportions of the various size groups of individual soil grains in a mass of soil. Refers to the proportions of clay, silt and sand below 2 mm. in diameter.

Top soil .. .. A general term which refers to the layer of soil moved in cultivation; the A-horizon.

Water-table .. .. (Ground-water level). The upper limit of the part of the soil or underlying material wholly saturated with water.

Weathering .. .. The physical and chemical disintegration and decomposition of rock and minerals.

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LIST OF STAFF ENGAGED ON SURVEY

Name	*Rank*	
S. V. Adu	Research Officer.	
D. O. Tenadu	Senior Technical Assistant	
J. O. Ansah	Scientific Assistant Grade 1	
Osei Achampong	Supervisor Grade 1	
J. A. Ashong	Supervisor Grade 1	
C. O. Agyakwa	Supervisor Grade 1	
C. T. Nartey	Clerical Officer.	
F. Adjei	Driver Grade 1	
K. Yeboah	Driver Grade III	
K. Obimpeh	Driver Grade II	Short attachments as reliefs.
D. K. Aning	Driver Grade II	
T. Kweku	Driver Grade III	

INDEX OF SOILS SERIES

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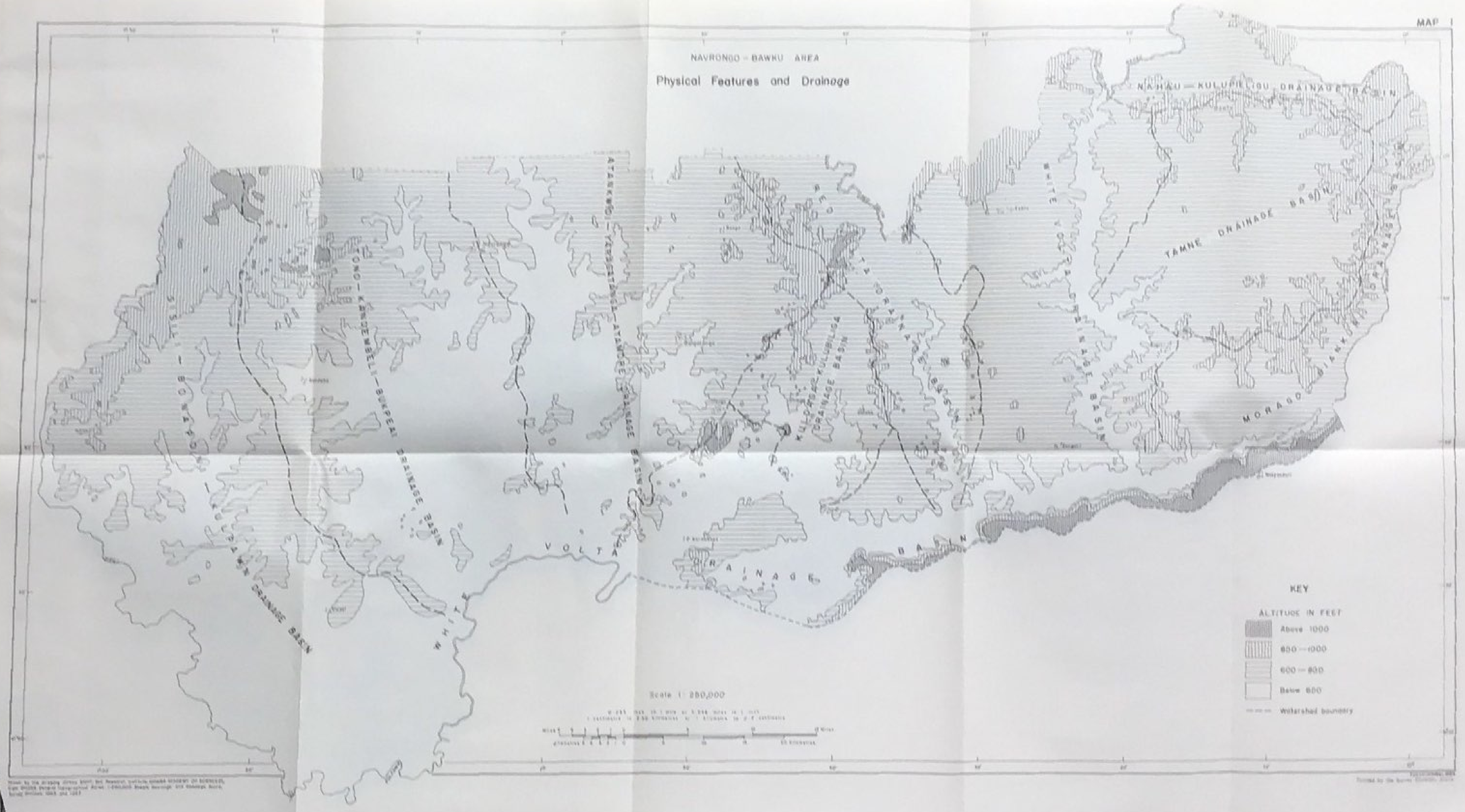
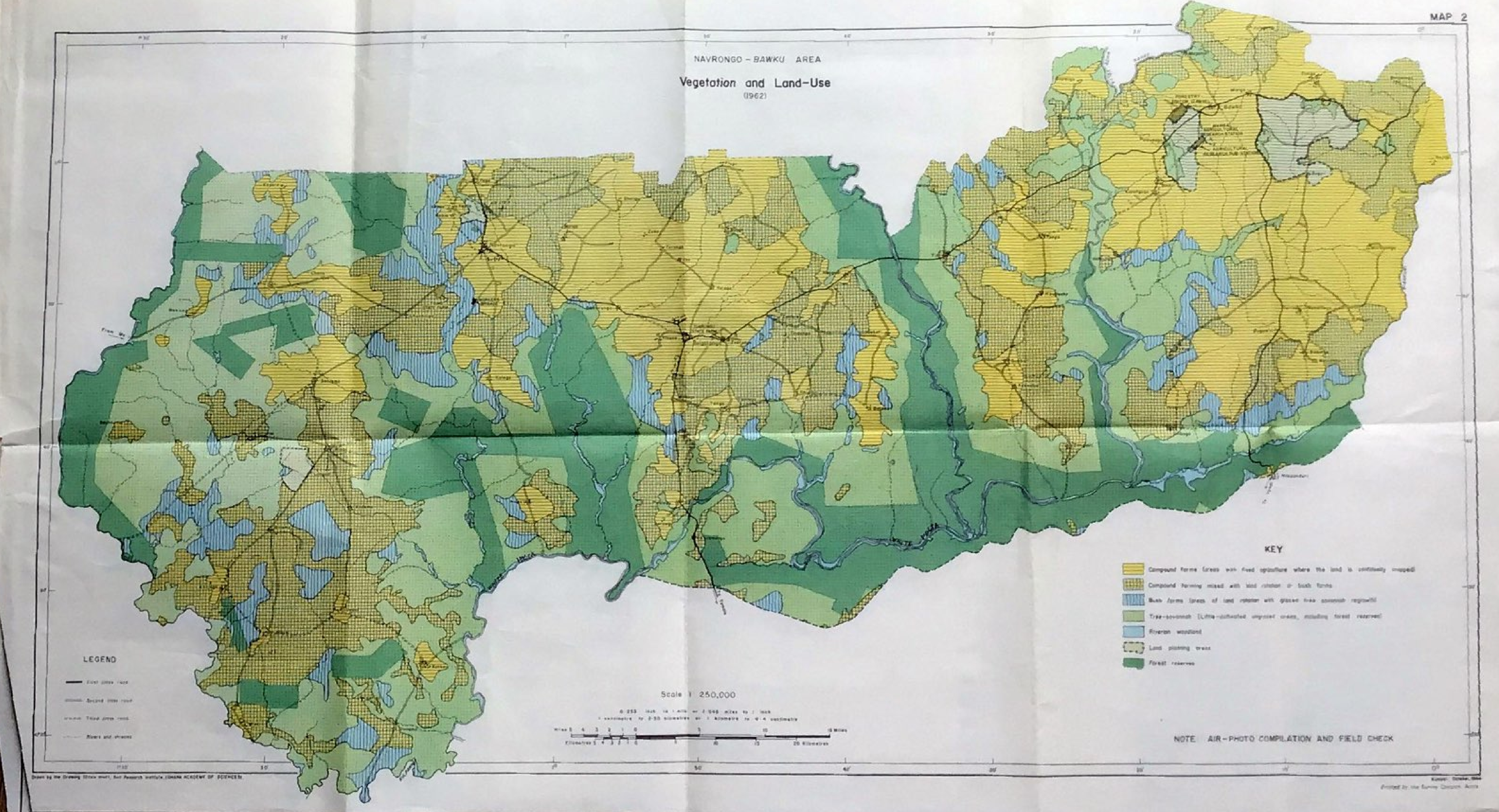
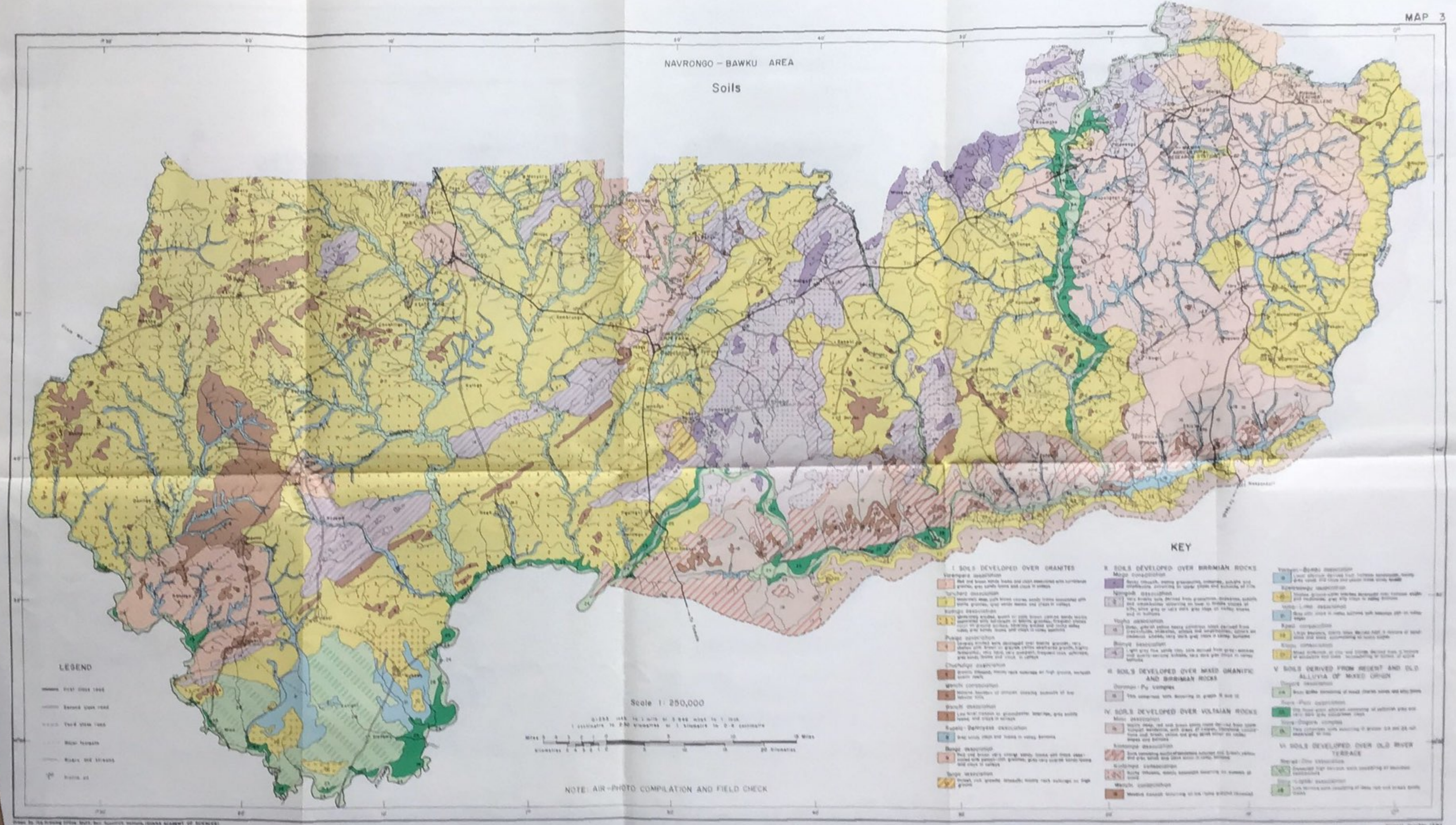
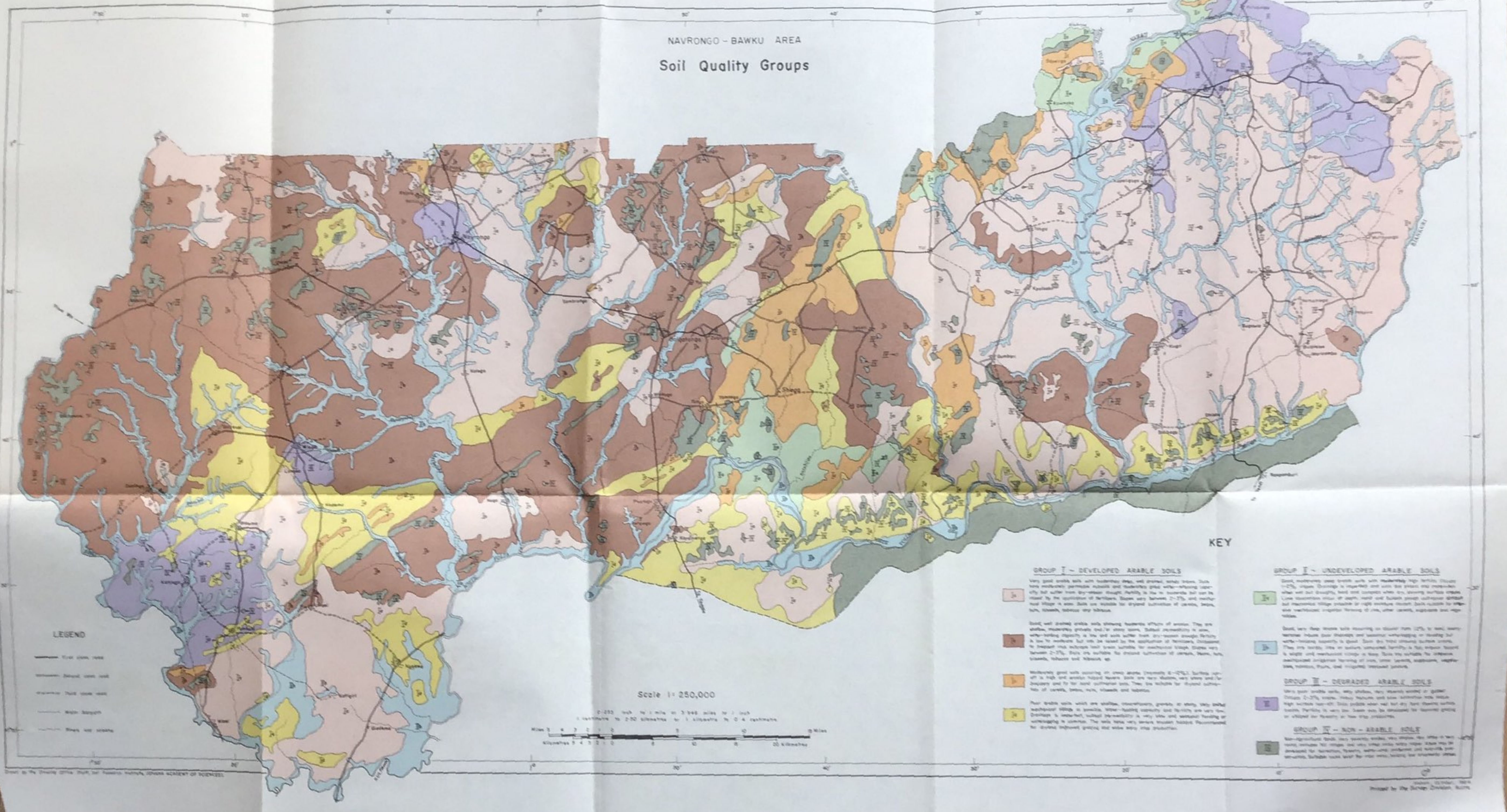

MAP 1
NAVRONGO – BAWKU AREA
Physical Features and Drainage
NAHAU — KULUPIELIGU DRAINAGE BASIN
TAMNE DRAINAGE BASIN
WHITE VOLTA DRAINAGE BASIN
RED VOLTA DRAINAGE BASIN
KULPAWN DRAINAGE BASIN
WHITE VOLTA DRAINAGE BASIN
KEY
ALTITUDE IN FEET
Above 1000
800 — 1000
600 — 800
Below 600
Watershed boundary
Scale 1: 250,000

MAP 2


NAVRONGO - BAWKU AREA
Vegetation and Land-Use
(1962)
KEY
Forest reserves
LEGEND
Scale 1: 250,000
NOTE AIR-PHOTO COMPILATION AND FIELD CHECK


MAP 3
NAVRONGO – BAWKU AREA
Soils
KEY
I SOILS DEVELOPED OVER GRANITES
II SOILS DEVELOPED OVER BIRRIMIAN ROCKS
III SOILS DEVELOPED OVER MIXED GRANITIC AND BIRRIMIAN ROCKS
IV SOILS DEVELOPED OVER VOLTAIAN ROCKS
V SOILS DERIVED FROM RECENT AND OLD ALLUVIA OF MIXED ORIGIN
VI SOILS DEVELOPED OVER OLD RIVER TERRACE
LEGEND
Scale 1: 250,000
NOTE: AIR-PHOTO COMPILATION AND FIELD CHECK


MAP 4
NAVRONGO - BAWKU AREA
Soil Quality Groups
KEY
GROUP I - DEVELOPED ARABLE SOILS
GROUP II - UNDEVELOPED ARABLE SOILS
GROUP III - DEGRADED ARABLE SOILS
GROUP IV - NON - ARABLE SOILS
LEGEND
Scale 1: 250,000
Navrongo
Shiega