Hydrochemistry of the Continental Terminal phreatic aquifer near Niamey (Niger)

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As part of Hapex Sahel (Hydrologic Atmospheric Pilot Experiment in the Sahel), this hydrogeological study consists of a detailed survey of the degree square of Niamey (Niger), limited by the parallels 13°N and 14°N and the meridians 2°E and 3°E. In fact, our survey is restricted to the part north of the River Niger, i.e. about 8000 km². The main objective is the evaluation of the rain infiltration to the phreatic aquifer through a piezometric and hydrochemical monitoring of 250 wells over a three year period.

The outcropping sediments are tabular deposits of late Tertiary Continental Terminal, a sequence of sandy, silty, clayey and lateritic deposits, covering the metamorphic and granitic basement in the west and earlier Tertiary Continental Intercalaire in the east. Depending on its thickness, with variation up to 200 m, Continental Terminal contains one to three water-bearing levels (called CT1, CT2 and CT3 upwards). The depth to the phreatic water table is between 2 and 75 m (median 35 m). Deeper aquifers CT1 and CT2 contain highly mineralized water.

In a landscape of eroded lateritic plateaux, the recent geodynamic evolution has degraded the old drainage network into numerous small endoreic systems. During the short rainy season (June to September), surface runoff concentrates in temporary pools, where most of the accumulated water infiltrates. These pools play a major role in the aquifer recharge. Piezometric fluctuations throughout the year are almost always lower than 1 m, but can reach up to 9 m. The majority of wells with high fluctuation belong to two zones : the northwest of the degree square, with significant heterogeneity, and a region about 30 km east of Niamey, which has the highest piezometric levels in the study area. The infiltration is estimated at approximately 50 mm per year, i.e. 10 % of the annual rainfall. Hydrochemistry confirms some of the hydrodynamic processes already deduced from the piezometric observations and emphasizes groundwater heterogeneity. The clear difference between deeper CT1 and CT2 on one side and CT3 on the other side shows the existence of leakage and contamination into the phreatic aquifer.

Electrical conductivity

The median of electrical conductivity in the phreatic aquifer is 90 µS.cm⁻¹ with a minimum of 20 µS.cm⁻¹ and a maximum of 2500 µS.cm⁻¹.

There is a close relationship between electrical conductivity EC and the ionic composition IC (i.e. sum of anions and cations) of the water :

$$EC = 59 \cdot IC$$

where EC is in µS.cm⁻¹ and IC in meq.l⁻¹. Electrical conductivity can therefore be used to map the hydrochemical variations in space across the aquifer.

On the map, three main regions appear :
- a northwest zone, where conductivity is highly variable on short distances and can rise up to 2500 µS.cm⁻¹. This strong heterogeneity is related to the wedging out of Continental Terminal over the basement : the CT3 water resources are very weak and the semi-pervious layer between CT3 and CT1 is thin. This enables a contamination from the deeper aquifer which is more mineralized . On the western border of the degree square, only one aquifer remains ;
- a large central zone, where conductivity is generally low (less than 100 µS.cm⁻¹) ;
- an eastern fossil valley, called Dallol Bosso, with conductivity varying from 100 to 1700 µS.cm⁻¹. This increased salinity can be explained by some local singularity in continental sediment and also by the intense evaporation due to the close distance between the water table and the ground surface.

In some cases, a great variation in conductivity can be observed on a short distance. Between other reasons, this is caused by :
- contamination from a deeper aquifer (naturally, through a thin semi-pervious aquitard or artificially, because of free-flowing artesian wells),
- rapid change in sediments of the aquifer, especially when evaporite deposits are present,
- local pollution of a well by cattle dung.

Distribution of major ions

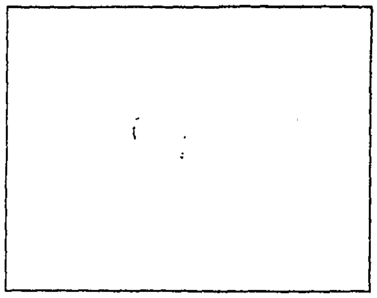
The Piper diagram illustrates the homogeneous composition in major ions for most of the samples.

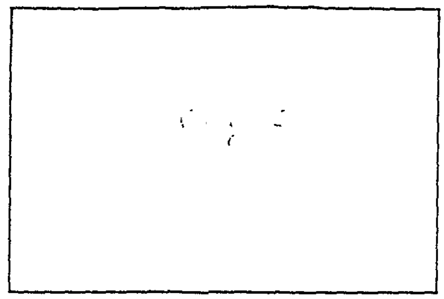
Na and Ca represent more than 75 % of cations, both in rather constant proportions, when K is always weak and Mg more variable.

HCO3 and NO3 constitute 80 % of the anions. The rest is split between a variable chloride and a generally slight sulphate.

As shown on the figure, HCO3 dominates for low conductivity (sum of anions lower than 0.6 meq.l-1) but it does not increase significantly when the total mineralization grows.

On the other hand, NO3 is always weak for low conductivity (approximately 20 % of anions when their sum is lower than 0.5 meq.l-1) and constitutes the essential anion for middle or high mineralization.



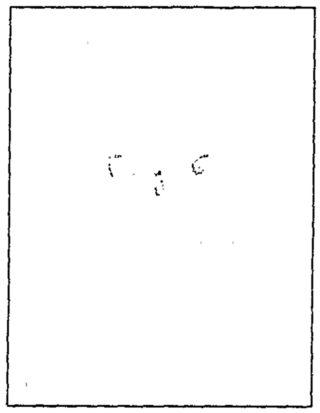


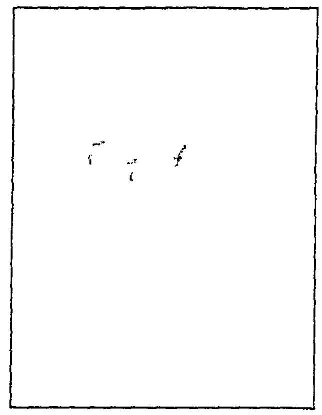
The highest values of conductivity (more than 800 µS.cm-1) do not match the other samples : their ion distribution is different and often closer to chemical composition in CT2 or CT1.

Thermodynamic equilibrium

Using the measurements of pH, temperature and contents of major and some minor ions, the thermodynamic distribution of minerals existing in groundwater has been calculated with the program WATEQF. The aqueous solution is always saturated or over-saturated with respect to quartz (which is justified in this very quartzous environment) but under-saturated with respect to amorphous silica. It is also under-saturated with respect to the carbonate system.

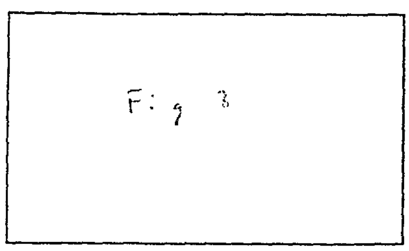
The activity diagrams for silicates show a fair homogeneity of the samples in the stability field of kaolinite. This reflects the probable homogeneity in the acquisition of mineralization. The kaolinite facies demonstrates either a short transit time which does not allow an evolution towards the smectite pole or a sequence of sediments not very alterable (quartz, gibbsite, kaolinite and iron oxide). Both explanations fit within the geological and hydrodynamic context.

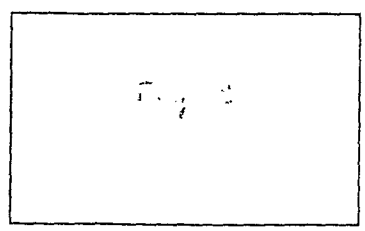




Stable isotopes

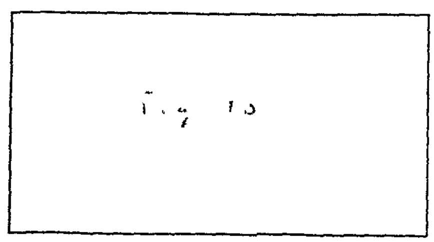
Isotopic contents in both deep aquifers CT2 and CT1 are homogeneous, but do not correspond with the present climatic state : in CT1 between -7.2 and -7.9 ‰ for ^{18}O, -55.7 and -58.9 ‰ for ^{2}H ; in CT2 between -6.5 and -7.7 ‰ for ^{18}O , -46.4 and -57.0 ‰ for ^{2}H. Such an aquifer recharge in a more humid and colder climate implies an infiltration older than 4000 years. This estimate of several thousands of years is verified by ^{14}C measurements east of the Dallol Bosso.





On the other hand, isotopic contents of CT3 are variable : from -2.0 to -5.4 ‰ for ^{18}O, from -15.2 to -34.4 ‰ for ^{2}H. An exception is the well of Karey Bangou which is reaching -6.7 ‰ for ^{18}O and 1500 µS.cm-1 for electrical conductivity ; its major-ion and isotopic chemistry reveals a mixing with water from a deeper aquifer.

Averages in the phreatic aquifer and in the rainfall (for 1991 and 1992) are similar, but the amplitude is larger in rain water. Most positive values are explained by evaporation either in regions with shallow water-table (Dallol Bosso e.g.) or in zones of slow infiltration. Most negative values, except contamination from a deeper aquifer, could be due to a rapid infiltration of the much more negative rains at the end of the rainy season without mixing in the unsaturated zone. This must be confirmed by a supplementary monitoring.



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Hydrodynamics
of the Continental Terminal
phreatic aquifer near Niamey

Fig 1

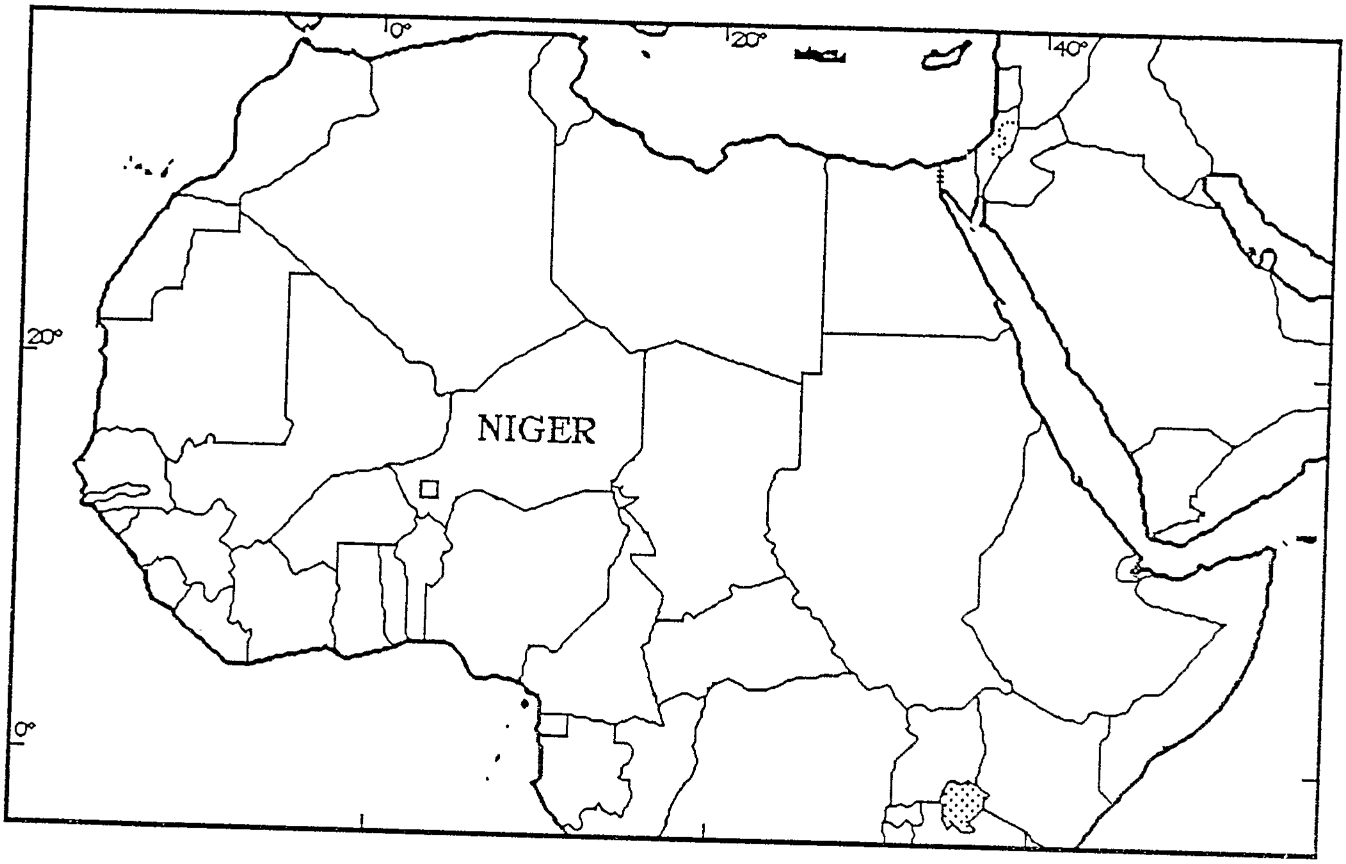
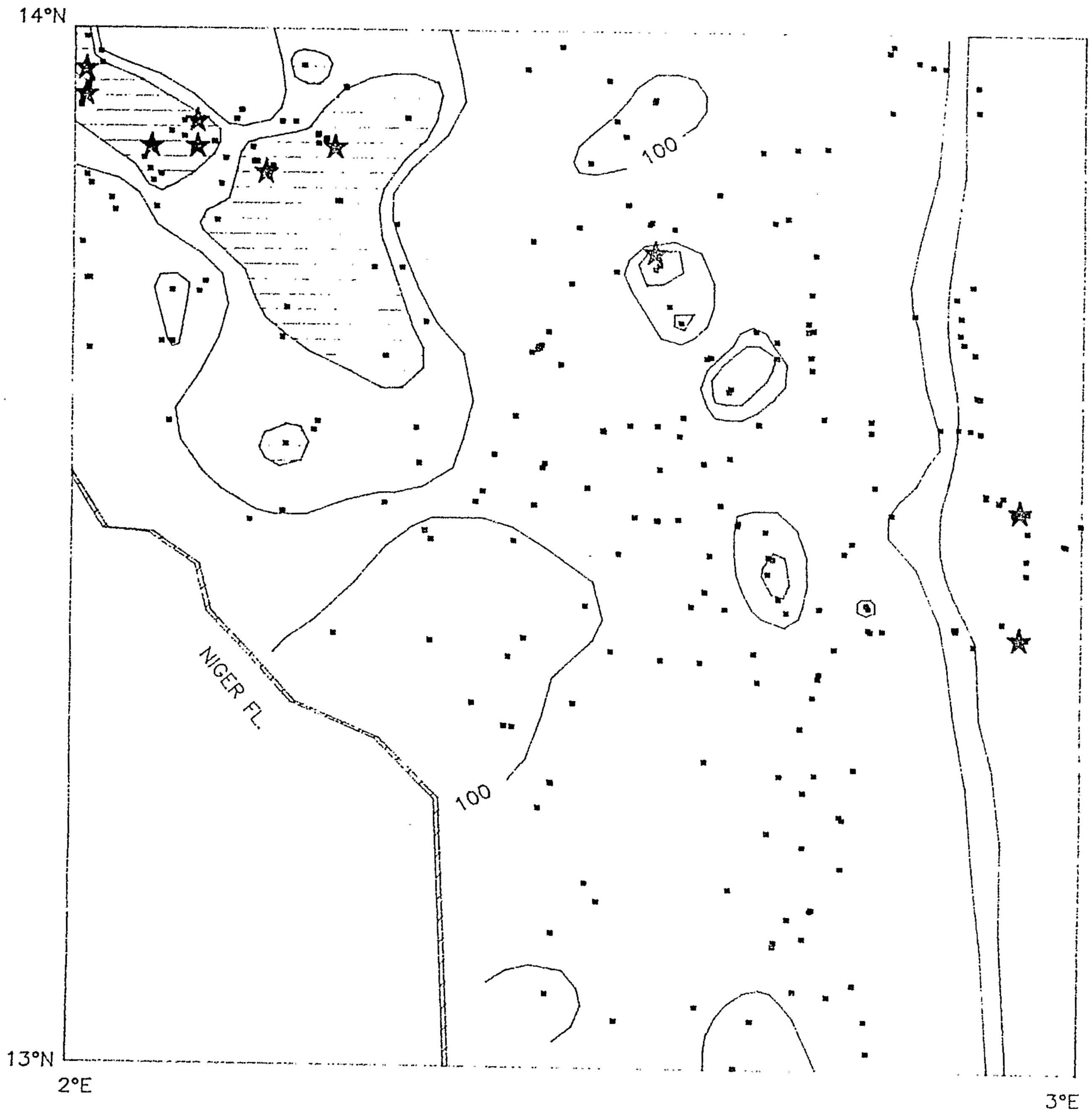


Fig 2



ELECTRICAL CONDUCTIVITY IN THE CT3 PHREATIC AQUIFER

Isolines of conductivity : 100 and 200 μS/cm

Hatched areas are higher than 200 μS/cm

Values higher than 1000 μS/cm are marked with a star

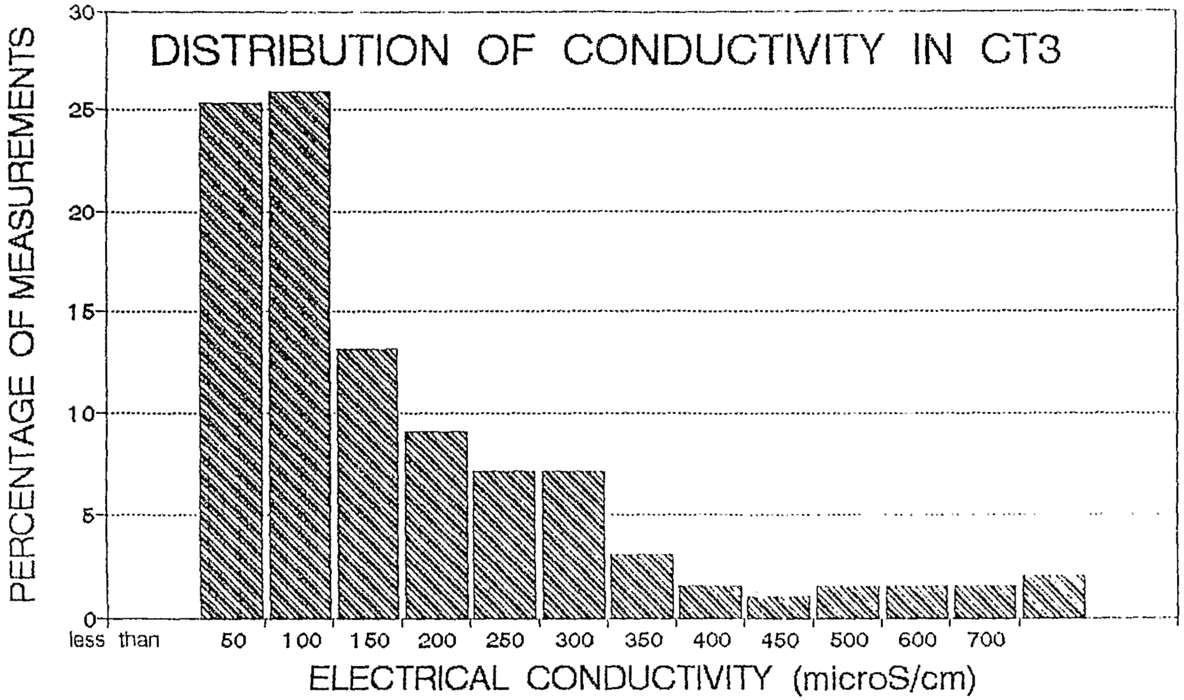
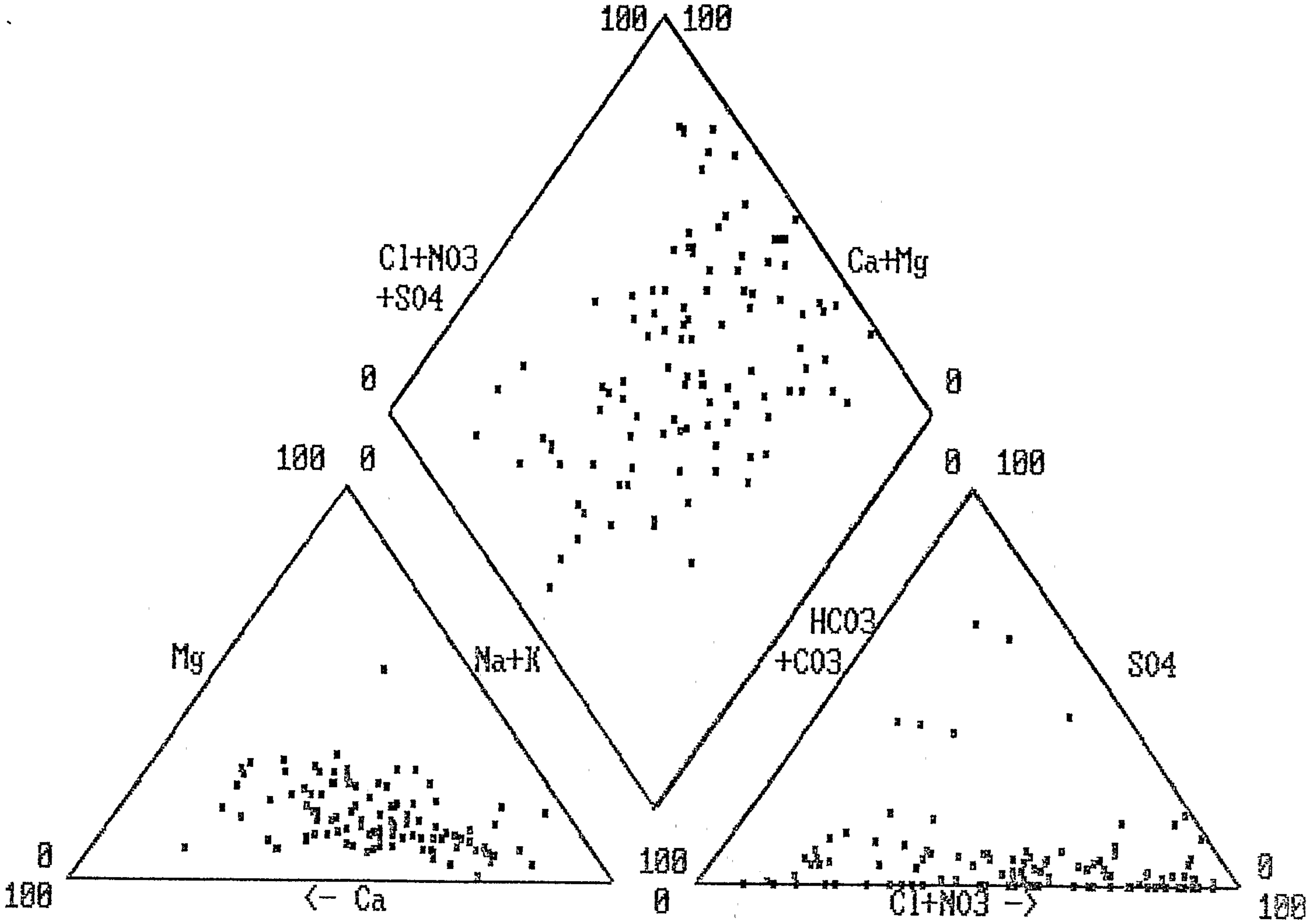

DISTRIBUTION OF CONDUCTIVITY IN CT3
PERCENTAGE OF MEASUREMENTS
30
25
20
15
10
5
0
less than
50
100
150
200
250
300
350
400
450
500
600
700
ELECTRICAL CONDUCTIVITY (microS/cm)

Fig. 4



MAJOR IONS IN CT3

Fig 5.

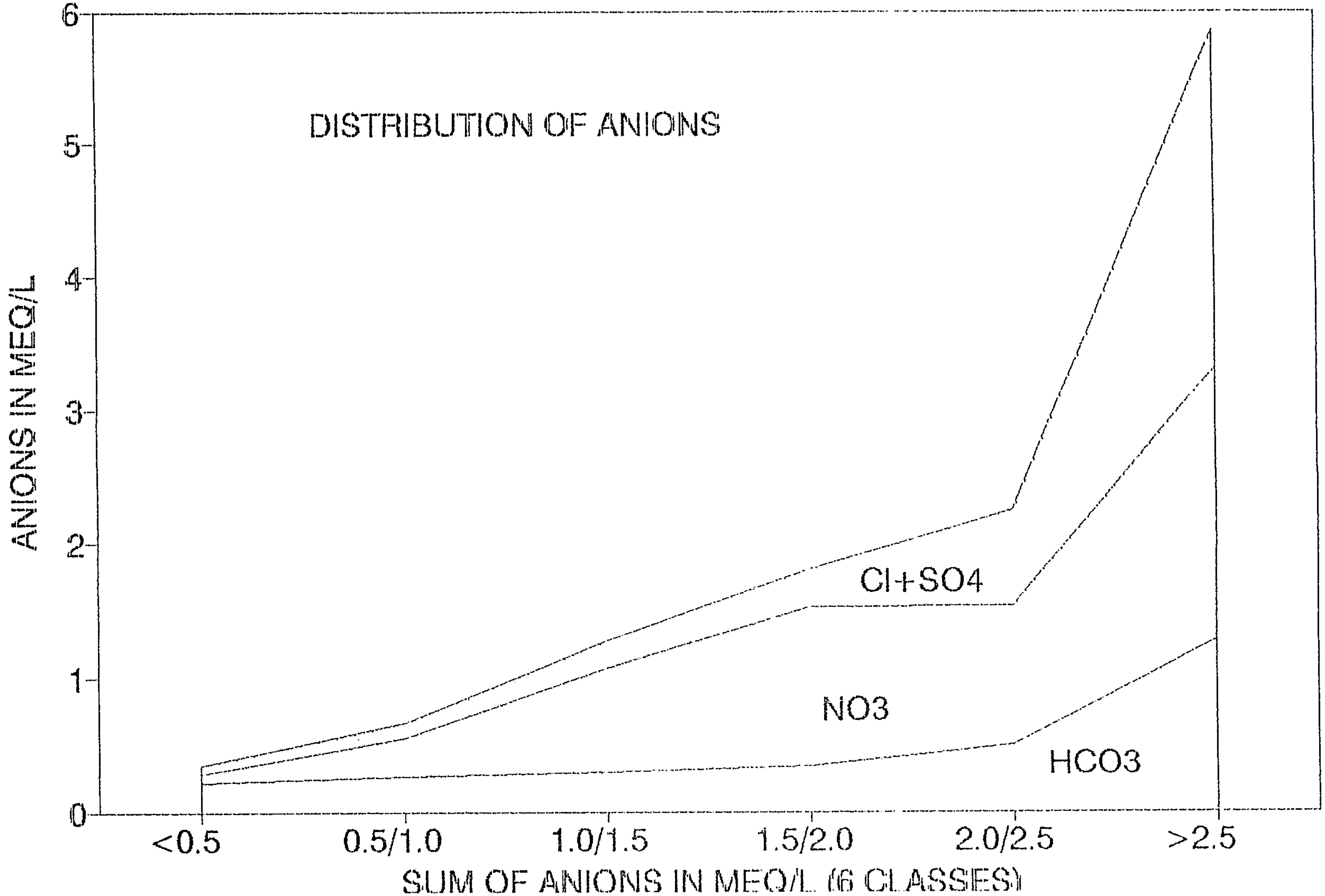
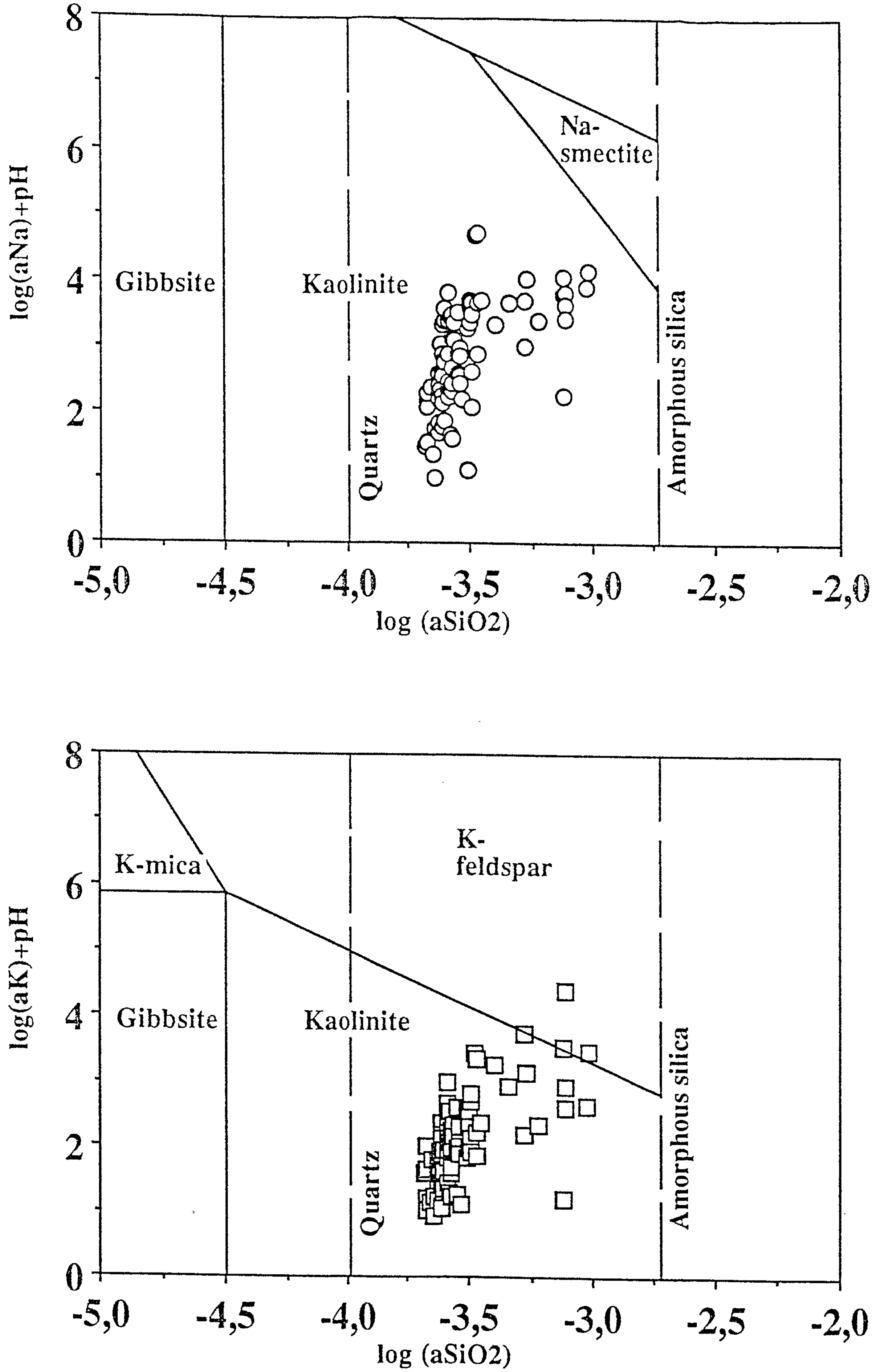
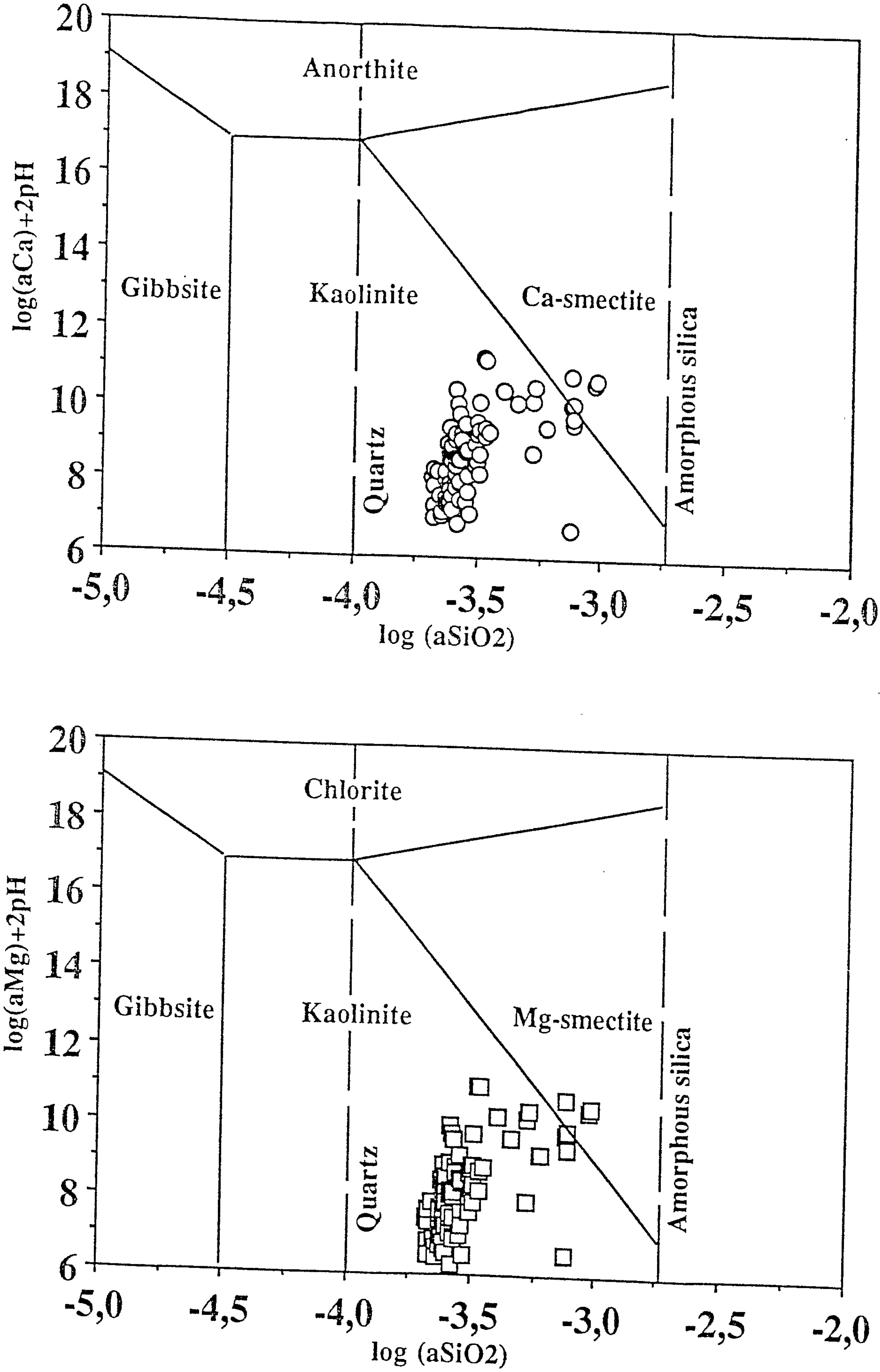

DISTRIBUTION OF ANIONS
ANIONS IN MEQ/L
0
1
2
3
4
5
6
Cl+SO4
NO3
HCO3
<0.5
0.5/1.0
1.0/1.5
1.5/2.0
2.0/2.5
>2.5
SUM OF ANIONS IN MEQ/L (6 CLASSES)

Fig. 6



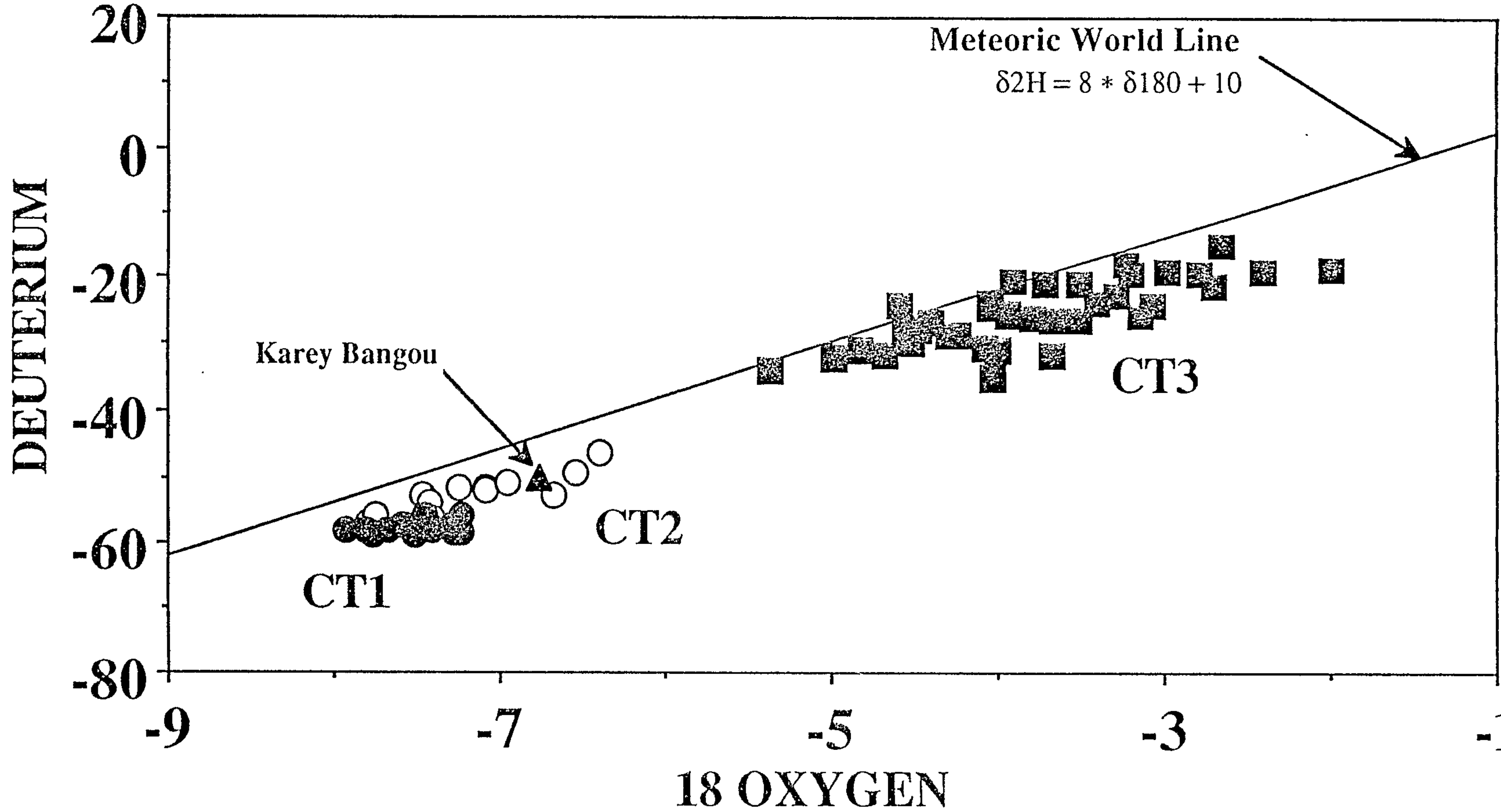
8
6
4
2
0
log(aNa)+pH
Gibbsite
Kaolinite
Quartz
Na-
smectite
Amorphous silica
-5,0
-4,5
-4,0
-3,5
-3,0
-2,5
-2,0
log (aSiO2)
8
6
4
2
0
log(aK)+pH
K-mica
Gibbsite
Kaolinite
Quartz
K-
feldspar
Amorphous silica
-5,0
-4,5
-4,0
-3,5
-3,0
-2,5
-2,0
log (aSiO2)

Fig. 7



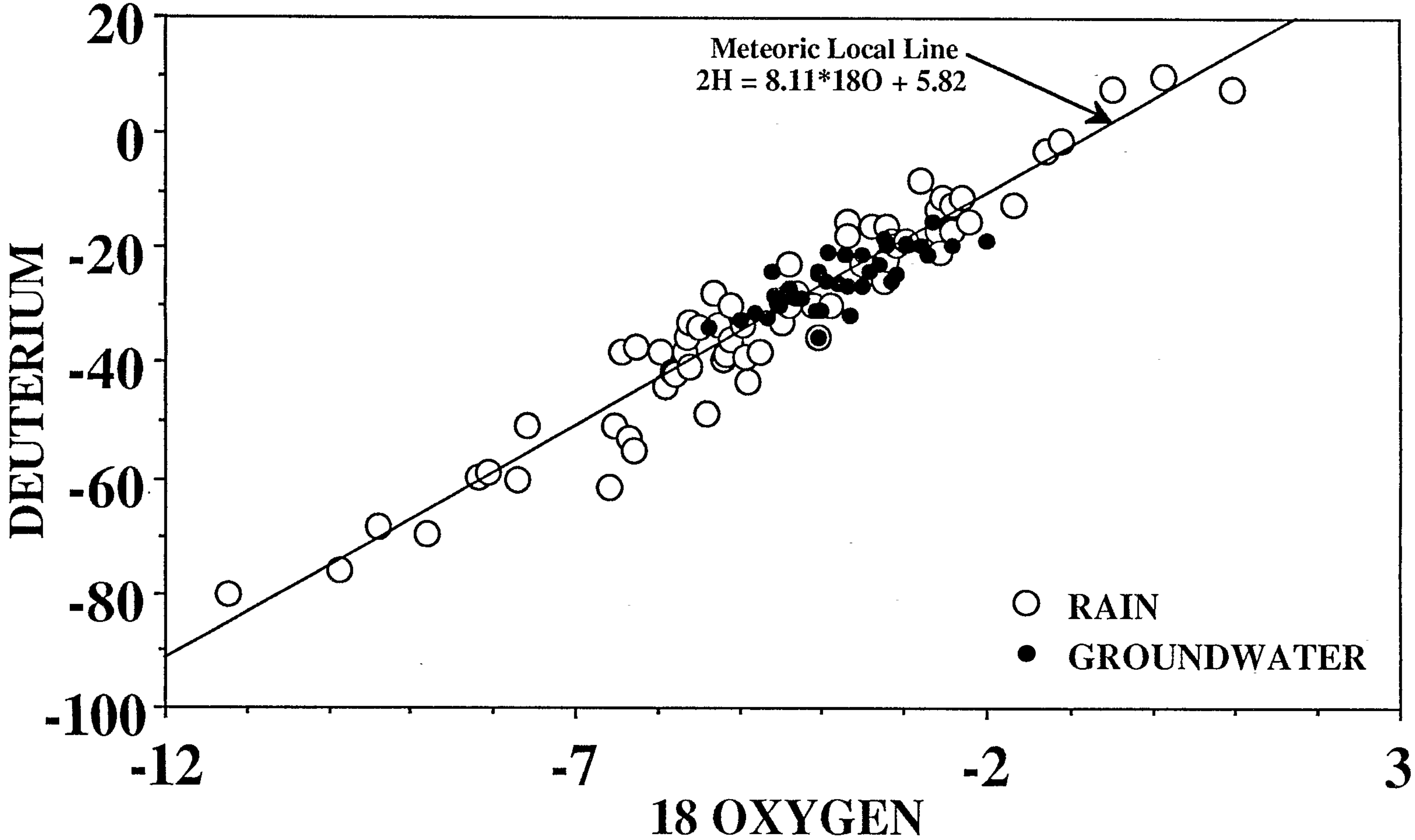
20
18
16
14
12
10
8
6
log(aCa)+2pH
Anorthite
Gibbsite
Kaolinite
Ca-smectite
Quartz
Amorphous silica
-5,0
-4,5
-4,0
-3,5
-3,0
-2,5
-2,0
log (aSiO2)
20
18
16
14
12
10
8
6
log(aMg)+2pH
Chlorite
Gibbsite
Kaolinite
Mg-smectite
Quartz
Amorphous silica
-5,0
-4,5
-4,0
-3,5
-3,0
-2,5
-2,0
log (aSiO2)

Fig 2



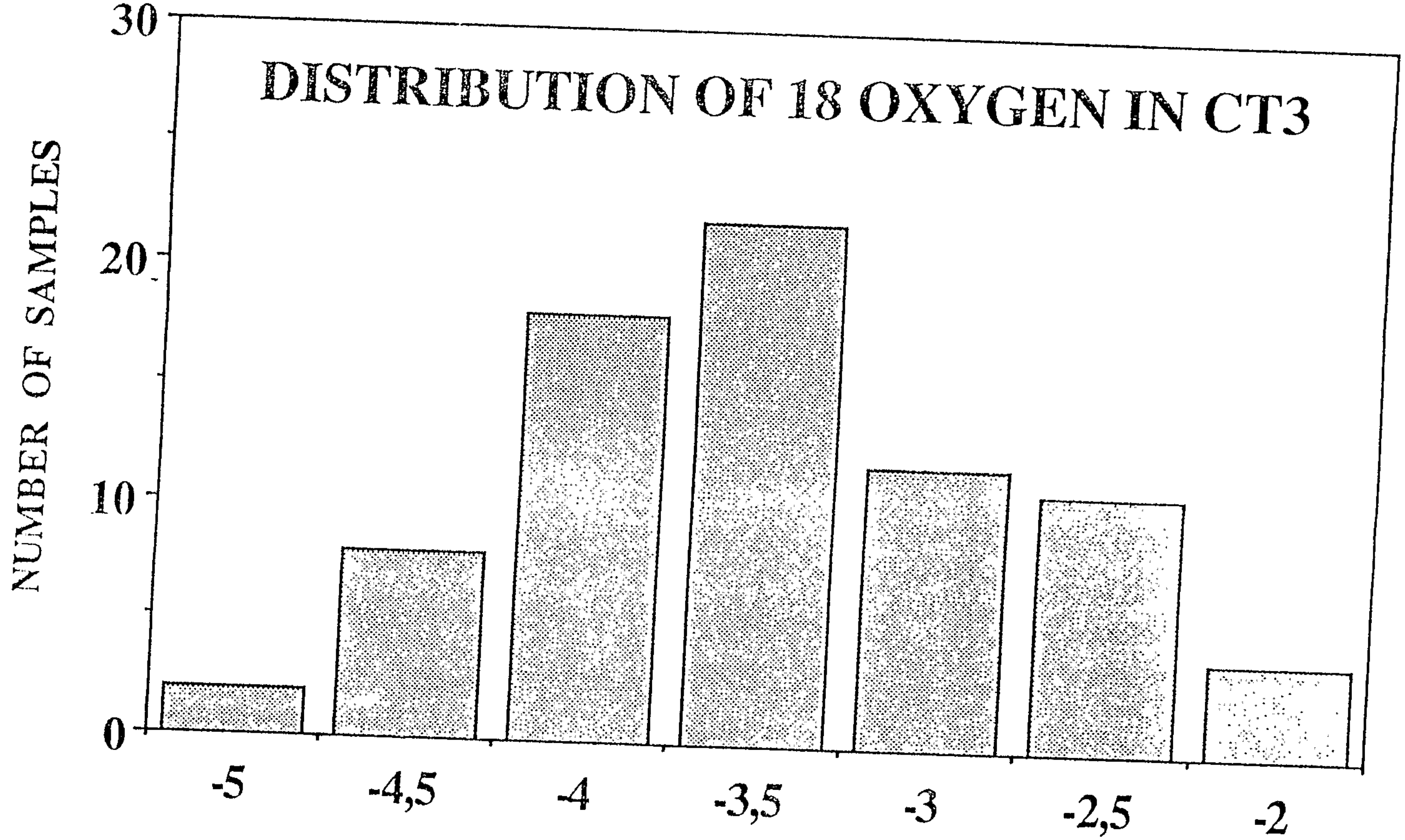
Meteoric World Line
δ2H = 8 * δ180 + 10
Karey Bangou
CT1
CT2
CT3
DEUTERIUM
18 OXYGEN
20
0
-20
-40
-60
-80
-9
-7
-5
-3
-1

Fig 9



Meteoric Local Line
2H = 8.11*18O + 5.82
DEUTERIUM
20
0
-20
-40
-60
-80
-100
-12
-7
-2
3
18 OXYGEN
RAIN
GROUNDWATER

Fig 10


DISTRIBUTION OF 18 OXYGEN IN CT3
NUMBER OF SAMPLES
30
20
10
0
-5
-4,5
-4
-3,5
-3
-2,5
-2