Principal freshwater-types and comparative hydrochemistry of tropical running water systems

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ABSTRACT

The results of water analyses originating from running water systems within the humid tropical regions (mainly Indo-Pacific islands and West Africa) are discussed in connection with geology and climate. According with the relative abundancies of ions, a scale of principal water types is presented: predominance of calcium-bicarbonate, magnesium-bicarbonate, sodium-bicarbonate with variable shares of chloride, as of sodium-chloride and sometimes ammonia-bicarbonate. The processes influencing the water chemistry of the river systems are discussed: selective ion exchange in inorganic clays and organic humic acids in soils, recirculation of groundwater.

KEY WORDS : Chemistry of freshwater — Tropical rivers — Ion composition — Ion exchange — Influence of climate and geology.

RÉSUMÉ

LES PRINCIPAUX TYPES D'EAU DOUCE ET L'HYDROCHIMIE COMPARATIVE DES COURS D'EAU DES RÉGIONS TROPICALES

Les résultats d'analyse d'eaux provenant de cours d'eau des régions tropicales humides (notamment des îles de l'Indo-Pacifique et d'Afrique de l'Ouest) sont discutés dans leur contexte géologique et climatique. En fonction de l'abondance relative des principaux ions, certains grands types d'eau ont été reconnus: prédominance de bicarbonate de calcium, de bicarbonate de magnésium, de bicarbonate de sodium, avec une proportion variable de chlorures; il en est de même pour le chlorure de sodium et parfois le bicarbonate d'ammonium. Les facteurs ayant une influence sur la chimie des cours d'eau sont discutés: échange sélectif d'ions avec les argiles et les acides humiques dans les sols acides, apport d'eaux souterraines.

MOTS-CLÉS : Chimie des eaux — Rivières tropicales — Composition ionique — Échanges d'ions — Rôle du climat et de la géologie.

1. INTRODUCTION

During the years 1970-1979 a series of running water systems of islands in the tropical part of Indo-Pacific region were investigated and comparative hydrochemical studies were made as well as in Western African area.

A survey of hydrochemistry of the investigated water systems is developed in correspondence with climate and geology. General tendencies concerning the fluctuation of the ion abundancies in profile of the rivers are given.

The hydrochemistry of the tropical fresh water is discussed following the influences caused by the regional decomposition and weathering of the rocks and soil, the recirculation of groundwater (MATTHESS, 1973), dynamic processes of ion exchange (OHLE 1938, 1955) from humic acids and zeolite

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clays. The ion exchange capacity increases with falling accumulation of hydrates (SCHEFFER and ULRICH, 1960). Magnesium ions are less adhered to humic acids than calcium ions. Beside this, Mg-humate is twice as soluable, even more are alkali humates (Na, K, Li) and ammonia humate. Iron and manganese chelates are nearly insoluble.

The investigated watersheds and rivers are those from entirely volcanic islands (basaltic rocks) like La Réunion (2 510 km^2, elevations up to 3 069 m), Comoro Islands-Anjouan (424 km^2, elevations up to 1 595 m), Mauritius (1 865 km^2, elevations up to 820 m); tertiary geology like the highly volcanic islands of Java (western and central part), Bali or Luzon (all three with mountain chains up to 3 000 m or more) or the flatter Andamans (elevations up to 900 m) or New Caledonia (shist and periodite, elevations up to 1 600 m). Different were the waters from extremely old crystalline watersheds like Ceylon (south-western humid part, mountains up to 2 500 m), Seychelles-Mahé (only 143 km^2, elevations up to 915 m), southeastern Nigeria or Cameroon.

In most of these areas the annual precipitation was between 2 000-5 000 mm, depending on altitude and exposure of the catchment regions.

The principal hydrochemical studies were made on running water systems in New Caledonia and southwest Ceylon (highlands), Seychelles (Mahé), Comoro Is. (Anjouan), Réunion Is. and Mauritius (WENINGER, 1968, 1972, 1977).

Comparative analysis were made in water samples from West Africa (mainly Cameroon), Andamans, Philippines (Luzon), Java, Bali, some Pacific Islands, Peru and Madagascar.

Investigation on waters of those regions are rare even from Southeast Asia. RUTTNER (1931) looked at Indonesian lakes, KOBAYASHI (1959) carried out a survey of the Thailand rivers, JOHNSON (1967-68) summarized the major features of freshwater of southern Malaya. BISHOP (1973) made a two year investigation on a small Malayan river (Sungai Gombak) and gave a detailed definition of the chemical environment like those given from the Amazonian region (SIOLI, 1964, 1968; GESSNER, 1960; KLINGE and OHLE, 1964; WILLIAMS, 1964; FITTKAU, 1970), also (Cit. BISHOP, 1973) on Panama-Colombia river-systems, MARLIER (1954) and MALAISSE (1969) on Central African rivers.

Most of these investigators except those in Panama, central and northern Thailand, described rivers extremely poor in nutrient salts with low conductivities and often low pH. The fauna and the algal production is mostly reduced in extremely soft water. As found by KOBAYASHI (1959), JOHNSON (1967), KLINGE and OHLE (1964) sodium is normally the dominant cation in extremely soft water of the humid tropical regions. Potassium concentrations were less dependent on the input from rainfall and on discharge volume and may become important when a local supply is available (BISHOP, 1973). The last mentioned gives mean contents for sodium between 1.81 and 2.59 p.p.m. and for potassium between 1.45 and 2.65 p.p.m. for the Gombak (Malaya).

Under WILLIAM's classification (1964) waters *with less than 2.5 p.p.m. calcium* are considered extremely poor. Most South-Malayan rivers fall into this category (JOHNSON, 1967; BISHOP, 1973) some have Ca^{++} contents lower than 0.10 p.p.m. Under those conditions even the decomposition of leaves may add some Ca^{++} to the upper river (THOMAS, 1970).

JOHNSON (1967) stated that for many local waters in southern Malaya direct correlations between alkalinity and calcium contents do not exist. KLEEREKOPER (1955) reported an organic colloid buffering system for various Rio Grande do Sul rivers (Brazil).

According to COLTERMANN and CLYMO (1969) the titration may include NH_4^+ and $H_3SiO_4^+$ with the HCO_3^- under particular conditions.

STUMM and MORGAN (1970) stated otherwise that this species have only little effect on the acidimetric titration.

The immobility of Fe and Al in tropical soil has been discussed by SIOLI (1968). These elements tend to remain static in the latosol soil. SHAPIRO (1966) has shown that humates may hold iron in solution under conditions in which it would normally be precipitated. BISHOP (1973) mentioned concentrations of 0.12-0.73 p.p.m. total iron for the Gombak (Malaya) DURUM and HAFFTY (1963) average compounds of 0.3 p.p.m.

A remarkable increasement of total — iron caused by heavy rainfalls, was obvious. GIBBS (1973) reviewed the percentages of incorporation-type of some heavy metals in the organic and inorganic load of Amazonas (iron: cationic exchange 0.02 %, "metallic coating" — $FeOH_3$-47.6 %, organic incorp. 6.6 %, inorganic incorp. 45.8 %). Ammonia is present in considerable concentrations in humic water systems of the mountain region.

The contents of ammonia in the humic drains of the mountain rain-forest surpass those mentioned by BISHOP (1973) for precipitation.

BISHOP (1973) mentioned that some of the nitrate and most of the ammonia were derived from the precipitation, the remainder is of botanical origin.

JOHNSON (1967) mentioned contents of usually 3.0 p.p.m. sulphate for Malayan rivers, BISHOP (1973) only those of 0.13-0.90 p.p.m. SO_4^{--} for the

Malayan Gombak (means, maximal 4.0 p.p.m.). The basic concentrations of precipitation are very low but increase fast in areas of industrialization and large cities.

The high mobility of silica from igneous rocks was described by KOBAYASHI (1960) and by DOUGLAS (1968) for different rivers. BISHOP (1973) mentioned contents between 9.8 and 11.7 p.p.m. SiO_2 for the Malayan Gombak River, this is identical to the mean concentrations of SiO_2 for Asian rivers.

Running water systems under conditions of tropical humid climate have partially similar processes of regulation concerning the ionic relations to those found in lakes by OHLE (1955). Above all the ionic exchange caused by humic substances may be considered which are widely distributed and extremely enriched in acidic soil of the watersheds.

Ca^{++} and HCO_3^- are adsorbed from the solution in equivalent quantities by lake sediments containing humic muds in absence of oxygen (OHLE, 1938).

Magnesium ions that are mostly bound to chloride or sulphate are not influenced. Iron — and manganese ions are mostly connected the chelates (humates) which are nearly insoluble (OHLE, 1955) or precipitated.

The exchange capacity increases with falling accumulation of hydrates (SCHEFFER and ULRICH, 1960). Magnesium ions are less combined with humic acids than calcium ions, beside this, Mg-humate is twice as soluable.

Highly soluable are alkali humates (Na, K, Li) and ammonia humate. The selective ionic exchange by the humic acids (mainly concerning Ca^{++} and HCO_3^-) causes the relative enrichment of alkali ions (mainly Na^+). This was first contested by LUNDQUIST u. THOMASSON (1924) and OHLE (1955) in humic soft water lakes. Another effect is the enrichment of magnesium ions in humic lake water as given by JUDAY *et al* (1938) and OHLE (1955) with mentioned Mg: Ca equivalent ratios of about 1.25-1.26 and also the relative enrichment of distinct anions (chloride).

The tendency of this ionic exchange system leads to similar abundance ratios of ions like in marine water — dominated by the relative enrichment of sodium, magnesium and chloride.

The hydrochemistry of running water is as well directly influenced by the surface discharge of the regional watersheds as also influenced by the recirculation of groundwater, according to the regional geochemistry of the different soil-and subsoil divisions. Oozing water, which is near the surface usually saturated in Ca $(HCO_3)_2$ is getting downwards relatively enriched by Mg^{++} and later on by Na^+ ions. Instead of HCO_3^- ions increase SO_4^{--} and Cl^- ions, because the Mg-salts are more soluble.

The high humidity in the tropics accelerates the dissolution and the transport of Na^+Cl^- and $Ca^{++}SO_4^{--}$ out from subsoil layers. The high rate of water renewal causes extraordinary low salinities of water, on the other hand are due to the dense vegetation, CO_2 and organic acids enriched, both accelerating the weathering of rocks (silicates).

Otherwise the amount of precipitation on windward or leeward watersheds differs very much. The restricted extensions of the water systems made it possible to give good surveys of the regional water types.

Of course the chemistry of a whole running water system may be seen as the result of inumerable processes in detail. Primary processes like weathering of the rocks in correspondence with geology and climate may be differentiated from secondary processes concerning the development of soil and vegetation. Oceanic islands seem to be good models to recognize the balance between physiography, geology, soil and vegetation and the chemical composition of the water systems — under conditions of more or less homogeneous humid climate.

The distribution of main cations in the composition of extremely soft river-water that is mostly existent in humid tropical climate and this of rain-water (precipitation) equalizes (WEDEPOHL, 1969).

According to increasements of salinity the cationic conditions change towards the average composition of sedimentary rocks (POLDERVAART, 1955). Under conditions of arid climate in dry areas results an increasement of salts with crystalization of carbonates and at last dominates sodium-chloride (GIBBS, 1970, 1971).

A survey of surface water states that the distribution corresponds with the geographical regions (HELD, 1970).

In the tropics dominates hydrogen carbonate — and silicate water, while in dry belts north and south from the humid equatorial region the water is enriched in chloride and sulphate. The region of the temperated climate of the northern and southern hemisphere is dominated by calcium-hydrogen carbonate water. ALEKIN (1962) developed a system concerning the relations of the dominating cations and anions (classes: HCO_3^-, SO_4^{--}, Cl^- water; group: Ca^{++}, Mg^{++}, Na^+ which are divided into 3 or 4 types corresponding the predominance of HCO_3^-, Ca^{++}, Mg^{++}, Na^+, Cl^-. Different classifications are given by CLARKE (1924) in p.p.m. %, while most others are based on PALMER (1911) in equ. %, like SCHOELLER (1962), DAVIS & DE WIEST (1967) or by QUENTIN (1969) mostly on mineral water and volcanic springs, also GERB (1958) and THEWS

(1972) who distinguished a standard water based on the local hydrogeology from "reduced types" in groundwater bodies. Concerning this investigations of tropical freshwater it was attempted to give a scheme in survey corresponding with the hydrochemical characteristics and the predominance of ions (mostly HCO_3^- class of the Ca^{++}, Mg^{++}, Na^+ group, with various enrichments of Cl^-).

2. METHODS

pH (field) — electropotentiometric
conductivity 20 °C — field apparatus
alkalinity (field) — 0.1 n HCl, Methylorange
limestone-aggressivity (field) — marble powder (HEYER-method)
free CO_2 (field) — 0.1 n Na OH, phenolphtalein
calcium (field) — complexometric, EDTA, Calcon (MERCK, pp. 72)
magnesium (field) — complexometric, EDTA, as the difference of total hardness (°German) (MERCK, pp. 72)
sodium — flame photometer
potassium — flame photometer
total iron — spectrophotometer, 1.10 phenantrolin (FREYER, pp. 41)
aluminium — spectrophotometer, eriochromecyanin (VGB, pp. 260)
ammonia (field) — Nessler's reagent (HELLIGE-Neocomparator)
nitrate — measured as nitrite (FREYER, pp. 21)
chloride — mercurinitrate (0.01 n), diphenylcarbazon (VGB, pp. 134)
fluoride — ion-selective electrode (ORION)
ortho-phosphate — spectrophotometer, molybdane-complex (EAWAG)
silicic acid — spectrophotometer, silicomolybdane-complex (VGB, pp. 266)
humic acids — spectrophotometer, direct adsorbtion 300 µm, (VGB, pp. 358) (KURAPKAT cit. VGB, SONTHEIMER, 1977)
sulphate — spectrophotometer, nephelometric (REGNET and UDLUFT, 1974)

3. HYDROCHEMICAL SURVEY OF THE INVESTIGATED FRESHWATERS

The principal components of the earth crust are magmatites (granites, granodiorites 22 % of volume, basalts and gabbros 43 % of volume) the remaining share are sediments and metamorphites (gneisses 21 % volume). The chemical composition of the magmatic rocks varies in correspondence to the actual share of specific minerals. In survey can be recognized that diminishing contents of silicon (74-48 % of weight) are accompanied with an increase of Ca, Mg, Fe, Mn, mostly P while the contents of K are also shorten.

The decomposition of rocks is caused by physical weathering, chemical processes (mainly hydrolization) and biological influences.

The results of hydrolization are, at a permanent loss of dissoluble products of disintegration (mainly Na^+, K^+, Ca^{++}, Mg^{++}, silicic acid) the formation of clay minerals (silicates with OH^- groups), which are like the organic matter (humic substances, humic acids) important for iron-exchange.

The capacity for ion exchange of well decomposed organic matter at pH 8 may be fixed at 180-300 meq/100 g.

This is much higher than this of clay minerals (*kaolinite, illite, chlorite, allophane, 3-50 meq/ 100 g*, smectite, vermiculite 70-200 meq/100 g, according to SCHEFFER and SCHACHTSCHNABEL, 1982).

Humic substances are composed of fulvo-acids, humic acids and humines. Humic acids are highly polymere sphaeric colloids, their acidic character and ability of cationic exchange is based on the occurrence of the COOH- and phenolic OH-group. The chelate complexes (humates) of polyvalent cations (Ca, Mg, Fe, Al and others) have only a very low solubility in water.

Comments about absorption and ionic exchange to adsorbent minerals in the subsoil (clay minerals, zeoliths, iron — and manganese hydroxides or oxihydrates, aluminium hydroxide and organic substances, mainly humic acids), were made by GRIM (1968), CARROLL (1959).

Zeolithes are most frequently registrated in volcanic rocks (basalts). The most active places of adsorbtion are the edges and fractions of the mineral structures (aluminium silicates). Cation exchange (for example Ca^{++} A + $2Na^+$ = $2Na^+$ A + Ca^{++}) — *in the sequence of fixation intensity* $H^+ > Rb^+ > Ba^{++} > Sr^{++} > Ca^{++} > Mg^{++} > K^+ > Na^+ > Li^+$) — can be distinguished from anion-exchange (in clay minerals SO_4^{--}, Cl^-, PO_4^{---}, NO_3^-, AsO_4^{---} can be exchanged).

The influence of pH is highly important and concerns in case of cation exchange at pH 5 already mostly alkali and earth-alkali ions (Na^+, K^+, Ca^{++}, Mg^{++}). The relation given by DEMOLON (1948) between basic exchange substances and the solution (water) can be influenced from additional inflow of other waters and drains. This can completely alter the chemical character of water (Na^+, K^+, Ca^{++}, Mg^{++} contents) during the partial or complete downstream flow.

Because of the wide distribution of exchangeable substances in the subsoil, ion exchange is really frequent in ground-water. Ion exchange can be recognized when the total of equivalents (Ca + Mg) is below the concentrations of HCO_3^- ions. The concentrations of Ca^{++}, which are originally equivalent that of HCO_3^-, are reduced due to exchange for Na^+. These Na^+ HCO_3^- water (like also Na^+ SO_4^{--} water) are widely distributed especially in basaltic subsoil drains (LÖHNERT, 1970; MATTHESS, 1958). Extraordinary efficiency of ion-exchange can be registrated when the exchange body is permanently influenced by Na^+ Cl^- enriched water or precipitation (like by sea side winds) resulting a Na^+ saturation. Such a "regeneration" of the exchange body is estimated by SCHWILLE (1955) and LÖHNERT (1970). The original relation of ions is transfered due to ion exchange corresponding the leach of the rocks ($Na^+ + K^+ = Cl^- \rightarrow Na^+ + K^+ < Cl^-$), SCHOELLER (1951, 1962).

Because of the extraordinary high rate of water circulation and renewance in humid areas the chemical composition of rain water is important. WEDEPOHL (1967), BISHOP (1973), mentioned worldwide means in rain : $Na^+ = 0.3$, HCO_3^- ($+ H_2Co_3$) $= 1.2$, p.p.m.

The range of concentrations in trace substances is highly changeable when only low rates of precipitation are observed. The main share substances show agreements with the extent of conductivities, are therefore dissolved (ions), JUNGE (1963), GREEN (1970) for Mato Grosso region.

The Na^+ concentrations are increasing at growing seaside winds, also Mg^{++} is partially influenced and Cl^-, BÄTJER and KUNTZE (1963), and get lower the farer the catchments are from the coastal line.

Water of surface systems can be seen as a mixture of recirculating groundwater and actual surface discharge. The composition of lowest discharge flows which are completely coming from groundwater is corresponding in ion-contents with groundwater itself, where they are higher than in surface flow.

The concentration of ions and dissolved matter in rivers is falling with growing discharge.

ALEKIN (1962) gives ion totals of some rivers (in p.p.m) Klar Älv, Sweden (28.7) ;Amazonas Obidos (30.3); Parana, mouth (90.6); Rio Negro, Mercedes (166.7); Machanudi, SE INDIA (73.3); Seraju, Java (122.3); Nil, Kairo (119.1).

A survey of ion totals (p.p.m.) of the own investigations may be given: crystalline rocks (granites, gneisses) West Africa, SE Nigeria, Cameroon, Gabon (21-47); SW Ceylon (22-46), SE Ceylon (279); Madagascar highlands (20-54), Seychelles-Mahé (23-59); Shistes-peridotites, New Caledonia (60-118).

Volcanic rocks, basalts — Anjouan, Comoro Is. (22-107) Reunion (28-198) Mauritius (33-133), Tahiti (127-173).

Tertiary ridges (various geology, volcanic and sedimentary rocks) Java, West Java, central part (102-239); Bali (268); Luzon (47-335), South Andamas (116-343); Guatemala (159-250).

The ion totals of humid areas on crystalline watersheds are homogenously low (20-60 p.p.m.), same mountain springs and surface drains on volcanic watersheds (22-33 p.p.m.) but the greater part of the investigated freshwater are not really poor in ions. The conductivities of all the samples range of about 35-200 µS, the contents in humic acids of 0.3 — 1.0 p.p.m. (ratio µS/humic acids: 20 — 220). The usual scheme of cation exchange series can be stated:

($Ca^{++}Na^+$) ($Ca^{++}Mg^{++}$), directly effected in the humus and subsoil layers and by recirculation of groundwater.

The investigated waters from southwest Africa had obviously different sequences of these ion exchanges. Because of extraordinary high contents of humic acids (3-26 p.p.m.) the usual cation exchange seems rather blocked up and ammonia and iron are enriched (ratio µS/humic acids: 2-14), the humic chelate complexes are saturated in the binding of these two. The usual connections in the sequence $Ca^{++}Mg^{++}Na^{++}$ predominance with falling conductivities can not be stated. This connections are also unsafe in cases of highland water (humid areas, Ca^{++} predominant, Cl^- enriched over 15 % equ.) which are in general poor in ions. The cation exchange is not developed, the contents of humic acids are absolutely low (0.33 p.p.m.) while the anion exchange (possibly effected by clay minerals) is visible.

The lowest totals of ions as a survey of the investigated islands occur in water-systems originat-

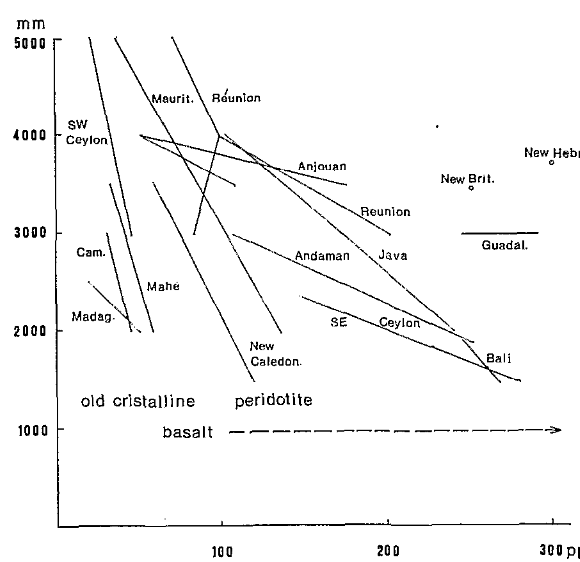

FIG. 1. — Influence of the rate of precipitation (mm) on the totals of ions (ppm) in the running water systems of the investigated watersheds (crystalline rocks, basaltic rocks and others)

TABLE I

Survey of the investigated main water types

abundant ions	Conductivity µ S. (20°)	Conductivity humic acids	humic acids (pp m).	volcanic watersheds	cristalline watersheds
Ca^{++} HCO_3^-	(220)	198	0.90	Rêunion, Java, Luzon amphitheatric valleys	Ceylon-dry region
Ca^{++} HCO_3^- Cl^-	(31)	34	0.33		Ceylon, headwater higlands, Fiji
Mg^{++} HCO_3^-	(137)	103	0.75	Anjouan Reunion cascades	New Caledonia shistes Ceylon-SE descent.
Mg^{++} HCO_3^-	(128)	99	0.77	New Caledonia peridotite Mauritius-lower flanks	Andaman head waters
Na^+ HCO_3^-	(145)	70	0.48	Reunion-active volcano "Cirques" flow out	Madagascar spring Amazonas affl.
Na^+ Cl^- HCO_3^-	(89)	62	0.70	Mauritius-south highl. Reunion-smaller valleys	Ceylon-upper cours. Madagascar
Na^+ Cl^- HCO_3^-	(20-37)	44	1.2-2.2	Mauritius-headwaters	Seychelles-all

TABLE II

Calcium-bicarbonate waters (Ca^{++} HCO_3^- are predominant) analytical data (conductivity 20 °C, pH, contents of the most abundant ions in ppm and their relative frequency in % of equivalents). Chloride is not enriched (< 15 equ. %)

	Cond. uS	pH	h. acids	NH_4^+	Na^+	K^+	Ca^{++}	Mg^{++}	Fe tot.	Cl^-	SO_4^{--}	HCO_3^-	SiO_2
Guadalcanal Streams													
p.p.m.	252	7.5	0.05	0.07	4.5	0.8	44	6.6	0.0	4.0	3.8	180	23
equ. %					6.6	0.7	75	18		3.5	2.6	94	
Guatemala, humid part													
p.p.m.	128	6.9	4.3	0.40	5.2	2.4	17	5.7	2.3	2.8	7.5	82	33
equ. %					14	3.7	52	28		5.0	10	85	
Luzon, Ifugao, Banaue													
p.p.m.	54	6.7	0.42	0.09	2.5	0.6	5.8	3.0	0.01	0.85	4.0	32	20
equ. %					17	1.2	45	38		3.7	13	63	
Luzon, Ifugao, Bontoc													
p.p.m.	200	7.6	0.60	0.13	11	1.2	25	6.5		7.4	28	84	22
equ. %					20	1.4	55	23		9.5	27	63	
Luzon, Laguna, Pagsaj.													
p.p.m.	43	6.9	3.5	0.29	3.5	0.7	4.3	0.9	0.48	4.6	1.0	20	12
equ. %					33	3.9	47	16		28	4.5	08	
Luzon, Laguna, Calamba													
p.p.m.	300	7.6	1.2	0.22	23	7.5	25	11	0.06	5.7	12	176	68
equ. %					31	5.9	38	28		4.9	7.6	88	
Cebu, Sibonga, Busay													
p.p.m.	370	8.1	1.2	0.11	16	1.5	59	14	0.15	5.2	29	242	12
equ. %					14	0.8	61	24		3.1	13	84	

		Cond. uS	pH	h. acids	NH_4^+	Na^+	K^+	Ca^{++}	Mg^{++}	Fe tot.	Cl^-	SO_4^{--}	HCO_3^-	SiO_2
Réunion "Cirq." Inter.														
	p.p.m.	183	8.4	0.40	0.02	15	2.4	18	8.3	0.12	2.6	3.8	127	19
	equ. %					28	2.7	39	29		3.2	3.6	93	
Tahiti Mid. course														
	p.p.m.	132	6.8	0.10	0.05	11	1.4	12	7.2	0.16	2.3	0.7	100	28
	equ. %					28	2.1	35	35		3.8	1.0	95	
Bali all regions														
	p.p.m.	263	7.5	0.90	0.06	23	4.6	23	13	2.4	10	9.4	140	43
	equ. %					30	3.6	35	32		10	7.0	82	
Anjouan subterr.														
	p.p.m.	179	7.1	0.70	0.01	13	2.5	13	7.5	0.5	6.0	1.1	160	34
	equ. %					29	3.3	34	33		9.1	1.2	89	
Madagascar highl.														
	p.p.m.	38	7.2	0.90	0.10	3.0	1.7	2.9	1.3	0.7	1.6	0.2	24	9.2
	equ. %					29	9.3	32	24		9.3	0.9	89	
	Chloride is enriched (15 equ. %)													
SW Ceylon lower courses														
	p.p.m.	29	6.7	0,20	0.07	2.2	0.8	2.5	1.1	0.9	2.4	0.7	16	6.9
	equ. %					27	5.8	34	25		20	4.2	74	
SW Ceylon headwaters														
	p.p.m.	20	6.1	0.50	0.14	1.4	1.0	1.4	0.5	0.6	2.4	0.5	10	3.7
	equ. %					26	11	30	19		27	4.0	68	
Fiji, Viti. Levu														
	p.p.m.	33	6.9	0,70	0.01	4.8	1.1	5.6	0.5	1.0	6.9	3.5	27	18
	equ. %					38	5.0	50	7,4		29	11	6[illegible]	

		Cond. uS	pH	h. acids	NH_4^+	Na^+	K^+	Ca^{++}	Mg^{++}	Fe tot.	Cl^-	SO_4^{--}	HCO_3^-	SiO_2
New Guinea, mountain stream	p.p.m.	58	7.1	0.19	0.16	3.9	1.5	9.2	1.5	2.3	1.4	2.6	40	38
	equ. %					22	4.8	58	15		5.3	7.1	87	
N.Guinea coastal region	p.p.m.	290	7.3	0.50	0.10	10.5	1.1	36	15	0.5	3.3	6.6	213	52
	equ. %					13	0.8	51	35		2.5	3.7	94	
Madagascar groundwater	p.p.m.	208	7.7	0.16	0.01	2.0	3.5	23	11	0.02	10	1.1	92	22
	equ. %					3.9	4.0	52	40		13	1.0	67	
Ceylon, dry part														
	p.p.m.	248	7.7	0.22	0.05	13	2.4	31	15	1.4	4.8	0.7	171	40
	equ. %					16	1.8	44	36		4.1	0.4	95	
Java, humid west														
	p.p.m.	76	7.4	1.3	0.10	4.2	1.7	9.1	3.5	0.2	3.0	5.4	48	27
	equ. %					19	4.5	45.5	29		8.5	11	79	
Java, central part														
	p.p.m.	237	7.6	0.90	0.04	18	4.2	21	8.2	0.2	12	8.0	110	50
	equ. %					28	4.1	40	26		14	6.9	79	
New Britain, Rabaul stream	p.p.m.	152	6.6	0.70	0.22	16	3.4	15	4.7	2.6	4.0	7.6	98	100
	equ. %					35	4.5	40	20		6.0	8.4	85	

TABLE III

Magnesium — bicarbonate waters (Mg^{++} HCO_3^- are predominant) analytical data (conductivity 20 °C, pH, contents of the most abundant ions in ppm and their relative frequency in % of equivalents). Chloride is not enriched (15 equ. %)

		Cond. uS	pH	h. acids	NH_4^+	Na^+	K^+	Ca^{++}	Mg^{++}	Fe tot.	Cl^-	SO_4^{--}	HCO_3^-	SiO_2
North Adaman lower courses	p.p.m.	246	7.2	1,0	0.06	7.9	1.1	15	25	0.13	8.3	3.8	173	18
	equ. %					11	0.9	23	65		7.4	2.5	90	
South Andaman lower course	p.p.m.	322	7.3	1.5	0.08	22	1.4	25	19	0.24	20	7.5	226	21
	equ. %					25	0.9	33	41		15	4.1	81	
Tahiti, lower courses	p.p.m.	96	7.4	0.05	0.05	9.0	1.2	6.5	6.3	0.32	3.6	0.5	70	31
	equ. %					31	2.4	26	44		8.1	1.0	91	
Anjouan, northwest	p.p.m.	156	8.1	1.2	0.01	11	2.0	11	8.2	0.60	6.4	0.4	94	27
	equ. %					25	2.7	30	36		10	0.6	87	
Anjouan, southwest	p.p.m.	100	7.6	1.1	0.01	7.7	1.4	5.9	4.6	0.20	5.1	0.3	54	28
	equ. %					31	3.3	28	36		14	0.7	85	
Anjouan, northeast	p.p.m.	114	7.9	0.9	0.01	7.8	1.6	8.1	5.1	0.35	5.1	0.5	62	28
	equ. %					27	3.2	33	34		12	0.8	57	
Anjouan, flood.cascad.	p.p.m.	43	7.6	1.1	0.04	4.0	0.9	3.6	2.2	0.42	1.6	0.4	27	9.5
	equ. %					31	4.0	32	32		12	2.0	84	
Reunion, Cascades	p.p.m.	53	7.9	0.6	0.01	5.2	1.2	3.8	3.1	0.11	2.9	1.5	35	17
	equ. %					32	4.0	27	38		12	4.0	83	
New Caledonia, shistes	p.p.m.	81	7.5	1.2		7.2	0.6	4.9	4.0		4.8	0.5	48	17
	equ. %					35	0.6	27	36		15	1.1	84	

		Cond. uS	pH	h.acids	NH_4^+	Na^+	K^+	Ca^{++}	Mg^{++}	Fe tot.	Cl^-	SO_4^{--}	HCO_3^-	SiO_2
Ceylon, southeast	p.p.m.	34	6.9	0.1	0.05	1.7	0.7	3.2	2.0	0.24	1.8	0.1	24	11
	equ. %					17	4.1	37	28		11	3.0	86	
Chloride is enriched (>15 equ. %)														
New Caledonia, lee-ward peridotite	p.p.m.	110	7.5	1.0		4.3	0.5	1.1	15		11	1.0	71	14
	equ. %					13	0.9	3.6	83		20	1.3	79	
New Caledonia, wind-ward peridotite	p.p.m.	95	7.7	0.4		4.6	0.5	0.4	12		12	1.5	49	10
	equ. %					17	1.0	1.5	80		29	1.6	69	
New Caledonia, peri-dotite highland	p.p.m.	63	7.0	1.1		5.3	0.4	0.3	6.2		12	0.5	29	6.0
	equ. %					30	1.3	1.7	67		40	1.2	59	
Mauritius, windward highlands	p.p.m.	66	6.8	o.5	0.04	7.8	1.0	2.5	5.0	0.41	14	3.7	18	10
	equ. %					37	28	14	45		46	8.8	40	
Mauritius, leeward west.highlands	p.p.m.	144	7,3	0.3	0.01	13	0.5	8.7	7.0	0.15	17	5.8	55	22
	equ. %					35	0.8	27	36		29	7.6	57	
South Andaman, upper courses	p.p.m.	117	6.7	1.3	0.12	9.7	1.3	8.7	5.9	0.14	10	3.6	62	13
	equ. %					31	2.4	31	35		21	5.4	73	
Anjouan, central lake	p.p.m.	35	8.6	1.7	0.02	1.5	1.1	1.6	1.6	0.36	2.2	0.2	13	0.4
	equ. %					21	9.0	26	42		29	2.0	69	

ing from crystalline watersheds, precambric gneisses in Ceylon, old granites on the investigated islands of the Seychelles' archipelago and also in Madagascar. Within this crystalline regions the contents of ions increase obviously towards the leeward watersheds and lowlands, that means toward the dry regions. Next in this scale of ionic conditions are water-systems originating from schistes (northern parts of New Caledonia, Fiji Islands, New Guinea).

The crystalline regions in humid climate are less influenced by the permanent loss of ions due to weathering than the volcanic watersheds which are very different in their resistance against weathering processes. Older volcanic rocks and especially soils are narrowing the more homogenous but less intensive increasement of ions by leach in old crystalline (Fig. 1). Connections between precipitation and *ionic totals. In dry climate the totals of ions* increase also on crystalline watersheds due to the activation of the chemical weathering processes (Ceylon). Between the ion totals from shistic or volcanic watersheds are these from peridotitic regions (New Caledonia). The ionic totals in water systems from volcanic areas are increased, in average in correspondence the falling age of the rocks. Highest totals occur in regions of recent volcanism (Java, Bali, Guadalcanal, Réunion), while these in Anjouan and especially from the highly leached watersheds in Mauritius (with partially acidic soil) are lower and sometimes already similar to the ion totals from crystalline watersheds.

The comparison of the different relative ion abundancies states usually the succession $Ca^{++} \rightarrow Mg^{++} \rightarrow Na^{+}$ with decreasing conductivities. Except certain headwaters from extremely humid crystalline mountain areas where the influence of ion exchange in the soil seems highly reduced due to the elutriation caused by permanent rainfalls. This waters are still $Ca^{++}HCO_3^{-}$ water, Cl^{-} is relatively enriched, although their conductivities are lower than these of the discussed Mg^{++} and Na^{+} series (Tabl. XV, I).

Chloride is only relatively enriched in water with lower actual conductivities of the same series.

Extraordinary humic waters, highly enriched in iron and ammonia, are not included in this survey because there can not be seen a clear connection between the succession of conductivities and ion abundancies.

The hydrochemistry of running water is as well directly influenced by the surface discharge of the watersheds as by the recirculation of subsoil groundwater. The geology of the watersheds is very important due to the very different resistance of rocks against the weathering processes. The totals of ions in water originating from volcanic watersheds (basaltic rocks) are usually much higher than in water draining crystalline rocks (gneisses, granites) but there seems to be no fundamentally difference in the abundances of ions. Of extraordinary influence on hydrochemistry of the drains is the development of the soil which is more or less forced by the local climate.

The water types that are mainly predominated by the primary chemical weathering of the rocks are widely distributed as well on volcanic islands (deep erosion of less resistant olivine basalts in the interior parts of amphitheatric valleys in Réunion; partially subterraneous drains on highly porous and surface weathered basalts in Anjouan, Comoro Is.) as also on crystalline watersheds (central highland drains in Ceylon). All these waters are characterized by the predominance of calcium (less magnesium) bicarbonate (Tabl. II).

The drains of highly porous watersheds that are already in a very advanced stage of surface weathering like these on older volcanic islands with dense vegetation (Anjouan, Mauritius), were enriched in magnesium-bicarbonate. This type seems mostly bound to older volcanic islands with an advanced development of soils which are also strongly eroded and have a high rate of recirculations of soil trickling water. "Secondary drains" of the soil and the subsoil are mostly influencing water chemistry. An extraordinary enrichment in Mg^{++} ions is naturally found in New Caledonia (peridotitic rocks) (Tabl. III). On crystalline islands was this type subordinated. The predominance of Mg^{++} ions may be reascned by the high rate of recirculation from groundwater (enriched in magnesium ions) in porous drains (MATTHES, 1979) and in ion exchange processes (OHLE, 1956); really subterraneous streams were mostly flowing in direct contact with the base rocks (Anjouan) and belong to the $Ca^{++}HCO_3^{-}$ water type. The most widespread and most frequent type registrated *in the running* waters of the investigated part of the humid tropics was characterized by an enrichment of sodium (sodium-bicarbonate-predominance), found as well on watersheds of volcanic origin as on crystalline rocks (Tabl. IV).

This type may be caused as well by primary rock's weathering and leach (chemical decomposition of the predominant alkali-silicates) as by a high rate of recirculating groundwater due to the extremely humid climate and precipitation (windward flanks) and advanced exchange.

The relative but also absolute enrichment of water in magnesium - and sodium-ions depends as it is reasoned by ionic exchange processes, on the elimination of calcium-ions as an effect of complex binding in zeolitic clays (widespread in

TABLE IV

Sodium abundant waters analytical data (conductivity 20 °C, pH, contents of the most abundant ions in ppm, their relative frequency in % equivalents). Chloride is not enriched (15 equ. %)

		Cond. uS	pH	h.acids	NH_4^+	Na^+	K^+	Ca^{++}	Mg^{++}	Fe tot.	Cl^-	SO_4^{--}	HCO_3^-	SiO_2
Amazonas affluent, Peru	p.p.m.	221	6.9	2.9	0.48	6.0	0.5	2.0	0.5	0.10	1.4	4.1	11	7.7
	equ. %					83	4.1	32	13		13	28	59	
New Guinea swamp drain	p.p.m.	615	7.6	0.3	0.05	43	1.6	31	8,2	1.0	10	7,2	220	44
	equ. %					45	1.0	38	16		7.2	4.7	88	
Madagascar spring pool	p.p.m.	11	6.8	0.8	0.04	1.5	0.6	0.0	0.4	0.04	0.5	0.3	7.9	8.3
	equ. %					42	33	0.0	20		9.7	3.9	84	
Réunion active volcano	p.p.m.	77	7.8	0.3	0.02	9.0	3.0	3.6	3.3	0.06	4.1	3.3	45	29
	equ. %					42	8.1	19	29		12	7.3	78	
Réunion Cirqu. flow out	p.p.m.	169	8.5	0.4	0.01	19	1.6	15	5.7	0.60	3.2	3.5	110	25
	equ. %					40	2.0	35	22		6.8	3.6	89	
Chloride is enriched (15 equ. %)														
Réunion Mt. pool	p.p.m.	24	6.9	1.6	0.05	4.0	0.4	1.2	1.2	0.50	3.0	0.8	15	2.1
	equ. %					48	3.0	17	27		24	5.0	70	
Mauritius lower course	p.p.m.	143	7.8	0.55	0.02	16	1.1	6.6	6.3	0.32	20	6.0	53	21
	equ. %					44	1.7	21	32		36	7.9	54	
Mauritius highlands mid. cours.	p.p.m.	101	7.8	0.70	0.02	11	0.9	4.1	5.0	0.24	16	2.9	37	15
	equ. %					43	2.1	18	36		40	5.3	54	
Madagascar highland pool	p.p.m.	44	6.5	0.85	0.03	4.5	1.0	2.6	1.3	11.5	4.2	1.5	18	13
	equ. %					43	5.7	28	23		26	6.8	66	

		Cond. uS	pH	h. acids	NH_4^+	Na^+	K^+	Ca^{++}	Mg^{++}	Fe tot.	Cl^-	SO_4^{--}	HCO_3^-	SiO_2
Madagascar highl. stream	p.p.m.	44	7.3	0.75	0.10	4.5	1.4	3.2	1.1	1.5	4.9	0.2	23	14
	equ. %					40	7.2	33	19		26	0.8	73	
Fiji, Viti Levu mid. course	p.p.m.	45	7.2	0.05	0.10	5.0	0.5	3.6	1.9	0.10	6.2	3.6	22	24
	equ. %					38	2.3	32	27		29	12	59	
Réunion smaller val.	p.p.m.	72	7.7	0.65	0.06	7.4	1.0	5.2	3.5	0.18	6.8	1.1	40	16
	equ. %					36	2.7	29	32		21	2.4	72	
Ceylon SW upper courses	p.p.m.	24	6.3	0.20	0.14	2.0	0.7	1.4	0.7	0.30	2.5	1.0	12	9.6
	equ. %					34	6.9	27	23		24	6.8	68	
Sodium - chloride water (Na^+ Cl^- are predominant)														
Mauritius headwater	p.p.m.	48	6.5	1.1	0.08	7.0	0.4	0.5	0.9	0.65	12	2.7	6.7	2.0
						64	2.3	4.9	15		67	11	21	
Seychelles Mahé NW mainrivers	p.p.m.	32	6.3	1.6	0.10	3.9	0.7	0.6	0.3	0.12	5.8	1.2	3.7	6.5
	equ. %					64	6.4	11	11		64	9.0	25	
Mahé NE headwater	p.p.m.	31	6.5	1.7	0.10	3.8	0.8	0.5	0.2	0.06	5.3	1.0	5.5	8.4
	equ. %					67	8.2	11	8.0		59	8.3	35	
Mahé NE lower cours.	p.p.m.	49	6.8	0.8	0.05	5.9	0.7	2.0	0.6	0.13	7.5	1.2	9.7	10
	equ. %					65	4.8	14	13		53	6.0	10	
Mahé leeward south	p.p.m.	83	6.9	1.2	0.06	9.7	0.9	2.6	1.5	0.23	13	3.5	16	12
	equ. %					60	3.3	18	17		52	10	37	
Seychelles Fraslin, LaDigua	p.p.m.	63	6.5	1.5	0.06	8.5	2.6	1.8	1.8	0.30	11	2.3	14	17
	equ. 4					59	10	14	13		53	8.0	38	
Mauritius highland marshes	p.p.m.	47	7.2	0.4	0.04	6.6	0.4	1.3	1.5	0.30	10	4.1	12	4.8
	equ. %					58	2.0	13	24		50	15	35	

basaltic areas) and by humic acids (mostly enriched in areas with dense vegetation and acidic soil).

The relative enrichment of chloride against the usually predominating bicarbonate ions was registrated only in waters extremely poor in ions, as well in bicarbonatic water with calcium-, magnesium-, and especially with sodium- predominance.

The development of very acidic soil, especially in the extremely humid highland areas (granitic watersheds of the Seychelles but also similar an old volcanic basalts in Mauritius), was obviously connected with the occurance of water pedominated by sodium-chloride. This water type is supposed to be strongly influenced by ion-exchange due to humic acids and to be very typical for the drains of distinct humid mountain rainforest regions in oceanic areas. The rate of precipitation is not as high as in the high mountain regions (Ceylonese highlands) and allows during the dry periods a regeneration of the ionic exchange systems in the acidic soil, further are the flooding effect and the erosion not too high. The eolic transport of sodium-chloride by the seaside winds may be of additional influence possibly under aspects of a regeneration of the ion exchange activities of the soil drains.

An exclusive reason of sodium-chloride enrichment by the seaside winds seems unlikely because it was not noticed in waters of similar small islands (Anjouan) even during the rain season, but in absence of very acidic soil. The quantity of circulating water in these humid areas is very high and the ion concentrations even in groundwater are usually very low. The conductivities of rain water ranges world wide between 5-30 µS (Matthes, 1973), already similar distinct tropical mountain streams. Different from the waters just discussed are these from rain forest areas in the lowlands which are extraordinarily rich in humic acids, iron, ammonia (western Africa) with various different predominating ions. This seems to be an advanced stage of acidic humic water, typical for lower peneplains of extended forested areas where the influence of primary weathering and decomposition of the rocks is less important. The hydrochemistry is mostly formed by the leach of acidic soil and rotting leaves. The ion exchange systems of the soil are more or less blocked up due to the enrichment with iron and ammonia and the enrichment of the circulating water by humic substances itself (Tabl. V).

The varieties of specific water types of one place or region increase accordingly with the variety of geology and climate. On young volcanic watersheds ($Ca^{++}HCO_3^-$ water type) and also on less extended old crystallinic ones (Na^+Cl^- water type) occur only one or two of the discussed typical waters while extended areas have a wide ranged scale. Especially the $Mg^{++}HCO_3^-$ water type seems connected with the decomposition and advanced leaching of highly weathered watersheds of mostly volcanic origin and intensive soil erosion (Tabl. VI).

The analyzed contents in minor ions are in general very low, especially in the humid headwater regions. Nitrates (usually 0.10-0.20 p.p.m.) as well as phosphates (usually 0.01-0.08 p.p.m.) are influenced by the intensive agriculture in highly populated valleys in Réunion, Mauritius, Luzon, parts of Madagascar (nitrate 2.9-27 p.p.m., phosphate 0.15-

Table V

Waters extraordinary enriched in humic acids, armonia and iron: analytical dates (conductivity 20 °C, pH, contents of the most abundant ions in ppm, their relative frequency in % equivalents

	Cond. µ	pH	h. acids	NH_4^+	Na^+	K^+	Ca^{++}	Mg^{++}	Fe tot.	Al^{+++}	Cl^-	SO_4^{--}	HCO_3^-	SiO_2
Cameroon streams														
p.p.m.	18.6	6.7	6.3	0.90	1.4	0.5	1.9	1.1	0.5	0.1	0.9	2.8	16	11
equ. %				16	20	4.2	31	29						
Kinshasa lake														
p.p.m.	10.5	6.2	2.0	0.40	1.0	0.5	0.08	0.35	0.6	0.1	1.9	2.2	4.3	8.8
equ. %				20	39	12	3.6	26			21	23	35	
SE Nigeria streams														
p.p.m.	10.6	6.3	4.3	0.24	0.8	0.5	0.6	0.2	2.6	0.06	0.7	1.9	11	13
equ. %				12	33	12	28	15			8.4	16	74	
Gabon streams														
p.p.m.	39	6.7	2.7	3.1	2.1	1.3	1.1	0.8	0.5	0.13	0.9	1.5	23	12
equ. %				41	22	7.9	13	16			5.9	6.9	86	
Rio Itaya Peru														
p.p.m.	49	6.4	27	4.0	2.0	0.8	4.0	0.6	3.5		4.3	20	5.5	11
equ. %				48	13	3.0	29	7.1			19	66	14	

TABLE VI

The suspected share of the different water types on the complete drain systems of the studied areas

	Ca^{++} HCO_3^-	Mg^{++} HCO_3^-	Na^+ HCO_3^-	Na^+ Cl^-	NH_4^+ (Fe)
Java, Bali	90%				
New Britain	90%				
Guadalcanal	90%				
Luzon	90%				
New Caledonia		95%			
Andamana		90%			
Anjouan (Comoro)	10-20%	80%			
Rêunion	20%	5-10%	70%		
Mauritius		10-20%	60%	20-30%	
Seychelles (Mahē)				95%	
Ceylon (humid SW)	50%	5%	45%		
Ceylon (dry SE)	85%	15%			
Madagascar (highl.)	70%		20-30%		
Cameroon	50%		30-40%		5-10%
SE Nigeria	20%		50-70%		5-10%
Gabon			40-50%		40-50%

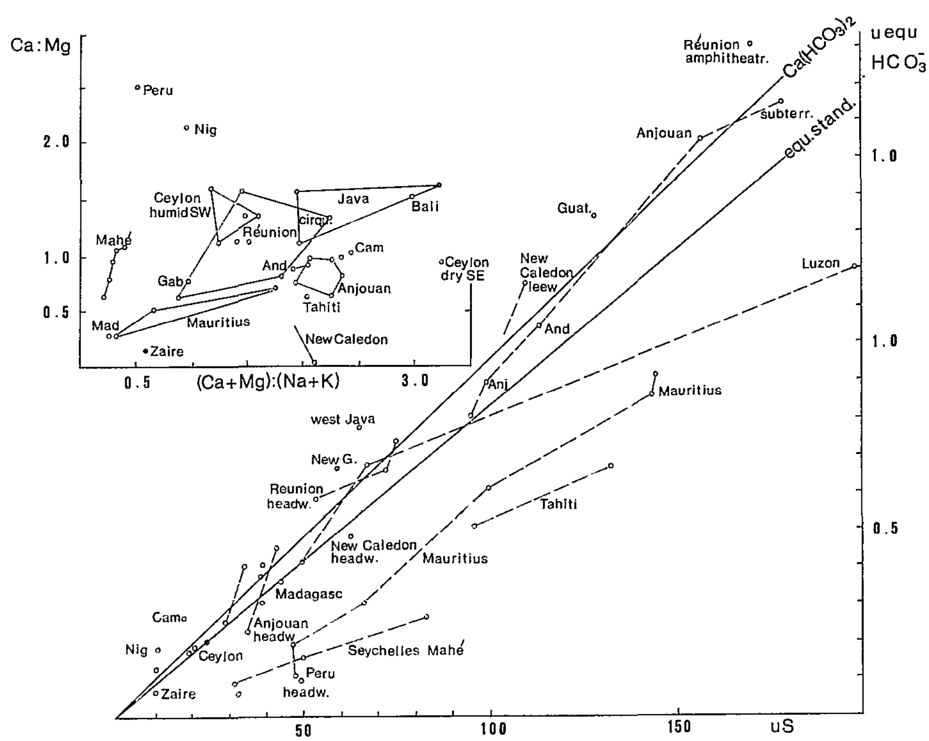

FIG. 2. — Diagram concerning the connections of conductivities (pS 20°) and alkalinities (uequ. HCO_3^-) of the investigated running waters, compared with those of a saturated solution of Ca $(HCO_3)_2$ and with the equivalent standard. Another diagram gives the connections between the predominant bivalent (Ca^{++}, Mg^{++}) and monovalent (Na^+, K^+) cations

1.1. p.p.m.). The contents of aluminium were in average about 0.03-0.20 p.p.m.

The tendency of watersheds with a very advanced stage of surface weathering and soil erosion, seems to be typical for medium aged volcanic or tertiary areas, producing waters and drains highly enriched in Mg^{++}. Young volcanic areas but also tertiary ridges influenced by recent volcanism are predominated by Ca^{++} water-drains.

Special types of old volcanic watersheds in humid climate give rise to the development of acidic soil as well as those in old crystalline areas causing soft water enriched in sodium. This seems to be a final stage of soft water especially accompanied by chloride peaks (Mauritius, Mahé).

The general view of alkalinity measurement states mostly the correspondence with the conductivities according to the saturation curve of calcium-bicarbonate. Although extreme types occur like the drains of highly weathered (mostly leeward) watersheds of volcanic rocks. These waters are characterized by a very high alkalinity possibly caused by overtitration due the influence of silicic acid (rivers in Réunion, Java, Anjouan, New Caledonia and others). Different from these systems are drains originating from old volcanic or crystalline watersheds in humid climate mostly on oceanic islands (Mauritius highlands, Tahiti, Luzon, Mahé of Seychelles). All these are soft water types relatively or absolutely enriched in alkali ions (Na^+, partially also K^+) possibly reasoned by ionic exchange processes in the humic soil. This may occur in humid tropical climate of the oceanic areas without real high mountains. Different in SW Ceylon, where the precipitation is extremely high and might wash out all the soils, not allowing a higher rate of ionic exchange. The soils on this mentioned oceanic islands are obviously under a permanent rhythm of wet leaching periods and regenerative dry periods allowing an optimum ionic exchange possibly also influenced by ions (mostly sodium-chloride) transported by the sea winds.

The extreme calcium poverty of these water is further emphasized by the Ca: Mg ratio, which gradually increased from 0.34-0.78 (BISHOP, 1973, for the Malayan Gombak). This Mg^- excess is also common in Amazonia (KLINGE & OHLE, 1964) and may be partially explained by the preferential uptake of HCO_3^- bound Ca^{++} over Mg^{++} salts by humus colloids in the soil, leading to a relative surplus of Mg^{++}.

In the metamorphic facies the magnesium concentration is much greater than that of calcium, but Ca^{++} is dominant in granites (downstream increase).

Means of Ca : Mg ratios (equivalent relations) of the mainly studied areas: Ceylon 0.95-1.62; Seychelles (Mahé) 0.65-1.03-1.30; Réunion 0.61-1.58; Anjouan 0.61-1.03; Mauritius 0.50-0.75; Java Bali 1.09-1.58; New Caledonia 0.04-0.75. This survey states low values on old volcanic watersheds and especially on perioditites. Low ratios are reported from humic lake water, JUDAY *et al.* (1938), OHLE (1955). The ratio (Ca + Mg): (Na + K) was discussed by JOHNSON (1967) for the soft water of Southern Malaya an Singapore and rejected as an index of trophicity. This ratio provides information on the parent formation of the watersheds and the extent of their influence on the water draining them (BISHOP, 1973; SIOLI, 1968, 1969).

The ratio for the Malayan Gombak river dropped from 0.78-0.22, changing from metamorphic rocks to granites, similar ratios are given by CORBEL (1964) for Ivory coast rivers. The mean ratios found by DOUGLAS (1968) for Australian water were from 0.7 from metamorphic and 0.5 from granitic lithologies with higher ratios up to 1.9 from pure sedimentary formations.

The means of the combined equivalent ratios [Ca + Mg]: [Na + K] vary between 1.16-1.56 (humid SW) and 3.22-4.35 (dry SE) in Ceylon, between 0.25-0.39 in Mahé (Seychelles), they are also low on old volcanic islands like Mauritius between 0.30-0.61 (highlands) and 1.16-1.72 (lower regions), but high on younger volcanic rocks-between 0.96-2.23 in Réunion and between 0.78-1.82-2.36 in Anjouan (Comoro Is.). In average the share of [Ca + Mg] is larger towards the lowlands or towards the more intensively chemical weathered leeward parts which are less leached by rainfalls. They are extraordinarily small on the Seychelles and Mauritius highlands, both extremely leached by the high precipitation.

Of great hydrochemical importance and relatively enriched in humid tropical areas under the dominating influences of the local climate on the igneous rocks, are silicates (alkali silicates) that are leached preferentially from the soil and subsoil rocks. The reactive silicates occur mostly as free silicic acid either dissolved or as colloids. BISHOP (1973) mentioned means of 11.7 p.p.m. SiO_2 for Asian rivers. Especially an old crystalline watersheds a correspondence is visible between the increasement of the conductivities and that of silicates which develops regularly.

This differs from water systems originating from basaltic watersheds on volcanic islands where the contents vary wide ranged due to the inhomogeneous leach of the young rocks. Drains from highly weathered watersheds are highly enriched in dissolved alkali-silicates. Such important variations could be registrated in Anjouan, Mauritius and Réunion, where the headwaters are sometimes poor in silicates due to the losses of rainfall leach. The contents vary in survey from 3.7-9.6 (humid SW) to 11.4-40 p.p.m. SiO_2 (dry SE) in Ceylonese rivers, from 6.5-17.3 p.p.m. SiO_2 on the granitic Seychelles, but much more wideranged on volcanic islands from 0.4-9.5 p.p.m. in flooded rivers and crater lakes to 27.1-34.4 p.p.m. in most of the rivers in Anjouan, similar in Réunion, 2.1 (pools), 16.1-28.9 p.p.m. SiO_2 or in Mauritius, 2.0-4.8 p.p.m. in the highlands but 20.9 p.p.m. in the lower regions or even in ranges between 23-100 p.p.m. on some volcanic islands.

Another ratio — conductivity: silicates (µS 20°, SiO_2 p.p.m.) is proposed. These ratios are low (< 5) on crystalline watersheds especially in the humid mountain regions, same on resistant basaltic rocks (Differentiated Series in Réunion) and on shistes. The ratios are high (6-10) in drains from less weathering resistant olivine basalts (deep

TABLE VII

Changement of the ionic relations on the Réunion watersheds

1. SURFACE DRAINAGE, PITON DES NEIGES

	means of mountain cascades alt. 800 m		means of Small valleys alt. 70 m		fluctuations	
	μ equ.	%	μ equ.	%	absol. %	relat. %
Ca^{++}	190	(27)	260	(29)	+ 37	(+ 2)
Mg^{++}	254	(36)	286	(32)	+ 13	(- 4)
Na^{+}	226	(32)	322	(36)	+ 13	(+ 4)
K^{+}	28	(4)	24	(3)	- 14	(- 1)
Cl^{-}	87	(12)	192	(21)	+ 121	(+ 9)
SO_4^{--}	31	(5)	22	(2)	- 29	(- 3)
HCO_3^{-}	580	(83)	650	(72)	+ 12	(-11)

2. DEEP ERODED AMPHITHEATRIC VALLEYS OF PITON DES NEIGES : means of the three main Cirques systems

	Cirques interior alt. 1000 m		flow out alt. 155 m		fluctuations	
	μ equ.	%	μ equ.	%	absol. (%)	relat. (%)
Ca^{++}	915	(39)	740	(35)	- 19	(- 4)
Mg^{++}	680	(29)	467	(22)	- 31	(- 7)
Na^{++}	652	(28)	839	(40)	+ 29	(+ 12)
K^{+}	62	(3)	42	(2)	- 32	(- 1)
Cl^{-}	73	(3)	138	(7)	+ 89	(+ 4)
SO_4^{--}	80	(4)	73	(4)	- 9	(- 0)
HCO_3^{-}	2090	(93)	1800	(89)	- 14	(- 4)

erosion of the Oceanite Series in Réunion or subsoil leach of Oceanites in Mauritius (6.6-23.9).

4. STUDIED AREAS IN DETAILED HYDROCHEMISTRY AND ION-FLUCTUATION

4.1. **Volcanic island**

Homogeneous increasements of the predominant Ca^{++} and HCO_3^- ions can be expected when the basalts are rather uniform and less resistant against the chemical weathering of the rocks (Guadalcanal, New Britain and others).

In La Réunion (aged in total about 1 million yrs.), the upper volcanic rocks — the younger Differentiated Series that cover the greater part of the shields of the extincted volcano (Piton des Neiges) and also of the active younger Piton de la Fournaise — are more resistant against weathering than the basic shield of the older basalts (Oceanites). On this account most of the valleys are built up only by weathered and eroded parts of the younger upper Differentiated Series of the volcano (surface drainage of the smaller valleys). In survey of the analytical means from the mountain-cascades (altitude 800 m) to the lower courses (altitude 48 m), Ca^{++} increases absolutely and relatively, Mg^{++} only absolutely, Na^+ absolutely and relatively like Cl^-, HCO_3^- only absolutely, while K^+ and SO_4^{--} decrease in relative and absolute percentage.

Geology see UPTON & WADSWORTH (1965), BUSSIÈRE cit. MCDOUGALL (1971), FISHER *et al.* (1967), MCDOUGALL & CHAMALAUN (1969).

In detail of investigations made on two surface draining smaller rivers (Riv. Marsouin, Riv. St. Marie), Na^+, K^+, SO_4^{--}, HCO_3^- ions increase downstreams absolutely and relatively (Ca^{++}, Mg^{++} ions increase only absolutely, but decrease relatively), while Cl^- ions decrease both.

Another system (Riv. Suzannes) shows a relative increasement (downstreams) of Ca^{++} and HCO_3^- ions (see Table VII).

The highland pools are mostly influenced in their hydrochemistry by the frequent rainfalls

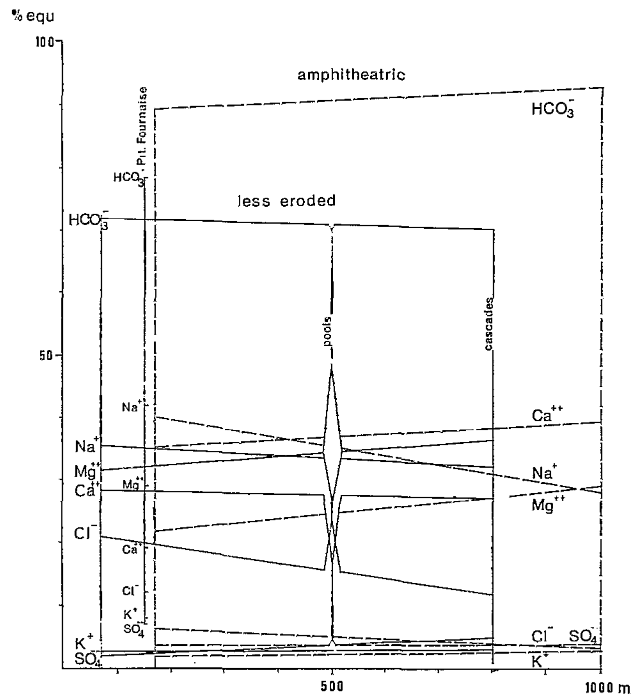

FIG. 3. — Reunion Island: Connections and fluctuations of the main ion equivalent percentages (means of % equ.) and the different altitudes (meters above sea level) of the main catchment areas of the rivers (smaller, less eroded valleys and deep eroded amphitheatric ones)

and by ionic exchange. Their water is poorer in Ca^{++} and Mg^{++} ions but contains more Na^+ and Cl^- (Fig. 3).

The main rivers in La Réunion flow out of the extraordinary deep eroded amphitheatric valleys which have in their interior part contact with the older downward basalts (Oceanites). Three of these "Cirques" are present in the extincted Piton des Neiges massif, their water systems are more enriched in ions (Ca^{++}, Mg^{++}, Na^+, K^+, SO_4^{--}, HCO_3^-) than these of the less eroded number of affluents, mostly cascades, that are flowing into the main system on the way downwards. These cascade affluents have usually rather soft water due to the short contacts of the precipitation water with the soil and rocks (resistant Differentiated layers) along the steep flanks. Therefore the flow out water of the amphitheatric valleys is generally poorer in ions than that of the interior bassin of the Cirque. Except from this, contents of sodium and chloride increase relatively and absolutely towards the mouth of the river (Tabl. VII), although in total the chloride concentrations are lower than in more surface draining smaller valleys.

A survey of the Réunion Island states the predominance of sodium — and bicarbonate ions Na^+ HCO_3^- type) partially enriched by chloride (especially in stagnant pools, also in some running waters from the leeward side).

The windward cascade region at the steep headwater flanks (main winds are coming from southeast) has the highest rate of rainfalls and obviously also of soil erosion that possibly causes the Mg^{++} predominance in these waters.

All water systems in deeply eroded amphitheatric valleys are highly enriched by Ca^{++} (less Mg^{++} and Na^+) and HCO_3^- ions.

Fig. 3 shows the percentage of the ionic relations from the different regions of the Piton des Neiges and the less extended active volcano Piton de la Fournaise. Two main drainage systems can be distinguished: the widely extended drain through the only surface eroding smaller valleys and cascades and in the other hand the extremely deep eroded *amphitheatric Cirques-systems (main rivers)*. The first systems follow in total the usual increasement in dissolved salts in downstream direction while the Cirques-systems show an "inverse" effect — their flow out has a water that is poorer in ions than the interior headwater part.

The studied island of the Comoro archipelago — *Anjouan* — is a medium aged volcanic island with already extincted volcano but post volcanic activities (thermal springs). The surface rocks are very porous and strongly eroded. The greater part of the islands was deforested, a fact which accelerates the most intensive erosion and weathering of the soil especially on the windward flanks towards the rain-bringing wind from north-west. Geology (1): SAINT OURS (1960), STRONG & FLOWER (1969), ESSON (1970). The catchment of the water samples was made during the last month of the rain season (the precipitation in March was more than 750 mm). In survey (Fig. 4) most of the water systems are characterized by the predominance of magnesium-bicarbonate ions (Mg^{++}, Ca^{++}, Na^+, HCO_3^- type).

The most eroded and strongly weathered fully windward north-western flanks (mostly cultivations) have the highest relative percentage of Mg^{++} (lowest of Na^+) while the leeward systems have lower contents. In water systems that are flowing or draining partially subterraneously — because of the

(1) Block lavas, highly undersaturated basalts (oceanites), ankaramites.

porousity of the rocks — Ca^{++} ions are predominant. There exists also an amphitheatric valley but the steep flanks are covered by extremely dense vegetation (Tatinga-system).

The passage through the upper course region of this amphitheatric watersheds causes first an absolute increasement of Ca^{++}, Mg^{++}, Na^{+}, HCO_3^{-}, while K^{+} and Cl^{-} ions are rather slightly decreasing. The relative ion-percentages of Ca^{++}, Na^{+}, K^{+}, Cl^{-}, SO_4^{--} ions are falling from the headwaters down to the upper interior basin of the valley, while these of Mg^{++} and HCO_3^{-} ions increase. Towards the lower course, higher relative contents of Na^{+}, K^{+} and Cl^{-} are visible (Tabl. VIII).

A typical river draining the strongly eroded northwestern flanks — the Mutsamudu River — shows that the top concentrations of Ca^{++} and Mg^{++} are in the headwater regions (altitude 500 m) especially in the watersheds of the affluents. While passing medium altitudes, the water of the main system contains less Mg^{++}, also less Ca^{++} and Na^{+}, because these main floods originate mostly directly from the less eroded forested flanks of the top region.

Therefore the main river is rather to be characterized as a transport system with only little changes in its hydrochemical details, while the smaller affluents especially the trickling headwater drain in ferralitic soil (WENINGER, 1977) are highly

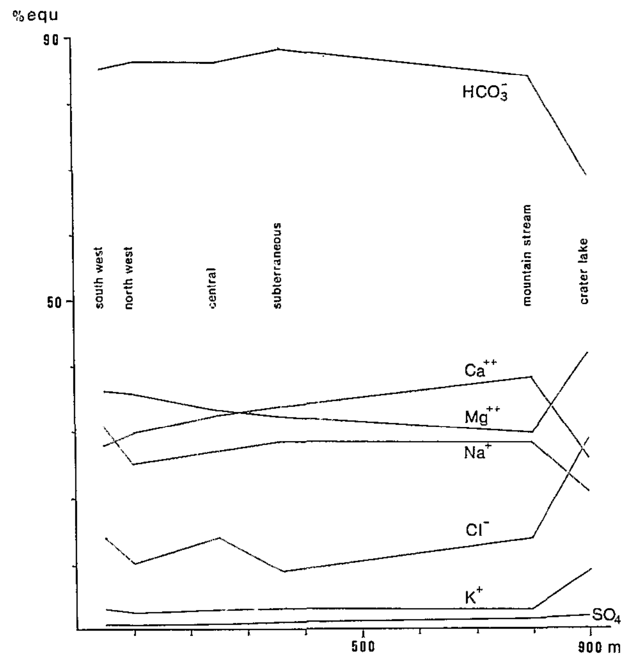

FIG. 4. — Anjouan (Comoro Is.) — Connections and fluctuations of the main ion equivalent percentages (means of % equ.) and the different altitudes of the main catchment areas of the rivers (meters above sea level). Catchments: crater lake and headwaters, upper courses (also subterraneous systems), lower regions of the windward southwest and northwest

TABLE VIII

Anjouan (Comoro Islands) — Changement of the ionic relations on the different watersheds

	Crater lake (St. 13) alt. 900 m		mountain stream (st. 14) alt. 800 m		difference relat. %	Tatinga upper course St. 11 alt. 600 m		difference relat. (%)	Tatinga middle course (st. 24) alt. 210 m		difference relat. (%)
	µ equ.	%	µ equ.	%		µ equ	%		µ equ.	%	
Ca^{++}	80	(26)	380	(38)	(+ 12)	440	(34)	(- 4)	520	(32)	(- 2)
Mg^{++}	131	(42)	296	(30)	(- 12)	485	(38)	(+ 8)	543	(33)	(- 6)
Na^{+}	65	(21)	283	(29)	(+ 8)	328	(25)	(- 4)	500	(31)	(+ 6)
K^{+}	28	(9)	33	(3 3)	(- 6)	33	(3)	(- 1)	62	(4)	(+ 1)
Cl^{-}	93	(29)	133	(14)	(- 15)	118	(9)	(- 5)	408	(22)	(+13)
SO_4^{--}	5	(2)	15	(2.0)	(- 0)	17	(1)	(- 1)	3	(0.2)	(- 1)
HCO_3^{-}	220	(69)	800	(84)	(+ 15)	1190	(90)	(+ 6)	1440	(78)	(- 12)

	means of the Southwestern watersheds		fluctuations absol. (%)	relat. (%)
	µ equ.	%		
Ca^{++}	300	(28)	- 21	(- 10)
Mg^{++}	385	(36)	+ 30	(+ 6)
Na^{+}	335	(31)	+ 18	(+ 2)
K^{+}	36	(3)	+ 6	(- 0.3)
Cl^{-}	144	(14)	+ 8	(- 0.0)
SO_4^{--}	7	(0.7)	- 53	(- 1.3)
HCO_3^{-}	880	(85)	+ 10	(+ 1:0)

influenced by chemical weathering of the soil layers.

Potassium increases more homogeneously in correspondence with falling altitude of the water system while chloride gets more in the lower course regions.

Mauritius is an older volcanic island (total age about 8. mill years). The upper basalts of the volcano's shield are rather resistant against weathering influences and are very similar to the Differentiated Series in Réunion island. The highest elevations in Mauritius are already eroded down to maximum altitudes of about 900 m above sealevel.

The highest plateau is still partially forested (reinforestation and small reserves of natural forest). The climate of this part — the Southern Highlands — is very humid and this causes the development of acidic soil, where tea cultivation is possible. These highlands are rich in headwater branches and marshes. Geology see WALKER and NICOLAYSEN (1954), MCDOUGALL and CHAMALAUN (1968). The headwater branches from this region (mean altitude of the catchment is 700 m) are similar in their hydrochemistry, predominance of Na^+ and Cl^-, those from the granitic Seychelles. This is obviously the result *of ionic exchange in the humic* layers of the whole headwater area. Because of the high contents of sodium — and chloride ions that were found already in the headwaters, these two are further on decreasing downstreams in their relative percentage (in average of all studied systems has Na^+ minus 20 % and Cl^- minus 17 % towards the lower courses, Ca^{++} and especially Mg^{++} ions increase downstreams corresponding HCO_3^- (+ 33 % in relative percentage) while the changement of K^+ ions is indifferent. All of the main ions increase absolutely in downstream direction (Fig. 5).

A comparison of the river systems in detail proves that the real highland streams in the south, especially the fully windward Riv. Poste in the main tea field region with acidic soil but also the more central Riv. Gallets, have a most remarkable enrichment of Mg^{++} ions (less of Ca^{++}) connected with HCO_3^-, while Na^+ and Cl^- rapidly decrease concerning their relative percentage down from 700 m to 5 m (altitude). Iron, in complex binding to humic acids, decreases like ammonia towards the middle and lower courses. The differencies in the relative shares of main ions between upper and lower course (580 m to 60 m) of the Riv. Anguilles, state the same tendencies especially the relative plus of magnesium ions and a minus of sodium ions (Tabl. IX).

Studies in river systems of the lower peneplains in the north of Mauritius (Riv. Rempart Est, catchments 140 m and 20 m above sealevel) stated beside losses of chloride — and calcium-ions, a relative plus of Mg^{++} and already also of Na^+ ions.

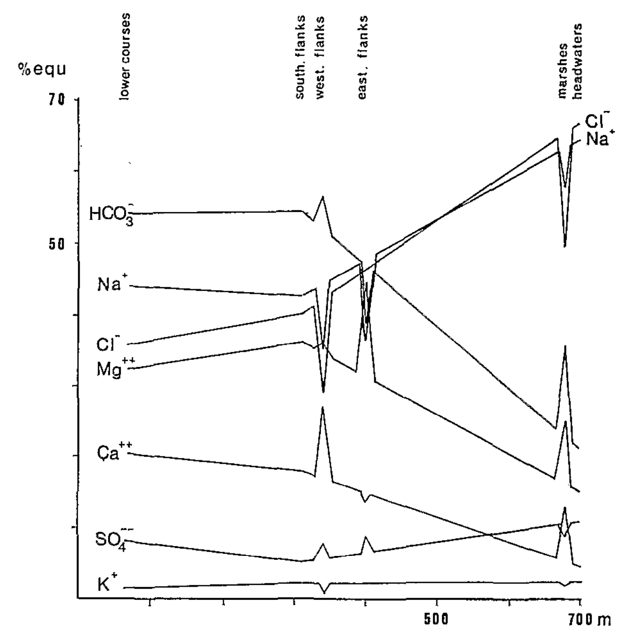

FIG. 5. — Mauritius — Connections and fluctuations of the ion *equivalent percentages (means of % equ.) and the different* altitudes of the main catchment areas of the river systems (meters above sealevel). Catchments: highland headwaters and marshes, upper courses at the southern and eastern windward flanks, the western leeward flanks and the lower courses

The mentioned tendencies concerning the alternations of ionic relations are mostly similar and only different in their gradual shares as these examples from the windward watersheds show.

The leeward systems contain more Ca^{++} and HCO_3^-, less Cl^-, but are of the same water type.

4.2. Islands with various geology mainly based on the old sub-marine Sunda-ridge which is covered by sedimentary and eruptive rocks mostly elevated in Tertiary

The majority of these islands have a number of active volcanos within their area (Java, Bali, Luzon). Very specific is the geology of New Caledonia with extended shiels of peridotites (extraordinary deep eruptive rocks).

On Java and Bali (Tabl. X) — going from the very humid western part of Java to the seasonal dry central Java and even Bali — the changement in ionic relations was similar to that found between the interior part and flow out of the amphitheatric valleys in Réunion. Na^+ and Cl^- relatively increase from the humic west to the drier east. Towards Bali in addition to these two, also Mg^{++} and again

TABLE IX

Mauritius — Changement of the ionic relations on the different watersheds

1. Analytical means

	headwaters alt. 720 m		lower cources alt. 65 m		fluctuations absol. (%)	fluctuations relat. (%)
	µ equ.	%	µ equ.	%	µ equ.	%
Ca^{++}	23	(5)	331	(21)	+ 1339	(+ 16)
Mg^{++}	73	(15)	516	(32)	+ 607	(+ 17)
Na^{+}	304	(64)	704	(44)	+ 132	(- 20)
K^{+}	11	(2)	27	(2)	+ 145	(- 0.5)
Cl^{-}	344	(67)	572	(50)	+ 66	(- 17)
SO_4^{--}	56	(11)	125	(8)	+ 123	(- 3)
HCO_3^{-}	110	(21)	860	(54)	+ 628	(+ 33)

2. Some studed river systems

	Riv. Poste (St. 15) alt. 700 m		Riv. Poste (St. 31) alt. 15 m		fluctuations relat. (%)	Riv. Rempart Est (st. 19) alt. 140 m		Riv. Rempart Est (st. 20) alt. 20 m		fluctuations relat. (%)
	µ equ.	%	µ equ.	%	%	µ equ.	%	µ equ.	%.	
Ca^{++}	40	(9.4)	340	(22)	(+ 13)	340	(22)	360	(21)	(- 1.0)
Mg^{++}	31	(7.3)	551	(35)	(+ 28)	477	(31)	584	(34)	(- 3.0)
Na^{+}	326	(76)	522	(40)	(- 32)	652	(43)	783	(46)	(- 3.0)
K^{+}	17	(4.0)	51	(3.2)	(- 0.6)	27	(1.8)	19	(1.0)	(- 0.8)
NH_4^{+}	3	(0.6)	1	(0.1)	(- 0.5)	3	(0.2)	1	(0.1)	(- 0.1)
Cl^{-}	341	(62)	487	(31)	(- 31)	586	(40)	563	(36)	(- 4.0)
SO_4^{--}	60	(11)	129	(8.2)	(- 3.8)	123	(8.4)	142	(9.2)	(+ 0.8)
HCO_3^{-}	151	(27)	951	(61)	(+ 34)	754	(51)	803	(52)	(- 1.0)
Fe-total ppm	0.52		0.07			.0.44		0.02		
humic acids	1.2		0.65			.0.77		0.52		

TABLE X

Changement of the ionic relations on Java and Bali

	humid western Java		central Java		changement %	Bali		changement
	µ equ.	%	µ equ.			µ equ.	%	%
Ca^{++}	445	(45.4)	1065	(40.3)	(5.1)	1140	(34.6)	(- 10.8)
Mg^{++}	286	(29.2)	672	(25.5)	(3.7)	1040	(31.6)	(+ 2.4)
Na^{+}	182	(18.6)	783	(29.7)	(+ 11.1)	978	(29.7)	(+ 11.1)
K^{+}	44	(4.5)	108	(4.1)	(0.4)	118	(3.6)	(- 0.9)
Fe^{+++}, Al^{+++}, NH_4^{-}		(2.4)		(1.0)	(- 1.4)		(1.0)	(- 1.4)
Cl^{-}	84	(8.5)	338	(14.0)	(+ 5.5)	293	(10.4)	(+ 1.9)
SO_4^{--}	112	(11.4)	167	(6.9)	(- 4.5)	196	(7.0)	(- 4.4)
HCO_3^{-}	780	(79.1)	1900	(78.5)	(0.6)	2300	(82.0)	(+ 2.9)

HCO_3^- relatively increase which might be seen as effect of soil erosion (advanced soil — weathering, like it was especially found on the Comoro Islands).

The climate of the Philippines, especially of the eastern regions, is tropical-humid. Predominant are northeast trades seasonal dominated by monsoons. The amount of precipitations in the mountain provinces of central Luzon reaches from 1 510 mm annual around the leeward area of Baguio to more than 4 670 mm in the mountain regions. The islands are based on the old submarine Sunda-ridge which is covered by sedimentary and eruptive rocks that has been elevated in Tertiary. The islands are still influenced by a number of active volcanos. Most rivers are passing extended rice field (paddies) areas, the upper courses come from forested flanks. All investigated water system had a predominance of calcium-bicarbonate. The water varied from very soft water-types in the headwaters (Luzon highlands and Laguna province) to water highly

TABLE XI

Philippines, Luzon (Ifugao province, Laguna province) and Cebu-Fluctuations of main ions in different water systems

LUZON, IFUGAO MOUNTAIN PROVINCE

	Mountain streams alt. 1850 m		River, middle alt. 1200 m		fluctuations	
	µ equ.	%	µ equ.	%	Absol. (%)	relat. (%)
Ca^{++}	292	(45)	1250	(55)	+ 328	+ 10
Mg^{++}	246	(38)	533	(23)	+ 117	+ 13
Na^{+}	109	(17)	457	(20)	+ 319	+ 3.0
K^{+}	8	(1.2)	31	(1.4)	+ 413	+ 0.2
Cl^{-}	24	(3.7)	208	(9.5)	+ 767	+ 5.8
SO_4^{--}	85	(13)	583	(27)	+ 586	+ 14
HCO_3^{-}	540	(83)	1380	(63)	+ 107	- 20

LUZON, LAGUNA PROVINCE

	waterfalls alt. 220 m		River, lower course alt. 50 m		fluctuations	
	µ equ.	%	µ equ.	%	Absol. (%)	relat. (%)
Ca^{++}	215	(47)	1250	(38)	+ 481	(- 9)
Mg^{++}	74	(16)	905	(28)	+ 1123	(+ 12)
Na^{+}	152	(33)	1013	(31)	+ 566	(- 2)
K^{+}	18	(3.9)	192	(5.9)	+ 967	(+ 2)
Cl^{-}	130	(28)	160	(4.9)	+ 23	(- 23)
SO_4^{--}	21	(4.5)	250	(7.6)	+ 1190	(+ 2)
HCO_3^{-}	320	(68)	2880	(88)	+ 800	(+ 20)

CEBU

	Stream upper Course alt. 250 m		Spring alt. 120 m		fluctuations relat. %
	µ equ.	%	µ equ.	%	%
Ca^{++}	2980	(61)	3050	(50)	(- 11)
Mg^{++}	1148	(24)	2796	(46)	(+ 22)
Na^{+}	687	(14)	221	(3.6)	(- 10)
K^{+}	38	(0.8)	18	(0.3)	(- 0.5)
Cl^{-}	145	(3.1)	135	(2.3)	(- 1)
SO_4^{--}	604	(13)	417	(7.1)	(- 6)
HCO_3^{-}	3960	(84)	5360	(91)	(+ 7)

enriched in ions (southern Cebu, in the rather dry Visayan region). In the highland system (central Luzon) was registrated that Ca^{++}, Cl^- and SO_4^- ions increased downstreams while Mg^{++} and HCO_3^- ions declined. The rivers from lower watersheds (Laguna, Cebu) were downstreams relatively enriched in the share of Mg^{++} and HCO_3^- ions while Ca^{++}, Na^+ and Cl^- decreased. The dynamics of the ion fluctuations were similar to these in Anjouan (Comoro Is.) also to smaller drains in Réunion and Mauritius (Tabl. XI).

The climate in the Andaman Islands is rather tropical-humid (especially of the forested South-Andaman). The islands are parts of the large tertiary Sunda ridges.

An increasement of relative concentrations of Ca^{++}, Mg^{++}, and HCO_3^- ions is visible, where Na^+, K^+, Cl^- and SO_4^- ions diminish, althoug htheir

TABLE XII

Andaman Islands (North-and South Andaman) — Fluctuations of main ions on the different watersheds

	S. Andaman		N. Andaman			
	upper courses alt. 300 m		lower cources alt. 30 m		fluctuation absol. (%)	relat. (%)
	μ equ.	%	μ equ.	%	μ equ.	%
Ca^{++}	432	(31)	1248	(33)	+ 189	(+ 2)
Mg^{++}	484	(35)	1538	(41)	+ 218	(+ 6)
Na^{+}	432	(31)	957	(25)	+ 126	(- 6)
K^{+}	34	(2.4)	35	(0.9)	+ 3	(- 1.5)
NH_4^-	6	(0.4	4	(0.1)	- 33	(- 0.3)
NO	3	(0.2)	1	(0.1)	- 67	(- 0.1)
Cl^-	291	(21)	572	(15)	+ 97	(- 6)
SO_4^{--}	75	(5.4)	156	(4.1)	+ 108	(- 1.3)
HCO_3^-	1020	(73)	3069	(81)	+ 201	(+ 8)

absolute contents get higher, Tabl. XII. The predominance of Mg^{++} and HCO_3^- ions is growing in downstream direction.

New Caledonia (Tabl. XIII).

Sodium — and chloride ions are relatively enriched in the headwater regions (plateaux) of the peridotite massifs. They are lowest downstreams of the leeward western flanks, where the rate of precipitation becomes much smaller. The extraordinary predominant magnesium ions are also even more enriched there in correspondence with the contents of bicarbonate. Details of geology see ARNOULD *et al.* (1954), about soils TERCINIER (1962).

4.3. **Old crystalline areas (granites and gneisses)**

The running water systems of the mainly studied Mahé (also Praslin and La Digue) of the Seychelles archipelago — which are all crystalline, granitic islands — use to be highly enriched in Na^+ and Cl^- ions. The contamination with the acidic soil causes also high contents of humic acids and ammonia, not so much of iron, especially during the rain periods. The water are due to the resistance of the granitic rocks against the influences of chemical weathering in the subsoil and the extraordinary effects of the very rich precipitation, generally poor in dissolved electrolyts and slightly acidic. Geology (1) see BAKER (1963). The hydrochemistry seems to be highly effected by ionic exchange. The analytical means of the upper courses from the windward mountainous northwest were compared with those from the leeward lower watersheds in the south of Mahé (Tabl. XIV). An absolute and relative enrichment of Ca^{++} and Mg^{++}, less of SO_4^{--} and HCO_3^- ions, could be registrated. All other ions, like Na^+, K^+, Cl^-, decreased concerning their relative ionic relations towards the lower catchments although their contents increased absolutely.

Catchments on one of the northeastern mountain rivers, the Rochon River, in altitudes of 360 m and 2 m above sea level, pointed a downstream increasement only of Ca^{++} and HCO_3^- ions (in relative percentage) while Mg^{++}, Na^+, K^+, SO_4^{--} and especially Cl^-, decreased (Fig. 6).

This stated that the main ionic exchange processes occur in the humid headwater regions mostly covered by mountain rain-forest. The affluents originating from the lower watersheds are not so much influenced by ionic exchange perhaps more from the chemical soil and subsoil weathering.

Another longer main drainage river system, the Grand Bois River flowing toward the west coast, was characterized too by the relative increasement of Ca^{++} (also of SO_4^{--}) while Na^+ and K^+ ions were rather stabile concerning their relative percentage, only Cl^- ions fell.

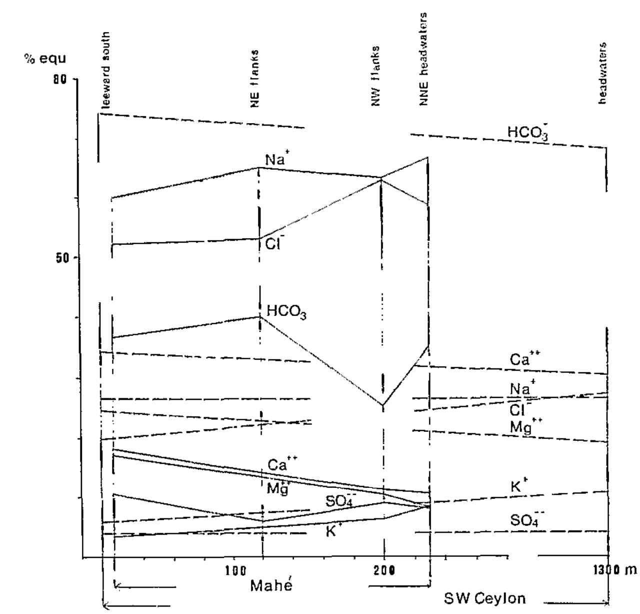

FIG. 6. — Mahé (Seychelles) — Connections and fluctuations of the ion equivalent percentages (mean of % equ.) and the different altitudes of the main catchments (meters above sea level). Catchments: windward northeastern and northwestern streams and the leeward southern lowland systems (50-280 m). Ceylon and the leeward—same connections in the low humid southwest (central highlands and lower courses, 30-1 300 m)

(1) A true soil layer is generally thin or absent. The granitic feldspars and ferromagnesium minerals have weathered to kaolinitic or iron staned clay.

TABLE XIII

New Caledonia — Fluctuations of main ions in water systems on the mainly peridotitic watersheds (Weninger 1968)

	Central peridotite plateau alt. 500 m		Leward west alt. 190 m		fluctuation absol. %	fluctuation relat. %	Windward east alt. 50 m		fluctuation absol. %	fluctuation relat. %
	μ equ.	%	μ equ.	%			μ equ.	%		
Ca^{++}	13	(2)	53	(4)	+ 308	(+ 2)	18	(1.5)	+ 33	(-0.5)
Mg^{++}	505	(67)	1230	(83)	+ 142	(+ 16)	944	(80)	+ 87	(+ 13)
Na^{+}	230	(30)	185	(13)	- 20	(- 17)	200	(17)	- 13	(- 13)
K^{+}	10	(1.3)	13	(0.9)	+ 30	(- 0.4)	12	(1.0)	+ 20	(- 0.3)
Cl^{-}	329	(40)	300	(20)	- 9	(- 20)	332	(29)	+ 1	(- 11)
SO_4^{--}	10	(1.2)	20	(1.3)	+ 100	(+ 0.1)	30	(2.6)	200	(1.4)
HCO_3^{-}	480	(59)	1170	(79)	+ 185	(+ 20)	800	(69)	+ 67	(

TABLE XIV

Mahé (Seychelles) — Changements of the ionic relations of the different watersheds

	mountainous NW upper course alt. 235 m		leeward S. alt. 21 m		fluctuations absol. (%)	fluctuations relat. (%)
	μ equ.	%	μ equ.	%		
Ca^{++}	26	(11)	126	(18)	+ 392	+ 7
Mg^{++}	20	(8)	120	(17)	+ 500	+ 9
Na^{+}	164	(67)	420	(60)	+ 156	- 7
K^{+}	20	(8)	23	(3)	+ 15	- 5
Cl^{-}	149	(59)	371)	(52)	+ 149	- 7
SO_4^{--}	21	(8)	74	(10)	+ 252	+ 2
HCO_3^{-}	88	(35)	260	(37)	+ 195	+ 2

	N. E system Rochon Riv. (St. 5) alt. 360 m		N. E system Rochon riv. (St. 27) alt. 2 m		fluct. relat. %	W. watershed Grand Bois (St. 4) alt. 400 m		W. watershed Grand Bois (St. 22) alt. 2 m		fluct. relat. %
	μ equ.	%	μ equ.	%		μ equ.	%	μ equ.	%	
Ca^{++}	16	(6.7)	110	(28)	(+ 21)	10	(4.0)	40	(14)	(+ 10)
MG^{++}	18	(7.5)	1	(0.3)	(- 7.2)	33	(13)	31	(11)	(- 2)
Na^{+}	161	(67)	252	(65)	(- 2.0)	161	(64)	183	(65)	(+ 1)
K^{+}	29	(12)	26	(6.7)	(- 6.3)	13	(5.0)	13	(4.6)	(- 0.4)
NH_4^{+}	11	(4.6)	4	(1.0)	(- 3.6)	6	(2.2)	1	(0.4)	(- 1.8)
Cl^{-}	170	(72)	231	(59)	(- 13)	155	(67)	163	(60)	(- 7)
SO_4^{--}	25	(11)	17	(4.4)	(-6.6)	3	(1.3)	27	(10)	(+ 8)
HCO_3^{-}	40	(17)	140	(36)	(+ 19)	69	(30)	77	(29)	(-)
Fe-tot. ppm	0.10		0.21			0.01		0.12		
humic acids	6. 4		0.63					1.30		

The main river systems (main drainage) in crystalline watersheds are extraordinarily homogeneous in hydrochemistry. The alternation of ions, as well absolutely as relatively, is very unimportant (compare Ceylon). Smaller systems are more influenced by chemical weathering of the soil, especially by those of affluents originating from lower regions.

Sodium — and chlorid-ions predominated in all watersheds. The contents of calcium (always a bit higher than Mg^{++}) were extremely low, they equalized these of K^{+} in the headwater.

Ceylon is mostly built of precambric crystalline gneisses, except of very small bands consisting of mesozoic limestones. (SIEVERS, 1964; COORAY, 1967). The studied river systems originate mainly from the humid southwest consisting of the mountainous part of the island. Rain-bringing winds come from southwest (rain season April-July, but all over year rain in the highland). Most water systems within the humid southwest are typical crystalline soft waters, the waters in the seasonal dry and dry part (southeast, east and north) are mostly highly enriched in dissolved salts (WENINGER, 1972) (Fig. 6, Tabl. XV).

TABLE XV

Fluctuations of main ions as given by the means of analyses from Ceylonese rivers (Weninger 1972) in the humid SW

	Central highlands headwaters alt. 1365 m		lower courses south west Ceylon alt. 65 m		fluctuations	
	µ equ.	%	µ equ.	%	absol.%	relat.%
Ca^{++}	70	(30)	123	(34)	+ 76	(+ 4)
Mg^{++}	43	(19)	88	(24)	+ 105	(+ 5)
Na^{+}	61	(27)	96	(27)	+ 57	(+ 0.2)
K^{+}	25	(11)	21	(6)	+ 16	(- 5)
Cl^{-}	68	(27)	66	(20)	+ 3	(- 7)
SO_4^{--}	10	(4)	14	(4)	+ 40	(+ 0.2)
HCO_3^{-}	170	(67)	250	(74)	+ 47	(+ 7)

The central highlands (mainly deforestated tea-field region near Maskeliya) are already partially leeward although they have extremely humid climate. Primarily chemical rock weathering seems to be of highest influence to the ionic composition of the water systems. The investigated waters were extraordinary poor in ions (lowest conductivities) although the abundancies of ions were similar to that of the systems from the dry eastern and northern part of Ceylon (except the lower contents of magnesium and chloride in the dry areas). Mostly found were waters with predominance of calcium — and bicarbonate ions: Ca^{++} (Na^{+}, Mg^{++}) HCO_3^{-} (Cl^{-})-type.

The rivers originating from the fully windward flanks — studied near Ratnapura and near Kitulgala — are characterized by the predominance of sodium ions and are mostly slightly enriched in chloride: Na^{+} (Ca^{++}) HCO_3^{-} (Cl^{-})-type. These windward flanks are to the greater part covered by rainforest. In spite of this influence is the hydrochemical type of the main rivers settled and destinated by the upper headwater peneplains (central highlands) — the already mentioned water type predominated by calcium (less Na^{+}) bicarbonate.

The *semihumid* partially windward cascade region in the steep highland descent to the southeastern plains has obviously high erosion of soil. These waters are more enriched in magnesium: Mg^{++} (Na^{+}) HCO_3^{-}-type, most possibly caused by the great influence of advanced chemical weathering of the soil. The rainfalls are not as abundant as at the fully windward watersheds and therefore the soils are not so much dominated by the leaching losses.

The fluctuations of the ions downstreams the main drainage to southwest stated an increasement of bivalent ions (Ca^{++}, Mg^{++}) and HCO_3^{-} toward the mouth, while the concentrations in Na^{+}, K^{+}, Cl^{-} and SO_4^{--} became relatively smaller. The increasement of Mg^{++} and HCO_3^{-} occurs permanently in downstream direction while Ca^{++} ions decrease first in the region of the fully windward flanks same as Na^{+} ions increase.

The studied river systems in western Africa originated from crystalline watersheds and their hydrochemistry was closely connected to the regional climate.

TABLE XVI

Western African watersheds — Fluctuations of the main ions

	S.E. Nigeria alt. 600 m		S.E. Nigéria alt. 200 m		fluctuations relat. (%)	Central Cameroon alt. 800 m		West Cameroon alt. 300 m		fluctuations relat. (%)
	µ equ.	%	µ equ.	%		µ equ.	%	µ equ.	%	
Ca^{++}	35	(32)	210	(47)	(+ 13)	124	(27)	36	(30)	(- 2)
Mg^{++}	11	(10)	90	(20)	(+ 9)	129	(28)	12	(9.3)	(- 20)
Na^{+}	35	(32)	117	(26)	(- 7)	160	(34)	43	(35)	(+ 6)
K^{+}	13	(12)	25	(5.5)	(- 7	29	(6.0)	18	(14)	(+ 6)
NH_4^{+}	18	(16)	9	(1.9)	(- 14)	19	(4.0)	11	(9.0)	(+ -)
NO_3^{-}	2	(2.0)	1	(0.2)	(- 2)	8	(1.8)	1	(; 2)	(- 0.6)
Cl^{-}	39	(35)	39	(8.7)	(- 26)	35	(8.0)	11	(7.6)	(- 0.4)
SO_4^{--}	20	(18)	27	(6.0)	(- 12)	40	(9.0)	60	(42)	(+ 33)
HCO_3^{-}	50	(45)	380	(84)	(+ 39)	360	(80)	70	(49)	(- 31)
humic acids ppm	0.16		2.5			0.58		6.8		
Fe total (ppm)	0.01		0.34			0.08		0.47		

The lowest conductivities were registrated in the water samples from Southeast Nigeria. The watersheds there were mostly covered by rain forest and extremely humid. Two catchments in different altitudes were compared, with the result of an increasement of Ca^{++}, Mg^{++}, HCO_3^-, also total iron and humic acids in downstream direction.

All remaining ions like Na^+, K^+, NH_4^+, NO_3^-, SO_4^{--} especially Cl^-, diminished (Tabl. XVI).

The enrichment of humic acids and total iron towards the lower regions corresponds with the extremely dense vegetation and the accelerated decomposition of organic substances in the lower forest regions, with influence to the partially stagnant water systems.

In mountain streams and rivers with mostly permanent high current velocity, like investigated in the Seychelles or in Ceylon, the humic substances (humic acids complexes, total iron, ammonia) were reduced rapidly downstreams due to bioflocculation or absorption, different from the lowland streams, GEISLER (1967). The water systems from the central highlands in Cameroon (altitude 60-1 000 m), which have seasonal humid climate, are more enriched in ions than streams from the humid rain forest region in western Cameroon. This rain forest systems have lower contents of Ca^{++}, especially of Na^+, Mg^{++} and HCO_3^-, also K^+ (only absolutely), NH_4^+, NO_3^-, Cl^-, while humic acids, total iron, SO_4^{--} are enriched (K^+, NH_4^+ ions are relatively enriched). Similar fluctuations of the ionic relations and abundance were observed in water systems from Gabon.

5. COMPARISION AND DISCUSSION

In survey of the investigated running water-systems, differs the downstream increasement of conductivities in crystalline areas (Ceylon, Seychelles-Mahé) at the lowest ranges in the hydrochemical most homogeneous main water drains to the already much higher ones in smaller systems on sometimes partially leeward flanks. The ionic enrichment in downstream direction on watersheds of volcanic origin is usually inhomogeneous. The ranges of conductivities are extraordinary wide-ranged, especially on young volcanic islands with deep eroded amphitheatric valleys and a high rate of subterraneous draining (Réunion, also partially Anjouan). In old volcanic islands is the ionic enrichment of the rivers still important, but the rates of increasement grow homogeneously like these of crystalline watersheds (Fig. 7).

The rivers are in survey of hydrology and hydrochemistry differentiated into two types — in main drains coming from the central mountain regions and smaller systems draining the flanks and less deep eroded valleys. While the central rivers, originating from the humid highlands of gneissic of granitic rocks, are extraordinary homogeneously in hydrochemistry, are these of volcanic watersheds highly influenced by the decomposition of the rocks and soil. Latter rivers are already highly enriched in ions in the upper course region of deep eroded young volcanic valleys.

The central drains of crystalline or also of old volcanic watersheds are therefore usually poorer in ions than most of their affluents originating from lower regions, which are more influenced by the chemical processes of weathering in the soil and subsoil ("stabilized weathering systems"). In total, the enrichment in ions (conductivity) corresponds with falling altitude of the catchments.

The central drains of young volcanic islands are otherwise already in the upper regions highly enriched in ions, much more than their lower tributaries, which are draining the less eroded flanks ("inverse fluctuation of ions"). The total enrichment in ions does not correspond with the falling altitude of the catchments. In survey, the advance of weathering processes with proceeding age of the rocks, is corresponding with the hydrochemical homogenization of the main water systems.

The downstream increasement of conductivity on crystalline watersheds, varies between + 0.7 µS and + 1.4 µS per 100 metres in main rivers of the windward part (Ceylon and Mahé) and more than + 15 µS/100 m in smaller streams flowing towards leeward hilly lowlands. The amphitheatric main drains in young volcanic Réunion have in total a diminution of ions (— 1.6 µS/100 m), while the conductivities of less eroded valleys increase (+ 2.4 µS/100 m). Same increasement vary on highly weathered basaltic rocks in Anjouan between + 7 µS and + 26 µS/100 m, in highland ricefield areas of Luzon: + 25 µS/100 m, similar in rivers of the old volcanic Mauritius, between + 13 µS (upper courses) and + 17 µS/100 m (lower courses).

The fluctuations of hydrochemistry in the main systems is mostly reasoned by the most significant influences of the affluents, that are either draining less eroded steep flanks (cascade-torrents, very poor in ions) or they originate from highly weathered flanks (drains trickling through soil and subsoil layers, enriched in ions).

The drains of large amphitheatric valleys are a significant model as studied in Réunion and partially in Anjouan. The water of the upper course regions is already enriched in ions, due to the chemical decomposition of the less weathering resistant old stratas of olivine basalts, which are exposed by the

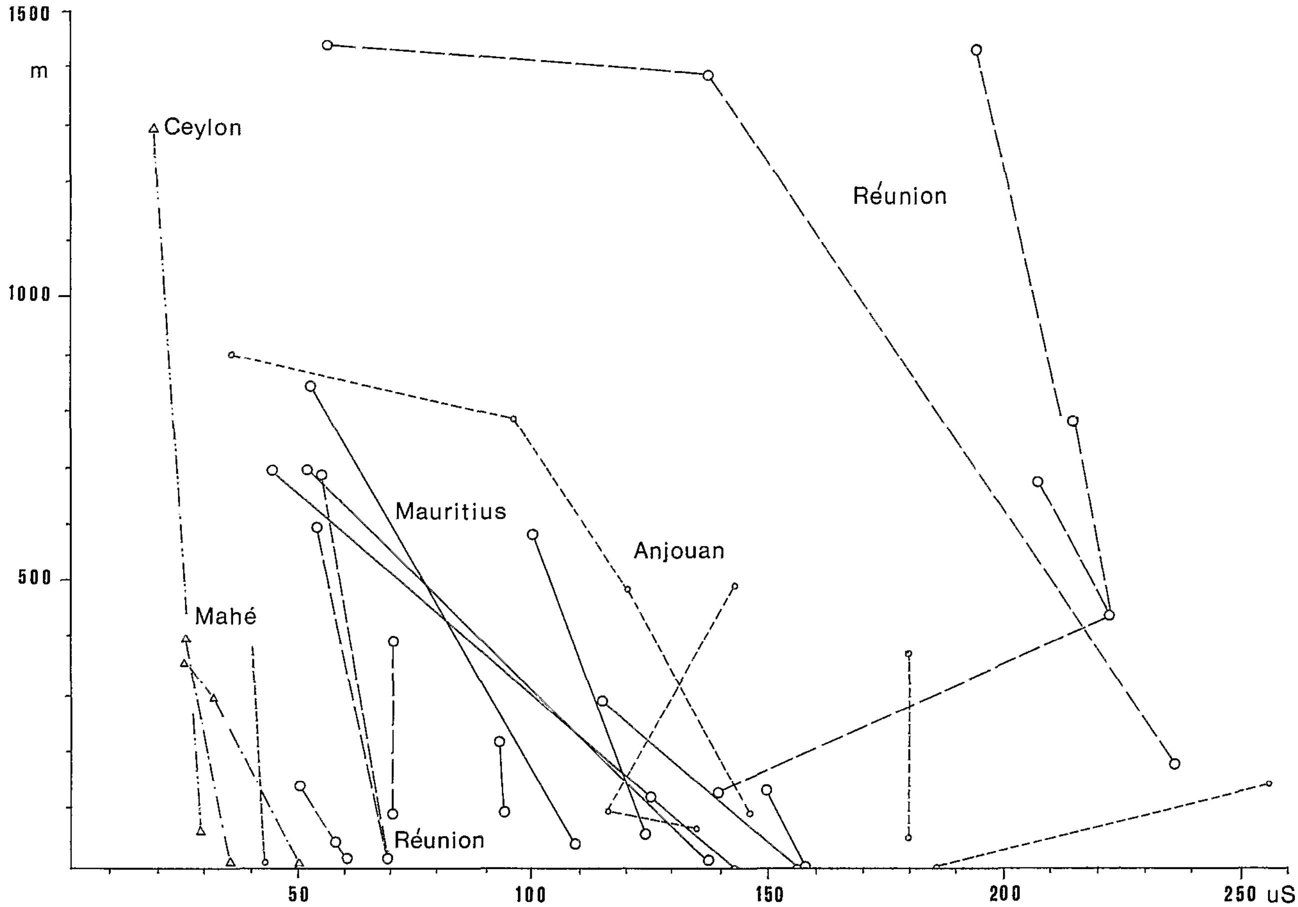

FIG. 7. — Diagram concerning the connections of conductivities (uS 20 °C) and altitudes (meters above sea level) of the catchments. Full lines: — Mauritius; long interrupted lines: Reunion short interrupted lines: — Anjouan, Comoro Island single point interrupted lines: Mahe Seychells; double point interrupted lines: — Ceylon

deep erosion (oceanites). Because of the great number of affluents draining the extremely steep flanks and which are as mentioned poor in ions — the main river's hydrochemistry is influenced itself and the contents of ions decrease towards the mouth (inverse connections concerning altitude of the catchments and conductivity of the water samples). Similar tendencies can even be registrated in small streams, but they are not distinct. From studies on a hydrochemical profile of a windward river system in Anjouan (Comoro Is.) resulted the knowledge of the relative increasement of calcium-ions along the upper course, while downstreams the contents were rather stabilized or slightly decreasing. Different from calcium was an obvious enrichment in magnesium — and sodium-ions, as also in bicarbonate, downstreams.

The hydrochemistry of the amphitheatric main systems, in Réunion and also one studied in Anjouan, is characterized by the diminution of calcium-, magnesium-, also potassium-ions (in Réunion) and of bicarbonate towards the lower courses and the exterior part of the "cirques". On the other hand increase sodium — and chloride ions downstreams.

The rivers that are draining the less eroded smaller valleys in Réunion are not too different in the tendencies of ion fluctuations, except the slower and more homogeneous enrichment in calcium-ions in correspondence with the profile of the running waters. The lowering of bicarbonate is compensated by more chloride.

The water of stagnant pools of young volcanic watersheds in the highlands and at the flanks (all areas with high amounts of precipitation), contain much more sodium — (potassium) and chloride-ions). The predominance of these ions may be as well reasoned by the aeolic ions-transport (seaside winds) as by ion-exchange due to the complex binding of calcium-ions.

The highlands of old volcanic islands (Mauritius) are already in an advanced stage of soaking of the soil and subsoil, due to the humid climate. The effective diminution of calcium- (magnesium-) bicarbonate-ions in the headwaters because of permanent losses by the heavy rainfalls and ion-exchange systems in the humic sediments, is compensated by the relative enrichment of sodium — and chloride-ions. This is possibly reinforced by seaside winds, which may be important for the reactivation of the ion-exchange systems in the acidic soil.

The middle and lower courses of these rivers in Mauritius are already highly enriched in Mg^{++} (Ca^{++}) and HCO_3^-, due to the intensivated chemical weathering of the surface rocks, like noticed everywhere in Anjouan. That meens, that the permanent renewal of ions in the drain-systems is much higher than the losses by the reinforced transport in course of the frequent rainfalls.

The drains of crystalline watersheds, like studied on the granitic Seychelles, are regularly downstreams enriched in calcium-bicarbonate-ions, while magnesium-ions diminute, especially in windward areas.

Sodium — and chloride-ions are downstreams enriched, but only absolutely, while their relative share becomes smaller. The contents of magnesium-ions are higher in leeward water-systems.

The survey states that the total fluctuations of ions are combined in correspondence with the different regions of a running water-system from a number of characteristic processes which are very often antagonistic in tendency. The resulting fluctuations are therefore mostly less efficient. This was especially mentioned by discussion of the valleys in Anjouan (Tatinga, Mutsamudu), which have antagonistic ion fluctuations as well in the upper as in the lower regions (Tabl. VIII).

The main draining systems are much more homogeneous in their ionic contents and fluctuations, especially in old crystalline areas (Ceylon, Seychelles). They are superficial drains and not influenced by subterraneous systems.

The ion-contents (conductivity) of the water-systems are mostly close collected with the altitude of the catchment area. Similar connections were registrated in the rivers from old volcanic watersheds (Mauritius), which are also supposed to be "stabilized", concerning the chemical weathering and decomposition of the surface rocks.

The hydrochemical fluctuations of water-systems draining the porous and highly surface-weathered rocks of the volcanic watersheds of the Comoro Islands (Anjouan), were to the greater part without visible connections concerning the different catchment areas. The river waters are combined from superficial but also subterraneous drains which are strongly influenced by the decomposition of basaltic rocks in the subsoil regions.

The survey states an increasement of sodium-ions as a result of windward exposure of the watershed, as well on volcanic or crystalline rocks. Only in case of highly surface weathered volcanic rocks with a very porous drain system (Anjouan, Comoro Is.) or in case of a very special geology (peridotites in New Caledonia), a predominance of magnesium ions in water originating from windward exposure was visible (Tabl. XVII).

The waters coming from leeward or even partially leeward flanks contain usually predominant magnesium-ions, as well in drains from old volcanic rocks (Anjouan, Mauritius), eruptive rocks (peridotites in New Caledonia causing everywhere an extraordinary enrichment of magnesium), in water drains from crystalline rocks but very limited to distinct areas (south Ceylon). The waters with top contents of calcium ions were rather restricted to areas of deep erosion and primary chemical weathering of basaltic rocks (amphitheatric valleys in Réunion or subterraneous drains in Anjouan or systems draining volcanic rocks with a high rate of primary chemical weathering) but also found in the central highlands of Ceylon where the gneissic rocks are drained under aspects of extreme precipitation and mountain climate (the contents of humic acids are not very high).

Anyway the contents of sodium (relative enrichment) compared with the other main cations, are higher on fully windward watersheds, while these of calcium and magnesium are usually as well absolutely as relatively enriched in systems from leeward watersheds. Different from these are the drains through very porous volcanic rocks (Anjouan) where the hydrochemical differentiations as caused by the regional climate are rather unsafe.

Following these aspects, the fluctuations of chemical compounds (ions) caused by heavy rainfalls and floods may be mentioned as studied on the Seychelles (Mahé) and Comoro Islands (Anjouan). In the extreme soft waters in Mahé, only humic acids and ammonia were enriched at higher discharge after rainfalls, while in the systems draining the decomposited watersheds in Anjouan a general increasement of ions was registrated.

The differencies in hydrochemistry between the upper course regions and the lower parts of the rivers, increase in correspondence with the higher age of the watersheds (their geology, surface weathering and soil).

A rather unimportant fluctuation, increasement

TABLE XVII

The influences of different local climate (windward — and leeward exposure of the watersheds) on hydrochemistry (relative % of main ions)

weatherside windward	partially windward	leeward watershed	
Na^+ Mg^{++} HCO_3^- Cl^- 42 29 78 12		Na^+ Mg^{++} HCO_3^- Cl^- 36 32 72 21	Réunion "smaller valleys"
	Na^+ Ca^{++} HCO_3^- Cl^- 40 35 89 - 7 Ca^{++} Mg^{++} HCO_3^- Cl^- 39 29 93 4		Réunion amphitheatric valleys
Mg^{++} Na^+ HCO_3^- Cl^- 36 25 87 10 north 36 31 84 14 south	Ca^{++} Na^+ HCO_3^- Cl^- 34 29 89 9 subterraneous	Mg^{++} Na^+ HCO_3^- Cl^- 34 27 87 12	Anjouan (Comoro Isl.)
Na^+ Mg^{++} HCO_3^- Cl^- 64 15 67 21 highl. 44 32 54 36 flanks 43 15 54 40 flanks	Mg^{++} Na^+ 45 37 Cl^- HCO_3^- 46 40	Mg^{++} Na^+ HCO_3^- Cl^- 36 35 57 29	Mauritius
Mg^{++} Na^{++} HCO_3^- Cl^- 67 30 59 40 highl. 80 17 69 29 flanks		Mg^{++} Na^+ HCO_3^- Cl^- 83 13 79 20	New Caledonie (peridotit. reg.)
Na^+ Ca^{++} Cl^- HCO_3^- 67 11 59 34		Na^+ Ca^{++} Cl^- HCO_3^- 60 18 52 37	Mahé (Seychelles) (granites)
Na^+ Ca^{++} HCO_3^- Cl^- 34 27 68 24 southwest	Ca^{++} Na^+ HCO_3^- Cl^- 30 27 68 27 Mg^{++} Ca^{++} HCO_3^- Cl^- 38 36 86 11 highlands southeast	Ca^{++} Mg^{++} HCO_3^- Cl^- 44 36 95 4 southeast	Ceylon (gneisses)
Prédominant : Na^+ 34 - 67% Mg^{++} 36% (80% peridotite)		Prédominant : Mg^{++} 38% Ca^{++} 44% Na^+ 36-60% (83% peridot)	

or diminution of ions in profile of the running water systems, was stated in young volcanic areas as well absolutely as relatively (100 % absolute changement, 10-15 % changement of the relative shares) like investigated in Réunion or Anjouan. Of interest was the diminution of Ca^{++}, Mg^{++}, HCO_3^- (especially in relative share %), in profile of rivers flowing through deep eroded amphitheatric valleys of these islands, while Na^+ and Cl^- were enriched. This facts occured because of the predominant influence of surface running cascadic tributaries (draining the mostly windward flanks of the main valley), mostly enriched in Na^+, less Mg^{++}, HCO_3^-, while the deep eroded main system is rich in Ca^{++}, Mg^{++}, HCO_3^- ions, due to direct decomposition of the basaltic rocks (oceanites).

The drains of the highly porous volcanic rocks in Anjouan (Comoro Is.), that were extraordinary weathered and decomposed due to accelerating influence of dense vegetation and soil erosion by deforestation, were predominated by Mg^{++}, less Na^+, HCO_3^-, according to the primary decomposition and leach of the volcanic rocks.

The elder volcanic island of Mauritius is already in a far advanced stage of surface decomposition and soaking by the influence of heavy precipitation, especially in the highlands. The occurance of extended areas with acidic soil (partially used for tea cultivations) may confirm this fact.

The downstream increasement of ions is therefore extraordinary high (absolute 66-1 340 %). Important is especially the increasement of Ca^{++}, less of Mg^{++}, and HCO_3^- ions, while Na^+, less K^+, and Cl^- ions relatively even diminish. The influence of ion-exchange processes in the highland soil can be presumed.

Various tertiary geologies as found in Andaman Is., Philippines, New Caledonia (peridotites) are characterized by high fluctuations of the ion concentrations, especially the absolute downstream increasement of the predominant ions (except Na^+, K^+, Cl^-, in some cases). The highest plus was registrated for Mg^{++}, HCO_3^-, sometimes also for Ca^{++}, HCO_3^-, or Na^+ (New Caledonia, with primary enrichment of Mg^{++}; or in parts of Luzon). The drains of crystalline areas seem to be characterized by a more or less homogeneous increasement of ions in the profile of the river systems.

The rate is lowest in the extraordinary resistant and soaked precambric gneisses of Southwest Ceylon (humid windward part). This low rate of ion fluctuations is similar to those of streams draining the young volcanic watersheds in Réunion or Anjouan (3-105 % absolute). It is much higher in water systems draining the strongly eroded granitic Seychelles (Mahé) with an extraordinary high share of Na^+Cl^-, resulting from ion exchange in the soil as well as from seaside winds. The rate is most important (of the crystalline areas) in Southeast Nigeria, obviously due to influences given by the dense rain forest vegetation and the soil in the lowlands.

Characteristic for these crystalline watersheds seems accordance of relative and absolute increasement of Mg^{++}, also Ca^{++}, HCO_3^- ions in downstream direction, while Na^+, K^+, Cl^-, are diminuted.

The tendencies of the relative ion abundancies are similar, as well in profile of the rivers (upper courses down to the lower courses) as in the differencies between windward and leeward watersheds.

A clear tendency in the abundance of Na^+ (less of Mg^{++} or Ca^{++}) and Cl^- (mostly still predominated by HCO_3^-) can be recognized. Highly weathered and decomposed porous volcanic rocks with an important rate of soil erosion (Anjouan, Comoro Is.) or even eruptive peridotites, have an all over predominance of Mg^{++}, HCO_3^-, except the subterraneous drains.

6. SUMMARY

This study deals with comparative hydrochemical investigations made on running water-systems of tectonic islands within the humid tropical belts of the Indo-Pacific and a few regions in western Africa, southern and central America. Concerning the frequent volcanic islands, studies were made on the Comoro Archipelago (Anjouan) and Mascarenes (Réunion, Mauritius) and similar catchments on different river-systems of volcanic or tertiary ridges of some other Indo-Pacific islands.

Detailed hydrochemical investigations on watersheds dominated by old crystalline gneisses and granites were made in southwestern Ceylon, on the Seychelles, partially in Madagascar, western Africa, Fidschi and the north of New Caledonia, where the southern peridotite regions had been intensively studied.

The main facts for the origin of the actual hydrochemical conditions are discussed, as are the decomposition of rocks (physical weathering and hydrolization) and the importance of ion exchange (most effective are humic acids, also clay minerals). Cation exchange (mostly Ca^{++}-Na^+) can be distinguished from anion exchange causing the enrichment of Cl^-. Extraordinary efficiency of ion exchange can be stated when the exchange layers (humic soil) are regenerated by Na^+Cl^- enriched seaside winds (Seychelles, Mauritius' highlands).

The totals of ions of the studied water-systems vary from 21-60 p.p.m. in crystalline gneisses and granites areas, from 59-98 p.p.m. on shistes and grauwacken of tertiary ridges, but in extraordinary wide ranges on weathered watersheds of volcanic formations (only 32 p.p.m. in the highland rivers of the old volcanic island of Mauritius, up to 183 p.p.m. and even 291 p.p.m. on the younger weathered volcanic superficies of Anjouan, La Réunion or Guadalcanal.

The studied water systems can be arranged corresponding with the actual abundant ions (relative equivalent %) into main water types.

The tendency of main ion abundancies in direction of a decline of the ion totals and a progressive growth of humic acid contents in the studied waters, goes from a predominance of calcium to magnesium and at least sodium. Within this different types of cationic abundancies is, as concerning anions, bicarbonate replaced by chloride, when the totals of ions diminish (Tabl. I). The enrichment of chloride was most important in the drains of oceanic islands with an already advanced stage of soil leaching and erosion, as well on crystalline — as on old volcanic rocks (Seychelles, Mauritius). The existence of a very effective ion exchange in the acidic highland soil and possibly a regeneration of this system by Na^+Cl^- transporting seaside wind is suggested (Fig. 2 et 5)

The dominating water type, mainly influenced by the primary weathering and the chemical decomposition of rocks accelerated by vegetation and soil activities (CO_2-enrichment), is the calcium-bicarbonate water. It is widely distributed, also in the humid tropics, especially in areas with calcium-enriched volcanic rocks (magmatites 36 200 mg Ca/kg), but also in soft water draining old crystalline massifs highly leached and less influenced by humic acids (central highlands in southwest Ceylon and Madagascar) (Tabl. II).

Magnesium-bicarbonate water dominates in areas with high soil erosion and a far advanced weathering decomposition of the watershed superficies (Anjouan, Mauritius). The geochemical frequency of magnesium is lower than of calcium (magmatites 17 600 mg Mg/kg), the magnesium-carbonates, but especially the magnesium-chlorides and — sulphates are less soluable.

Strongly selective cation exchange with complex calcium-humic acid binding can be suggested (Ohle, 1955, 1963), while in mineral clays the exchange binding capacity toward magnesium can be supposed to be more solid than toward calcium (Matthess, 1977). Both processes could be presumed

to be antagonistic, that calcium is at an early stage of the hydrochemical decomposition of the volcanic rocks easily washed out, while magnesium is enriched in the mineral clays of the subsoil by ion exchange. During a more advanced stage of leaching and weathering of the watersheds and an increasement of humic substances in the soil, the selective ion exchange of calcium by the humate-complexes might become more important again, causing a relative enrichment of magnesium in the water drains.

Concerning these developments, the high contents of magnesium in the rocks (partially olivine basalts) might be noticed. Highly enriched in magnesium are peridotites (New Caledonia), same are the waters originating from this region (WENINGER, 1968) (Tabl. III).

The discharge of water systems draining the watersheds of the extraördinary porous rather young volcanic rocks, are either completely (Grand Comore) or partially subterraneous (Anjouan). The water of this subterraneous drains contains higher concentrations of ions, dominating are again calcium-bicarbonate. The lower subsoil drains are therefore still mainly influenced by the primary hydrochemical decomposition of the rocks which may possibly be intensivated by carbondioxide-enriched mineral springs from the depth. Old volcanic islands (Mauritius) have already mainly a superficial water discharge and important subterraneous drains seem to be absent. Accordingly to this fact, they were lacking the calcium-bicarbonate water (Tabl. VIII, IX).

In survey of the results, magnesium-bicarbonate water occurs mainly in humid areas with rather strongly marked seasonal rainfalls, but without permanent leaching of the weathered superficies. This causes on already advanced weathered watersheds, the hydrochemical decomposition down to deep subsoil layers and the displace in the abundancies of dissolved ions (Tabl. XV).

Sodium-bicarbonate waters are dominating all watersheds of the humid tropics, where the drains are permanently leached by climatical reasons causing mostly extraordinary low concentrations of ions. This water type seems in general predominant on the weatherside flanks as well on crystalline as on resistant volcanic rocks, that are in some cases overlying easierly weathered older formations (Réunion) (Tabl. IV, VII).

Very typical are these sodium dominated soft waters in the drains of acidic soil (old volcanic highlands in Mauritius, granitic or gneissic massifs in the Seychelles or Ceylon), which are more enriched in humic acids. Like mentioned, are these waters enriched in chloride, more effective than humic water with calcium — or magnesium predominance and low contents of ions (Tabl. IX, XIV, Fig. 5, 6). Intensivated ion-exchange is suggested. Obviously a final stage concerning the extreme influences by humid substances, was registrated in waters draining large rain forest areas (western Africa, Tabl. XVI), with extraordinary high contents of ammonia and iron in complex bindings. This type seems to be a characteristical lowland type, while the greater part of the investigated running waters on the islands has mainly extended upper courses, followed by a short mouth. Higher contents of humic acids occur only in the headwater region of the highlands.

The varieties of specific water types increase accordingly with the variety of geology and climate.

In general view, alkalinity states correspondence with conductivity of a saturated calcium-bicarbonate solution.

Extraordinarily high alkalinities were registrated in drains from highly decomposed leeward volcanic or tertiary watersheds (rivers in Réunion, Anjouan, Java, New Caledonia), while water systems from old volcanic plateaux bearing humic acidic soil or those from crystalline watersheds have enlowered alkalinities (compared with the particular conductivities of the $Ca[HCO_3]_2$ solution). This is reasoned by the enrichment of sodium ions due to ion exchange.

The survey of the Ca: Mg ratios states low values on water from old volcanic watersheds or peridotites (0,04-0,75). Concerning the ratio [Ca + Mg]/[Na + K] a bigger share of [Ca + Mg] is visible toward the lowlands or toward the less leached leeward regions, while little values were in Seychelles' and Mauritius' water systems (0,25-0,61).

Silicates are of high importance in tropical freshwater. The contents vary wide ranged due to the inhomogeneous weathering and leaching especially of young volcanic watersheds. Another ratio — conductivity/silicates — is proposed. It is low (< 5) in drains from crystalline rocks.

The downstream increasement of conductivities, in survey of the investigated running water-systems, is lowest in the main drains of crystalline areas like Ceylon and Seychelles (+ 0,7 until + 1,4 µS/100 m), already higher on partially leeward watersheds of the same crystalline regions (+ 15 µS/100 m). In drains from volcanic watersheds a rather inhomogeneous enrichment of ions can be stated and the ranges of conductivities are extraordinary wide, especially in deep eroded amphitheatric valleys in Réunion (— 1,6 µS/100 m until + 2,4 µS/100 m).

The flows from old volcanic watersheds show still an important downstream increasement of conductivities, but it grows homogeneously like in the drains from crystalline areas (Mauritius: + 13 *until* + 17 μS/100 *m, connected with falling* altitude of the catchments.

The downstream fluctuations of the ion frequencies (relative and absolute) were compared (Fig. 3, 4, 5, 6). From samplements before and after heavy rainfalls resulted either growing or falling concentrations of ions due to differencies in the structure of the watersheds (Anjouan or Seychelles).

The survey of complete running water systems shows, that the total changements of the ion abundances are combined from a number of regional tendencies, which are mostly antagonistic and are diminishing the complete final fluctuations as a whole. This proves by chance at the "inverse diminution" of ions (except Na^+, Cl^-) in the discharge drains of deep eroded amphitheatric valleys on volcanic islands due to the strong inflow of surface draining affluents coming from the steep flanks (cascades). In surface draining less eroded valleys of younger volcanic islands (also Réunion) increased otherwards the relative shares of Ca^{++}, Na^+ and Cl^- in downstream direction, while these of Mg^{++} and HCO_3^- diminish. The latter both grow larger in the drains of weathered and porous volcanic rocks (Anjouan, Luzon, Cebu).

In the heavily eroded and weathered windward systems in Anjouan (Comoro Islands) resulted a relative increasement of Ca^{++} in the upper courses of the rivers while downstreams Mg^{++}, Na^+, HCO_3^- were enriched.

Less eroded valleys in Réunion have similar ion fluctuations in the profile of hydrochemistry, the share of Ca^{++} ions grows homogeneously, losses of HCO_3^- are partially compensated by Cl^-. Stagnant pools from volcanic massifs contain more Na^+ (K^+) and Cl^- ions, influenced by seaside winds and reactivated ion exchange.

The ion fluctuations in water flows draining the porous basaltic rocks of the Comoro Islands, were to the greater part without visible connection concerning the different locations of catchments in profile of the rivers.

The effective diminution of Ca^{++} (Mg^{++}) and HCO_3^- ions in the headwaters of old, highly leached volcanic highland plateaux (Mauritius), is compensated by the relative enrichment of Na^+ and Cl^- ions, similar to crystalline watersheds. This seems to be caused by intensive ion exchange that is reactivated by seaside winds. The middle — and lower courses of the Mauritius' rivers are otherwise already enriched in Mg^{++} (Ca^{++}) and HCO_3^- ions due to the reinforced leach and eluation of the subsoils in the lower peneplains. The main rivers are mostly homogeneous in their hydrochemical profile and show less ion fluctuations, especially in old crystalline areas.

The majority of running water systems from old volcanic islands (Mauritius), effusive rocks (New Caledonia), tertiary ridges (Andaman Islands) and old crystalline gneissic and granite massifs (Ceylon, Seychelles, partially West Africa), are mostly superficial draining flows and their conductivities accumulate homogeneously downstreams (Fig. 7). They are characterized by the increasement of Ca^{++}, Mg^{++} and HCO_3^- but respectively the decline of Na^+, K^+ and Cl^- (Fig. 5, 6). This situation seems typical for stabilized old weathering — and leaching systems.

The survey states an increasement of Na^+ ions as a result of windward exposure as well on volcanic as on crystalline watersheds. Only in cases of highly decomposed and weathered volcanic rocks (Anjouan) or of a very specific geology (New Caledonia, peridotites), a predominance of Mg^{++} ions was visible in windward exposure of the watersheds. Water flowing from more or less leeward flanks contains usually predominantly Mg^{++} ions as well on old volcanic basalts (Anjouan, Mauritius), eruptive peridotites (New Caledonia) as limited to restricted areas also on gneissic rocks (southern Ceylon). The relative top share of Ca^{++} were restricted to the deep eroded amphitheatric valleys (Réunion) or to subterraneous drains (Anjouan) as well as to crystalline highlands (Ceylon) (Tabl. XVII).

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REFERENCES

Alekin (O. A.), 1962. — Grundlagen der Wasserchemie. Eine Einführung in die Chemie natürlicher Wässer. VEB Deutsch. Verl., Leipzig. 260 S.

Arnould (A.), Avias (J.), Routhier (P.), 1946-1954. — Carte géologique de la Nouvelle-Calédonie. O.R.S.T.O.M., Paris.

Baker (B. H.), 1963. — Geology and mineral resources of the Seychelles Archipelago. *Geol. Survey, Kenya Mem.*, 3 : 1-40.

Bätjer (D.) & Kuntze (H.), 1963. — Untersuchungen des Niederschlagwassers im Küstengebiet Ostfrieslands und Oldenburgs. — *Küste* 11 : 34-51, 4 Abb., 10 Tab., Heide i. Holstein.

Bishop (J. E.), 1973. — Limnology of a small Malayan River Sungai Gombak. Monogr. Biolog. J. Illies (ed.). Vol. 22, 485 pp. Dr. W. Junk B. V., Publishers, The Hague.

Carroll (D.), 1959. — Ion exchange in clays and other minerals. — *Bull. Geol. Soc. Amer.*, 70 : 749-780, 3 Tab., New York.

Clarke (W. F.), 1924. — The data of geochemistry. 5. Ausg. *US Geol. Surv. Bull.*, 770 : 841 S., Washing.

Cooray (P. G.), 1967. — An introduction to the geology of Ceylon. Spolia Zeylanica, Vol. 31 : 1. Colombo.

Corbel (J.), 1964. — L'érozion terrestre, étude quantitative. *Ann. Géogr.*, 73 : 385-412.

Davis (S. N.) & De Wiest (R. J. M.), 1967. — Hydrogeology. 2. Aufl., J. Wiley, New York-London-Sydney, 463 p.

Demolon (A.), 1948. — Dynamique du sol. — 4. Aufl., 414 S., 119 Abb., Paris.

Douglas (I.), 1968. — The effects of precipitation chemistry and catchments area lithology on the quality of river water in selected catchments in Eastern Australia. *Earth Science Journal*, 2 : 126-144.

Durum (W. H.) and Haffty (J.), 1963. — Implication of minor element contents of some major streams of the world. *Geochim. Cosmochim. Acta*, 27 : 1-11.

Esson (J.), Flower (M. F. J.), Strong (D. F.), Upton (B. G. J.), Wadsworth (W. J.), 1970. — Geology of the Comores Archipelago, Western Indian Ocean. *Geolog. Magazine*, 107 : 549-557.

Fisher (R. L.), Johnson (G. L.), Heezen (B. C.), 1967. — Mascarene Plateau, Western Indian Ocean. *Bull. Geol. Soc. Amer.*, 78 : 1247-1266.

Fittkau (E. J.), 1970. — Limnol. Conditions in the headwater region of Xingu River, Brazil. *Trop. Ecol.*, 11 : 20-25.

Fittkau (E. J.), 1971. — Ökologische Gliederung des Amazonas Gebietes auf geochemischer Grundlage. *Münster. Forsch.*, 20/21 : 35-50.

Freier (R. K.), 1964. — Wasseranalyse. Walter de Gruyter u. Co., Berlin.

Geisler (R.), 1967. — Limnologish-ichtyologische Beobachtungen in Südwest-Ceylon. *Int. Revue ges. Hydrobiol.*, 52 (4) : 559-572.

Gerb (L.), 1953. — Reduzierte Wässer. — *Gas-u. Wasserf.*, 94 : 87-92, 157-161. München.

Gerb (L.), 1958. — Grundwassertypen. — *Vom Wasser*, 25 : 16-47, 6 Tab., Weinheim/Bergstraße.

Gessner (R.), 1960. — Limnologische Untersuchungen am Zusammenfluss des Rio Negro and des Amazonas (Solimoes). *Int. Revue ges. Hydrobiol.*, 45 : 55-79.

Gibbs (R. J.), 1970. — Mechanisms controlling world water chemistry. *Science*, 17 : 1088-1090.

Gibbs (R. J.), 1971. — Mechanisms controlling world water chemistry — evaporation-crystallization process. *Science*, 172 : 871-872.

Gibbs (R. J.), 1973. — Mechanisms of Trace Metal Transport in Rivers. *Science*, 180 : 71-73.

Goltermann (H. L.) and Clymo (R. S.), 1969. — Methods for Chemical Analysis of Freshwater. IBP Handbook No 8. Blackwell Scient. Oxford, 172 pp.

Grim (R. E.), 1968. — Clay Mineralogy. McGraw-Hill, New York, 596 p.

Green (J.), 1970. — Freshwater ecology in the Mato Grosso, Central Brasil. 1. The conductivity of some natural water. *J. nat. Hist.*, 4 : 289-299.

Held (H. D.), 1970. — Kühlwasser. Vulkan Verlag Dr. W. Classen, Essen.

Johnson (D. S.), 1967. — On the chemistry of freshwater in southern Malaya and Singapore. *Arch. Hydrobiol.*, 63 : 477-496.

Johnson (D. S.), 1968. — Malayan black water. *Proc. Symp. Recent adv. Ecol.*, 303-310.

Juday (C.), Birge (E. A.) and Meloche (V. W.), 1938. — Mineral contents of the lake water of northeastern Wisconsin. — *Trans. Wisc. Acad. Sci. Arts Lett.*, 31 : 223-276.

Junge (E.), 1963. — Air Chemistry and radioactivity. Academic Press. New York-London, 382 p.

Kleerekoper (H.), 1955. — Limnological observations in Northeastern Rio Grande do Sul, Brazil. *Arch. Hydrobiol.*, 55 : 553-567.

Klinge (H.) and Ohle (W.), 1964. — Chemical properties of rivers in the Amazonian area in relation to soil conditions. *Verh. Int. Ver. Limnol.*, 15 : 1067-1076.

KOBAYASHI (J.), 1959. — Chemical investigations on river water of southeastern Asiatic countries (Rep. I). The quality of water of Thailand. *Ber. Ohara Inst. Landw. Biol.*, 11 (2) : 167-233.

KOBAYASHI (J.), 1960. — A chemical study of the average quality and characteristic of river water in Japan. *Ber. Ohara Inst. Biol.*, 11 (3) : 313-358.

LÖHNERT (E.), 1970. — Grundwasserchemismus und Kationentausch im norddeutschen Flachland. *Z. deutsch. geol. Ges. Sondern. Hydrogeol. Hydrogeochem.* : 139-159, Hannover.

LUNDQUIST (G.) u. THOMASSON (H.), 1924. — Sjön lekvattnet i Värmland. En Limnologisk orientering. *Sv. Geol. Undersökning Ser. C. Avhandl. och uppsatser*, 323 : 1-40.

MALAISSE (F.), 1969. — Les facies d'un cours d'eau tropical : La Luanza (Haut Katanga, Rep. dem. Congo). *Verh. Internat. Verein.*, 17 : 936-940.

MARLIER (G.), 1951. — Recherches hydrobiologiques dans les rivières du Congo Oriental. I. Composition des eaux. *Hydrobiologie*, 3 : 217-227.

MARLIER (G.), 1954. — II. Étude écologique. *Hydrobiologia*, 6 : 225-264.

MATTHESS (G.), 1958. — Geologische und hydrochemische Untersuchungen in der östlichen Vorderpfalz zwischen Worms und Speyer. *Notizbl. hess. L.-Amt Bodenf.*, 86 : 335-378, Wiesbaden.

MATTHESS (G.), 1973. — Die Beschaffenheit des Grundwassers. Lehrbuch d. Hydrogeologie, Bd. 2, Herausgeb. Richter W., Berlin-Gebr. Borntraeger, Stuttgart, 315 p.

MC DOUGALL (I.) and CHAMALAUN (F. H.), 1969. — Isotopic dating and Geomagnetic Polarity Studies on Volcanic rocks from Mauritius, Indian Ocean. *Bull. Geol. Soc. Amer.*, 80 : 1419-1442.

MC DOUGALL (I.), 1971. — The geochromology and evolution of the young volcanic island of Reunion, Indian Ocean. *Geochimica* Acta, 35 : 261-288.

MERCK (E.), Ag Darmstadt.-Klomplexometrische Bestimmungsmethoden mit Titriplex. 3. Auflage.

OHLE (W.), 1938. — Die Bedeutung der Austausch vorgänge zwischen Schlamm und Wasser für den Stoffkreislauf der Gewässer. *Vom Wasser*, 13 : 87-97.

OHLE (W.), 1955. — Ionenaustausch der Gewässersedimentw. *Mem. Ist. Ital. Idrobiol.*, suppl. 8 : 221-245.

OHLE (W.), 1963. — Kolloidkomplex als Kationen- und Anionaustauscher in Binnengewässern. *Vom Wasser*, 30. Bd., 50-64.

PALMER (C.), 1911. — The geochemical interpretation of water analyses. *US Geol. Surv. Bull.*, 479 : 31 p.

POLDERVAART (A.), 1955. — Chemistry of the earth's crust. *Geol. Soc. Amer. Spec. Paper*, 63 : 119-144.

QUENTIN (K. E.), 1969. — Beurteilungsgrundsätze und Anforderungen an Mineral und Heilwässer. Handb. Lebensmittelchemie, 8, 2 : 1043-1056, Springer, Berlin-Heidelberg-New York.

REGNET (W.) and UDLUFT (P.), 1974. — Schnellbestimmung von Sulfat durch Trübungsmessung. *Hydrochem. u. hydrogeol. Mitteil.* 1 ; München : 121-128.

RUTTNER (F.), 1931. — Hydrographische und hydrochemische Beobachtungen auf Java, Sumatra und Bali. *Arch. Hydrobiol. Suppl.* VIII.

SAINT OURS (J. de), 1960. — Études géologiques dans l'extrême nord de Madagascar et l'Archipel des Comores. Service Géologiques, Tananarive.

SCHEFFER (F. u.), ULRICH (B.), 1960. — Humus und Humusdüngung. Lehrbuch der Agrikulturchemie und Bodenkunde. 3 : 1-266. Ferd. Enke Verlag Stuttgart.

SCHEFFER (F.) and SCHACHTSCHNABEL (F.), 1982. — Lehrbuch der Bodenkunde. Verlag F. Enke. Stuttgart, 11. Auflage, 143 p.

SCHOELLER (H.), 1951. — Relation entre la concentration en chlore des eaux souterraines et les échanges de bases avec les terrains qui les renferment. *C. R. Hebd. Séances Acad. Sci.*, Paris, 232 : 1432-1434.

SCHOELLER (H.), 1962. — Les eaux souterraines. Masson, Paris, 642 p.

SCHWILLE (F.), 1953. — Natriumhydrogencarbonat- und Natriumchlorid Wässer im tieferen Untergrund des Mainzer Beckens. *Notizbl. hess. L.-Amt Bodenf.* 81 : 314-335, Wiesbaden.

SCHWILLE (F.), 1955. — Ionenaustauch und der Hemismus von Grund- und Mineralwässern. *Z. dt. geol. Ges.*, 106 (1) : 16-22.

SHAPIRO (J.), 1966. — The relation of humic color to iron in natural water. *Verh. Internat. Verein. Linol.*, 16 : 477-484.

SIEVERS (A.), 1964. — Ceylon, Gesellschaft und Lebensraum in den orientalischen Tropen. Franz Steiner Verlag GmbH. Wiesbaden.

SIOLI (H.), 1964. — General features of the limnology of Amazonia. *Verh. Internat. Verein. Limnol.*, 15 : 1053-1058.

SIOLI (H.), 1968. — Hydrochemistry and geology in the Brazilian Amazon region. *Amazoniana*, 1 : 267-277.

SIOLI (H.), 1969. — Ökologie im brasilianischen Amazonasgebiet. *Natur*-wissenschaften, 56 : 248-255.

SONTHEIMER (H.), 1977. — Humin- und Ligninbestimmung durch UV-Spektren. *A. Wasser-Abwasserforschung*, 10 (3/4).

STRONG (D. F.) and FLOWER (M. F. J.), 1969. — The significance of sandstone inclusions in lavas of the Comores Archipelago. *Earth Planet, Sci. Letters*, 7 : 47-50.

STUMM (W.) and MORGAN (J. J.), 1970. — Aquatic Chemistry. J. Wiley and Sons, Inc. New York, 583 p.

TERCINIER (G.), 1962. — Les Sols de la Nouvelle-Calédonie. Institut Français d'Océanie, O.R.S.T.O.M., Paris.

THEWS (J. D.), 1972. — Zur Typologie und Grundwasserbeschaffenheit im Taunus und Taunusvorland. *Abh. hess. L.-Amt Bodenf.*, 63 : 42 p., Wiesbaden.

THOMAS (W. A.), 1970. — Weight and calcium losses from decomposing tree leaves on land and in water. *J. Appl. Ecol.*, 7 : 237-241.

UPTON (B. G. J.) and WADSWORTH (W. J.), 1965. — Geology of Reunion Island, Indian Ocean. *Nature*, 207 : 151-154.

UPTON (B. G. J.) and WADSWORTH (W. J.), 1966. — The basalts of Reunion Islands, Indian Ocean. *Bull. Volcanol.*, 29 : 7-24.

VGB (Verein. d. Grosskesselbesitzer), 1962. — Analysenverfahren für den Kraftwerksbetrieb. Vulkan Verlag, Dr. W. Classen, 1. Auflage.

WALKER (F.) and NICOLAYSEN (L. O.), 1954. — The petrology of Mauritius. *Colonial Geology and Mineral Resourses*, 4 (1) : 3-43.

WEDEPOHL (K. H.), 1969. — Composition and abundance of common sedimentary rocks. Handbook of Geochemistry. Vol. 1 : 250-271. Verlag Springer, Berlin, Heidelberg, New York.

WENINGER (G.), 1968. — Beitrag zum Chemismus der Gewässer von Neukaledonian. (SW Pazifik). *Cah. O.R.S.T.O.M., sér. Hydrobiol.*, 2 (1) : 35-55.

WENINGER (G.), 1972. — Results of the Austrian-Ceylonese Hydrobiological Mission 1970. Part II — Hydrochemical Studies on Mountain Rivers in Ceylon. *Bull. Fish. Res. Sri Lanka (Ceylon)*, 23 : 77-100.

WENINGER (G.), 1977. — On inland water chemistry of Indian Ocean's islands (Seychelles, Comores, Réunion, Mauritius). *Cah. O.R.S.T.O.M., ser. Hydrobiol.*, 11 (4) : 297-319.

WILLIAMS (W. D.), 1964. — Some chemical features of Tasmanian inland water. *Austral. mar. freshw. Res.*, 15 : 107-122.