are desired. In addition, in the future, legal and regulatory investigation is desired for groundwater management on a national level.

(2) Continuation of Discharge and Water Level Observation

It is necessary to continue the observation of stream discharge and groundwater level carried out in this study. The facilities for discharge observation are not functioning well at many stations. In order to continue observation, it is necessary to basically examine and assess the facilities for the entire Sokoto-Rima river basin.

(3) Groundwater Exploration

The success of well drilling depends on the results of the groundwater exploration. In particular, in the basement rock area, the drilling sites must be chosen based on the results of detailed hydrogeological survey and geophysical prospecting. This procedure offers positive results in drilling and is effective by its low cost. It is desirable for the concerned agencies to put to use the guidelines proposed in this study and to accumulate knowledge and experience in groundwater investigation.

(4) On-the-Job-Training

Groundwater development has its own comprehensive technology and the component technology are alone far-reaching, thus vast knowledge and experience are essential. Consequently, a necessary condition for the groundwater engineer is that he/she possess the technology which corresponds to the specialized fields of groundwater exploration, well drilling, pumping test, quantitative analysis, development and monitoring. In the future, it is expected that the concerned agencies choose the proper personnel for the detailed design stage and the construction stage of the project in order to bring up the level of the engineering staff through on-the-job-training.

10.2.2 Implementation of the Water Supply Project

(1) Project implementation

It is judged that the proposed project is feasible in a technical and socio-economical sense. It is also judged that the project has a high priority considering the retarded socio-economy in Sokoto State. Therefore, early implementation of the project is recommended. Besides, the successive implementation of other 26 villages desirable

(2) Operation and maintenance

It is recommended that the daily operation and maintenance be carried out by the water association composed of the village inhabitants. It is also desirable that the SSWB strengthen its financial and technical base in terms of the operation and maintenance of the water supply in the middle to large scale villages.

(3) Autonomous management of groundwater resources

Groundwater is a precious natural resource for the area in which it exists. It is a resource which might be developed and managed by experienced and knowledgeable surrounding inhabitants. It is desirable that the utilization and management of the groundwater resources be discussed and that research is done throughout the project implementation.

(Appendix 1)

Water Supply Project Implementation Planning for the 26 Candidate Villages

upper : 10^6 yen
lower : U$

Area	Project cost \ Project year	Design 1st	Construction 2nd	Construction 3rd	Construction 4th	Total
Basement Rock Area (8 Villages)	1. Intake facilities (A:1,B:2,C:5 villages)	—	488	112	—	600
		—	3,485,714	800,000	—	4,285,714
	2. Elavated tank (36 units)	—	120	32	—	152
		—	857,143	228,571	—	1,085,714
	3. Water distribution facilities (7 points)	—	41	16	—	57
			292,857	114,286	—	407,143
	4. Rehabilitation (1 village)	—	—	—	—	—
		—	—	—	—	—
	Total (1～4)	—	649	160	—	809
		—	4,635,714	1,142,857	—	5,778,571
	5. Design & Supervision cost	50	10	—	—	60
		357,143	71,429	—	—	428,571
	Construction cost	50	659	160*	—	869
		357,143	4,707,143	1,142,587	—	6,207,143
Sedimentary Rock Area (18 Villages)	1. Intake facilities (A:2,B:4,C:6 villages)	—	—	103	194	297
		—	—	735,714	1,385,714	2,121,429
	2. Elevated tank (18 units)	—	—	53	92	145
		—	—	378,571	657,143	1,035,714
	3. Water distribution facilities (10 points)	—	—	18	28	46
		—	—	128,571	200,000	328,571
	4. Rehabilitation (6 villages)	—	—	20	20	40
		—	—	142,857	142,857	285,714
	Total (1～4)	—	—	194	334	528
		—	—	1,385,714	2,385,714	3,771,429
	5. Design & Supervision cost	—	40	20	20	80
			285,714	142,857	142,857	571,429
	Construction cost	—	40	214	354	608
		—	285,714	1,528,571	2,528,571	4,342,857
Ground project cost		50	699	374	354	1,477
		357,143	4,992,857	2,671,429	2,528,571	10,550,000

1. Estimated period : January 1990
2. Foreign currency exchange rate : 1 U$=140 Yen=7.4 Naira
3. Escalation is not considered.
4. * : Construction will be carried out in Birnin Yauri village.

Appendix 2 Cost Estimation for Water Supply System

	Village Name (Local Gov.)	(1988−2000) Population Service (Population)	Hydrogeological Feature	Water Consumption ℓ/c/d	Water Demand m³/d Average (ℓ/min)	Water Demand m³/d Daily Max (ℓ/min)	Recommended Electrical Resistivity Sounding	Recommended Water Supply System Design: System Type	Recommended Water Supply System Design: Preliminary Design	Estimate Construction Cost 1000¥: Intake	Estimate Construction Cost 1000¥: Elevated Tank	Estimate Construction Cost 1000¥: Distribution Pipeline	Total 1,000¥	Total $
3	Bambaram (Anka)	10,000 (13,500)	Basement	15	243 (405)	290 (486)	10settlements(Estimate) Prospecting points 150 Ave.P/Depth 100m	B	10Deep Boreholes 70m,50~60ℓ/min 10Unit W.S/System	111,675	23,817	8,134	143,626	
9	Tungwa Kofa (Kaura Namoda)	1,500 (2,000)	Basement	15	36 (60)	43 (72)	3 Settlement Prospecting Points 40 Ave.P/Depth 100m	A	4 Deep Boreholes 50m,18ℓ/min 4 Hand Pumps	18,150	—	—	18,150	
11	Bajida (Zuru)	4,000 (5,400)	Basement	15	92 (162)	117 (194)	Concentrated village Prospectiong Points 45 Ave.P/Depth 100m	C	3 Deep Boreholes 100m,60~70ℓ/min 3 Unit W.S/System	46,462	9,729	3,281	59,472	
12	Sanchi (Zuru)	15,000 (20,200)	Basement	15	364 (606)	436 (727)	Semi-Concentrated Village Prospecting Points 75 Ave.P/Depth 100m	C	5 Deep Boreholes 100m,150ℓ/min 5 Unit W.S/System	106,470	36,018	12,229	154,717	
13	Illelare Auwal (Gummi)	10,000 (13,500)	Sedimentary	20	324 (540)	389 (648)	Concentrated Village Prospecting Points 15 Ave.P/Depth 150m	C	3 Deep Boreholes 120m,200~230ℓ/min 3 Unit W.S/System	61,672	32,085	10,911	104,668	
16	Raha (Yauri)	2,200 (3,000)	Sedimentary	30	108 (180)	130 (216)	Concentrated Village Prospecting Points 5 Ave.P/Depth 150m	B	1 Deep Boreholes 120m,220ℓ/min 10 Unit W.S/System	20,587	10,764	3,646	34,997	
17	Birnin Yauri (Yauri)	22,000 (29,600)	Basement	※Very poor groundwater potential 8	284 (473)	384 (568)	Concentrated Village Prospecting Points 150 Ave.P/Depth 100m	C	10 Deep Boreholes 70m,40~60ℓ/min 10 Unit W.S/System	111,675	31,671	16,156	159,502	
19	Gumbai (Birnin Kebbi)	6,000 (8,100)	Sedimentary	※W.S/System(A Type)was constructed by S.A.R.D.A										
20	Maruda (Birnin Kebbi)	3,000 (4,000)	Sedimentary	※Ditto										
21	Tsafanade (Bodinga)	2,000 (2,700)	Sedimentary	30	97 (162)	117 (194)	Semi-Concentrated Village Prospecting Points 5 Ave.P/Depth 150m	B	1 Deep Boreholes 120m,200ℓ/min 1 Unit W.S/System	20,587	10,350	3,281	34,218	
22	Kimbar Bawa (Bodinga)	300 (400)	Sedimentary	15	7 (12)	8.6 (14)	Concentrated Village Prospecting Points 5 Ave.P/Depth 150m	A	1 Deep Boreholes 70m,18ℓ/min 1 Hand Pump	6,337	—	—	6,337	
24	Tabki (Yabo)	200 (270)	Sedimentary	20	6.5 (11)	7.8 (13)	Concentratad Village Prospecting Points 5 Ave.P/Depth 150m	A	1 Deep Boreholes 100m, 15ℓ/min 1 Hand Pump	9,037	—	—	9,037	
27	Kwakwazo (Warno)	4,000 (5,400)	Sedimentary	15	97 (162)	117 (194)	Concentrated Village Prospecting Points 15 Ave.P/Depth 150m	C	3 Deep Boreholes 120m 60~70ℓ/min 3 Unit W.S/System	26,575	10,350	3,281	40,206	
28	Danjiro (Wurno)	2,000 (2,700)	Sedimentary	20	65 (108)	78 (130)	Concentrated Village Prospecting Points 10 Ave. P/Depth 150m	C	3 Deep Boreholes 120m, 70ℓ/min 2 Unit W.S/System	20,125	6,210	2,187	28,522	

No.	Village Name (Local Gov.)	(1988–2000) Population (Service Population)	Hydrogeological Feature	Water Consumption ℓ/c/d	Water Demand m³/d Average (ℓ/min)	Daily Max (ℓ/min)	Recommended Electrical Resistivity Sounding	Recommended Water Supply System Design: System Type	Preliminary Design	Estimate Construction Cost 1000¥: Intake	Elevated Tank	Distribution Pipeline	Total 1,000¥	$
29	Bakyasuwa (Talata Mafara)	3,000 (4,000)	Basement	15	72 (120)	86 (144)	3 Settlements Prospecting Points 45 Ave. P/Depth 100m	B	3 Deep Boreholes 70m, 50~70ℓ/min 3 Unit W.S/System	33,502	6,210	2,412	42,124	
30	Jamgako (Talata Mafara)	22,000 (29,600)	Basement	※Poor groundwater potential 8	284 (473)	384 (568)	Concentrated Village Prospecting Points 150 Ave. P/Depth 100m	C	10 Deep Boreholes 70m. 40~60ℓ/min 10 Unit W.S/System	111,675	31,671	10,771	154,117	
31	Rahayel (Bagado)	1,500 (2,000)	Sedimentary	30	72 (120)	86 (144)	Concentrated Village Prospecting Points 5 Ave. P/Depth 150m	B	1 Deep Boreholes 120m 150ℓ/min 1 Unit W.S/System	15,137	7,245	2,412	24,794	
33	Kalgo (Silame)	3,000 (4,000)	Sedimentary	30	144 (240)	172 (288)	Concentrated Village Prespecting Points 10 Ave. P/Depth 150m	C	2 Deep Boreholes 120m 150ℓ/min 2 Unit W.S/System	30,274	14,490	4,824	49,588	
35	Sabiye (Silame)	3,000 (4,000)	Sedimentary	30	144 (240)	172 (288)	Concentrated Village Prospecting Points 10 Ave. P/Depth 150m	C	2 Deep Boreholes 120m 150ℓ/min 2 Unit W.S/System	30,274	14,490	4,824	49,588	
36	Tozai (Isa)	5,000 (6,700)	Sedimentary	30	241 (402)	289 (482)	Concentrated Village Prospecting Points 10 Ave. P/Depth 150m	C	2 Deep Boreholes 120m 250ℓ/min 2 Unit W.S/System	41,175	31,905	8,106	81,186	
37	Mayasa (Isa)	10,000 (13,500)	Basement	※ Poor groundwater potential 8	130 (216)	156 (260)	Concentrated Village Prospecting Points 75 Ave. P/Depth 100m	C	5 Deep Boreholes 80m 40~60ℓ/min 5 Unit W.S/System	60,337	12,916	4,375	77,628	
38	Tsamaye (Isa)	5,500	Sedimentary	※ Rehabilitation Work for Existing W.System(B Type) 30	190(330)	228(396)	Concentrated Village	B′	2 Intakes (Power 200ℓ/min Pump & Generator only) 2 D/Pipelines					
39	Zamache (Wurno)	1,500 (2,000)	Sedimentary	30	72 (120)	86 (144)	Concentrated Village Prospecting Points 5 Ave. P/Depth 150m	B	1 Deep Borehole 120m 150ℓ/min 1 Unit W.S/System	15,137	7,245	2,412	24,794	
40	Kalmalo (Gwadabawa)	50,000	Sedimentary	※ Rehabilitation Work for Existing W.S/System (B Type) 30	1,800	2,160(1,500)	Concentrated Village	B′	1 Intake (Power Pump & Generator only) Others					
41	Araba (Gwadabawa)	3,200	Sedimentary	※ Rehabilitation Work for Existing W.S/System (B Type)			Concentrated Village	B′	1 Intake (Power Pump & Generator only) Others					
45	Giro (Bunza)	7,300 (9,800)	Sedimentary	※ W.S/System (B Type) was constructed by (S.R.R.B.D.A)										
									Total	896,863	297,166	103,247	1,297,271	

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GLOSSARY

Alluvium : A general term for clay, silt, sand, gravel, or similar unconsolidated material deposited during comparatively recent geologic time by a stream or other body of running water as a sorted or semisorted sediment in the bed of the stream or on its floodplain or delta, or as a cone or fan at the base of a mountain slope.

Aquiclude : A saturated, but poorly permeable bed, formation, or group of formations that does not yield water freely to a well or spring. However, an aquiclude may transmit appreciable water to or from adjacent aquifers.

Aquifer : A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield economical quantities of water to wells and springs.

Aquitard : A geologic formation, group of formations, or part of a formation through which virturally no water moves.

Artesian well : A well deriving its water from a confined aquifer in which the water level stands above the ground surface; synonymous with flowing artesian well.

Artificial recharge : Recharge at a rate greater than natural, resulting from deliberate actions of man.

Bedrock : A general term for the rock, usually solid, that underlies soil or other unconsolidated material.

Coefficient of permeability : An obsolete term that has been replaced by the term hydraulic conductivity.

Coefficient of storage : The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head.

Coefficient of transmissivity : See Transmissivity.

Confined aquifer : A formation in which the groundwater is isolated from the atmosphere at the point of discharge by impermeable geologic formations; confined groundwater is generally subject to pressure greater than atmospheric.

Darcy's law: A derived equation for the flow of fluids on the assumption that the flow is laminar and that inertia can be neglected.

Drawdown : The distance between the static water level and the surface of the cone of depression.

Electrical conductance : A measure of the ease with which a conducting current can be caused to flow through a material under the influence of an applied electric field. It is the reciprocal of resistivity and is measured in mhos per foot (meter).

Electrical resistivity: The property of a material which resists the flow of electrical current measured per unit length through a unit cross-sectional area.

Equipotential line : A contour line on the water table or potentiometric surface; a line along which the pressure head of groundwater in an aquifer is the same. Fluid flow is normal to these lines in the direction of decreasing fluid potential.

Evapotranspiration : Loss of water from a land area through transpiration of plants and evaporation from the soil.

Fault : A fracture or a zone of fractures along which there has been displacement of the sides relative to one another parallel to the fracture.

Floodplain : The surface or strip of relatively smooth land adjacent to a river channel, constructed by the present river and covered with water when the river overflows its banks. It is built of alluvium carried by the river during floods and deposited in the sluggish water beyond the influence of the swiftest current.

Groundwater table : The surface between the zone of saturation and the zone of aeration; the surface of an unconfined aquifer.

Hardness: A property of water causing formation of an insoluble residue when the water is used with soap. It is primarily caused by calcium and magnesium ions.

Head : Energy contained in a water mass, produced by elevation, pressure, or velocity.

Hydraulic conductivity: The rate of flow of water in gallons per day through a cross section of one square foot under a unit hydraulic gradient, at the prevailing temperature (gpd/ft^2). In the SI System, the units are $m^3/day/m^2$ or m/day.

Hydraulic gradient. : The rate of change in total head per unit of distance of flow in a given direction.

Hydrogeologic : Those factors that deal with subsurface waters and related geologic aspects of surface waters.

Limestone : A sedimentary rock consisting chiefly of calcium carbonate, primarily in the form of the mineral calcite.

Metamorphic rocks : Any rock derived from pre-existing rocks by mineralological, chemical, and/or structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, shearing stress, and chemical environment, generally at depth in the Earth's crust.

Observation well : A well drilled in a selected location for the purpose of observing parameters such as water levels and pressure changes.

Perched water: Unconfined groundwater separated from an underlying main body of groundwater by an unsaturated zone.

Permeability : The property or capacity of a porous rock, sediment or soil for transmitting a fluid; it is a measure of the relative ease of fluid flow under unequal pressure.

Pumping test : A test that is conducted to determine aquifer or well characteristics.

Recharge: The addition of water to the zone of saturation; also, the amount of water added.

Runoff : That part of precipitation flowing to surface streams.

Sedimentary rocks : Rocks resulting from the consolidation of loose sediment that has accumulated in layers.

Specific capacity : The rate of discharge of a water well per unit of drawdown, commonly expressed in gpm/ft or m^3/day/m. It varies with duration of discharge.

Static water level. : The level of water in a well that is not being affected by withdrawal of groundwater.

Storage coefficient : See Coefficient of storage.

Storativity : See Coefficient of storage.

Total dissolved solids, TDS : A term that expresses the quantity of dissolved material in a sample of water, either the residue on evaporation, dried at 356°F (180°C), or, for may waters that contain more than about 1,000 mg/ℓ, the sum of the chemical constituents.

Transmissibility : See Transmissivity.

Transmissivity : The rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. Transmissivity values are given in gallons per minute through a vertical section of an aquifer one foot wide and extending the full saturated height of an aquifer under a hydraulic gradient of 1 in the English Engineering system; in the International System, transmissivity is given in cubic meters per day through a vertical section of an aquifer one meter wide and extending the full saturated height of an aquifer under hydraulic gradient of 1.

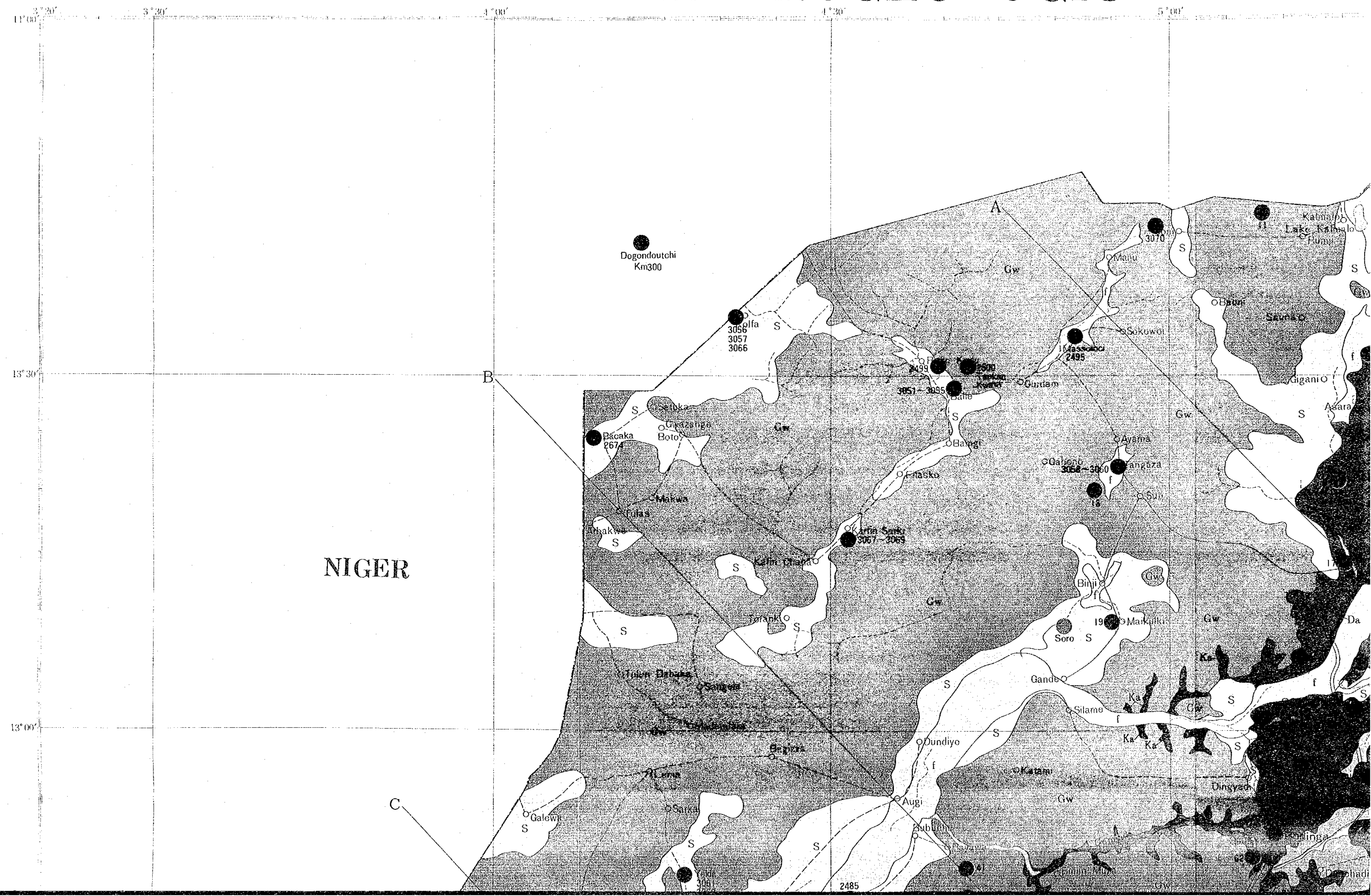
Unconfined aquifer : An aquifer where the water table is exposed to the atmosphere through openings in the overlying materials.

Water table: The surface between the vadose zone and the groundwater, that surface of a body of unconfined groundwater at which the pressure is equal to that of the atmosphere.

Weathering: The in-situ physical disintegration and chemical decomposition of rock materials at or near the Earth's surface.

Well screen: A filtering device used to keep sediment from entering a water well.

HYDROGEOLOGICAL MAP



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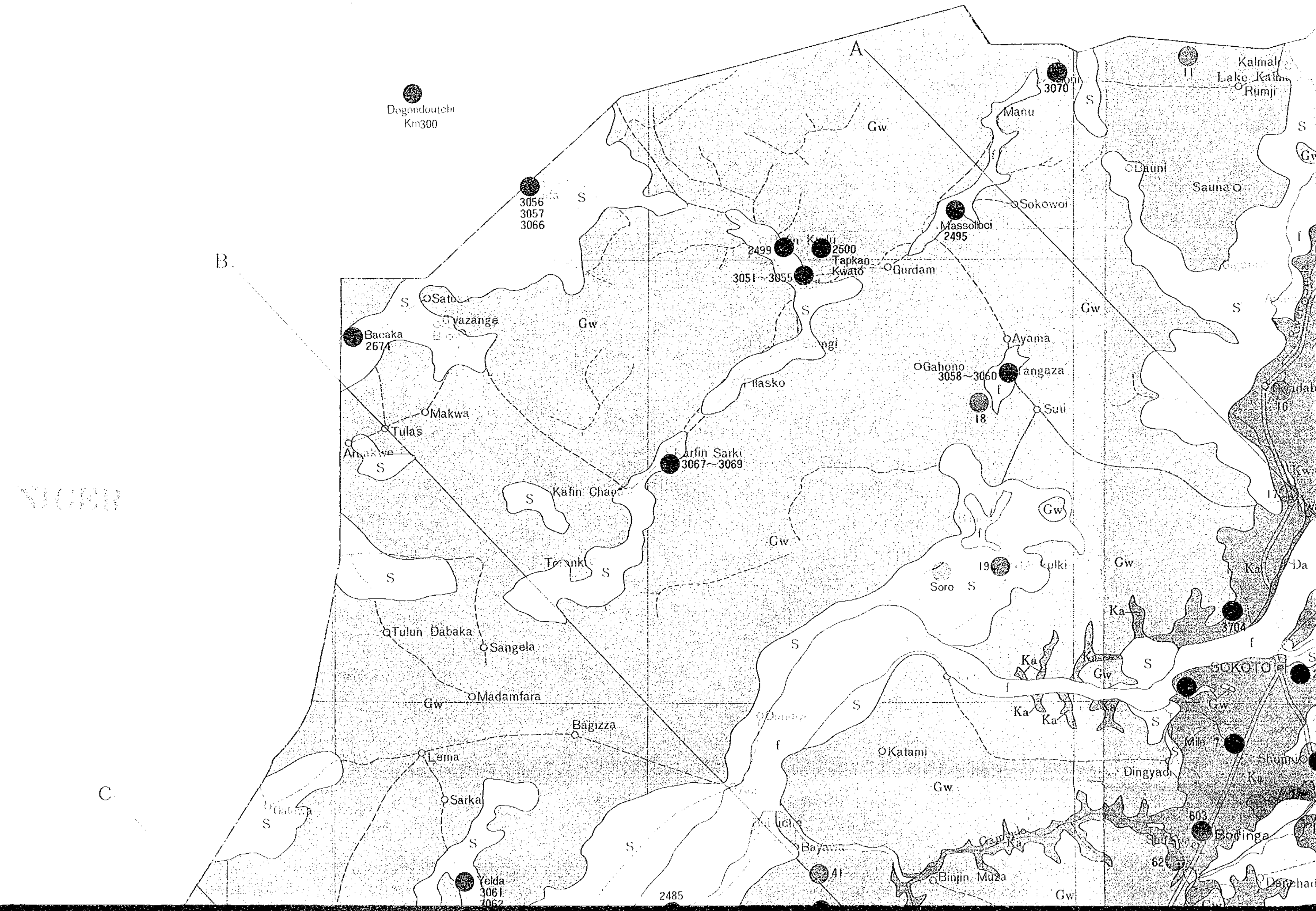
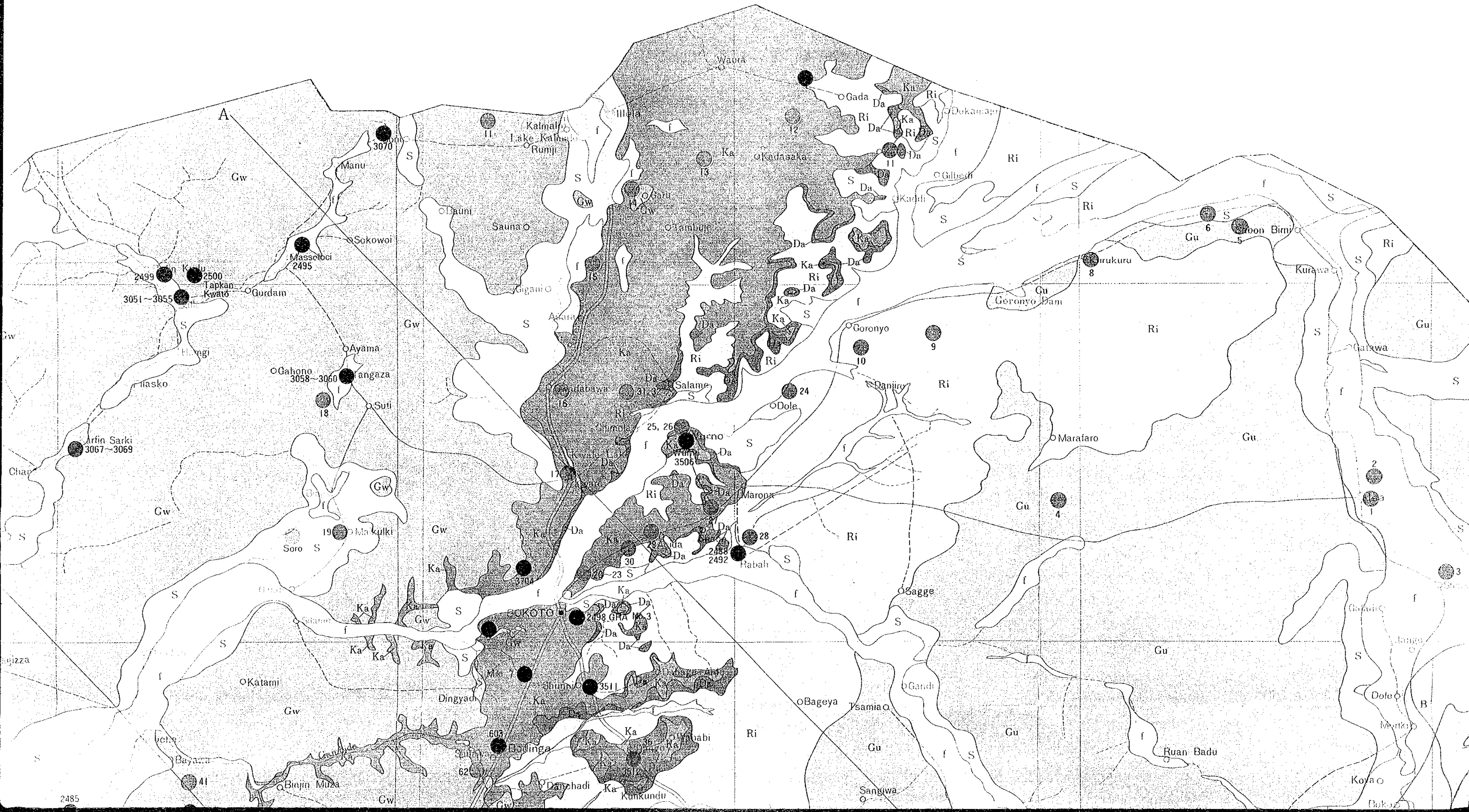


ROGEOLOGICAL MAP OF SOKOTO STATE, NIGERIA



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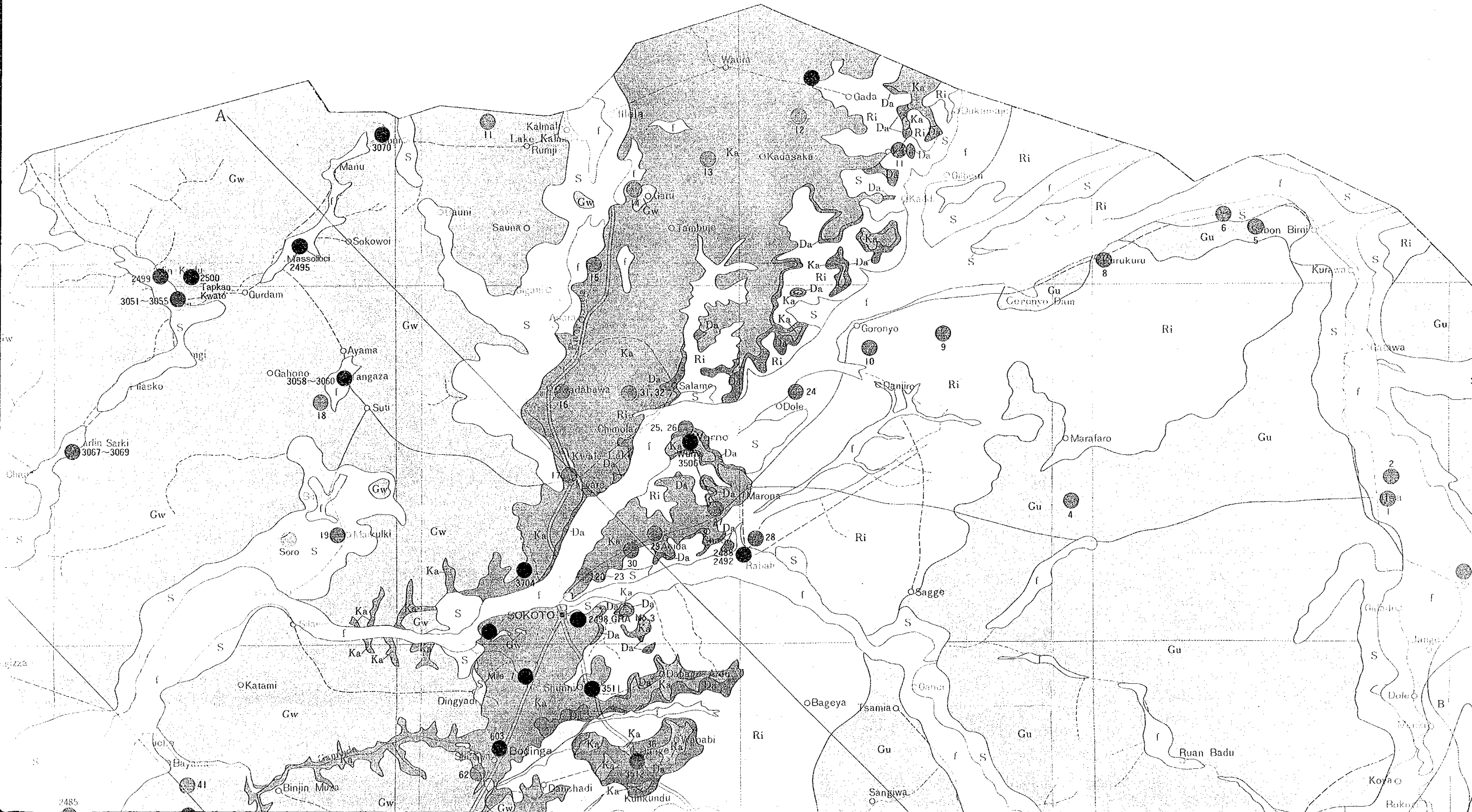

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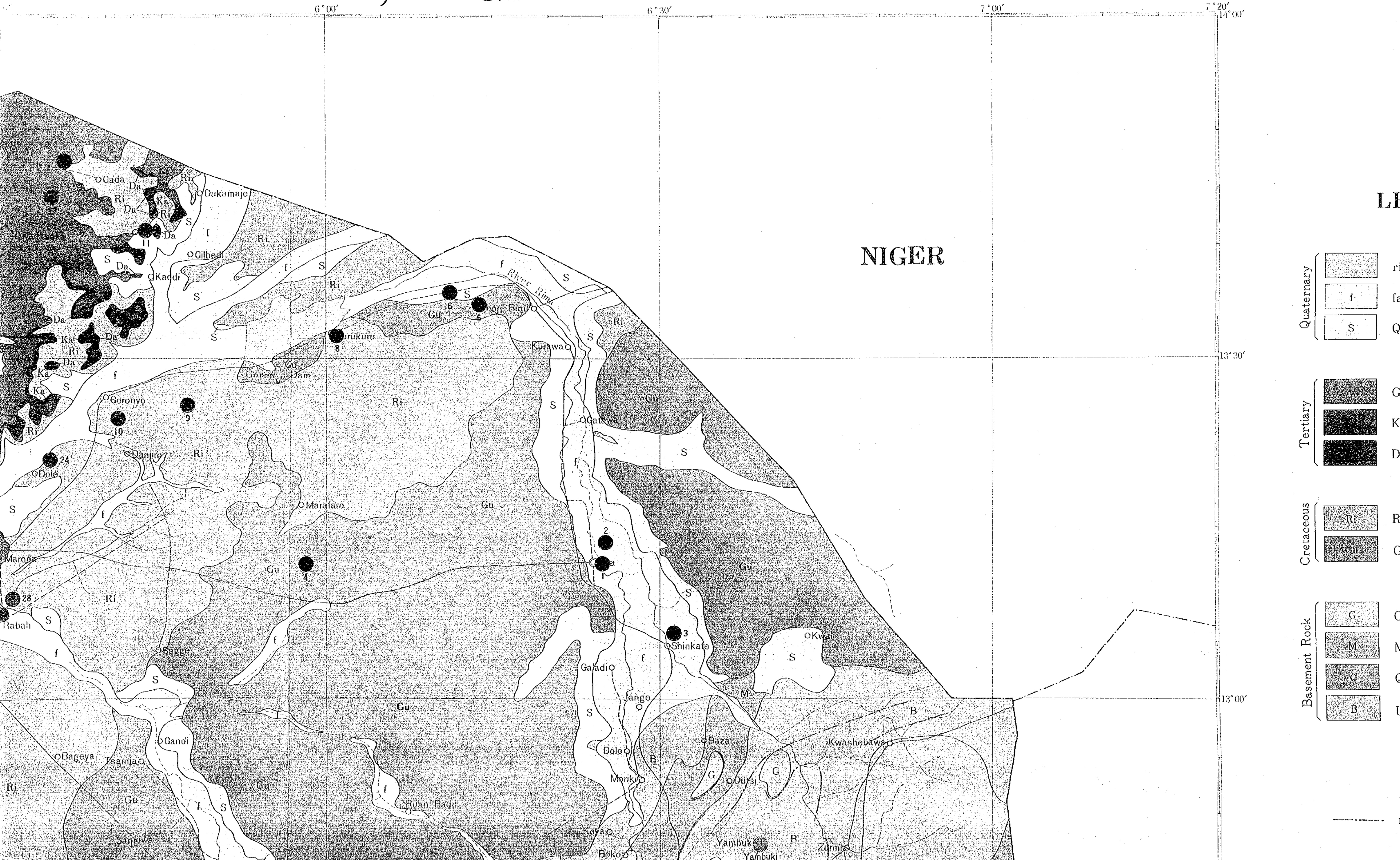

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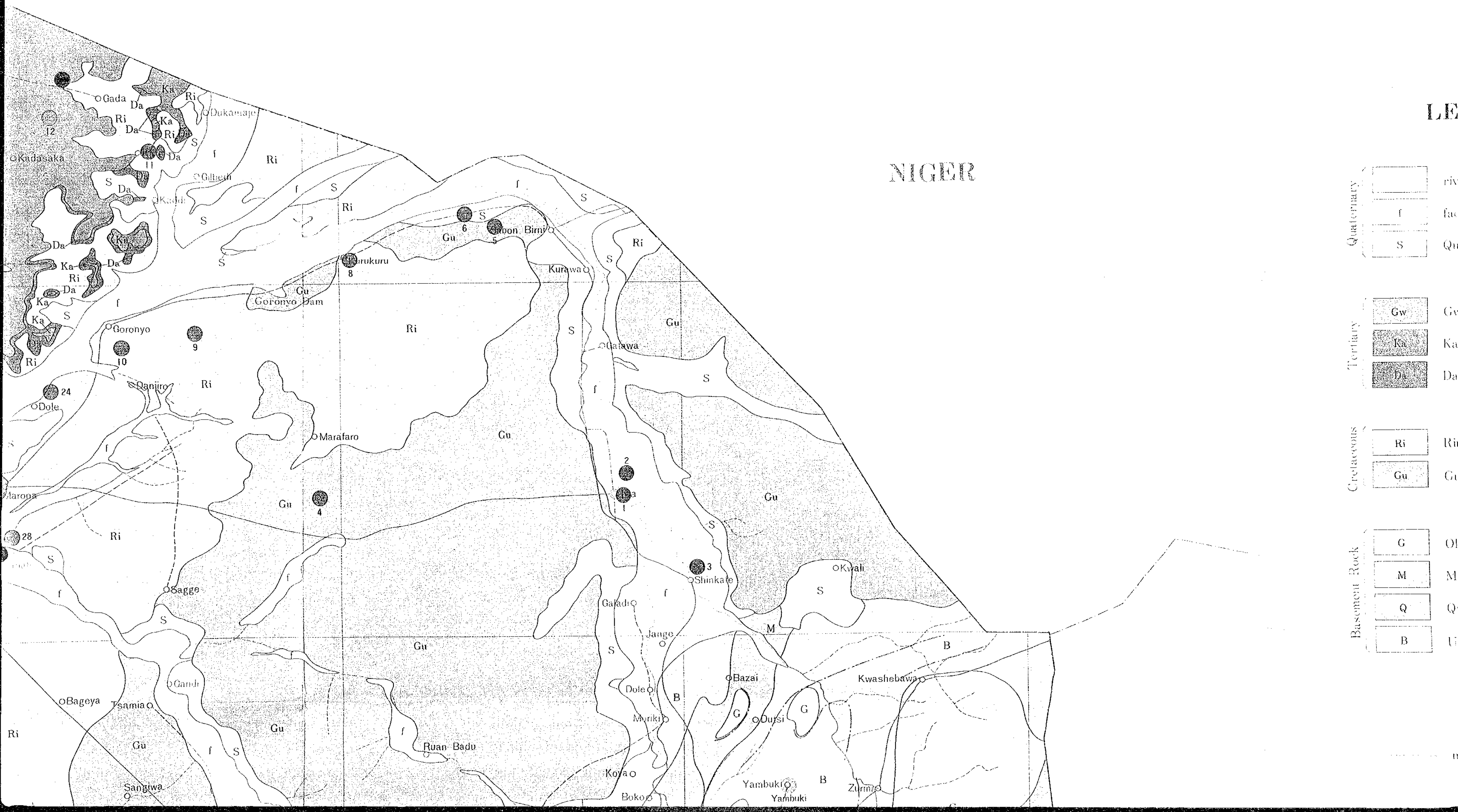

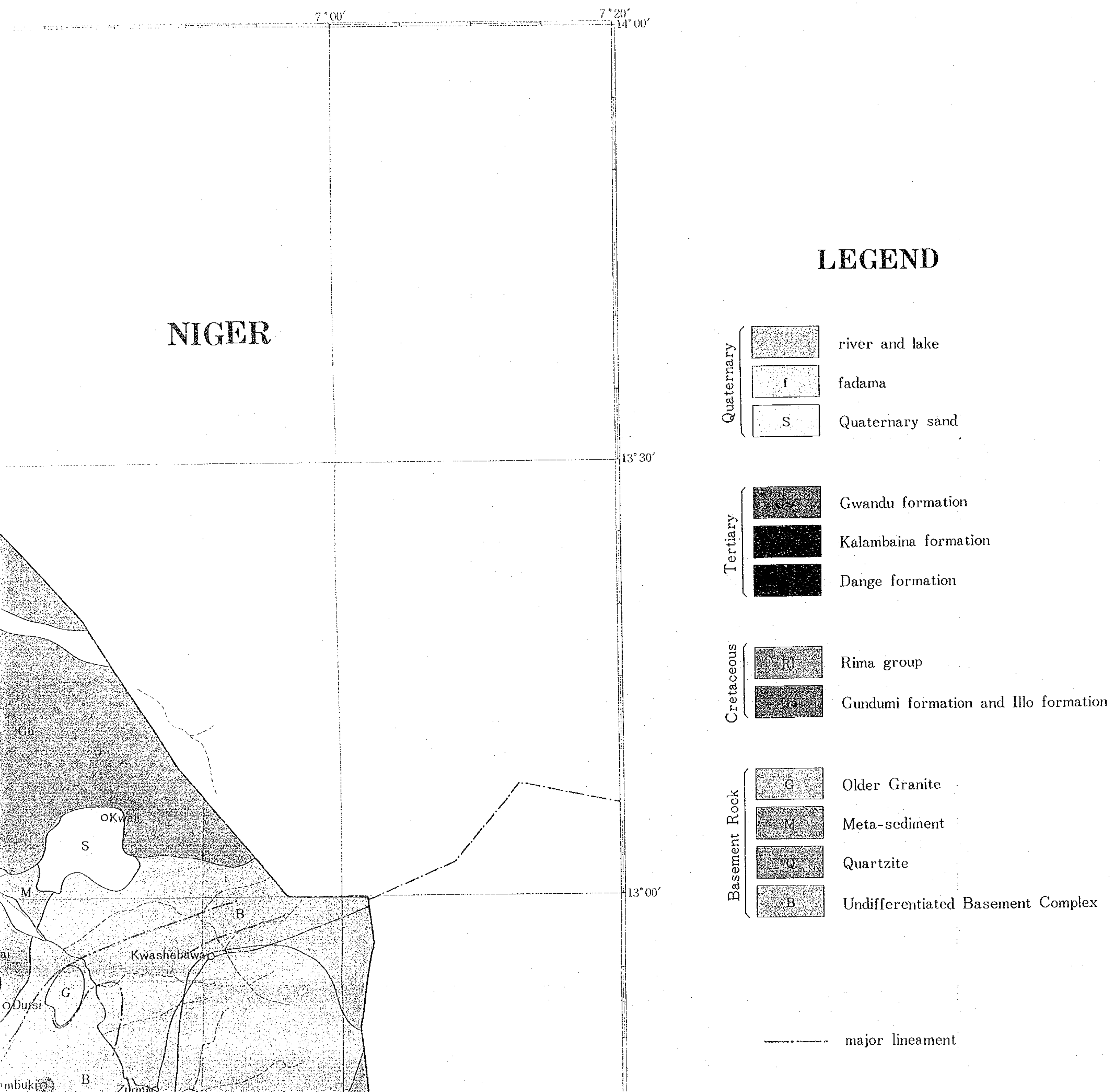

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major lineament

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Basement Rock
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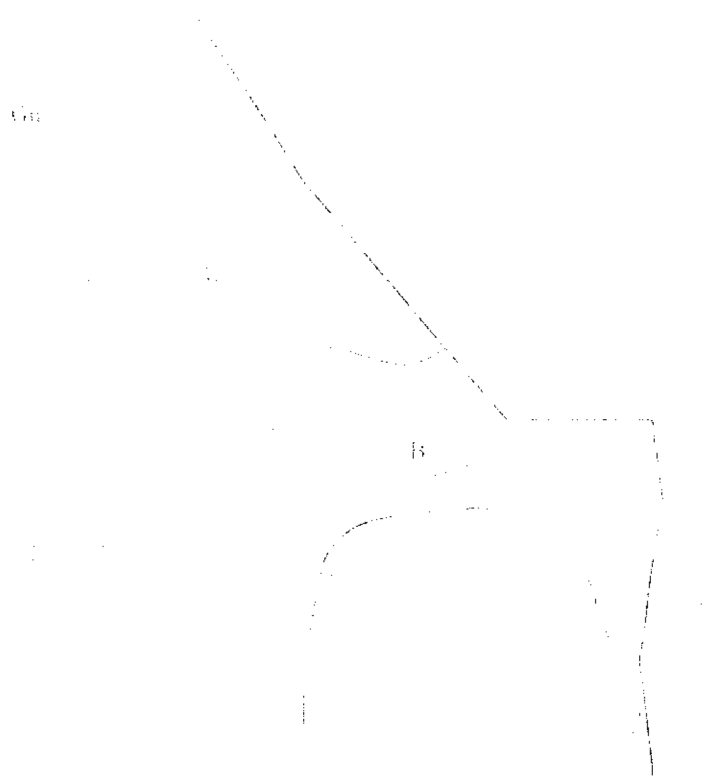

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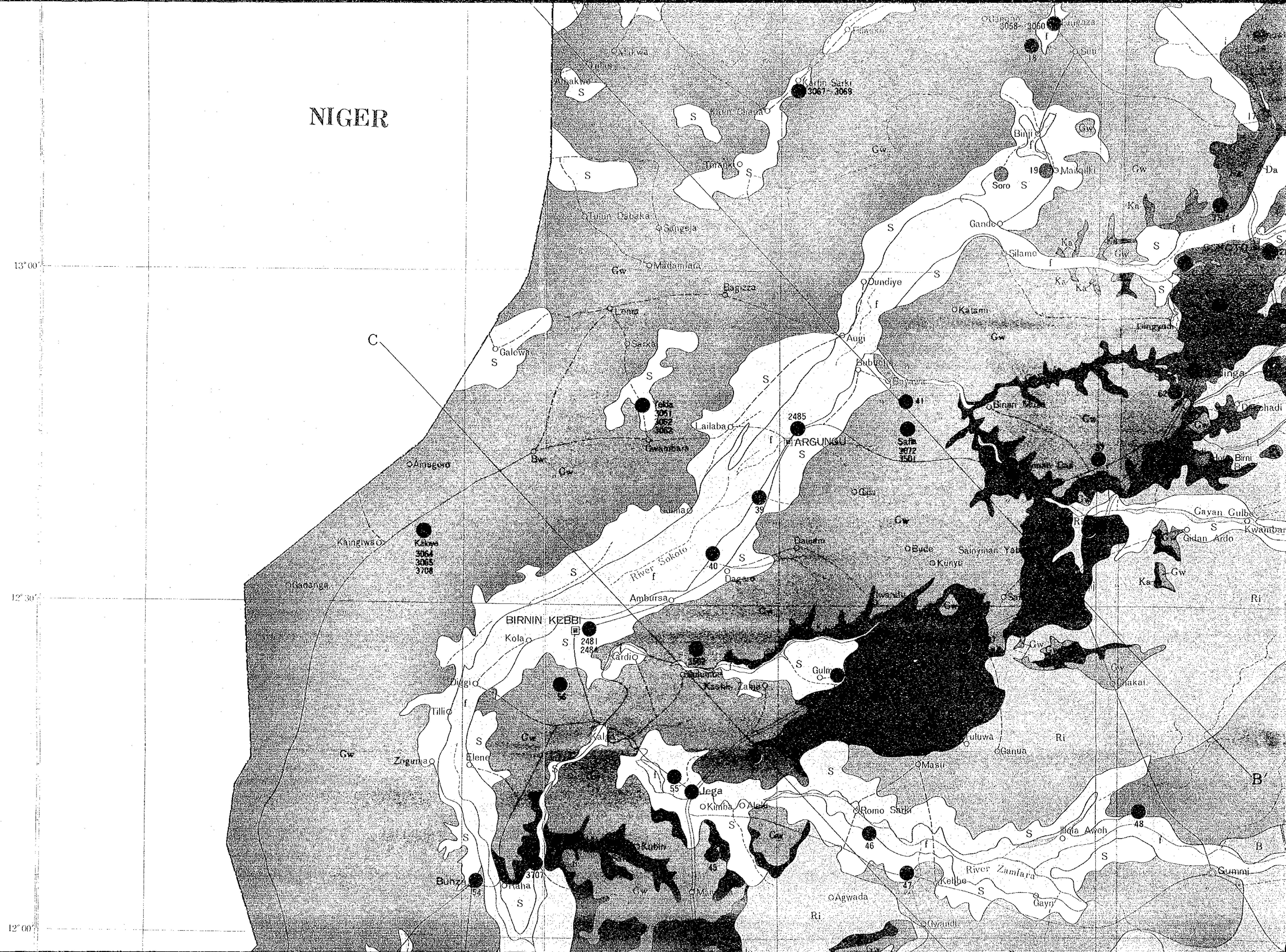

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