

THE DISTRIBUTION OF FLUORIDE IONS IN THE
GROUNDWATERS OF THE
BARINGO-BOGORIA LAKE BASIN //

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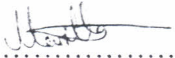


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This dissertation is submitted to the Department Of Geology as a partial fulfillment for the award of Master of Science in Geology at the University of Nairobi.

Declaration.

I Marietta W. Mutonga declare the work that I have carried out was purely my original idea, it has not been done by anyone else. It was carried out as partial fulfillment in the award of the degree of Master of Science in Geology at the University of Nairobi.



.....
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This dissertation has been submitted with our knowledge as university supervisors

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Abstract

The ground waters of the area extending from the southern shores of Lake Bogoria to the northern shores of Lake Baringo, within the floor of the Rift Valley Kenya have been examined in relation to fluoride concentrations. The area is defined by co-ordinates $35^{\circ} 45'$ - $36^{\circ} 20'$ E and $1^{\circ} 00'$ - $0^{\circ} 15'$ N, it covers approximately 6000 km^2 . Fluoride concentrations as high as 50 ppm had been reported in this area, resulting in abandonment of some boreholes. Most members of the community suffer various effects of skeletal and dental fluorosis.

One hundred and twenty sampling sites were visited with one hundred of the boreholes being sampled, while surface sources included samples from; Lakes Baringo and Bogoria, the main rivers Molo and Perkerra and nine springs, seven of which are Lake Bogoria springs. The ion selective electrode technique was used to analyze for fluoride concentration. Other chemical constituencies analyzed included Mg, Ca, and HCO_3^- for correlation purposes. PCWATEQ was used to analyze the chemical data to find out the main minerals comprised in these rocks that maybe responsible for the fluoride ions. These minerals include biotite, phlogopite, fluorspar, fluoroapaptite, etc mainly found in weathered volcanic and sedimentary rocks in this area.

Recharge of the groundwater bodies is mostly by lateral ground water flow from the Tugen hills where rainfall is higher than the lowland plains. This was established from the piezometric map drawn and the three dimension view of the piezometric levels. Maps showing the distribution of the fluoride ions in the ground water were also drawn using ArcView 3.2 and Surfer. The results showed that the ions were mainly concentrated within the central part of the study area, which lies on through of the rift valley. The concentrations were mainly controlled by geology.

A correlation of the fluoride concentration to that of Mg^{2+} , Ca^{2+} and HCO_3^- showed fluoride had negative linear relationship with Mg^{2+} , and Ca^{2+} ions, however it has a general positive linear relationship with HCO_3^- . The pH of most waters sampled ranged from 7-10 on the pH scale. This means that waters with high concentrations of Mg^{2+} , Ca^{2+} will generally have low concentrations of fluoride ions. The results of statistical analysis also indicate that Na^+ has the highest mean for cat ions and HCO_3^- has the highest mean for anions and that these ions have a very high positive correlation with fluoride ions.

With the water in this area having concentrations of fluoride that exceed the set standard of 1.5ppm, the prevalence of skeletal and dental fluorosis was evident. Due the low social economic standards of the community Bonechar defluoridation method was adopted. The efficacy of this technique rated at ninety percent. The findings in study will facilitate future planning and development of groundwater resource in this area by the various stake holders.

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CHAPTER 1

1.0 INTRODUCTION

The distribution of water on the continents varies greatly. There are transitions of all kinds from one extreme to the other, i.e. the water surplus of the tropical rain forest, is in sharp contrast to the deserts which are practically barren because of the scarcity of water. The quality of water also varies significantly from waters with extremely low concentrations of a few ions to others with high concentrations of ions of many different kinds.

In the last two decades it has been the goal of every government to provide safe and clean water for its people so as to ensure a healthy and productive population. This however has been futile. In the study area development of institutions such as schools and dispensaries is hampered by unavailability of potable water.

Provision of adequate and reliable supply of clean water within reasonable walking distance is key to stimulating economic growth and public health, thus poverty alleviation. In this regard the government and non-governmental organization have been working with communities in drilling boreholes. But this is not enough; a further step has to be taken to ensure that the water is not only clean but also safe. This is especially true of the groundwaters from most parts of the Rift Valley province in Kenya, which contain high concentrations of fluoride.

1.1.1 LOCATION

The study area extends from the southern shores of Lake Bogoria to the north of Lake Baringo, which lies a few kilometers north- east of Marigat. The geographical co-ordinates are $35^{\circ} 45' - 36^{\circ} 20' E$ and $0^{\circ} 15' - 1^{\circ} 00' N$, in which the general elevation is on average 965 metres above sea level.

The northern part falls within Baringo district while the southern part falls within Koibatek district. Kabarnet is the district headquarters of Baringo district but the central part of the study area falls within Marigat Town. The area is sparsely populated, Kambi ya Samaki in the western shores of Lake Baringo is the largest settlement in the area. Further north, there are small

small centres of population; Loruk, Nginyang, Chemolingot, Tangulbei, Kapendo, Salabani, Lometo Solai, etc (Figure 1.1).

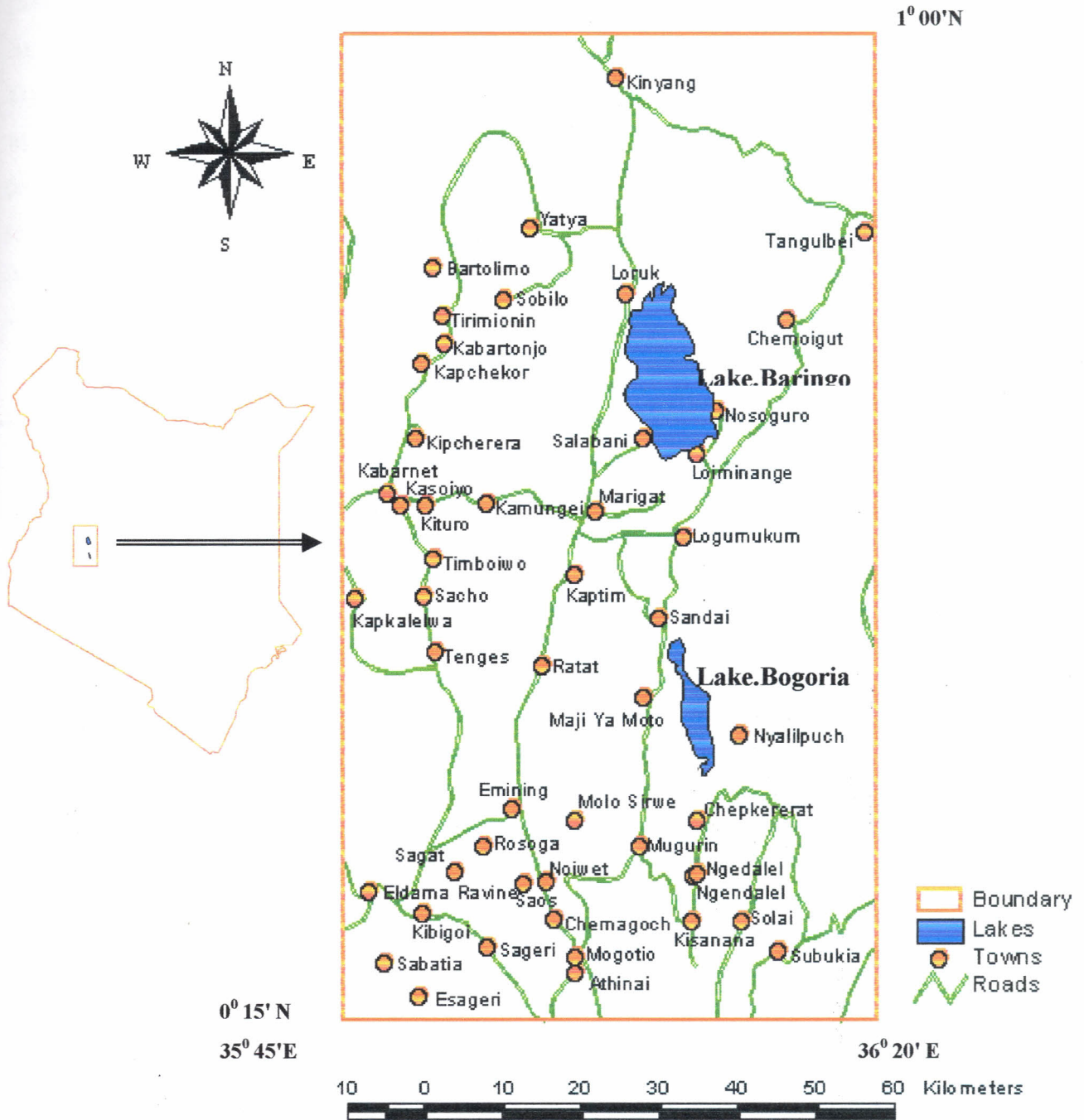


Figure 1.1 Map of the Study Area

1.1.2 ACCESS

The study area is about 50 km north of Nakuru Town. A good tar-sealed road provides access from Nakuru to the southern part of the area. This road skirts along the western shores of Lake Baringo and at the settlement of Loruk situated at the north-west corner of the lake, the tar-seal ends at a junction. One branch continues northwards as a poorly maintained all weather road which passes along the western side of the Rift floor through Nginyang, Kapendo and Lomelo. It provides access via several poorly defined and rough tracks to the low ground between volcanic centers within the rift. The other branch is a good murrum road to the western shores of Lake Baringo. All the earth roads and trails become impassable during the wet season and are liable to be cut by flooded rivers (Figure 1.1).

1.1.3 CLIMATE

Rainfall around Lake Baringo is about 650 mm per annum moving northwards it reduces to less than 200 mm per annum. The southern part receives relatively more rainfall at about 1500 mm per annum. Rainfall is distinctly seasonal with rainfall maxima occurring around April-August and a dry season from September-March. Maximum daytime temperature along the floor of the rift is generally in the range of 30°C-35°C.

(Ramsar information sheet, 2002)

1.1.4 ECONOMIC ACTIVITIES

Land is used for a variety of beneficial economic activities that include the following;

- Conservation of biodiversity
- Pastoralism and livestock grazing
- Honey gathering for local and external markets
- Small-scale irrigation- projects.
- Tourism for local and foreign visitors
- Community access to medicinal plants
- Fishing for domestic and commercial purposes
- Watering of livestock

- Subsistence farming of mainly maize and vegetables
- Settlements of communities at appropriate sites

1.1.5 DRAINAGE

Lakes Baringo and Bogoria catchment extends close to the structural limit of the Baringo-Bogoria half graben. The area is about 6905 km² consisting partly 6200 km² for Lake Baringo and 705 km² for Lake Bogoria. There are about ten water inflows into Lake Baringo from the south, south-east; and west (Figure1.2). Some of which are permanent while others are semi permanent.

The main feeder for Lake Baringo is River Molo ,which rises from the south on the Mau escarpment but is joined by numerous tributaries flowing off the eastern flanks of the Kamasia /Tugen Hills.The Perkerra (which drains the Mau Escarpment west of Eldama Ravine and the Kamasian Hills) is the largest flowing river in the area, and extensive irrigation is carried out at Marigat utilizing its waters. Endau also drains the Tugen Hills and flows on the western side of the lake, whilst the Mukutan and Ol-Arabel drain the Ngelesha escarpment and flow into the south-eastern side of the Lake (Ramsar information sheet 2002).

Lake Baringo has no surface outflow but is a fresh water lake. This is attributed to the fact that it has subsurface outlet discharges in the north at Kapendo (McCall, 1976) and also that it accrues great quantities of fresh waters from its inflowing waters. Molo and the Perkerra rivers are perennial rivers whereas the seasonal rivers are Endau, Arabel and Mugurin. These rivers bring to the lake a lot of silt and dissolved substances. The permanent rivers, however, contain very small amount of silt and dissolved substances compared to the semi -permanent rivers.

Lake Bogoria is a saline lake fed by a few springs on the escarpment above it and some small seasonal tributaries on the west including the Emsoss river fed by large hot springs. The Wasegess flowing in from the north is joined by many tributaries from the Laikipia escarpment (Figure1.2), it curves west-ward to debouch onto the Baringo plain at Sandai gorge and finally reaches Lake Bogoria a mile south of Lobo. It's the only powerful stream that feeds this lake and dries up in years of drought .The salinity of the lake increases to the south, reflecting the greater recharge from the northern end. There is a possibility of subsurface drainage towards Lake Baringo, situated some 1.5 m lower (Hackman et.al., 1988), but most of the loss from this lake

is undoubtedly due to evaporation, hence the high salinity. This could also be attributed to some extent to geothermal activity and the high amount of dissolved silt found in this area.

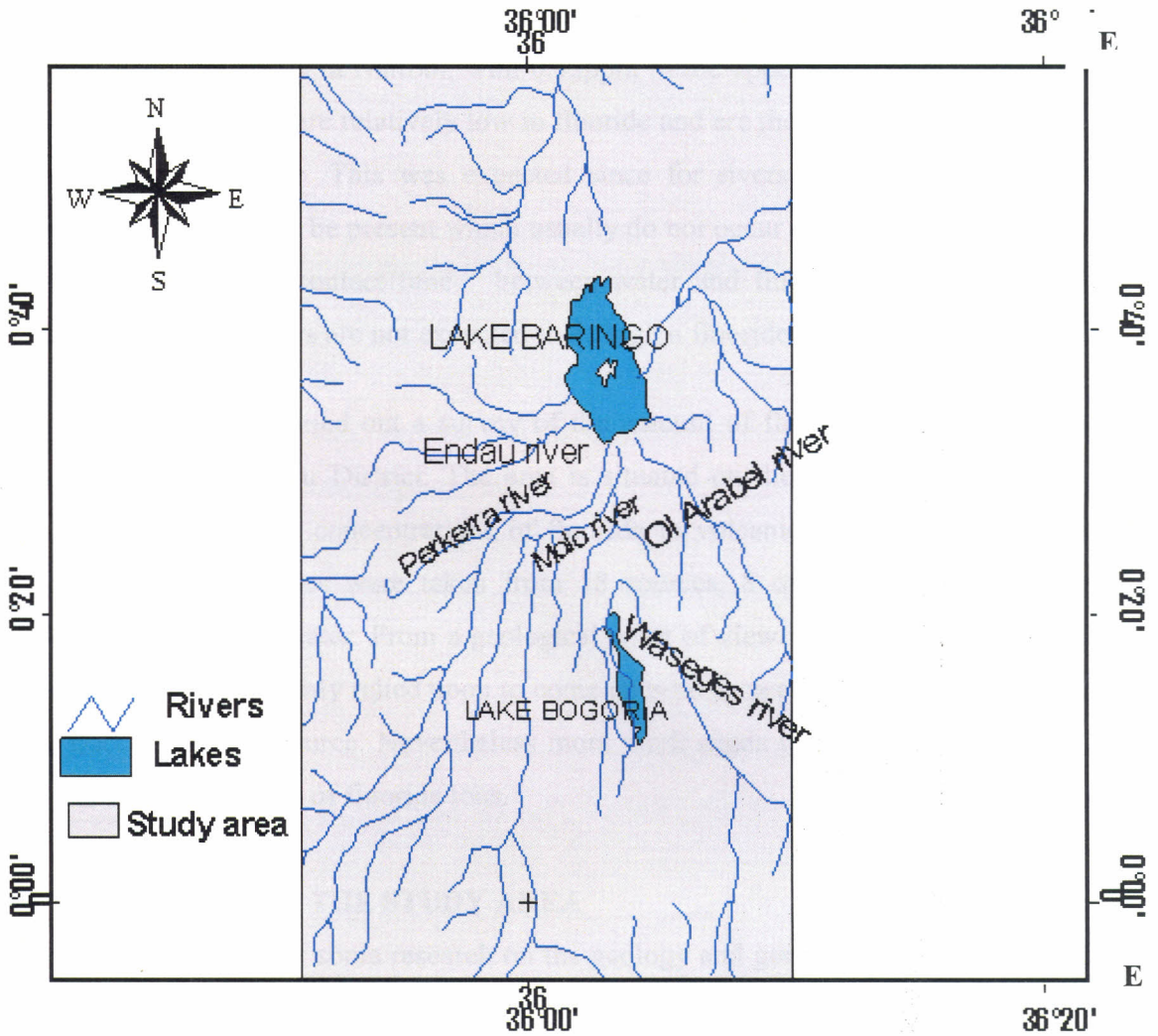


Figure 1.2 Drainage of the Study Area

1.2 PREVIOUS WORKS

1.2.1 PREVIOUS WORKS IN KENYA

Nair and Gitonga (1984) found that fluoride content of ground water in Kenya ranged from 0.1ppm to over 1ppm in the majority samples. Surface water contained a maximum of 34ppm. Over 30% of Kenyans suffered from dental fluorosis and in isolated regions where the

people depended on ground water for domestic use, nearly 100% of the population manifested different degrees of dental fluorosis.

Gikunju et.al., (2002) accessed 60 river water samples in Nairobi and central provinces in Kenya. They found the highest concentration to be in Laikipia District and the lowest to be in Murang'a District. By region and district, the mean fluoride concentration ranged from 0.12ppm for rivers in Laikipia to 0.24ppm for rivers in Nairobi, with 0.32ppm in the upper basin of the Athi River. The results indicated that rivers are relatively low in fluoride and are therefore safe in this respect for domestic and industrial use. This was expected since for rivers to attain high levels of fluoride, special conditions must be present which usually do not occur on the surface but only in the ground. Ordinarily a long contact time between water and fluoride-bearing minerals is needed, and therefore river waters are not expected to be high in fluoride content.

Mavura and Tiffany (2002) carried out a survey of the amount of fluoride in ground- potable water in Njoro Division, Nakuru District. The area is situated on the great rift valley of East Africa; they attributed the high concentrations of fluoride to volcanic eruptions that occurred thousands of years ago. Samples were taken from 18 sources, 8 of which were only from boreholes, the rest from piped water. From a geological point of view the number and choice of samples taken cannot be reasonably relied upon to come up with such a conclusion unless the tap water can be traced from the source. Nevertheless more work needs to be done in this area, to actually find out the main source of fluoride ions.

1.2.2 PREVIOUS WORK IN THE STUDY AREA

Dunkley et.al.,(1993) carried out some research on the geology and geothermal activity from the northern sector of the Kenyan Rift. From their geochemical fluid analysis data they found concentrations of fluoride to be as high as 140ppm for the hot springs, 35ppm in some cool springs and 44ppm in some of the rivers in the Suguta valley which is directly north of the study area. However their main interest was the geothermal potential of the northern sector of the Kenyan rift.

The Catholic Diocese of Nakuru (Catholic Diocese of Nakuru unpublished notes on defluoridation 2004) has been working in rift valley and have found that in natural waters fluoride is not

confined to ground water from deep boreholes, but is also found in natural springs, some rivers and lakes which have high fluoride content. such as the waters of Lake.Turkana and Lake.Baringo which have fluoride contents of approximately 10ppm. Several springs and shallow wells in Nakuru district have fluoride levels above 8ppm. However, they have not been able to come up with concentration zones in relation to geology so as to advice on the best places to site boreholes not adversely affected by high fluoride content.

Wambugu and Karingithi (2005) observed high calcium and magnesium in the water from boreholes around the Arus-Bogoria geothermal prospects. They further noted that the pH of most boreholes around this area varied between 6.5 and 8.0.

1.2.3 PREVIOUS WORKS IN OTHER PARTS OF THE WORLD

Handa (1975) found that the fluoride content in ground waters in India varied considerably. Among factors which controlled the concentration of fluoride were; the climate of the area and the presence of accessory minerals, fluorite and (or) apatite in the rock mineral assemblage through which ground water was circulating. Regional and tectonic factors also played some part in the fluoride concentration in the groundwaters. In general he observed that there was a negative correlation between calcium and fluoride concentrations and a positive correlation between fluoride and bicarbonate concentration in ground waters with high fluoride content. Thermodynamic calculations showed that some of these high fluoride ground waters were supersaturated with respect to fluorite. In water sources from Rajasthan, high fluoride concentrations were generally accompanied by high nitrate concentrations. However in some parts in India, the fluoride content of ground water was below 0.5mg/l, indicating that fluoridation of water supplies would be desirable in some places.

Rao (1964) in the Kurnool district of India observed that no definite relationship could be established between fluoride contents and each of the other main chemical features of water such as pH, hardness, alkalinity, chlorides, nitrates and total dissolved solids. A general relationship between the fluoride ion and the ratio of total alkalinity to total hardness was observed. Surface waters were recorded to be low in fluoride content, whereas in groundwater wide differences were noted. Among different water sources, surface water streams, rivers, canals and impounded

reservoirs were found to have very low fluoride content. Wide differences were noticed in the concentration of the ion in the samples from wells having approximately equal depth and situated in the same vicinity. Waters from wells dug in rocky unconsolidated strata had more content of the fluoride ion than the consolidated strata. It was observed that waters obtained from dug wells in black cotton soil and limestone areas had comparatively low content of the fluoride ion.

Suma,et.al.,1998 observed that abnormal levels of fluoride in phreatic groundwater caused serious health hazards in humans and physiological damages in plants. This study showed that occurrence of fluoride was highly sporadic and localized in eastern and southeastern Karnataka, India and the concentration of fluoride varied from 1 to 7.4 mg/l. The geological strata near the wells influenced the fluoride content in phreatic groundwater. Effective and cheap methods of defluoridation were few and hence biological defluoridation may have been the best alternative to the conventional methods. They also found that the toxicity of fluoride was also influenced by high ambient temperature, alkalinity, calcium and magnesium contents in the drinking water.

(Gumbo,1987) described the hydrochemistry of fluoride and fluoride ranges in different regions in Tanzania and attributed the variation in fluoride content among the regions principally to the concentration and mode of occurrence of fluoride in rocks of the region with which water has interacted. He estimated that the daily intake of fluoride in Northern Tanzania to be 26-44mg/l and that food contributed to a high degree to this intake.

Nanyaro et.al., 1984 found that ground waters in parts of northern Tanzania were characterized by exceptionally high fluoride concentrations in some rivers(12-26mg/l), springs(15-16mg/l) and alkaline ponds and lakes (60-690mg/l). In lowland rivers most of the fluoride was derived from weathering of F-rich nepheline and carbonatitic rocks as well as soils. While in the rivers draining Mt. Meru crater, gaseous emanations through mineral springs may also have contributed to the concentrations. The flashing of F-rich sodium bicarbonate "magadi" from the surface and top soil at the onset of the rainy season also affected the F-concentrations in shallow ground water and in surface water bodies. The steady flux of fluorides in ground water and overland flow and interflow containing dissolved "magadi" into internal alkaline ponds and lakes increased Fluoride (as well as Chloride) contents as a result of continuous evaporative enrichment over a

long period. The excessive Fluoride concentrations in drinking water caused endemic dental and skeletal fluorosis in people and in animals.

Mjengera and Mcharo (1990), recorded varying levels of fluoride in different districts in Tanzania with Ameru having as high as 76 mg/l in one of its rivers and a borehole in Bahati giving 54 mg/l. The lowest fluoride values were observed in Mbulu district ranging from 1.0-4.2 mg/l. The region has volcanic rocks and ash which have greatly contributed to the high fluoride content in the surface waters. Of the dominant geologic features were Mt.Meru and Nguroto craters. They also observed that the concentration of fluoride differed considerably in different aquifers due to different geologic formations. The hypothesis that the deeper you go the higher the fluoride content did not hold.

1.3.0 PURPOSE AND SCOPE OF THE STUDY

The study area has a big catchments comprising Lake Baringo and Bogoria catchments with about ten water inflows into Lake Baringo. Nevertheless, due to the scarcity of water especially during the dry seasons when the rivers dry up, the most important type of water points in the area are springs and ground water abstractions (mainly boreholes, wells).

Provision of adequate safe supply of water for various purposes has been one of the major priorities of the government in improving the welfare and livelihoods its people, by safe water its normally meant microbiologically safe water. However, this has not been good enough in areas where the groundwater has a high amount of fluoride, such that shifting the water supply from unsafe surface water to safe groundwater has introduced fluoride poisoning (fluorosis). The study area has not received the attention it deserves in relation to fluoride; most members of the community are suffering from various degrees of dental and skeletal fluorosis. It is important to note that no epidemiological research has been done with respect to the later. Concentrations as high as 50 ppm (WRAP Report 1987) had been reported as a result of which some boreholes had even been abandoned. There was therefore dire need for the chemical concentration of fluoride be established. The Catholic Diocese of Nakuru had done a lot of work in this area by drilling boreholes for the communities however they had not come up with the chemical suitability of the water, as a result there was a lack of understanding as to the chemical suitability of this groundwater especially in relation to fluoride concentration. It was important that the fluoride

concentration zones be established in relation to geology, with a view to protecting the community who may be unaware of the long term harmful effects of this water that contains high concentration of fluoride ions. (Fluoride ions in water cannot be seen or be detected by taste and the effects are not felt until years later). With this in mind .

1.3.1 OBJECTIVES OF THE STUDY

- Carry out geochemical analyses of the ground waters in this area mainly to determine fluoride concentration.
- Delineate the distribution of fluoride and relate the geology to fluoride distribution.
- Find the ground water flow regime to decipher discharge and recharge areas
- Document on the Defluoridation techniques applicable and practical in this area.

1.3.2 JUSTIFICATION FOR THE STUDY

Although there are no precise figures, it is estimated that between 100 and 200 million people (per comm Kim Muller EAWAG 2005) in developing countries are suffering from various degrees of fluorosis due to high levels of fluoride contents in drinking water. The African Rift valley which extends from Syria and Jordan in the Middle East to Mozambique is associated with high fluoride levels in ground waters. There are significant variations in fluoride levels in wells within the same area Redda et.al, (2006).

In areas where the natural water (main source of water) contains fluoride. The World Health Organization (WHO) recommends a maximum of 1.5 ppm fluoride content in water used for cooking or drinking. WHO even recommended a lower value in an area with hot climate (because people drink more). Kenya has adopted the WHO guideline of 1.5 ppm.

This however has been problematic due to the scarcity of water in most parts of the country and therefore people have been forced to take on average groundwater's containing 8ppm and above. Fluorides occur naturally in many water supplies and if present in excessive amounts may give rise to dental fluorosis in children. The water may eventually cause cumulative fluorosis with resulting skeletal damage in both children and adults (WHO 1971).

In water and in particular ground water fluoride concentrations of 10ppm or more are rare Hem (1959). However in this area fluoride concentrations have been found to be as high as 50ppm and in some places this may even be exceeded. Regionally, by far the highest concentrations of fluoride have been recorded in the Rift Valley Redda et. al., (2005).

1.3.3 OCCURRENCE OF FLUORIDES

Fluoride is hardly found in nature in an elemental form because of its electro negativity and exceptionally high chemical reactivity. It forms salts even in inert gases and can still react at 253°C. In rocks, fluoride occurs mainly in silicate minerals and fluorides. Its a relatively abundant element of the earth's crust (average content being 650 ppm).

It occurs notably as Fluorspar (CaF_2), Cryolite (Na_3AlF_6) in igneous rocks (granite), Fluoroapatite ($\text{Ca}_5(\text{PO}_4)_3\text{F}$) in sedimentary rocks (limestone and sandstone) and as Villiaumite (NaF) in volcanic rocks. Emelues and Tatlow (1971).

Fluoride is generally concentrated in the later stages of crystallizing magmas and in the residual solutions and vapors. These juvenile sources can escape as gases and fumaroles and get dissolved in the ground water. Higher concentrations are encountered in siliceous igneous rocks (750 ppm), alkali rocks (950 ppm) and hydrothermal solutions (400ppm), Dear et.al.,(1960).

Fluoride in water usually originates from different types of minerals as mentioned above. These fluoride minerals are nearly insoluble in water. Hence fluorides will be present in ground water only when conditions favor their solution. Its also present in sea water (0.8-1.4 ppm), in mica, and in many drinking water supplies.

Micas Have the general formula $\text{W}(\text{X},\text{Y})_2-3\text{Z}_4\text{O}_{10}(\text{OH},\text{F})_2$,

Where ;W is Na or K while Y, X represents AL, Fe, Li or Mg and

Z represents Si or Al.

The Fluoride content in mica's varies considerably as follows:

Table 1.1 Fluoride content in Mica's (Dear et. al., 1960)

Mica	Concentration
Biotites	70-500ppm
Phlogopite	3300-37000ppm
Lepidolite	19000-68000ppm
Muscovite	170-14800ppm

1.3.4 SIGNIFICANCE OF THE STUDY

In this area data is isolated in relation to the chemical suitability of the water, as a result there is a lack of understanding as to the chemical suitability of this groundwater especially in relation to fluoride concentration. The main source of household water supplies in this area is from groundwater i.e. boreholes. There is a spatial variation in the distribution of fluoride in the Rift Valley even within the same vicinity Redda et.al., (2006). This study will therefore help in delineating the spatial distribution of fluoride so as to come up with guidelines of preferred zones for groundwater exploitation. The results of this study will be extremely useful to the ministry of water resources and other agencies that are involved in formulating water policies, planning and implementing water development programmes as well as providing social and health services fluorosis affected communities and regions.

CHAPTER 2

THE STUDY AREA

2.1 GENERAL GEOLOGY

The geology of the study area is closely related to the formation of the East African rift valley system which, in the project area, is bounded to the west by Elgeyo escarpment (over 3000 m.a.s.l) and to the East by the Laikipia escarpment (over 2000 m.a.s.l) Tugen hills, which rise to almost 2,500 m in the rift valley floor, separate the lowlands of the Kerio valley to the west and Lake Baringo basin on the eastern side. The altitudes of these parts of the study area fall below 1,000 m. There are numerous seasonal rivers in the project area, most of whose bed contain massive boulders.

The study area is covered by over 300 m of Tertiary volcanic rocks (tuffs and lavas), which form a thick blanket over massive gneiss of the Mozambique belt. Stratigraphically the formations underlying the study area are Tertiary sediments and volcanics and Quaternary sediments.

The Tertiary sediments consist of Turkana grits in the northwest of Saimo in Tugen hills. The Kamega formation consists of siltstones, conglomerates and orthoquartzites of middle Miocene age. Gomorra formation was deposited during the Upper Miocene and Lower Pliocene and is found north of Kabartonjo. The youngest Tertiary sediments are the Chemoron formations they are fluvio-lacustrine deposits (silts and diatomite) which were deposited in tectonic depressions during the Upper Pliocene. They outcrop north-west of Marigat.

Basalts, phonolites and trachytes represent Tertiary volcanics (Figure 2.1). They consist of several flows which are separated by tuffs and sediments. These rocks in the study area are represented by the Kapchererat basalts in the north and Samburu basalts on the Laikipia escarpment. The phonolites cover large areas in the Tugen hills. The middle and Upper Pliocene volcanics represented by basalts are found in extensive outcrops in the western slopes of the Tugen hills and north of Eldama Ravine (Figure 2.1).

The Quaternary sediments are represented by Kapthurin beds (north of Marigat), which consist of silts and gravel deposits in lacustrine and deltaic environment. Locally, piedmont deposits of silt and clay (Loboi plains sediment), occupy a large area between the lakes. The thickness of the sediments is probably more than 1000m suggesting that Lake Baringo was formerly much bigger

than at present and may have been linked to the lenses of coarse deposits along the major scarps, alluvial deposits in and along the rivers and lacustrine deposits of Lakes Kamnarok, Bogoria, and Baringo. The rocks of the Basement system include various types of gneisses, schist, quartzite and marbles. The only outcrop of the Basement rocks in the rest of the district is found along the foot of the Saimo escarpment in the Tugen Hills, Veins and dykes of coarse pegmatites locally occur along the escarpment. Structurally the tectonic events during the rift formation produced faults of different magnitudes and trends.

In general the study area can be divided into three major structural units;

- The Tugen hills,
- The Baringo-Bogoria basins (central trough) which is intensely faulted,
- The step faults produced by a series of horst and grabens.

The central and northern parts of the Baringo-Bogoria basin are characterized by a series of small faults concentrated especially to the west and north of Lake Baringo.

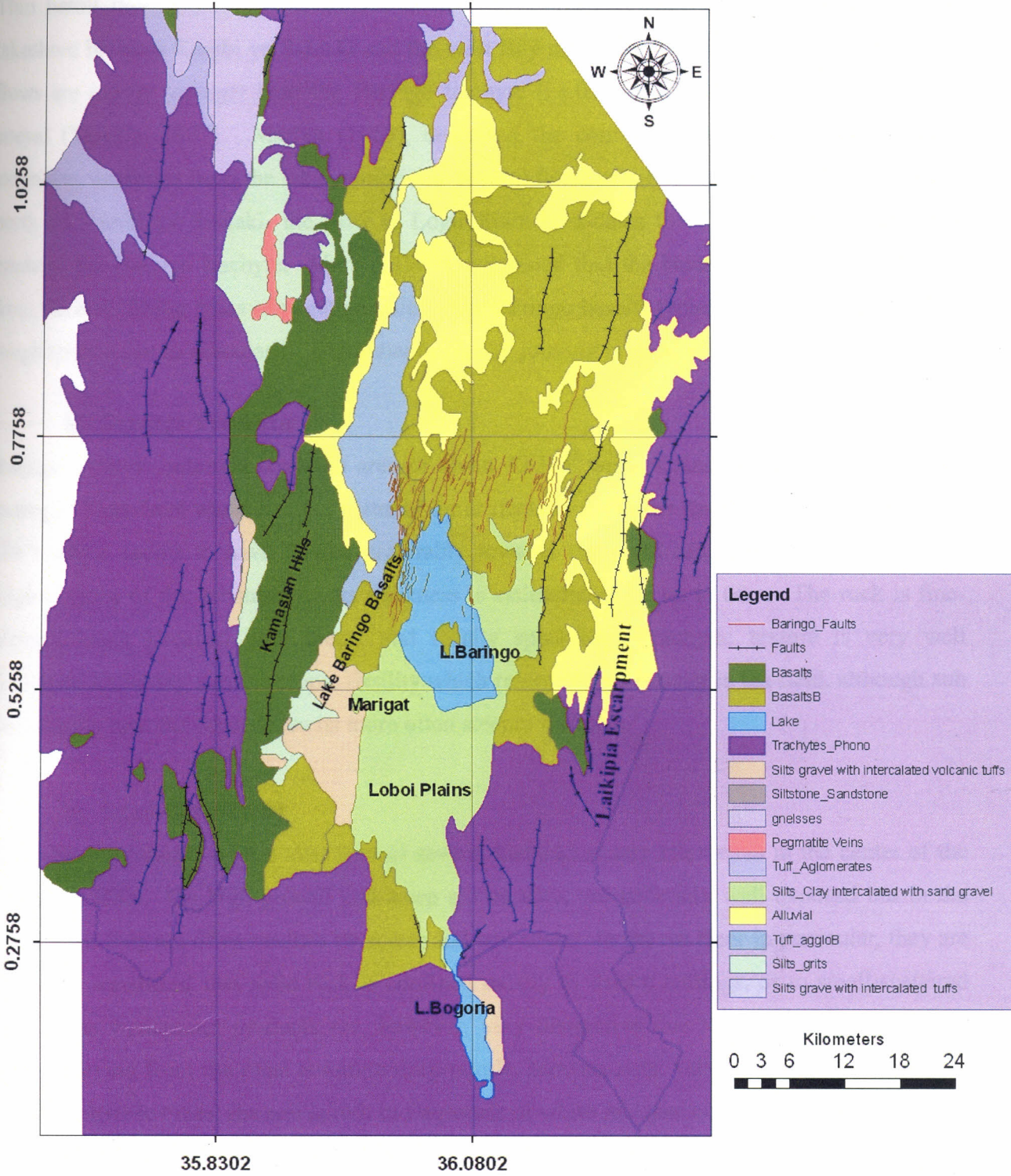


Figure 2.1 Geological map of the study area(modified from report 104 Geology of the Baringo-Laikipia area Hackman et.al,1988)

2.1.1 MAIN ROCK TYPES

a) Baringo Basalts

Thin basalt flows occur on the west side of Lake Baringo. They are well exposed on the lakeshore between Kambi ya Samaki and the west Bay and further north at Logoratibim. These flows are mostly younger than the Baringo trachyte (i.e. 0.23 m.a.) but are in part essentially coeval (Truckle, 1977). Martyn (1969), described the configuration of ribbon like outcrop extending westward from the lake, comprising several flows of different ages. On the lake shore north of Kambi ya Samaki, the flow at Logiratibim post-dates the Logamarok phonolite but predates the Baringo trachyte. Martyn (1969), suggested that the basalts were mostly extruded from the east, filling areas of negative relief. The Baringo basalts typically weather black with a rough texture due to vesicularity, Columnar or blocky jointing is usual.

b) Baringo Trachytes

Baringo trachyte outcrops cover an area of about 12 km² west of Kambi ya Samaki on Lake Baringo. They were was the major material for artifacts found in the Kapturin basin Talon (1978). The trachyte seems to have flowed preferably towards the north east, presumably due to the original slope of the substratum. Its thickness is estimated to be up to 60m. The rock is fine-grained, black streaked with green, and locally speckled. Trachytic texture is very well developed imparting a macroscopic fissility which resembles schistosity in the field, although sub horizontally near the source area its more often steeply inclined.

c) Samburu Basalts

These basalts outcrop over a total area of several hundred square kilometres in the center of the Kamasian Hills. On high ground and steep slopes they, are generally well exposed but in the lower areas they are often masked by screes and soil cover. In the rift floor in particular, they are so deeply weathered that solid rock is confined mostly to stream cuttings, or to small-scattered float. The weathering products are, however, very distinctive due to their bright and varied colors, varying from the most common deep purple, browns, reds, yellows and greys. Over the more porphyritic types, the soil is rich in fragments of white feldspar which, where grass cover is absent, gives the impression of the aftermath of a hailstorm. After the rain, the wide grass-free

expanses typical of the area become glutinous mud and tenacious clay which make walking across them a slow misery.

d) Kapthurin and Chemeron beds

The Kamasian sediments are generally referred to as faulted sediments according to Gregory's earliest description, but in fact they are now seen to consist of two groups the Chemeron and Kapthurin. The Chemeron group is strongly faulted being deposited before the last two episodes of rift faulting. The Chemeron beds underlie the strongly grid faulted Lake Bogoria lavas that form an integral part of a complex horst and graben structure, this contrasts the Kapthurin sediments unfaulted farther west. This minor faulting is part of the last episode of rift valley faulting in the Baringo basin which was confined to a narrow zone in the center of the rift. It lowered the base level, forming a shallow hollow structure in the Kapthurin lake beds and allowed a further accumulation of sediments, represented in the present area by the later infillings exposed near Marigat.

e) Phonolites

These have been grouped into two;

1) Lake Bogoria/Hannington phonolites.

These were named by McCall (1967) from Lake Hannington, these phonolites outcrop widely in the east and south of the present area. (Figure 1.4). They are usually dark grey or black in color except the bottom of flow, which sometimes have a deep purple color. Large vesicles are common locally

2) Ngelesha phonolites

According to McCall (1967), Ngelesha phonolites are exposed in different areas as follows;

- a. At the foot of the Ngelesha escarpment east of Lake Baringo
- b. Overlying the Samburu basalts on the east side of the Waseges valley, 8 km east of Lake Bogoria.
- c. North of the entrance to the Iguamiti river gorge below the Marmanet Escarpment (McCall, 1967) described these phonolites as dark greenish black, compact fine textured lavas showing only sparse feldspar phenocryst with vesicles often filled with zeolites and are characterized with spheroidal weathering.

Carney(1972),mapped these lowest lavas further north along the Ngelesha-Aruru Escarpment he recognized four members;

4,Upper mottled aphyric phonolites(most widespread north of Mukutan gorge).

3,Bedded yellow lapilli tuffs(primarily air fall)

2,Middle biotite phonolite(one flow in the Mukutan gorge).

1,Lower dark phonolites, with rare nepheline phenocryst at the base of the Aruru–Ngelesha escarpment. Petrographically the lowest flows most resemble, McCall's description their dark, fissile appearance, and characteristic nepheline microphenocryst are suggestive of trachyphonolites. (Refer to for Figure 1.2 for physical location of the features mentioned above)

2.2 PHYSIOGRAPHY

The study area includes a spectacular section of the Baringo basin, or the Baringo-Bogoria half graben. Occupying the central part of the study area is a rift which is approximately 30km wide, extending from Nginyang in the north-west, at about 800 metres above sea level to Despieu plateau south of Lake.Bogoria where the rift floor elevation rises to 1800 m. Faults trending NW-SE control an array of an echelon re-entrants in the alignment of the eastern wall of the rift. The bounding fault escarpment traces out sigmoid curvi-lineaments enclosing partly alleviated embayment in the adjacent rift floor (Hackman et.al., 1988). The rift floor displays considerable physiographic diversity, which has been described by Hackman et.al., 1988 as follows (Figure 1.2);

- a) **The central volcanoes** are marked by low angled 'central' composite cones of Korosi (1448 m) and Paka (1696 m) that dominate the median rift, north of Lake Baringo. These volcanic complexes are both about 15 km in diameter (Figure1.2). Paka, with a central crater filled by a late basalt flow, is on its eastern flanks by a swarm of faults trending NNE. The same trend is seen on Korosi, manifesting as an alignment of scoria cones-the main fissure system may well extend under Lake Baringo to Ol Kokwe Island, which is a submerged southern salient of the Korosi Massif.
- b) **Faulted volcanic escarpments** separate the alluvial and Quaternary volcanic middle zone of the rift from the plateau which form the outer rift shoulders. Between Lake Bogoria

and the main Laikipia escarpment is a complex of escarpments up to 12 km broad, deeply dissected by the Wasegess and lower Ol Arabel river systems, including the Siracho escarpments which flank the west side of Lake Bogoria and rise to the south to Kaptiony Hill(1788m),and the Kahone range, east of the Lower Wasegess. These escarpments, mostly supporting a Combretum type of vegetation, form a complex series of interlocking ramps, trending N and NNW, which, north of Lake Bogoria, slope regionally towards the north.(Hackman et.al.,1988). Karau (1486 m) may be considered a northern extension of this belt of escarpment, separating Lake Baringo from the Mukutan-Komol basin (Figure 1.2). The same ridge continues into the massif of Chepchuk (1395 m), faulted against the eastern flanks of Korosi. The Pliocene ridge of phonolitic trachytic volcanics whose western flanks have been mutilated by the middle rift Pleistocene faulting, and has its counterpart in the Loyamarok Plateau on the other side of the rift to the north of Lake Baringo.

- c) **Volcanic plateau** south west of Lake Bogoria includes the Despei plateau (McCall, 1967) and the Lake Bogoria Plateau (Figure 1.2). The Despei Plateau devoid of surface drainage, is a broken hilly complex of horst and grabens, essentially a southern continuation of the Siracho escarpment, which swings to the south-west at Emsoss south of the lake and further south maintains a SSW trend as the Mugurin escarpment(1790 m). Within other minor escarpments to the east (Muchongoi, Solai), the Lake Bogoria plateau, attains an elevation of (1545 m). Its relief reflects in detail an elaborate anatomizing pattern of grid faults which transect the dominantly trachyphonolitic lavas drained by the north flowing parallel configuration of the Mugurin-Ndoloita-Loboi Systems. The area is covered by the mixed Acacia bush typical of the Baringo Basin.
- d) **The Alluviated and Lacustrine** area covers the area between lakes Baringo and Bogoria. The waters of Lake Baringo (22 km long and 13 km wide) are believed to egress at its northern end by subsurface seepage to emerge at Kapendo springs, 110 km to the north (McCall,1967). The Soda Lake.Bogoria occupies a spectacular trough 18 km long and up to 5 km wide, bounded on the east side by the cliffs of Siracho Escarpment rising over 700 m above the lake surface. Lake Bogoria has no exit, although some seepage may occur to the north through the Loboi silts. Its main recharge is from the Waseges River at

the north end. The two lakes separated by the 20 km wide Loboï plain which is swampy. The ground water in this area is saline, although the Perkerra river has been used for an irrigation scheme. The interlacustrine watershed reaches a maximum elevation of 999 m about 4km north Lake Bogoria Evidence suggests that the two lakes were combined during Late Pleistocene ("Loboï lake" of Farrand et.al.,1976).

To the north, the Mukutan-Komol and Tangulbei basin extends also along the eastern side of the rift for about 40 km. It comprises a plain of aggradations, in part probably a paleolacustrine belt at about 1200 m extending up to 10km wide, flanked by Aruru-Tangulbei Escarpment to stand of Karau-Chepchuk ridges to the west.(Figure1.2) (Carney,1972).

In the Nginyang area, west of Paka, there, are extensive alluvial tracts, the Loyamarok plain drained by the Kogore river and the Burususwa valley in the extreme north west, both tributaries of the Nginyang River.(Figure1.2). These lowlands are diversified by extensive salients of lava and pyroclastic satellites of Paka and Korosi volcanoes. South of Lake Bogoria, small alleviated basins nestle between the curved escarpment the largest of which is upper Waseges valley below the iguamiti gorge. Lake Solai has been reduced to a swampy depression.

Legend

Alluvial plains



Plateaus



Escarpments



Volcanic centers



Fault lines



Lakes

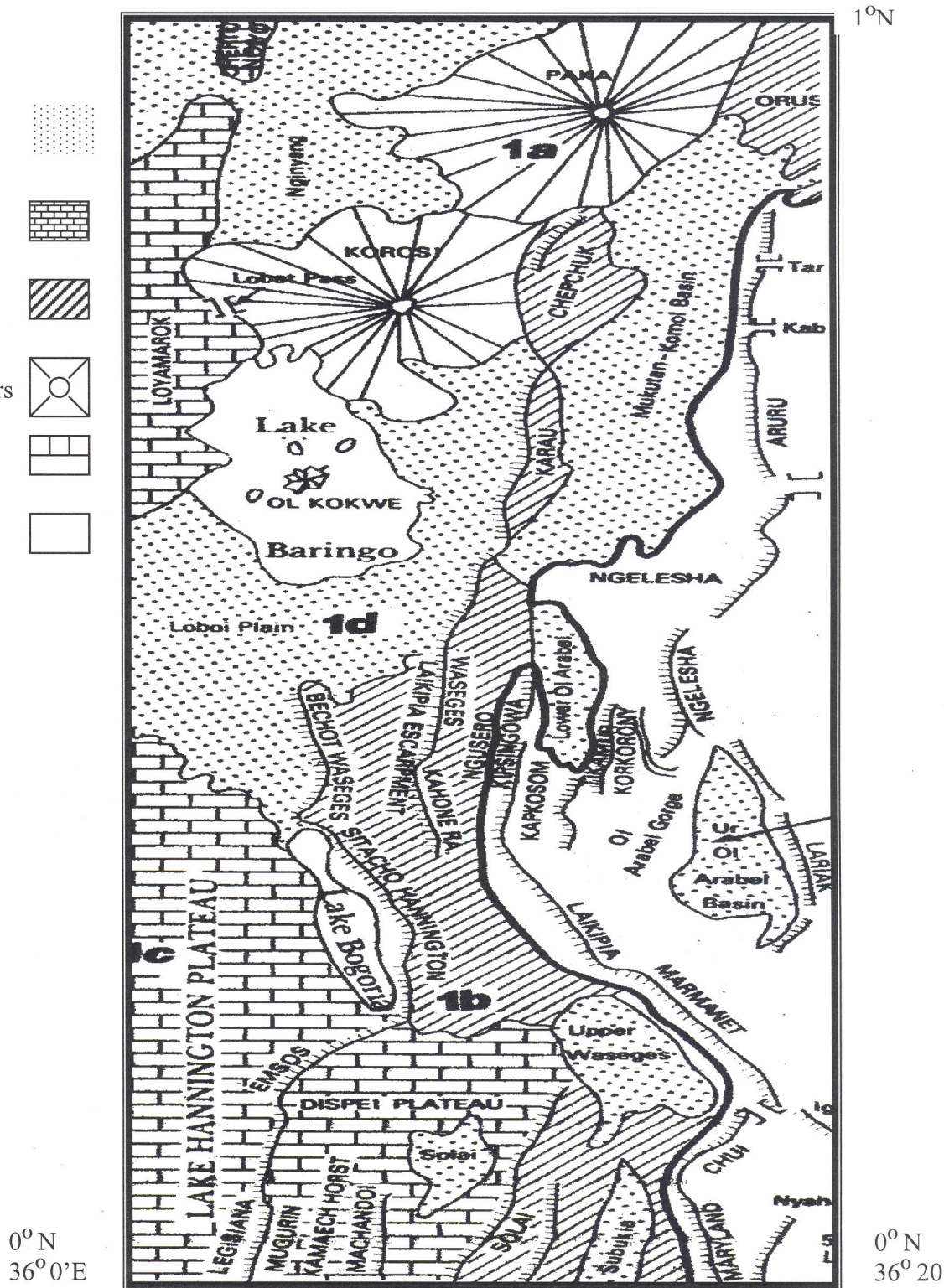


Figure 2.2 Physiographic zones (Modified from B.D. Hackman et al., 1988 Figure. 4)

CHAPTER 3

DATA ACQUISITION AND DESCRIPTION

3.1 METHODS OF INVESTIGATION

A preliminary study of the area was carried by collecting and collating previous available literature, data and information of any work done in the study area, this served as basis for building up the research work, by identifying milling gaps and setting up the strategy on how to fill them.

A review of the geological formation of the study area was also carried out hand in hand with sample collection, to come up with a geological map that could be used to relate the fluoride concentration to the geological formation.

Geochemical analyses of the groundwater's in this area(done on samples collected mainly from boreholes and springs)mainly in relation to fluoride was essential as chemical constituents in excess or deficient may be hazardous to health. Data obtained from this chemical analysis was used in delineating the distribution of fluoride in the ground water.

After delineating the spatial distribution of fluoride ions in groundwater's, some of the effects(using photos)of taking water highly contaminated with fluoride were shown.For both human and cattle it causes dental and skeletal fluorosis. This negatively impacts on the livelihood of communities in this area whose main stay is livestock production. A technique of defluoridation was also documented

The chemical data obtained was also analyzed using PCWATEQ in order to find out minerals responsible for the high concentrations of fluoride ions. PCWATEQ is a special adaptation of WATEQF for IBM computers for analyzing geochemical data. WATEQF is a Fortran IV computer programme that models the thermodynamic data speciation of inorganic ions and complex species in solution for a given water analysis. The original version(WATEQ) was written 1973 by A.H Truesdell and B.F.Jones See Appendix C for results.

The total depth and water rest levels were also recorded in order to come up with a reliable groundwater contour map that could be used to delineate ground water discharge and recharge

areas. Flow directions as well as geological effects on groundwater flow come out clearly. Most of the boreholes in this study are community owned and have been drilled during the period 2003-2005 under the Belgium technical cooperation (BTC) with the government of Kenya. This data was from contractors since most of the boreholes are sealed at the time the data is collected. The main contractors are; The Catholic Diocese of Nakuru, hence the data collected is highly reliable. See appendix

To show the effects of high fluoride concentrations Kambi ya Samaki primary was visited and by physically counting number of pupils whose teeth exhibited various degrees of fluorosis from class one to eight and getting a percentage, some photographs were also taken to support the evidence.

3.2 SAMPLING

Sampling is a vital part of the studies of natural water composition and is perhaps the major source of errors in the whole process of obtaining water quality information as noted by Hem (1959) as cited in Maina(1982). The extent to which a small sample may be considered representative of a large volume of material depends on several factors such as homogeneity of the material being sampled as well the number of samples collected.

The geographic co-ordinates and altitude were also be taken at the point of collection using a Geographic Positioning System(GPS). This was essential when it came to plotting the data points (Figure 3.1) or relating any chemical constituents to a particular datum point using Arc view GIS and other software.

For this study, random sampling was adopted, samples were taken from different boreholes and a few springs, whereby more than 100 samples were collected (Figure 3.1). This was based on the geochemical principle that the more the samples and well distributed they are, the more representative they are of the study area (Hem 1959; Ongweny 1973).

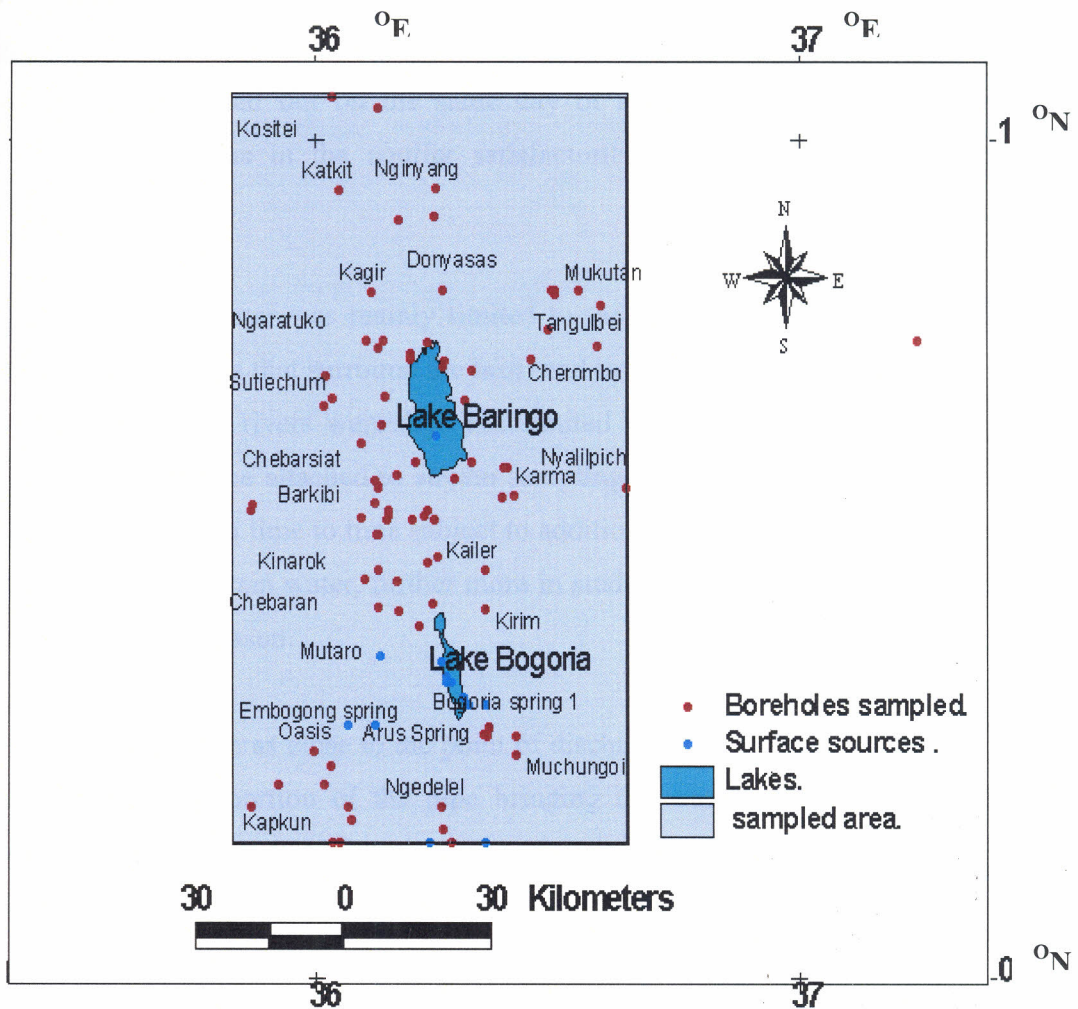


Figure 3.1 Sampling points

Polyethylene bottles were preferred for the collection and storage of water samples for analysis because;

- 1) No contamination of metals dissolved from the walls of the containers; a hazard that is always present in case of glass vessels.
- 2) Breakage during transport is minimized.

Stringent measures were taken when cleaning the bottles to prevent contamination. These containers were cleaned with metal free nitric acid (HNO_3) then rinsed several times with distilled water and deionised water. While in the field, each container was again rinsed at least twice with the water about to be sampled.

After collecting each of the samples, the sample bottles were tightly closed for transport to the laboratory. This was important to maintain a close pH value to that in the borehole as possible. The pH test was carried out on the same day of sampling. Such pH determination should represent the conditions in the aquifer satisfactorily (assuming micro bioactivity was very minute).

Sampling of surface water was mainly limited to the two major lakes Lake Baringo and Lake Bogoria (and the springs that surround the lake) and to the major rivers Perkera and Molo as most of the semi permanent rivers were dry. The limited use of data obtained in surface sources dictated little importance attached to stream sampling, since the quality of surface water (Rivers especially) changes from time to time subject to addition of pollutants and dilution by for example the relatively silt-free rain water, further more in study area most the river beds are barren since it was during the dry season.

The samples were taken as close to the point of discharge as possible, limiting the contact of the sample water to that portion of the pipe bringing the water to the surface. Water from the borehole was allowed to flow for sometime after pumping before collecting the sample. Such precautions were taken to ensure that the sample was as representative as possible of the source.

3.3 CHEMICAL ANALYSES

The Samples were analyzed for the following chemical constituents fluoride, chloride, sodium, calcium ,potassium ,magnesium, bicarbonate, nitrates. The following parameters were also determined conductivity, total hardness, pH. see appendix for results.

The analytical techniques employed in this study are shown in the table below.

Table. 3.1 Chemical analytical techniques applied

Methods of analysis used	Parameters
Ion selective Electrode	Na, F, NO ₃ , K, Ca
Edta Tritimertric Method	Hardness
Argentometric method	Cl
Calculation Method	Mg , HCO ₃
Instrumental measurement	Conductivity
Turbidimetric Method	SO ₄
Electrometric method	pH

- **Ion selective Electrode**

Electrodes are now available for the measurement of single ion activities of a number of ions in solution. These electrodes are essentially membranes mounted at the end of glass or plastic tubes. The nature of the membrane determines the ion to which the electrode responds. The Body of the electrode contains a reference solution of constant composition. When the electrode is placed in a solution, an electric potential develops across the membrane. The magnitude of the potential develops on the concentration of the ion activity and electrode potential is logarithmic. A measurement of the potential against the fixed potential of the reference electrode thus provides a measure of the concentration. Addition of buffers frees the electrode method from the interference caused by such relatively common ions such as aluminium, hexametaphosphate and orthophosphate which adversely affect the colorimetric methods.

For pH determination, the reference electrode is immersed in a solution containing a fixed concentration of hydrogen ions. A position, which allows the electric current to pass, separates

the reference solution from the solution in which the electrode is immersed to determine the pH value. Buffers used for calibrating the instrument were pH 4.0, 7.0 & 9.0.

- **Turbidimetric technique**

The principle behind this technique is that the sulphate ion is precipitated in a hydrochloric acid medium using barium chloride in such a way as to form barium sulphate crystals. The absorbance of barium sulphate suspension is measured by a spectrophotometer at $420\mu\text{m}$ and sulphate ion concentration is determined by comparison of reading from a standard curve. Suspended matter, which may interfere, is filtered out before commencing on analysis. It is important to note that no ions other than sulphate will form insoluble compounds with barium under strongly acid conditions in normal water.

3.3.1 FLUORIDE DETERMINATION

Ion selective electrode method

Among the many methods suggested for the determination of fluorides, the ion selective method was the most satisfactory because most of the other methods are time consuming, expensive and inaccurate due to interference by other ions causing problems of accuracy. Therefore, the method chosen for analyzing fluoride must be of such sensitivity that even small quantities down to less than 1mg/l can be detected accurately.

Apparatus;

1. Reference electrode (Ag/AgCl) (Metrohm 6.0733.1), with 3M potassium chloride solution as electrolyte in inner and outer filling.
2. Fluoride sensitive electrode (Metrohm 6.0502.15)
3. pH Meter (With 0.1 mV readings)
4. Magnetic stirrer.
5. Plastic/glass ware

Reagents;

1. Standard F^- solution (1.00, 10.00 mgF/l)
2. Total ionic Adjustment Buffer (Fluoride TISAB)
3. Fluoride TISAB (1+4) (diluted)
4. Potassium chloride solution (3M) (standard reagent)

Procedure

1. The electrodes and metre were prepared for measuring in the sample. The electrodes were rinsed in distilled water.
2. In a 15ml plastic beaker, 5.0ml of 1.0mg/l fluoride standard solution(C_1) was added.
3. 5.0ml fluoride TISAB was added (NB Use of the diluted TISAB on low ion strength sample is recommended for most cases)
4. A stirrer is then added and the tip of both electrodes is placed in solution.
5. The reading on the mV Metre was noted (the procedure was repeated for more accurate results (U_1))
6. Procedure 1-5 was repeated with 10.0mg/l Fluoride Standard solution (C_2) (in that order).
7. The reading on the mV Meter was noted(the procedure was repeated for more accurate results (U_2))
8. The procedure was repeated for unknown samples (U_s).

General rules

Start with the samples of lower fluoride concentration.

If the readings change more than 20mV between two samples repeat measurement. After working 1 hour with the electrodes recalibrate.

Calculation Interval

0.2 to 20mgF/l:

$$\text{mg F/l I sample} = \text{Antilog} \left\{ \frac{(U_s * (\log C_2 - \log C_1)) - (U_1 * \log C_2) + (U_2 * \log C_1)}{(U_2 - U_1)} \right\} \quad (1)$$

Where:

U_1 = measurement in mV of the first standard

C_1 = concentration of F in mg/l for the first standard

U_2 = measurement of mV of the second standard

C_2 = Concentration of F in Mg/l for the second standard

U_s = measurement in mV for the sample.

Main Interference's:

Al, OH

Interval 30 to 250 mg Na/l:

$$\text{mg Na/l in sample} = \text{Antilog} \left\{ \frac{(U_s \times (\log C_3 - \log C_2)) - (U_2 \times \log C_3) + (U_3 \times \log C_2)}{\quad} \right\} \quad (2)$$

$$(U_3 - U_2)$$

Where:

U_1 = measurement in mV for the first standard

C_1 = Concentration of Sodium in mg/l of the first standard (2 mg Na/L)

U_2 = measurement in mV for the second standard

C_2 = Concentration of Sodium in mg/l of the second standard (20 mg Na/L)

U_3 = measurement in mV for the third standard

C_3 = Concentration of Sodium in mg/l of the third standard (200 mg Na/L)

U_s = measurement in mV for the sample

Reagents :

- Sodium fluoride, NaF
- Tris (hydroxymethyl) aminomethane, $\text{NH}_2\text{C}(\text{CH}_2\text{OH})_3$
- Conc. Nitric acid, HNO_3 (optional)
- Sodium chloride, NaCl

Stock sodium solution

In a 500ml volumetric flask with funnel

1. Dissolve 0.9132g Sodium fluoride and dilute to mark with distilled water.
(1.00 ml is 1.00 mg Na or 1000mgNa/l)

Store in 500ml plastic bottle (PP) with airtight lid

Sodium standard solution (200 mg Na/l)

In a 250ml volumetric flask:

1. Add 50.00ml Stock Sodium solution and dilute to mark with distilled water.

Sodium standard solution (20.0 mg Na/l)

In a 250ml volumetric flask:

1. Add 25.00ml of 200 mg/L Sodium solution and dilute to mark with distilled water.

Sodium standard solution (2.00 mg Na/l)

In a 250ml volumetric flask:

1. Add 25.00ml of 20 mg/L Sodium standard solution and dilute to mark with distilled water.

All standard solutions should be stored in 250-ml glass flasks with airtight lid.

To protect against contamination a transfer parts of each standard solution to 50ml plastic (PE) bottles and use them as "working standard solutions".

Sodium TISAB (Total Ionic Strength Adjustment Buffer)

In a 250ml Erlenmeyer flask with funnel:

1. Add approximate 200 ml distilled water
2. Add 30.27g Tris(hydroxymethyl)aminomethane
3. Stir and adjust pH to 8..10 with Nitric acid (HNO_3) (this step is optional, the solution has pH lower than 10 most times)
4. Transfer to 250ml volumetric flask and dilute to mark with distilled water

Store in 250ml-glass flask with air tight lid.

Sodium TISAB (1+4):

In a 250ml volumetric flask add 50ml Sodium TISAB and dilute to mark with distilled water.

Store in 250ml glass flask with air- tight lid.

To protect against contamination transfer part of the solution to a 50ml plastic (PE) bottle and use it as "working TISAB (1+4) solution".

Sodium chloride (0.1M)

In a 250ml volumetric flask

1. add 1.46g NaCl and dilute to mark with distilled water.

Store in a 250ml glass bottle with air tight lid.

Note : See Appendix B for analytical procedures for other ions.

3.4 Data Analyses

Data was first analyzed to show the mean relative to the Maximum and Minimum values for each parameter. Standard deviation for each from the mean was also determined and the WHO standards set for all the chemical parameters tested shown. Linear regression analyses was used as a tool to determine whether two ranges of data correlated in order to find out whether large values of one set were associated with large values of the other (positive correlation), whether small values of one set were associated with large values of the other (negative correlation), or whether values in both sets are unrelated (correlation coefficient near zero).

Trend lines were used to graphically display trends in data and to help in prediction.

Arc view GIS was used to show the spatial distribution of boreholes in the study area.

Then show the various concentrations of fluoride. This is shown in Chapter Four

Surfer 32 was used to come up with contour maps showing the spatial distribution of fluoride ions.

CHAPTER 4

RESULTS AND INTERPRETATION

4.1 INTRODUCTION

Chemical analysis carried out in this study area were nearly all on ground water, exceptions being the two lakes and some of the major rivers. It has been remarked (Hem, 1959; Powell in Ven te Chow, 1964) as cited in Maina 1982) that a single sample from a groundwater source may represent closely the quality of water from that source for many years. The importance of groundwater quality has also been noted by Walton (1970) and Todd (1959) when they stated that quality of groundwater is of nearly equal importance to quantity. Data obtained from such chemical analysis is subject to interpretation.

A first step in data interpretation is the evaluation of the available data with respect to completeness, accuracy and reliability (Hem, 1959). Further, (Piper, 1944) remarked that most natural waters contain relatively few dissolved constituents with cations and anions in chemical equilibrium with one another. Checking on the accuracy of the data involved looking for reported zero concentrations for sodium or reported zero values less than a round number for sodium. (Hem, 1959) noted that any such reports probably contain some analytical error which may cause the total equivalents per million of cations to exceed the total anions. Analyses reporting zero values for some common constituents also may also be looked upon with suspicion, especially such combinations as zero calcium when some magnesium is present or zero chloride, except in very dilute waters. (Hem, 1959).

The data obtained from this study area is not subject to question of its completeness and reliability as the author carried out the analysis specifically for the study. A problem which may arise is that accuracy, but this is also minimized by the fact that the study is on groundwater where chemical constituents do not change frequently as is the case with surface water. Data collection, which was spread over a period of one month, should not affect accuracy of the data which should be representative of the waters in the area over a relatively long time.

A high standard of accuracy was maintained even on the data obtained from the analyses of these waters. As discussed above in Table 4.1 concentration values obtained were all above

detection limits. In fact no sodium value less than round figure is given. Further it is observed that all the waters had some chloride. All the water had some calcium, however low the concentration may have been and that there is no zero calcium value obtained where magnesium is present in one sample.

Table 4.1 The Chemical Composition of some ground waters with high and low fluoride levels in Lakes Baringo-Bogoria Basin

Sample Source	Location (GPS)		FL ⁻	pH	HCO ₃	SO ₄	Cl	NO ₃	Ca	Mg	Na	K	Hardness	Conductivity
	Long	Lat												
Tangulbei Mission	36.287	0.796	5.30	8.4	170	45	130.0		5.6	7.2	207.0	2.4	18.0	940.0
Tangulbei commun	36.287	0.801	1.90	8.1	252	30	30.0	0.5	8	7.2	169.0	6.5	50.0	735.0
Luyeya	36.134	0.685	7.20	8.3	1081	46.4	101.0		14.5	0.2	483.0	14.6	91.0	179.0
Katuwit Barbello	36.056	0.725	4.70											
Mutaro	35.967	0.340	6.00	8.3	178	16	12.0		4		100.0	31.0	10.0	400.0
Katuwit	35.966	0.394	5.30	7.7	1336	35.2	88.2		23.7	4.1	541.0	42.3	76.0	199.0
Komolion community	36.083	0.691	3.60	8.4	640	24	80.0		12	11.0	411.0	30.0	75.0	1700.0
Komolion dispensary	36.086	0.697	3.60	7.7	440	13	52.0		24	11.0	178.0	22.0	106.0	880.0
Nyalilpich	36.417	0.514	4.00	7.7	460	9.6			60	13.6	105.0	8.4	206.0	72.0
Mkongwo			3.60	8.7	705	20.2	203.0		18.3	3.7	424.0	12.3	400.0	880.0
St. Joseph	36.063	0.346	13.20	8.4	430	31	26.0		2.1	0.2	183.0	1.0	360.0	78.0
kiptangwany	36.138	0.554	6.00	7.9	230	5.3	0.5		4.9	0.1	83.0	3.4	10.6	39.0
Yatoi	35.961	0.493	0.90	7.6	522	1.2	9.5	1.9	25.2	6.9	160.0	5.0	91.4	73.0
Sutiechum	35.868	0.634	1.40	7.4	317	115	9.5	1.9	3	1.0	219.0	3.0	12.0	114.0
Kiplechiony	36.244	0.702	17.00	8.9	523	167	125.0	2.3	4.1	0.4	318.0	5.4		0.0
Ngaratuko	36.945	0.727	0.48	6.9	345	63	99.5	0.6	15	8.4	163.0	10.2		0.0
Naiben	35.975	0.729	0.47	7.9	492	10	8.5	6	37	10.2	139.0	7.5	134.0	75.0
Biretuonin	35.869	0.677	2.37	7.3	315	192	20.0	0.6	70	35.0	73.0	9.2	320.0	83.0
Chebarsiat	35.937	0.580	0.46	7.6	390	13	95.0	5.2	76	14.0	73.0	3.0	245.0	91.0
Donyasas	36.001	0.905	13.80	8.3	1103	37	25.0	0.6	45	415.0	5.0	5.0	157.0	177.0
Katkit	35.893	0.948	7.10	10.6	233	21	40.0	11	12	1.4	378.0	11.0	37.0	152.0
Chepkoi II	35.967	0.717	3.20	7.9	357	27	0.1	2	10	4.3	118.0	6.0	43.0	60.0
Katolimwa	36.190	0.502	1.00	8.3	289	4.4	0.1	1.8	25	11.0	38.0	9.0	109.0	46.0
Loitip	36.108	0.462	0.70	7.7	451	6.5	0.1	0.8	30	7.0	62.0	11.0	106.0	69.0
Kirim	36.159	0.336	0.45	7.2	631	0.3	13.0	1	183	0.0	406.0	11.0	406.0	85.0
Ngoswe	36.030	0.467	10.12	8.0	1211	93	36.0	36	26	0.0	54.0	9.0	48.0	94.0
SidanNgambo	36.056	0.483	13.04	10.5	630	3944	0.1	73	55	3.2	3349.0	16.0	150.0	1296.0
Iligarua	36.049	0.474	13.68	8.3	2503	2705	614.0	94	34	6.0	2557.0	21.0	112.0	958.0
Arusin	35.971	0.607	2.20	9.9	291	30	26.0	1.7	0.4	4.0	256.0	7.0	18.0	90.0
KiplechonyII	36.024	0.702	2.20	8.4	231	5	12.0	8	10.4	2.7	111.0	8.0	35.0	45.0
Barkibi	35.960	0.523	0.70	13.7	8.3	2503	215.0	<0.5	34	6.0	2557.0	21.0	0.0	

Sample Source	Location (GPS)		FL-	pH	HCO ₃	SO ₄	Cl	NO ₃	Ca	Mg	Na	K	Hardness	Conductivity
	Long	Lat												
Salabani(Nasinya)	36.000	0.533	1.60	7.1	10.6	233	21.0	0.2	0.2	12.0	0.0	0.0	0.0	
Chepkoiimet	36.038	0.313	3.90	7.1	309	20	14.0	13	19	10.0	102.0	7.0	42.0	52.0
Kailer	36.072	0.414	12.00	8.5	1813	215	130.0	13	4	3.0	863.0	4.0	284.0	
Muchogoi			11.00											
kiplelechiog	36.025	0.708	17.00	8.9	523	167	125.0	32.3	4.1	6.0	318.0	5.4		
Ngaratuko	35.945	0.727	0.50	6.9	34.5	63	100.0	0.6	15	0.1	163.0	10.2		
Tabarngetuny	35.964	0.445	1.80	8.0	556	7	16.0	1.5	20	3.0	188.0	14.0	61.0	
Ndonyosas	36.001	0.905	13.80	8.3	1103	37	25.0	0.6	44.8	11.0	415.0	5.0	157.0	177.0
Chemeril	36.068	0.909	4.50	7.1	323	27	27.0	4	14	0.8	122.0	10.0	37.0	65.0
Sosiende	36.163	0.394	13.00	10.5	630	3944	8.4	73	55	3.2	3349.0	19.0	150.0	1276.0
Kagir	35.955	0.799	2.10	7.9			36.0	2.9	9.6	4.9	325.0			
Ramacha 1*	36.034	0.553	dry											
Karma	36.214	0.504	0.42	7.6			15.0	7.7	42.4	49.6	50.0			
Rugus	36.123	0.641	0.70	7.3	617	4	30.0	2	45	10.0	227.0	9.0	155.0	98.0
Tabarweche	36.000	0.379	2.40	7.9		59.4	9.0	1.3		15.5	134.0			
Cherombo	36.366	0.719	0.68	7.5		11.4	80.0	5	20	15.5	165.0			
Kapkun	35.893	0.001	0.66	7.4		1.4	10.0	16.7	60.1	29.6	134.0			
Kinarok	35.937	0.470	0.65	8.4	522	4	23.0	0.8	16	12.0	180.0			
Cheparsiat	35.937	0.580	0.50	7.6	390	13	95.0	1.7	76	14.0	73.0	3.0	245.0	91.0
Kiplelchionyl	36.024	0.702	17.00	8.9	523	167	125.0	2.3	4.1	0.4	318.0			
Kaptombes	36.056	0.406	1.60	9.6		39	76.0	2		1.0	6.8			
Kambi turkana	35.985	0.481	1.80	9.0		5.04	15.0	2	2.4	1.5	186.0			
Marigat Div office	35.985	0.472	0.50	11.0	4	7	4.0	1.2	26	8.0	16.0	3.0	97.0	
Silonga	36.001	0.333	0.84	8.4		8.7	37.0	3	15.2	8.8	185.0			
Ngambo(logasi)	36.056	0.483	13.00	10.5	630	3944	804.0	73	55	3.2	3349.0			
Kiplelchionyl 2			2.20	8.4	231	5	12.0	8	10.4	1.0	111.0		8.0	31.0
Arusin	35.971	0.605	2.18	9.9	291	30	26.0	1.7	0.4	4.0	256.0			
Barkibi	35.967	0.517	0.70	7.4		5	10.0	1.6	52	7.0	84.0			
Tabargetuny'	35.964	0.445	1.80	8.0	556	7	16.0	1.5	20	3.0	188.0			
Marigat Sec Sch	35.983	0.466	0.50	7.6	143	4	7.0	1.2	26	8.0	16.0		155.0	26.0
Natan	36.200	0.544	4.00	9.5	581	42	81.0	2	23	315.0	2.0	17.0	135.0	
Ramacha 2	36.193	0.544	0.70	7.3	617	4	30.0	2	45	10.0	227.0			
Mosuro 2	36.104	0.528	27.00	8.3		5376	4150.0	9.8	6.4		8016.0			
sagasaki	35.867	0.083	0.80	8.4		0.25	12.0		39	42.0	97.0	17.0		770.0
Eldama ravine	35.783	0.083	2.10	7.0		0.3	15.0							760.0

Sample Source	Location (GPS)		FL-	pH	HCO ₃	SO ₄	Cl	NO ₃	Ca	Mg	Na	K	Hardness	Conductivity
	Long	Lat												
Tangulbei	36.283	0.800	0.20	8.7		14	31.0		21	21.0	158.0	3.3		960.0
chemlingot	35.967	1.067	2.50	2.5		25	22.0	0.01	3	0.5	273.0	5.0		126.0
Nginyang	36.070	0.950	18.00	7.6	3708	453	670.0	0.01	2	22.0	1304.0	16.0		200.0
Kabarnet water supply	35.733	0.483	1.40	7.6		2	6.0	0.00	12	1.0	23.0	7.6		15000.0
Kositei	35.883	1.083	11.00	9.0		72	8.0	0.00	2.5	8.4				430.0
Chesirimoni	36.083	0.800	2.80	8.1		0.25	30.0	0.00	4		210.0	8.0		5600.0
Ngambo	36.067	0.467	35.00	8.6		309	904.0	0.01	2	2.9				180.0
kabarnet town	35.738	0.490	0.70	7.3		0.3	3.0		9.6	1.9	15.0	8.6		
SidanNgambo			4.00	9.5	581	42	81.0	2	4.8	3.0	315.0	6.3	17.0	135.0
Kiptum	35.883	0.000	0.45	7.2			20.0	0.01	1.2					
Kelewa	35.917	0.033		6.9	244	0.3	12.0	0.00		0.9		10.0		130.0
Edama Ravine	35.733	0.050	3.00	6.7		1.3	6.0	0.00	3					
Kisanana	36.083	0.017	3.60	7.0	140	0.3	11.8	0.00	0.6					
Ndabibi	36.100	0.000	1.30	7.1		8	8.0	0.00	4	0.1	38.0	0.6		310.0
Edama ravine	35.733	0.050	1.00	7.6		3.8	10.0	0.00	5	4.9	57.0	4.0		245.0
Sinoni Muchogoi	36.215	0.153	0.52	7.2		14	6.0	0.32	8	2.9	55.0	9.1	32.0	291.0
Muchungoi	36.164	0.152	1.30	7.6		17		0.23	14	75.0	4.8	98.0	204.0	0.5
Muchungoi	36.167	0.167	2.10	7.8		18	20.0	0.26	0.8	5.3	98.0	5.9	24.0	499.0
Muchungoi	36.158	0.158	0.84	8.2			7.0	6.89	4.8	2.0	14.5	5.1	20.0	586.0
Muchungoi	36.217	0.124	0.64	7.4			15.0	0.26	8	2.4	41.0	8.0	30.0	250.0
Muchungoi	36.168	0.164	0.68	7.5		11	384.0		83.2	15.1	68.0	4.4		782.0
Mukutan	36.328	0.801	2.10	8.3		60	62.0	0.59	4.8	0.5	180.0	6.6	14.0	804.0
Mukutan	36.274	0.746	1.80	8.0		20	46.0	0.30	6.4	8.3	135.0	7.2	50.0	692.0
Tangulbei	36.370	0.779	1.20	8.4		51	250.0	8.00	24	12.6	390.0	25.0	112.0	2050.0
Olkokwe island	36.070	0.600	5.77	7.6		133.0	32.0	0.67					422.0	0.6
Oasis	35.850	0.130	2.00	7.9		7.0	72.0		52	11.0	125.0	19.0		530.0
kisanana centre	36.050	0.033	2.10	7.2		7	34.0		5	0.4	101.0	10.0		1600.0
A.I.C Ebenezer	35.880	0.110	2.80	7.9		9.0	72.0		4	20.2	129.0	23.0		592.0
Ngubereti	35.910	0.050	3.00	8.2		8.0	76.0		19	5.1	83.0	22.0		481.0
Ngedelel	35.910	0.050	2.70	7.4		9.0	57.0		8	0.1	11.0	1.0		335.0
Kisanana Center			2.10	7.2		34.0	34.0		5	0.4	101.0	10.0		510.0
Bogoria spring 1	36.160	0.200	6.00	9.8		20	2979.0				498.0	85.0		
Bogoria spring 2	36.130	0.200	6.50	9.7		22	2739.0				340.0	14.0		
Bogoria Spring 3	36.090	0.240	4.20	9.2		15	602.0				142.0	37.0		
Bogoria Spring 4	36.100	0.230	1.90	8.8		12	2240.0				544.0	37.0		

Sample Source	Location (GPS)		FL ⁻	pH	HCO ₃	SO ₄	Cl	NO ₃	Ca	Mg	Na	K	Hardness	Conductivity
	Long	Lat												
Bogoria Spring 5	36.090	0.230	3.60	9.3		11	2206.0				669.0	14.0		
Bogoria Spring 6			3.70	8.1		8	73.0				14.0	4.0		
Bogoria Spring 7	36.120	0.210	7.80	9.7		6	3295.0				494.0	2.0		
Arus Spring	35.960	0.170	2.72	7.7		20	34.0				9.0	12.0		
Embogong spring	35.100	0.170	3.30	6.5		7	69.0				42.0	8.0		
Lake Baringo	36.050	0.500	6.90	9.1	384	23	48.5		9.2	5.2	192.0	18.8		
Lake Bogoria	35.970	0.270	1690.00	10.6			16938.0							
Lake Bogoria hot spring	36.080	0.260	108.80	9.2			550.2							4520
River molo	36.058	0.358	4.54											
River perkerra	36.162	0.397	0.39											

Table 4.2 Statistical analysis of the data

Parameters	Min (ppm)	Max (ppm)	Mean (ppm)	Std Deviation (ppm)	WHO Std(1996) (ppm)
pH	2.50	13.70	8.09	1.40	6.50-8.50
F-	0.20	1690.00	25.77	185.30	1.50
K	1.00	98.00	11.92	14.86	No Std
Mg	>0.1	415.00	15.97	54.03	100.00
Na	2.00	8016.00	385.97	986.78	200.00
Ca	0.80	183.00	21.58	25.94	250.00
NO ₃	0.01	94.00	8.55	17.26	
Cl-	0.05	16938.00	384.03	1171	250.00
SO ₄	0.25	5376.00	248.00	886.11	250.00
HCO ₃	4.00	3708.00	537.14	608.24	

Estimates standard deviation based on a sample. The standard deviation is a measure of how widely values are dispersed from the average value (the mean).

$$\text{Standard deviation} = \sqrt{\frac{n \sum X^2 - (\sum X)^2}{n(n-1)}} \quad (3)$$

$$\text{The mean} = \frac{\sum X}{n} \quad (4)$$

Where n is number of samples and X is the concentration of the sample

Statistical analysis (Table 4.2) of the data portrays very large standard deviation, most of which exceed the mean value. This alone to a large extent indicates enormous temporal and spatial variations in water composition in the study area.

Some of the parameters also exceed the Who Standard set standard for drinking water. The mean values for Na, Cl, F are way above the set standards.

The maximum values observed in this data are from Lake Bogoria which has unique high chemical concentrations, it has the highest recorded fluoride concentration of 1690 ppm.

Table 4.3 Borehole depth analyses

Boreholes Depth	Mean	Max	Min	Std deviation
Depth(metres)	89.6m	200m	14m	43.23m

The depth of the boreholes varies from as low as 14m to 200m depending on the formation encountered.

Table 4.4 Pearson's product moment correlation coefficient(r) for the data collected

Parameters	Ca ²⁺	Na ⁺	K ⁺	F ⁻	Cl ⁻	HCO ₃ ⁻	Mg ²⁺	SO ₄	pH	Con	Hardness
Ca ²⁺		0.09	0.06	-0.14	-0.03	0.03	0.11	0.15	0.06	-0.08	0.62
Na ⁺	0.09		0.09	0.76	0.54	0.32	0.09	0.94	0.06	0.03	0.06
K ⁺	0.06	0.09		0.06	0.44	0.27	0.11	0.09	0.29	-0.02	0.07
F ⁻	-0.14	0.76	0.06		0.43	0.66	-0.05	0.54	0.22	-0.07	0.13
Cl ⁻	-0.03	0.54	0.44	0.43		0.62	0.09	0.38	0.23	-0.04	0.10
HCO ₃ ⁻	0.03	0.32	0.27	0.66	0.62		0.19	0.19	0.02	-0.04	0.26
Mg ²⁺	0.11	0.09	0.11	-0.05	0.09	0.09		0.05	0.19	-0.04	0.03
SO ₄	0.15	0.94	0.09	0.54	0.38	0.19	0.05		0.33	0.04	0.03
pH	0.06	0.06	0.29	0.22	0.23	0.02	0.19	0.33		0.01	0.02
Conductivity	-0.08	0.03	-0.02	-0.07	-0.04	-0.04	-0.04	0.04	0.01		-0.09
Hardness	0.62	0.06	0.07	0.13	0.10	0.26	0.03	0.02	0.02	-0.09	

Pearson product moment correlation coefficient, r, a dimensionless index that ranges from -1.0 to 1.0 inclusive and reflects the extent of a linear relationship between two data sets.

$$r = \frac{\sum XY - (\sum X)(\sum Y)}{\sqrt{n\sum X^2 - (\sum X)^2} \sqrt{n\sum Y^2 - (\sum Y)^2}} \quad (5)$$

Where;

X is a set of independent values.

Y is a set of dependent values

From the Table 4.4 we observe that Fluoride ions have a negative linear relation with Calcium and Magnesium ions however it has a very strong linear relationship with HCO_3^- , Na ions.

There is a positive linear relationship between fluoride ions and bicarbonate ions(Figure4.1).This shows that bicarbonate waters are most likely to have concentrations of fluoride ions.

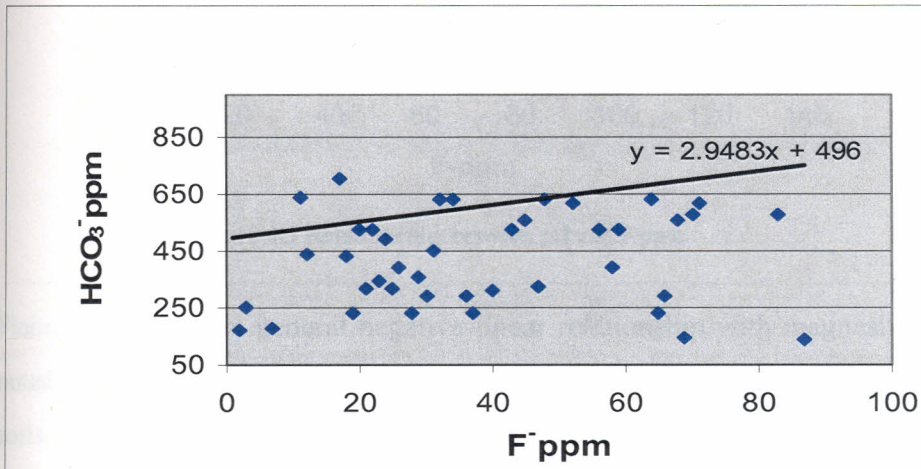


Figure 4.1 Relationship between HCO_3^- and F-ppm

There is a negative linear relationship between fluoride and calcium ions(Figure 4.2), this inference is supported by the fact that the solubility of a sparingly soluble scale of CaF_2 is dependent on the concentration of Ca ions in water and that the later is in turn influenced by common ion effect ,and fluoride minerals such as apatite and fluorspar that contain CaF_2 .

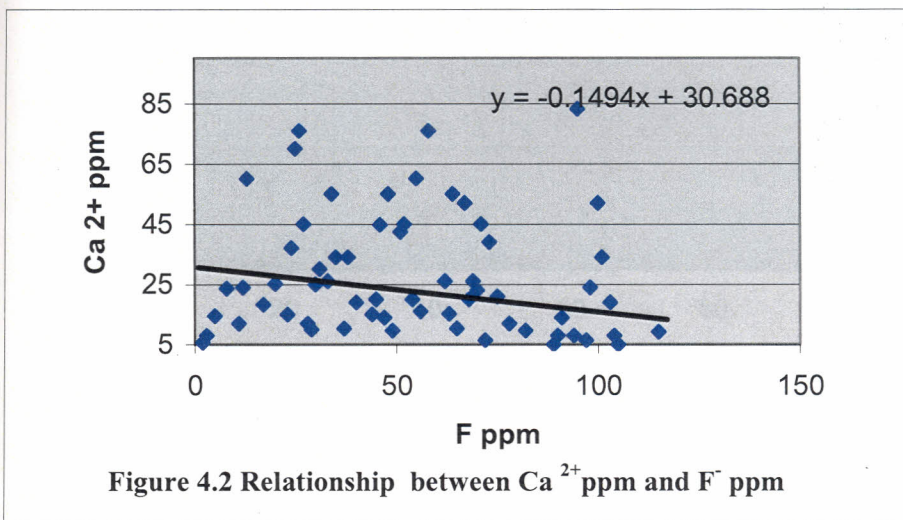


Figure 4.2 Relationship between Ca^{2+} ppm and F⁻ ppm

Most samples pH fall in the range of 7-10 on the pH scale moving towards alkalinity(Figure4.4)

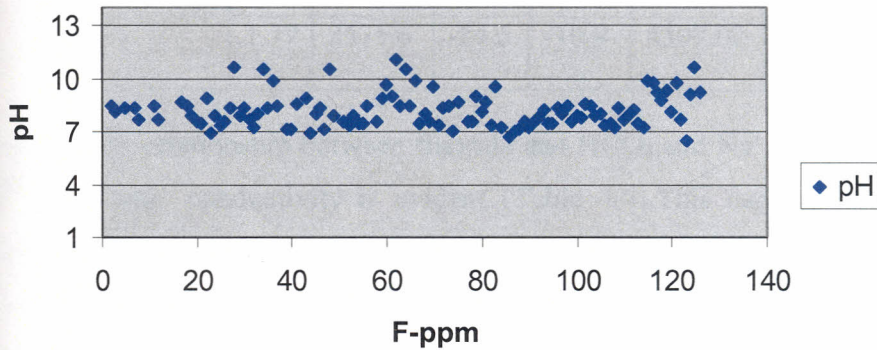


Figure 4.3 Relationship between pH and F-ppm

Fluoride ions have a general negative linear relationship with magnesium ions .the relationship noted might have a bearing on the dissolution of fluorides from Brucite magnesite huntite and soils. Note that the correlations in Figures 4.4 and 4.2 are quite weak due to the fact we are not dealing with a perfectly homogeneous CaF_2 system but a heterogeneous system where the water interacts with different minerals such as biotites, calcite ,brucite, fluospar as shown in the appendixes, these are all source of fluoride, magnesium, calcium all in varying concentrations.

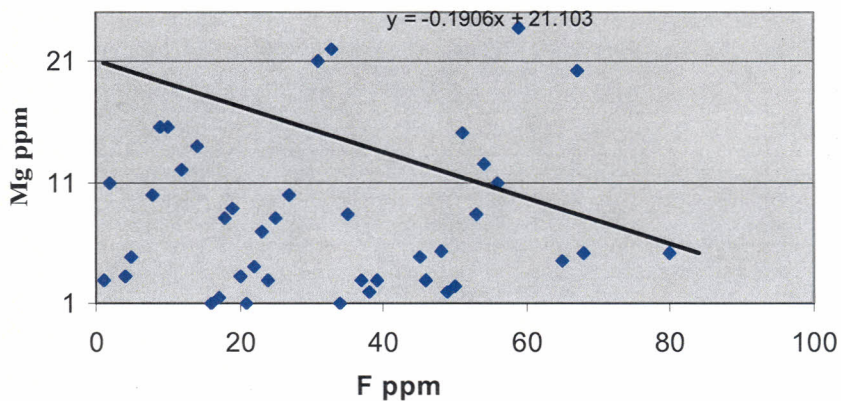


Figure 4.4 Relationship between Mg^{2+} ppm and F-ppm

Table 4.5 Covariance between fluoride ions and various parameters .

Parameter	pH	HCO ₃ ⁻	Ca ⁺²	Mg ⁺²	Na ⁺	K ⁺	Conductivity
F-	1.77	2575.6	-24.5	-10.9	4397.02	4.58	-1040.42

A very strong relationship between fluoride and HCO₃⁻ and Na⁺ and a negative relationship with Mg⁺², Ca⁺² and conductivity is evident (Table 4.4). This can be explained by the fact that dissolved salts such as Na⁺ and HCO₃⁻ are high in concentration while the contents of Mg and Ca are very low in concentration thus the water is very soft. Therefore generally speaking fluoride containing waters are normally very soft.

Most of the waters plot on the HCO₃⁻ side implying that most the waters in the study are generally associated with high bicarbonate ions therefore as inferred (Figure 4.5) alkalinity may have some bearing on dissolution of fluorides from weathered rocks and soils. There is also some chloride in this waters this was expected since chloride a major dissolved constituent of most natural water. Some waters also show some acidity evidenced by samples falling on the 70-55% grid on the sulphate tip.

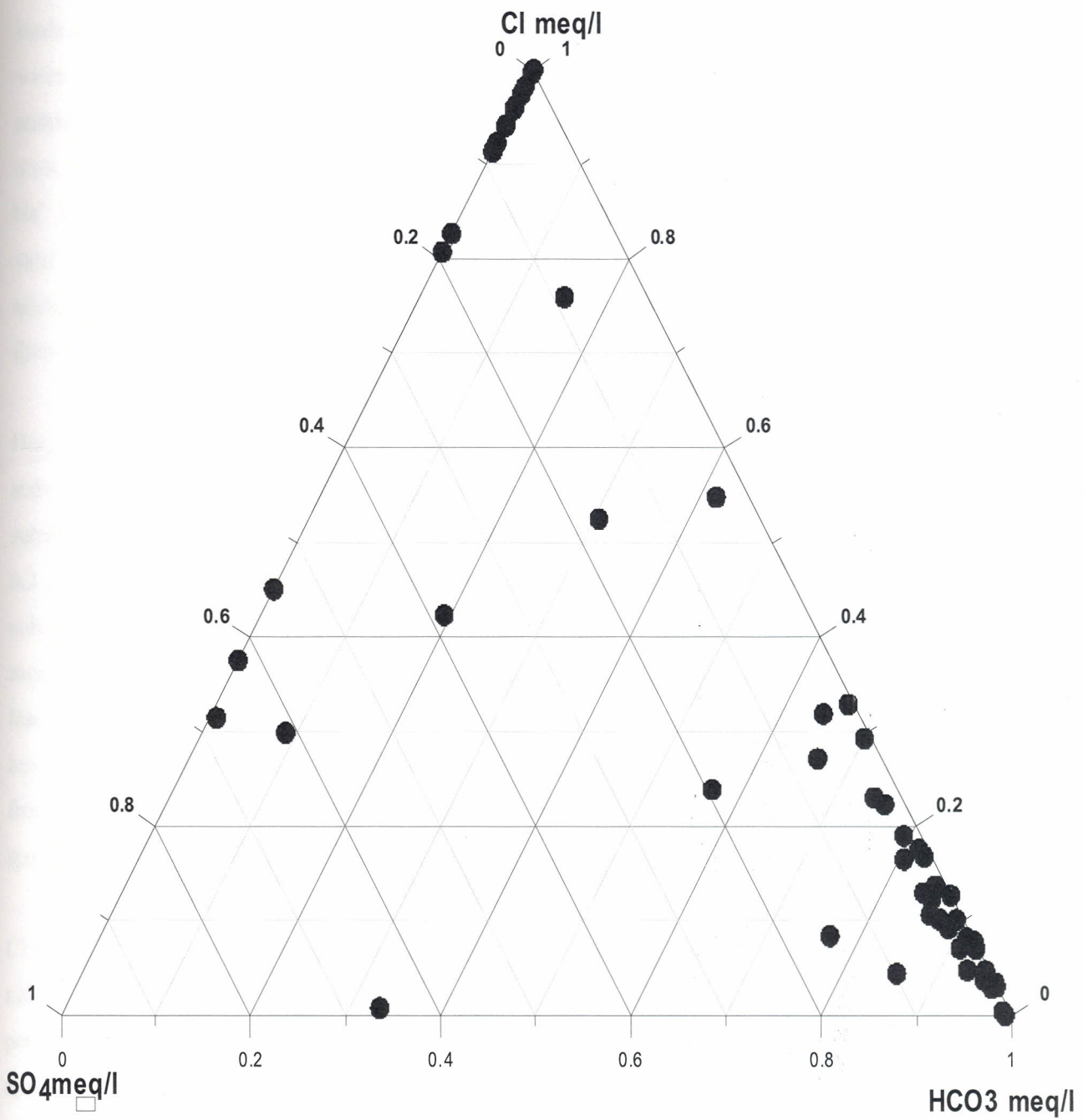


Figure 4.5 Ternary diagram

4.2 CHEMICAL CHARACTERISTICS OF CONSTITUENTS CONSIDERED IN THE STUDY

Water is an excellent solvent and all ground waters contain salts carried in solution. However, the kinds and concentrations of salts depend upon the environment, movement and source of ground water (Todd, 1959). (Davis and De Wiest 1966 as cited in Maina, 1982) observed that the number of major dissolved constituents in groundwater is limited. Piper (1944) observed that the most abundant cation constituents are two Alkaline earth's Ca^{2+} and Mg^{2+} , and also one alkali Na^+ . He noted that K^+ also occurs, but is less abundant than sodium. Further, he observed that the most common anions-constituents were the weak acid bicarbonate (HCO_3^-) as also two strong acids, Sulphate (SO_4^{-2} and Chloride (Cl^-). Less common cation and anion constituents such as fluoride (F^-) were observed to occur in appreciable quantities.

4.2.1 Sulphate

Despite a relatively large amount of sulphur, mostly in the form of sulphates, in water and in sedimentary rocks, sulphur is only a minor constituent of igneous rocks. Natural sources of sulphates are sulphide ores, gypsum and anhydrite. Concentrations of sulphate from less than 0.2 ppm are found in nature. The lowest concentrations of sulphate are in rainwater, snow and subsurface water subject to sulphate reduction. Ground water from igneous and metamorphic rocks or from sediments derived from them, generally contain less than 100 ppm and may contain less than 1ppm if sulphate reducing bacteria are active in the soil through which recharge water has percolated. In the study area the data exhibits very wide variations the standard deviation from the mean is 886 ppm which is very high showing that there is enormous temporal and spatial variations in water composition in the study area.

4.2.2 Chloride

Chloride is a minor constituent of the earth's crust, but a major dissolved constituent of most natural water. All chloride salts are highly soluble, so chloride is rarely removed from water by precipitation except under the influence of freezing and evaporation (Hem 1959). Sodalite and apatite are the only common minerals in igneous and metamorphic rocks which contain chloride as an essential constituent although micas, hornblende and natural glass may also contain significant amounts, most chloride in ground water comes from different sources.

1. Solution of halite and related minerals in evaporite deposits
2. Solution from the fall out from the atmosphere particularly in arid regions.

3. A locally important source may be from volcanic water in hot spring systems.

Shallow ground water in regions of heavy precipitation contains from 1.0 to 30 ppm of chloride. Concentration of 1000 ppm or more are common in ground water from arid regions. In this study the concentrations had a mean of 384.03 ppm and a standard deviation of 1117 ppm.

4.2.3 Pottasium

Common sources of potassium in this area are products formed by weathering of Feldspars (orthoclase & microcline), some micas (such as biotite), and clay minerals. All natural waters contain low measurable amounts of potassium. This is due to the relative immobility of potassium owing first to the fact potassium enters into the structure of certain clay and clay minerals during weathering and second due to the high resistance to weathering of many potassium minerals in relation to sodium minerals (Hem, 1959). In this study the concentrations had a mean 11.9 ppm and a standard deviation of 14.86 ppm.

4.2.4 Sodium

The primary source of most sodium in natural water and in this area in particular is from the release of soluble products during the weathering of plagioclase feldspars (albite sodium end member) Hem, (1959). Clay minerals may have also released large quantities of exchangeable sodium.

4.2.5 Calcium

In this area calcium in the waters could be the result of weathering which releases calcium from minerals such as apatite, wollastonite, fluorite, calcite, aragonite, clays and various members of the feldspar, amphibole and pyroxene group. In as much as calcium is both abundant in the earth's crust and extremely mobile in the hydrosphere, it is one of the most common ions in the subsurface water. Concentrations of calcium in normal potable water generally range between 10 ppm and 100 ppm. The mean (22.58 ppm) value for this ion in this area fall within this range. However as observed with magnesium ions this value is quite low permitting the high values of fluoride ions observed.

Table 4.6 Results of Biretuonin as per PCWATEQ

PHASE	IAP	KT	LOG IAP	LOG KT	IAP/KT	LOG IAP/KT
18ANHDRITE	5.809E-07	4.130E-05	-6.236	-4.384	1.406E-02	-1.852
22ARAGONITE	2.136E-09	4.613E-09	-8.670	-8.336	4.630E-01	-3.34
15IARTIN	4.408E-26	3.981E-19	-25.356	-18.400	1.107E-07	-6.956
20 BRUCITE	9.642E-18	183.890E-12	-17.016	-11.410	2.478E-06	-5.606
13 CALCITE	2.136E-09	3.313E-09	-8.670	-8.480	6.447E-01	-.191
12 DOLOMITE	2.129E-18	8.128E-18	-17.672	-17.090	2.619E-01	-.582
63 FLUOR	5.995E-12	1.096E-11	-11.222	-10.960	5.468E-01	-.262
19 GYPSUM	5.806E-07	2.498E-05	-6.236	-4.602	2.324E-02	-1.634
65 HALITE	2.708E-06	3.819E+01	-5.567	1.582	7.091E-08	-7.149
118 HUNTITE	2.115E-36	3.090E-31	-35.675	-30.510	6.845E-06	-5.165
11 MAGNESIT	9.968E-10	5.754E-09	-9.001	-8.240	1.732E-01	-.761
67 MIRABI	3.347E-08	7.709E-02	-7.475	-1.113	4.341E-07	-6.362
59 NAHCOL	2.453E-05	2.831E-01	-4.610	-.548	8.664E-05	-4.062
61 NATRON	1.230E-10	4.887E-02	-9.910	-1.311	2.518E-09	-8.599
150 NESQUE	9.960E-10	6.152E-06	-9.002	-5.211	1.619E-04	-3.791
66 THENAR	3.356E-08	6.622E-01	-7.474	-.179	5.067E-08	-7.295
62 THR NAT	1.233E-10	1.334E+00	-9.909	.125	9.248E-11	-10.034
60 TRONA	3.025E-15	1.603E-01	-14.519	-.795	1.887E-14	-13.724

4.2.6 Bicarbonate

Ground water generally contains more than 10 ppm but less than 800 ppm bicarbonate. Concentration between 50 and 400 ppm are most common. Only rarely will ground water have pH values of less than 4.5 causing bicarbonate to be converted to carbonic acid, or pH values of more than 8.2, so that the bicarbonate ions will dissociate to carbonate ions (Hem, 1959). In the study the bicarbonate ions average 537.14 ppm and the mean pH values are also quite high there is therefore a possibility of this ions dissociating to carbonate ions the main reason the waters of Lake Bogoria are cloudy with a concentration of bicarbonate ions being 3708 ppm.

4.2.7 Fluoride.

It is generally agreed that volcanic activity and the resistant volcanic rocks are responsible for the exceptionally high fluoride concentration in natural waters. In East- Africa Volcanics and various extrusive rocks are concentrated in the rift zone (Nanyaro et. al.,1984). Fluoride is frequently found in igneous rocks as a component of amphiboles such as hornblend and certain other materials. Alkaline rocks(Basalts, trachytes and phonolites that cover most of the study area are in general high in fluoride than most other igneous rocks . According to (Hem, 1959) in ground water fluoride concentrations of 10ppm or more are rare.¹ However this not true of the study area most of the samples are above this value with a few pockets having less than 10ppm.The WHO

¹Fluoride concentrations of 10ppm or more are rare (Hem, 1959).

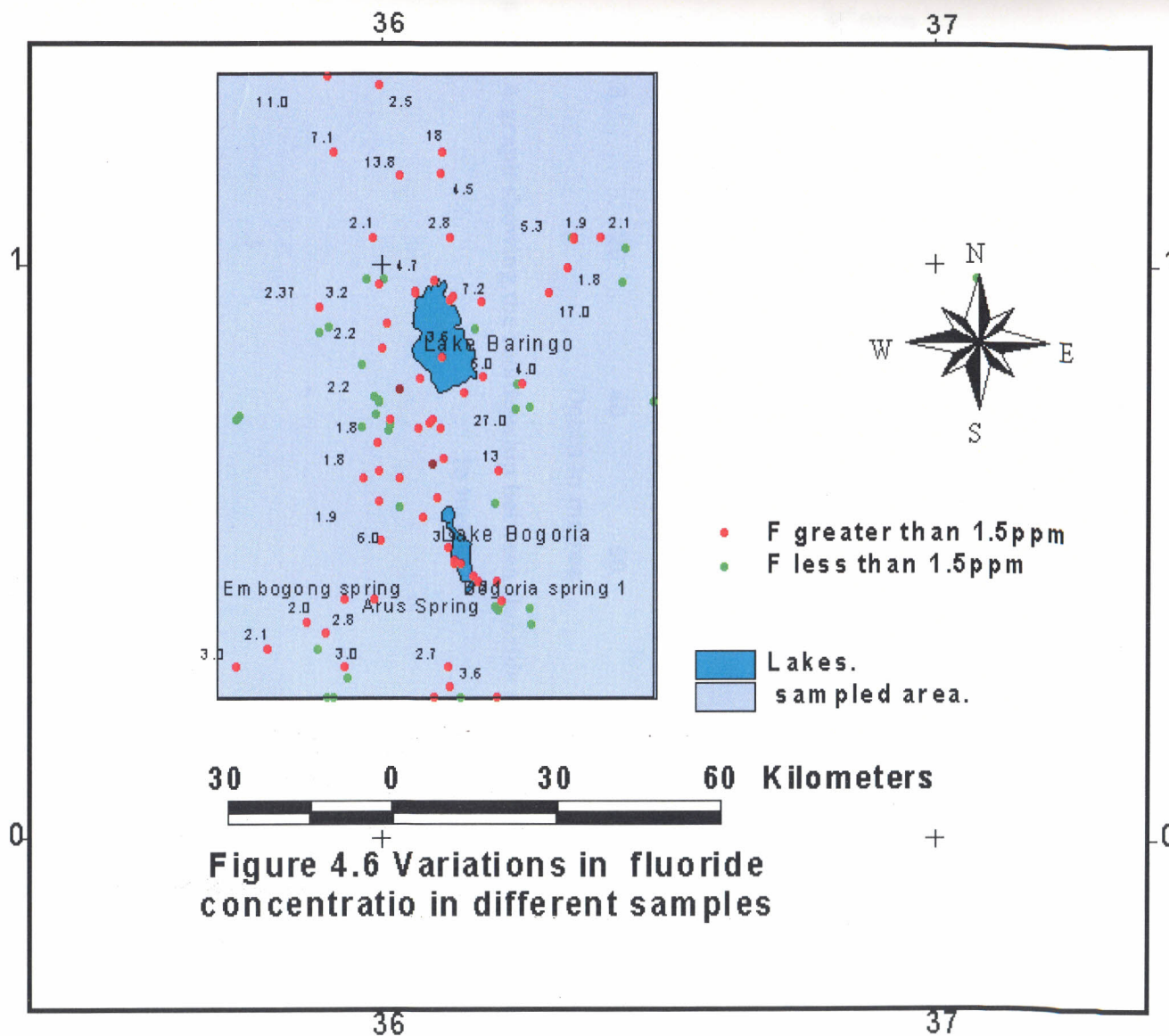
set standard of 1.5ppm has been exceeded by a very large magnitude with a mean of 25.7ppm and a standard deviation of 183ppm(Table 4.2).Its possible from PCWATEQ Table 4.6 run that mica's(albite, phlogopite ,adularia see appendix for more) from the weathering of the above mentioned rocks i.e.trachytes, basalts maybe responsible for the high fluoride concentrations.

4.2.8 pH

(Hem,1959) observed the pH values are often used as a measure of the solvent power of water or as an indicator of the chemical behavior certain solution may have toward rock minerals The pH values are therefore a means of stating the balance of certain chemical equilibria in water solutions(Hem,1959).For this reason laboratory determinations were preferred to field determinations for purposes of this study, as earlier stated laboratory determinations may better represent conditions under which the water will be used(Hem,1959). Most of the waters in this area have a pH that ranges from 7-10 on the pH scale.

4.2.9 Magnesium

The common sources of magnesium in the hydrosphere are dolomite in sedimentary; olivine ,biotite, hornblende, and augite in igneous rocks; and serpentine, talc, diopside ,and tremolite, in metamorphic rocks. Despite the higher solubilities of most of its compounds, magnesium is generally found in lesser concentrations in natural water than is calcium (Hem, 1959).This is probably owing to the slow dissolution of dolomite together with the greater abundance of calcium in the earth's crust. Common concentrations of magnesium range from about 1-40ppm.Water from rocks rich in magnesium may have as much as 100ppm.



No relationship could be established between fluoride concentration and depth of the boreholes. Wide differences were noticed in the concentration of the ion in the samples from boreholes having approximately equal depth and situated in the same vicinity. As shown in figure 4.7

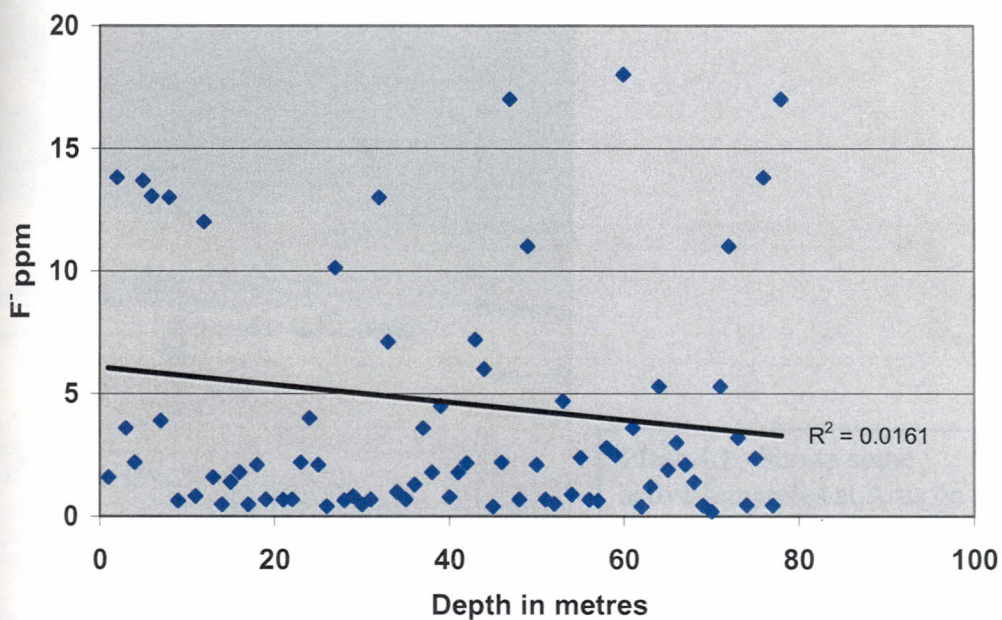


Figure 4.7 A graph showing the relationship between fluoride concentration in ppm and depth in metres



Plate 4.1 Shows some active fumaroles at Arus on River. Molo



Plate 4.2 Shows a very active geyser that rises several metres high at temperature above 100°C

In Figure 4.9 we observe fluoride concentrations haloes mainly within the central part that's composed of alluvial tracts and basalts and also to the north of Lake Baringo where faults small faults are concentrated and to the south on Lake Bogoria where there is a high manifestation of geothermal activity. The same is observed in Figure 4.10 Fluoride concentrations greater than 2ppm(in red are more pronounced in the central part of the study area; north of Lake Baringo, on the Lobi plains and in the south around Lake. Bogoria

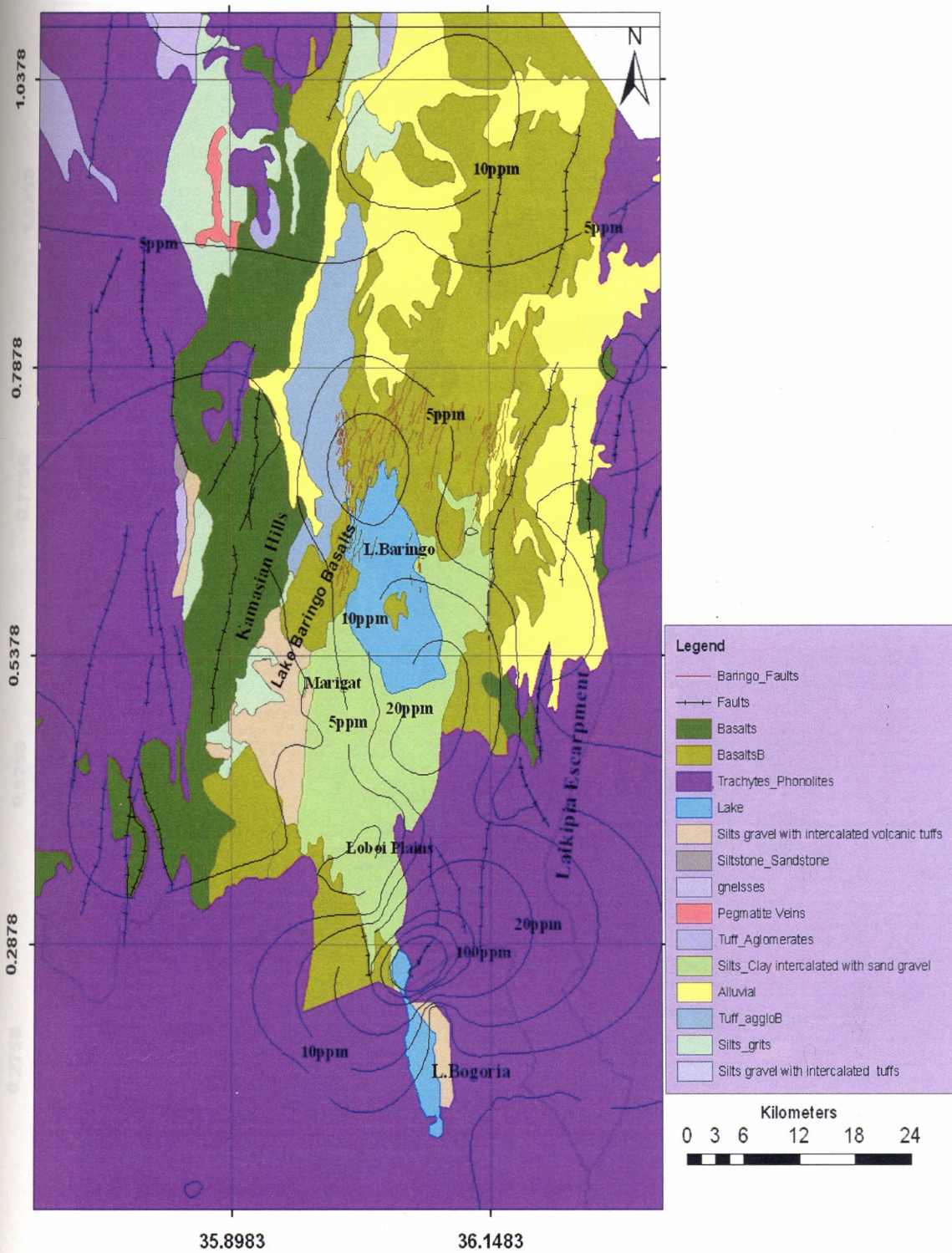


Figure 4.9 Distribution of fluoride ions in relation to geology

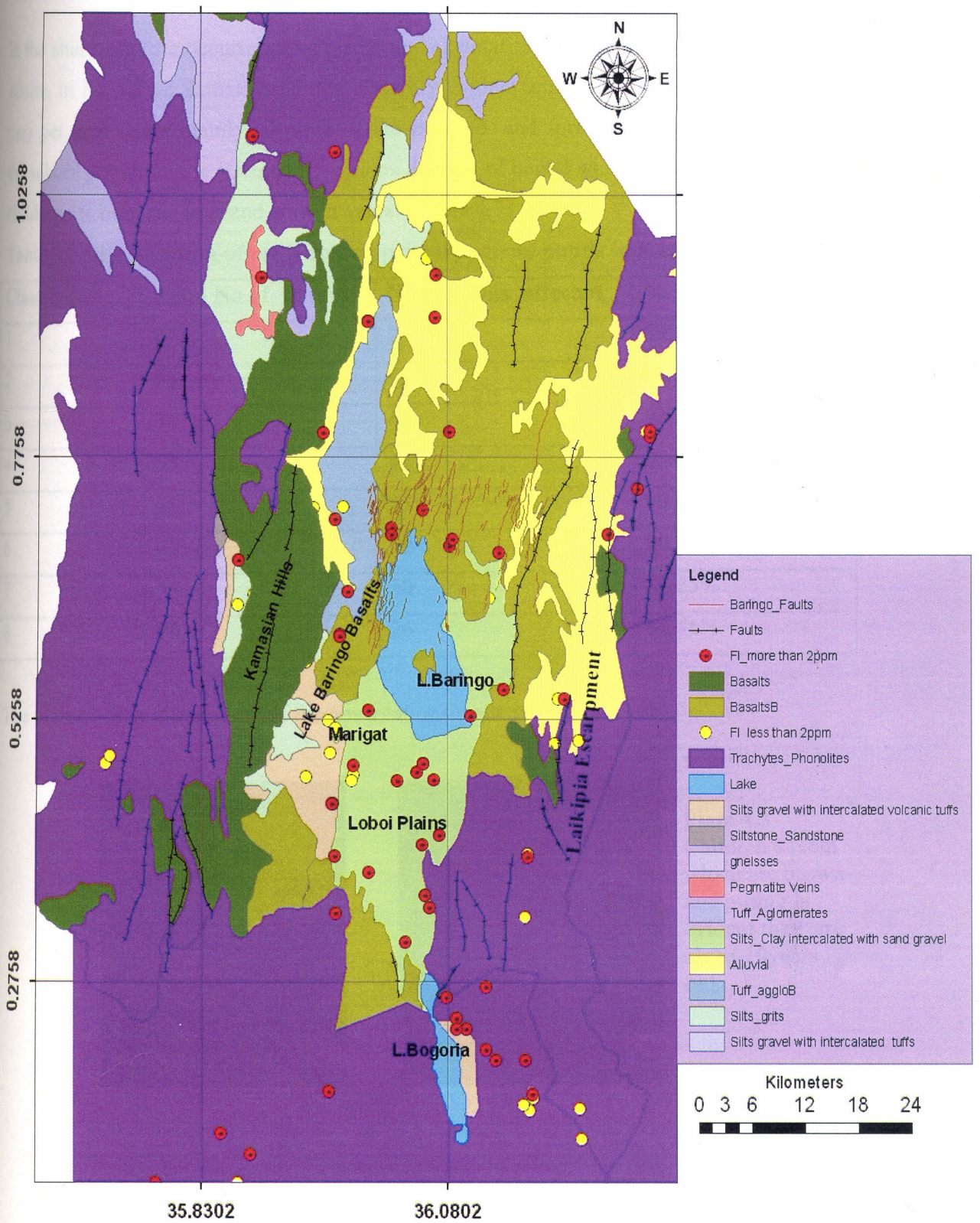


Fig 4.10 Fluoride concentration in ppm in relation to geology, Fluoride less than 2ppm yellow in color and more than 2ppm red in color.

4.3 Fluorosis

In the study area the occurrence of dental and skeletal fluorosis was noted in children and even in adults. In Kambi ya Samaki area this was very evident among the students of the primary school they get their water mainly from the Lake Baringo and surrounding boreholes. Ninety percent of the school population is affected by various degrees of dental and skeletal fluorosis. The ages of the children is between four and sixteen years. (Table 4.7)

Table 4.7 Discoloration of teeth among primary school pupils in Kambi ya Samaki

Class	Total No.of Pupils	No.of pupils affected	% No
1	87	75	89.33%
2	74	68	91.89%
3	74	69	93.24%
4	55	47	85.45%
5	61	55	90.16%
6	65	59	90.77%
7	56	50	89.25%
8	28	26	92.86%

The plates below show some of the observations made in the study area.



Plate 4.3
Children's teeth which are brown and pitting is evident they are about 10 years old.



Plate 4.4 Adult
 Browning and chipping of the teeth. The teeth are already damaged while still in the formation stages in the gums. Once the new teeth become visible its too late to intervene.

4.3.1 Classification of mottled enamel

The most widely used assessment of dental fluorosis is that developed by (Dean, 1942) Who classified the degree of clinically observed mottling into seven categories, ranging from 'normal' to 'severe' as given below

1. Normal the enamel is translucent, smooth and presents a glossy appearance;
2. Questionable-seen in areas of relatively high endemicity and occasional cases are border line and one would hesitate to classify them as apparently normal.
3. Very mild-small, opaque. Paper white areas are seen scattered irregularly over the labial and buccal tooth surfaces;
4. Mild the white opaque areas involve at least half of the tooth surface , and faint brown stains are sometimes apparent; Plate 4.2b
5. Moderate generally all tooth surfaces are involved, and minute pitting is often present on the labial and buccal surfaces (brown stains are frequently a disfiguring complication).Plate 4.2
6. Moderately Severe pitting is marked, more frequently and generally observed small tooth surfaces and brown stains, if present, are generally of greater intensity and
7. The severe hypoplasia (Plate4.2) affect the form of tooth and stains are widespread and vary in intensity from deep brown to black (this condition may sometimes be referred to as 'corrosion' type of mottled enamel).



Plate4.5 Skeletal fluorosis

Disturbed growth of skeleton resulting in deformities. This is especially a problem in the joints as it restricts movement, in several cases causing complete immobility.

CHAPTER 5

5.0 HYDROGEOLOGY

5.1 INTRODUCTION

Ground water occurrence is controlled by the available geological conditions. The project area is situated in a zone with low-medium to high ground water potential. Ground water occurs in weathered and fractured zones in volcanic rocks; sediments interbedded between volcanic rocks; and alluvial and torrent wash deposits. Fresh volcanic rocks are known to be virtually compact and with no intergranular or primary porosities and thus their storage and transmitting capacities are limited. Large variations in rainfall are related to the physiography of the area which influences the distribution of available recharge. It was noted that rainfall and availability of permanent river water, away from Lake Baringo decreases generally towards the north.

The ground water potential of the Lobo plains is low because of the low transmissivity of the sediments and presence of saline water at depth. It is advisable to limit drilling to shallow aquifers that are recharged by rivers because the confined aquifer conditions and the presence of clay in the large swamps suggest that localized recharge is very limited.

The shore of the northern half of Lake Baringo and the area north of it are covered with Quaternary volcanics (trachytes, basalts and pyroclastics) and sediments. The recharge conditions in this area are favorable due to expected higher permeability of the volcanic rocks. However, the aquifers are quite deep at about 100m below ground level.

The Mukutan-Tangulbei basin is characterized by trachytes overlain by alluvial deposits in some parts underlain by basalts and phonolites. The area is considerably fractured with elongated faults running north-south, which form good recharge elements. A major escarpment runs from the area near Tangulbei to the south near Lake Bogoria. On the down throw side, which is to the west of Laikipia Plateau infiltration of rainwater occurs through the faults and fractures and therefore the aquifers here are largely controlled by these structures. Some of the sediments have substantial thickness and form good aquifers.

The hydraulic properties of aquifers estimated from borehole data suggest low permeability, although deeper regional estimates of permeability derived from considering the subsurface flow

from the Lake. Baringo suggest significant high values.(Lugalia Geologist CDN) One explanation for the different estimates is that older rocks buried at depth within the rift floor have been subjected to more prolonged histories of repeated faulting in response to rift tectonics and therefore are more strongly fractured than the younger lithologies penetrated by shallow boreholes that have been drilled for water. Furthermore, no borehole have been drilled within the volcanic centers themselves and most have been drilled along the axis of the inner trough . These areas are much more strongly fractured than the adjacent areas that have been drilled for water, and therefore may poses higher permeability than those suggested by shallow borehole data.

Due to the physiographical and geological conditions, the area can be classified into three distinct hydrogeological regimes as follows;

5.2 HYDROGEOLOGICAL REGIMES

5.2.1 Weathered surfaces between successive lava flows

The weathered surfaces between lava flows occur in the Tertiary volcanic rocks of the area in which groundwater is stored in old weathered zones and older formations as well as between successive flows. The thickness of these lavas varies from place to place and groundwater is thus to be found at varying depths and several aquifers maybe struck in a borehole depending on the degree of lava succession.

Ground water may be interconnected through fissures and porous material, which partly compose the old land surface deposits.

5.2.2 Faults, Fractures and Fissures

The complex structural character of faulting and fissuring has modified the ground water storage within the body of the lava flows and the pattern of its flow and consequent discharge. The yields cannot be predicted with certainty due to rock displacements which either bring the aquifers nearer to or further away from the surface.

The fault planes may sometimes be filled with impermeable clay material which act as barriers to groundwater movement and may also result in the fault zone being a poor aquifer storing water.

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5.2.3 Alluvial Deposits

Alluvial are dendritically distributed in the area. The alluvial aquifers consist of various types of sands, gravels which are mainly overburden found along the numerous drainage channels and seasonal sand rivers in the area. Shallow wells excavated in these alluvial serve as important sources for livestock and domestic needs. During the dry seasons the water level drops lower, the wells are progressively deepened attaining depths of over 6 meters.

5.3 RECHARGE AND GROUNDWATER FLOW.

Groundwater movement from recharge area to discharge area depends on the available recharge, the aquifer characteristics and mode of recharge. Recharge of the groundwater bodies in the area is mostly by lateral ground water flow from the Tugen hills where rainfall is higher than the lowland plains. Groundwater availability below most of the rift floor is considerably lower than its flanks presumably because of lower recharge, intense faulting and the presence of clayed deposits and to some extent geothermal activity. The recharge potential is high during the rainy seasons. Lake Baringo recharges groundwater in the rift floor.

In addition infiltration capacities are high due to the vegetation cover and the relatively permeable soils. The direction of ground water flow is generally from west, southwest into (Fig 5.1 & 5.2) Lake Baringo, and north-to-north east into Nginyang River in the Lake Turkana basin to the north. The discharge area within the rift floor marks (Figure 5.1) the existence of old land surface deposits between two different lava flows or faults and fissures. In most cases, faults and fissures that act as aquifers and conduct water from high to low ground i.e. recharge is mainly by lateral flow.

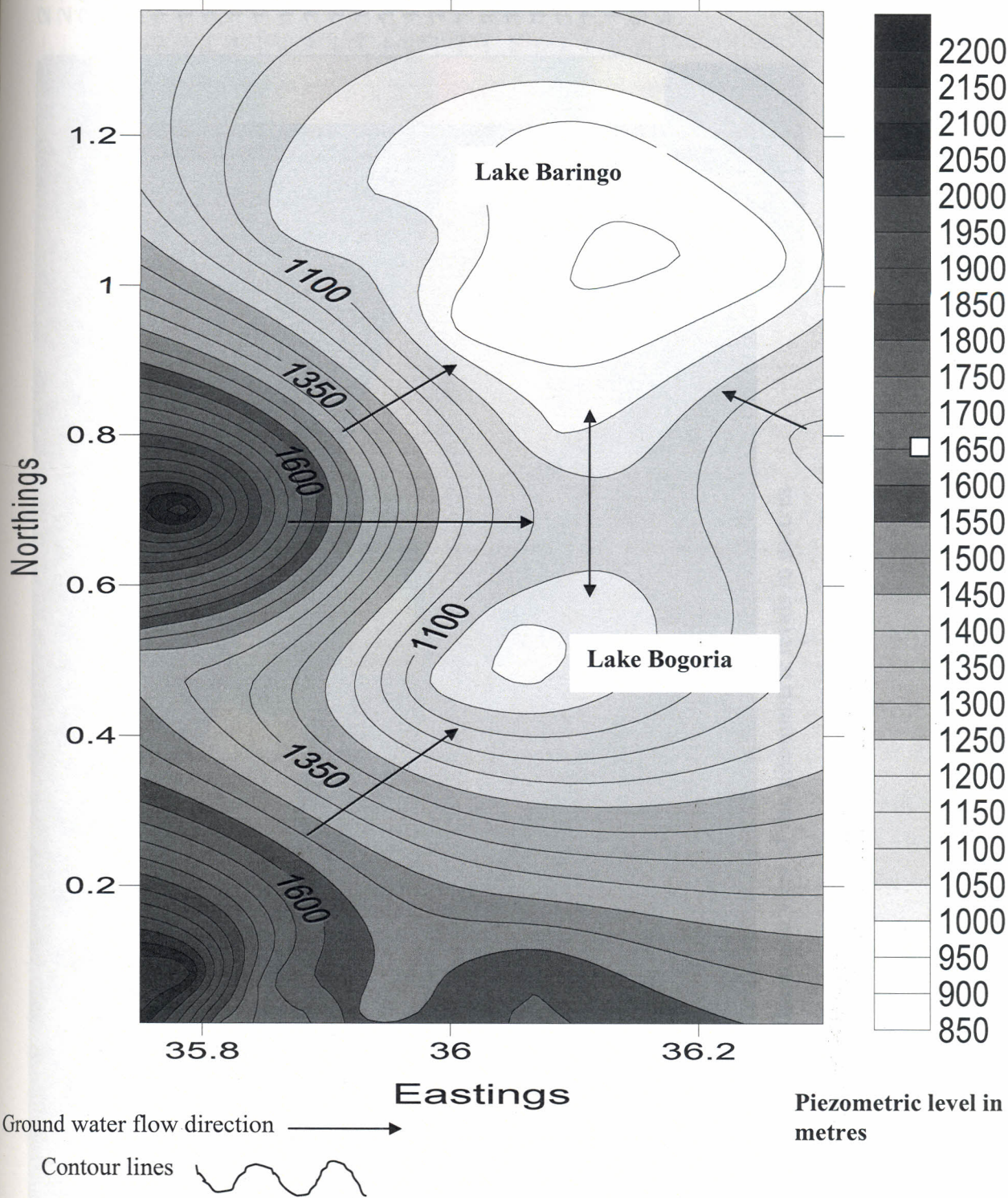


Figure 5.1 Contour map showing Piezometric levels of water in the Study area

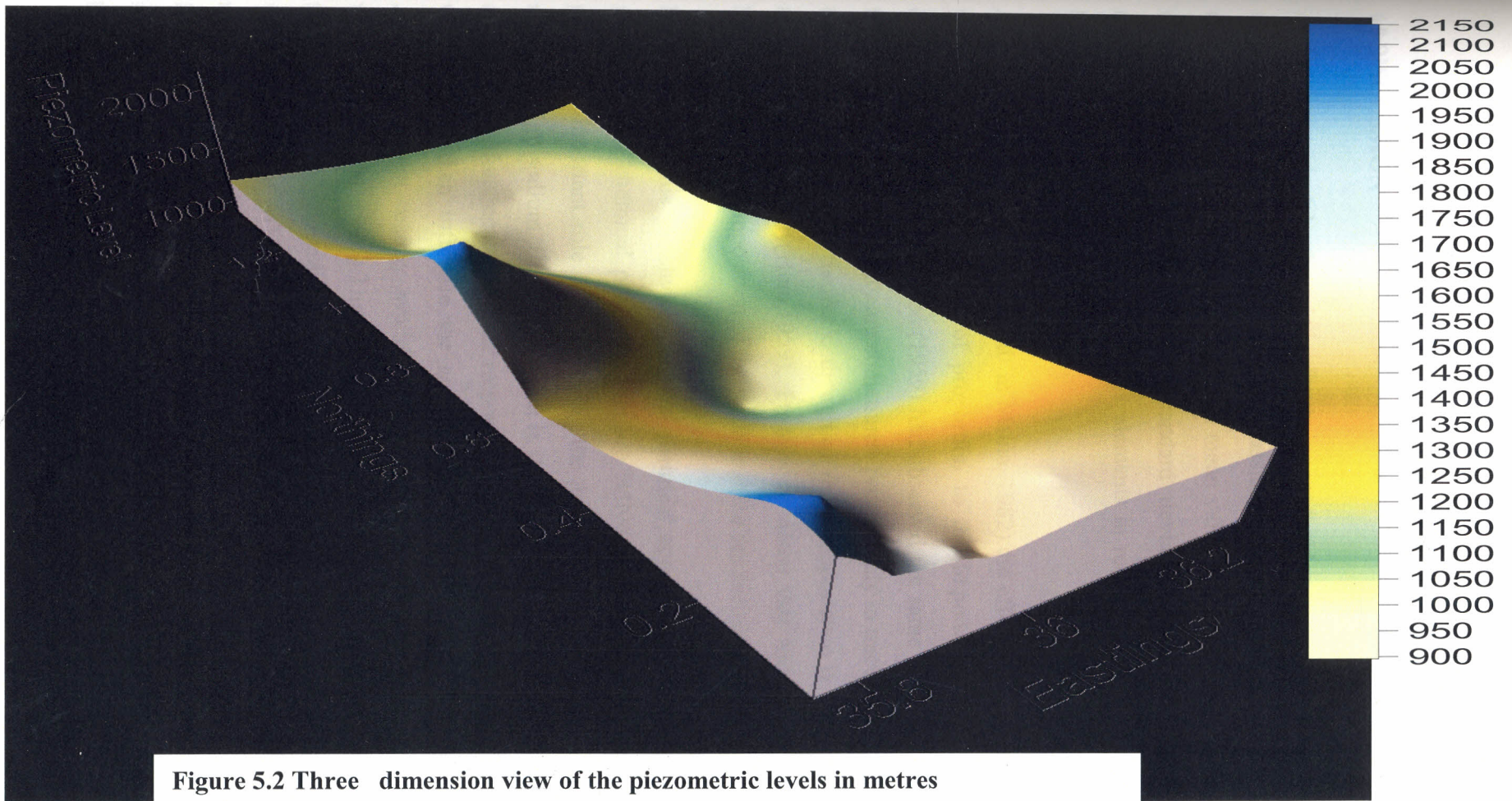


Figure 5.2 Three dimension view of the piezometric levels in metres

CHAPTER 6

6.0 DISCUSSION

As shown in table 4.1 sodium is by far the most abundant ion with a mean 385.97ppm of and std deviation ± 986.775 ppm .Calcium and Potassium have mean values of 21.58ppm and 11.92ppm respectively while magnesium and has a mean value of 15.97ppm .Fluoride and chloride have mean 25.77ppm, 384.03ppm and standard deviation of ± 185.3 ppm and ± 1171 ppm respectively . Thus the most abundant elements in rocks are not necessarily the ones with the highest concentration in water.

According to (Walton, 1970; cited in Maina, 1982).the effect of elements occurring in rocks on water quality can be far out of proportion to the importance of such salts in the mineral composition of the rocks . Hem(1959) had observed the same and further noted that the things that most affect water quality are sometimes present only in traces in the rocks. It has been noted that the composition of the rock, though of major importance is only one of the many factors affecting water quality(Hem,1959). Further he noted that there is no clear cut relationship between chemical composition of the water and the enclosing rocks.

In this respect this concludes that the chemical composition of the water is as a result of geological and chemical processes that are active in this environment .These processes have played an important role in determining the groundwater chemistry in the present study. The relatively high sodium ,fluoride content in the waters in this study reflect on the geology of the area. Individual elements however respond differently to the various different weathering agents which would then influence the concentration of elements in groundwater. For example ,potassium is not readily available in solution since the containing rocks are resistant to weathering(Maina, 1982).The element is reconstituted into insoluble minerals that are formed in the process of weathering (Hem,1959). This may explain why potassium is less abundant in water than sodium. When in solution, the chemical response of elements also varies .Sodium is released from the weathering of plagioclase minerals and clay minerals is a case in point .When leached from the rocks from rocks it tends to remain in solution (Hem,1959). Furthermore sodium does not take part in any important precipitation reaction like calcium and magnesium because nearly all sodium compounds are readily soluble in water.

This may explain why sodium concentration is relatively higher than any other major cation constituents in this study area. The mean values of sodium and potassium are 385.97ppm and 11.92ppm respectively. Calcium and magnesium have mean values of 21.58ppm and 15.97ppm.

As a whole the study area has high concentrations of both cations and anions. This was expected since the area has relatively high temperature that increases the rate of evapotranspiration and the rainfall is quite low with exceptions of the Tugen hills and the Laikipia escarpments. It should be borne in mind that the groundwater table closely follows the topography of the study area as was discussed in chapter three.

6.1 OCCURRENCE OF FLUORIDES

Fluoride is hardly found in nature in an elemental form because of its electronegativity and exceptionally high chemical reactivity. It forms salts even in inert gases and can still react at 253°C. Fluorine is enriched in the last magmatic columns of the upper chamber together with other volatiles. These juvenile sources can escape as gases and fumaroles in the ground water. In rocks fluoride occurs mainly in silicate minerals and fluorides. It is a relatively abundant element of the earth's crust (average content 650ppm). It occurs notably as fluor spar (CaF_2), Villiamite (NaF) in vesicles in volcanic rocks, Cryolite (Na_3AlF_6), Fluoroapatite, ($\text{Ca}_5(\text{PO}_4)_3\text{F}$) found in sedimentary rocks (limestone and sandstone), as Cryolite in igneous rocks (granite) and as Phlogopite (Fluormica).

Abnormal level of fluoride in water is common in fractured hard rock (Suma et al 1998) zone with pegmatite veins. The veins are composed of minerals like topaz, fluorite, fluor-apatite, villiamite, cryolite and fluoride-replaceable hydroxyl ions in ferromagnesium silicates. Fluoride ions from these minerals leach into the groundwater and contribute to high fluoride concentrations. Occasionally, mica group of minerals like muscovite and biotite also contribute to water fluoride content. See results (appendix) as per PCWATEQ run on some of the samples.

Fluor spar occurs in structurally weak planes like shear fracture zones, joints and at the contact of host rock and vein quartz. Rock minerals weather and form calcium and magnesium carbonates, which serve as good sinks for fluoride ions. However it is the leachable state of fluoride ions that

determines the water fluoride levels. The leachability is governed by pH of the draining solutions and dissolved carbon dioxide in the soil.

It dissolves in water from weathered fractured bed rock. While the weathering process could have produced fluoride in water, secondary processes can influence the concentration. Evapotranspiration will increase it, while precipitation as calcium fluoride will diminish or prevent it from increasing both dissolution and secondary processes influence dissolution will influence concentration of other ions in the same way. (Gumbo; 1990).

In soils, fluoride content is dependent on the initial concentration of the parent rock from which the soil is derived. Soils are formed as a consequence of rock weathering due to its interaction with air, water and organisms. Therefore, where rocks with minerals bearing high fluoride concentration weathering could result in the production of highly fluoride soils."The presence of dissolved fluorides in natural water is possible only when conditions favors long residence time of the fluoride species in solution"(Gaciri and Davies,1992). In natural water, fluoride content of both surface and ground water depends on the wide variety of factors including;

- ✓ Availability and solubility of the parent fluoride minerals with which the water interacts,
- ✓ Porosity of the rocks or soils through which the water passes,
- ✓ The hydraulic conductivity,
- ✓ The temperature of interaction between rock and water,
- ✓ The hydrogen ion concentration of water i.e. pH and
- ✓ The concentration of calcium and magnesium ions in water.

For instance in areas of tholeiitic basalts, it has been observed that Calcium tends to be in excess and under these conditions the concentration controlling mineral is likely to be calcium fluoride. "its well known fact that water with low hardness .i.e. low Mg and Ca contents ,and high alkalinity i.e. high HCO_3 contents and pH level presents the highest risk of fluoride" (Nanyaro and Mugure 1984). In the study area ,we find that there is a positive linear trend between the concentration of bicarbonate ions and the concentration of fluoride, however we find that there is a negative linear trend between the concentrations of Fluoride and Calcium, and Magnesium.(Fig 4.1,4.2 & 4.4). Most of the pH values fall in the range of 7-10 (Figure 4.3)

Surface water is generally lower in fluoride concentration than groundwater. The latter have longer contact time with rocks and therefore have more fluoride content than surface water. The variation in the fluoride content of water in the area is attributable to concentration and mode of occurrence of fluoride in rocks of the region with which water has interacted, as well as the flow pattern and residence time of water in the soil or aquifers.

No relationship could be established between fluoride concentration and depth of the boreholes in this area. Wide differences were noticed in the concentration of the ion in the samples from boreholes having approximately equal depth and situated in the same vicinity. As shown above, the concentration of fluoride differs considerably in different aquifers due to the geological formation and the mineral content. The hypothesis that the deeper you go the higher the fluoride concentration becomes does not hold (Mjengera and Mcharo 1990). The most important aspect with fluoride content in ground water sources is the geological formation and its mineral content rather than depth.

Table 6.1 Concentrations fluorides in various rocks.

Rocks	Concentrations of F⁻ ppm Koritnig (1951)	Concentrations of F⁻ ppm Allman and Koritnig (1978)
Magmatic rocks		
Granite	850	830-2950
Gabbro + Basalt	400	300-480
Syenite	950	600-1450
Sedimentary rocks		
Slate	740	
Sandstone	270	
Chalk	350	10-1100
Dolomite	180	<1210
Metamorphic rocks		110-400
Regional metamorphism		80-1100
Contact metamorphism		260-4700

From the table it's evident that fluoride concentrations are generally high in magmatic sedimentary and also in metamorphic rocks.

Table 6.2 Fluorine contents of some lavas from the Gregory Rift of East Africa

Location of sample	Sample description	Average fluoride(ppm)	Remarks
Oloibortoto(Kenya), Escarpment	Olivine Basalts	320	3 Samples
Oloiboroto(Kenya)	Olivine Melenepheline	1500	1 Sample
Kwahara(Tanzania)	Melilites Olivine	1650	4 Samples
Nguruman Escarpment	Olivine Melenepheline	1700	1 Sample
Sinai R.(Kenya)	Phonolite	1100	1 Sample
Athi river	Phonolite	1950	1 Sample
Magadi(Kenya)	Trachytes	1200	2 Samples
Oldonyo Lengai(Tanzania)	Natrocarbonatites (Pophyritic variety)	28,200	5 Samples (1988)
Kilimanjaro (Tanzania)	Olivine basalts	1000	4 Samples
Hawaii Basalts	Basalts	360	Average 130 Samples
Kimatsuura(flood basalt(Japan)	Alkali Basalt	393	GSJ rock reference samples

The table has been cited in Gaciri and Davies (1992)

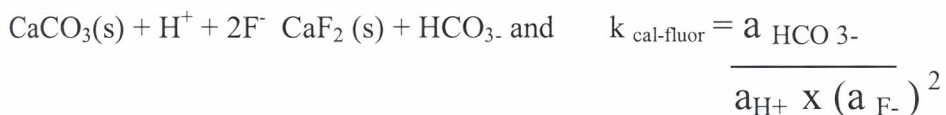
From above we observe that conditions within the rift .i.e.(comparatively high temperatures and precipitation) favor effective chemical weathering (Nanyaro et. al.,1984)the composition of the water therefore reflects partly the lithology of the basins under consideration for example the abundance of intermediate plagioclase in these alkaline rocks is considered the primary influence

on Ca^{+2} and Na^+ . The study area is composed mainly of trachytes, phonolites and basalts which when weathered release considerable concentrations of fluoride ions.

6.2 Hydrochemistry in water

The evolution of fluoride rich natural water results from leaching. In general the leach ability of the element in rocks, depends on the strength of the bonding forces. The more the element is tied up with silicate lattices, the less available it is to weathering. However, when associated with hydrothermal sulphides or present in intergranular film, it becomes more readily leachable. The concentration of natural water depends also upon the residence time of the ion in that medium, which is mainly controlled by factors such as pH. Unconsolidated or poorly indurated volcanic pyroclastic material such as deposits that cover large areas of the rift system are easily decomposed and leached. It has been noted that fluoride leaching is more pronounced in warm humid areas than in cooler less humid places. However, the solubility product of a mineral is also an important aspect that determines the concentration of fluoride in any natural water under a given environment the table 6.3 shows some solubility values of various salts associated with fluoride.

Compositional characteristics of these waters include high alkalinity (pH generally greater than 7) (Figure 4.3) and richness in the components Na^+ , K^+ , HCO_3^- , as well as Cl and F (table 4.1 ; these species have high solubility's in water. Ca and Mg are low, as they are precipitated largely as carbonates. Only limited incorporation of F is permitted in CaCO_3 structure, such that there is always a net balance of F in solution in solution. The higher solubility product of CaCO_3 ($k_{sp}=1 \times 10^{-8}$) favors precipitation over ($K_{sp}=3.4 \times 10^{-11}$). For the computation of thermodynamic equilibrium in groundwaters which are in contact with calcite and fluorite solid phases, Handa (1975) used a combined mass law equation relating both the solute species as follows:



Handa (1975) showed from this relationship that if the pH of ground water remained reasonably constant, any increase or decrease in bicarbonate concentration would be accompanied by a

corresponding increase or decrease in concentration of fluoride ions as $k_{\text{cal-fluor}}$ is constant. Thus a positive correlation was established between these two variables. (Figure 4.1 & 4.5).

Infiltrating rainfall in the process of percolation through rocks gets enriched in fluorides, until thermodynamic equilibrium of groundwater is established. The surface runoff carries substantial amounts of fluorides (in the form of highly fluoride dissolved salts) into shallow groundwater, rivers, ponds and lakes.

Table 6.3 Solubility of various salts associated with fluoride

Salt	Ionic Composition	Solubility Product
Brushite	$\text{Ca}(\text{HPO}_4) \cdot 2\text{H}_2\text{O}$	2.32×10^{-7}
Tricalcium phosphate	$\text{Ca}_3(\text{PO}_4)_2$	2.83×10^{-30}
Octacalcium phosphate	$\text{Ca}_8\text{H}(\text{PO}_4)_6$	2×10^{-49}
Hydroxyapatite	$\text{Ca}_5(\text{PO}_4)_3\text{OH}$	2.34×10^{-59}
Fluorapatite	$\text{Ca}_5(\text{PO}_4)_3\text{F}$	3.16×10^{-60}

The values cited above are those of Moreno et al (1974) Nature:247:64 (FA)

from the values above we see that solubility products are quite low therefore solubility will only occur when the right conditions are present i.e. mainly right temperature, pH.

The groundwater has a high pH this could explain the results in study carried out by (Wambugu and Karingithi 2005) in the Arus-bogoria area and also what is recorded in this present study, where they found the waters to have high concentrations of Ca and Mg ions. Ca and Mg are soluble at very high pH. This is true of the Lake Bogoria.

Ash ejected during quaternary volcanism forms part of the unconsolidated sediments it has high fluoride content, since they are more leachable than the rocks. Groundwater seeping through the ash material (in this case the lobi plains that cover the area between the two lakes) to lakes therefore results in high fluoride concentration, which gets increased by evaporation especially in lakes of closed basins e.g. L. Bogoria which has the highest concentration of fluoride in this area. (Figure 6.1).

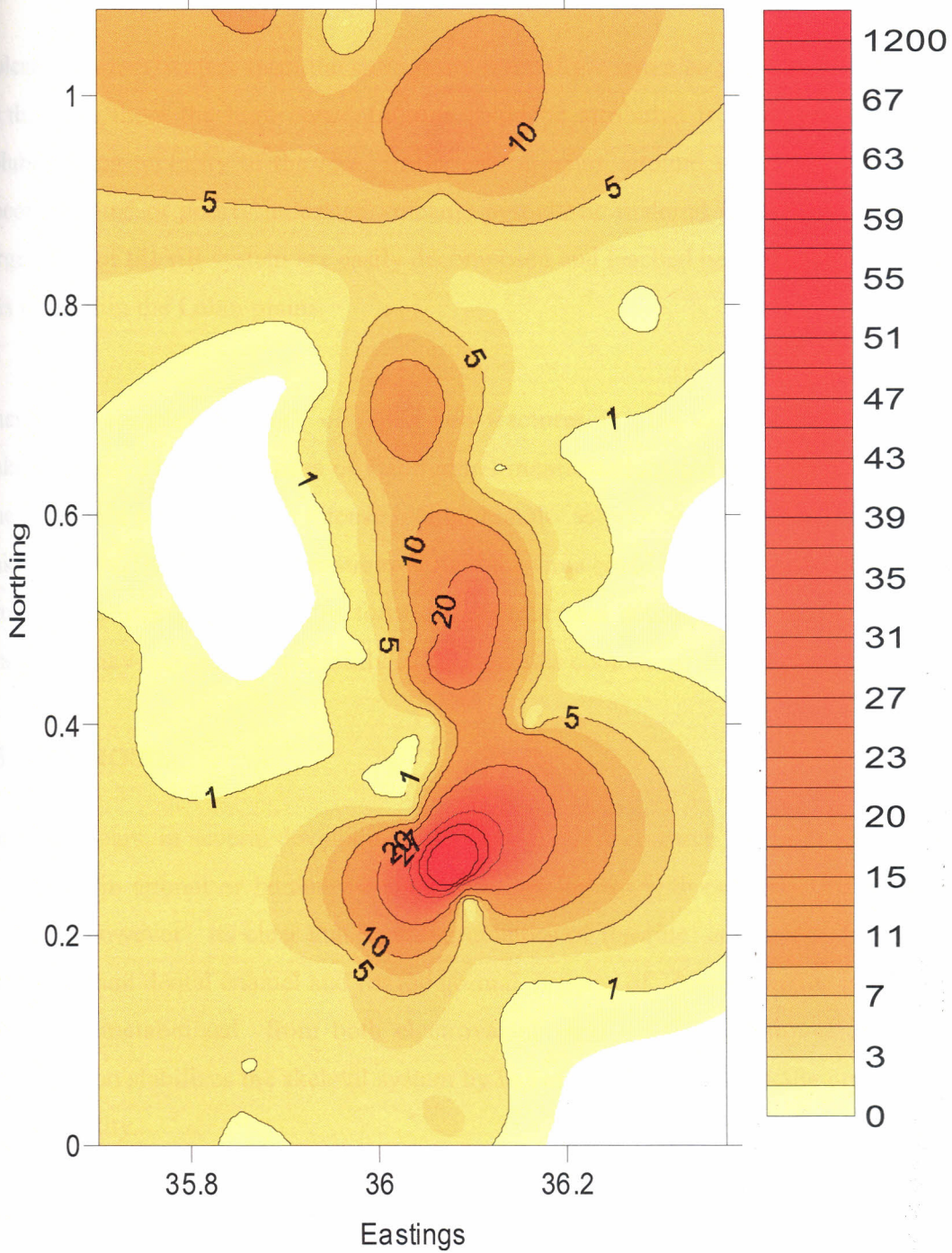


Figure 6.1 Contours showing the different fluoride concentrations zones

The Figure above delineates fluoride concentration which generally increases in the general flow direction of the groundwater. (Figure5.1) The figure shows that fluoride is higher in concentrations in the discharge area than in the recharge area. The blue ring in the figure above figure shows a distinct band of fluoride concentration above 100ppm ,this is around Lake Bogoria and its surrounding springs. In the northern part of the study we have we have Paka and Korosi

volcanic centers, waters from the springs are normally warm also some fumaroles were recorded in this area there the high concentrations could be attributed to high temperatures increasing solubility and mobility of the ions. In the central apart around Lake. Baringo we have highly unconsolidated or poorly indurated volcanic pyroclastic material and sediments such that cover large areas of the rift system are easily decomposed and leached hence the high concentrations of this ion within the Lobo plains.

There is a complex network of faults and fractures in the south of the study area around Lake. Bogoria. The occurrences of Geothermal manifestations are controlled by these structures. The two main localities with intense hydrothermal activity are at Arus and along the shores of Lake. Bogoria. The high concentrations around this area could therefore be attributed to the high in situ temperatures (manifested in form of hydrothermal activity) that result from the tensional strain that may increase the solubility of the minerals containing fluoride ions in the rocks.

6.3 FLUOROSIS

For many years, in several developing countries, fluoride research has been in progress. The role of fluorine in animal or human metabolism is not known with certainty. From the information available, however it's clear that a certain quantity of fluorine is essential for the formation of caries-resistant dental enamel and for the normal process of mineralisation in hard tissues. The element is metabolized from both electrovalent and covalent compounds. A low fluoride concentration stabilizes the skeletal system by increasing the size of apatite crystals and reducing their solubility.

(Smith and Hodge 1981) have related the concentrations of fluorides to the biological effects as follows;

Table 6.4 Effect of fluoride ingestion in human beings and cattle(Smith and Hodge 1981)

Concentration of fluoride in ppm.	Medium	Effects
0.002	Air	Injury to vegetation
1	Water	Dental Caries reduction
2 or more	Water	Mottled Enamel
8	Water	10%Osteosclerosis
50	Food and Water	Thyroid Changes
100	Food and Water	Growth retardation
120	Food and Water	Kidney changes

From Table 6.3 clear that fluorides adversely affect the physiology of human skeleton, at least up to a level of 8mg/l in drinking water. Ingestion of 20-80 mg/day or more of water over a period of 10-20 years results in crippling fluorosis and severe osteosclerosis. Calcification of certain ligaments rendering movement of joints difficult is usually associated with at least 10mg/l of fluoride in drinking water. The acute lethal dose for man is between 2.5mg/l and 5mg/l depending upon the solubility of the compound and the susceptibility in man.

The great affinity of fluorine for calciumphosphate is perhaps the most important for the accumulation in all tissues exhibiting physiological or pathological calcification.(Plate 4.3)About 95% of the fluoride in the body is deposited in hard tissues and it continues to be deposited in calcified structures even after other bone constituents(Ca,P,Mg,CO₃ and Citrate) have reached steady state. Age is also an important factor in deciding what extent fluorine is incorporated in the skeleton. A pattern similar to that in bones is followed the fluoride concentration in teeth. The up take almost ceases in dental enamel after the age of about 30 years.

6.4 DEFLUORIDATION

It would be expected that by reducing the level of fluoride in drinking water to the optimum the beneficial effects will be maximized while the adverse effects will be minimized. This is the rationale on which defluoridation of water is based.

Considerable efforts have been made in the area of Defluoridation. Several methods have been described in the literature for removal of fluoride from drinking water, but only a few are used in practice. This is due to several shortcomings in the treatment when moving from the laboratories to the “real world”(Peter Jacobsen CDN).

When evaluating if a method is suitable one has to know the settings in which the defluoridation plants are used. Defluoridation in a remote rural village obviously requires another approach than in a water works for a big city. However a golden rule which applies everywhere is “treatment should only be applied if absolutely necessary”.

Several parameters should be considered when selecting Defluoridation method.

- Efficiency: Can the Defluoridation reduce the fluoride level to acceptable values (typical below 1.5 mgF/l).
- Costs of Defluoridation, both with regard to establishing the plant and the running costs.
- Running of the plant: Level of required supervision, dependency of electricity, complexity of operation e.g. dosing of chemical.
- Maintenance of the plant, costs and availability of spare parts.
- Possible safety hazards – handling of dangerous chemicals, consequences of wrong dosing of chemicals, inefficient fluoride removal, possible chemical residual in the treated water.
- Supply of chemical for defluoridation.
- The culture of the community is the raw material generally acceptable to the community e. g are the raw materials “sacred”

Note that **No** single method is the best on all occasions, the choice of method is therefore dependent on the local circumstances.

In Bangkok Thailand where they use bone char as a defluoridation media.

Laboratory investigations were conducted into:

- The most practical dimensions for the container;
- The type and volume of the filter ingredients;
- The flow rate of the water through the filter;
- The quantities of water of different fluoride concentration that could be defluoridated using one filter bag;

- The chemical and biological content of water before and after Defluoridation.

It was found that with a flow rate of 4 litres an hour the defluoridator reduced the flored content of 480 litres of water from 5mg to less than 1mg/litre. The first 20 litres of filtered water were normally discarded after which the water was clean, odorless and ready to be used for drinking or cooking.

The chemical and biological constituents of filtered water were within the limits recommended by the world health organization (1996). The defluoridator also retained impurities such as sand, clay and dust, so the treated water was clean, colorless and had improved taste. The ICOH defluoridator was tested in 100 households in a few districts in Chiang.

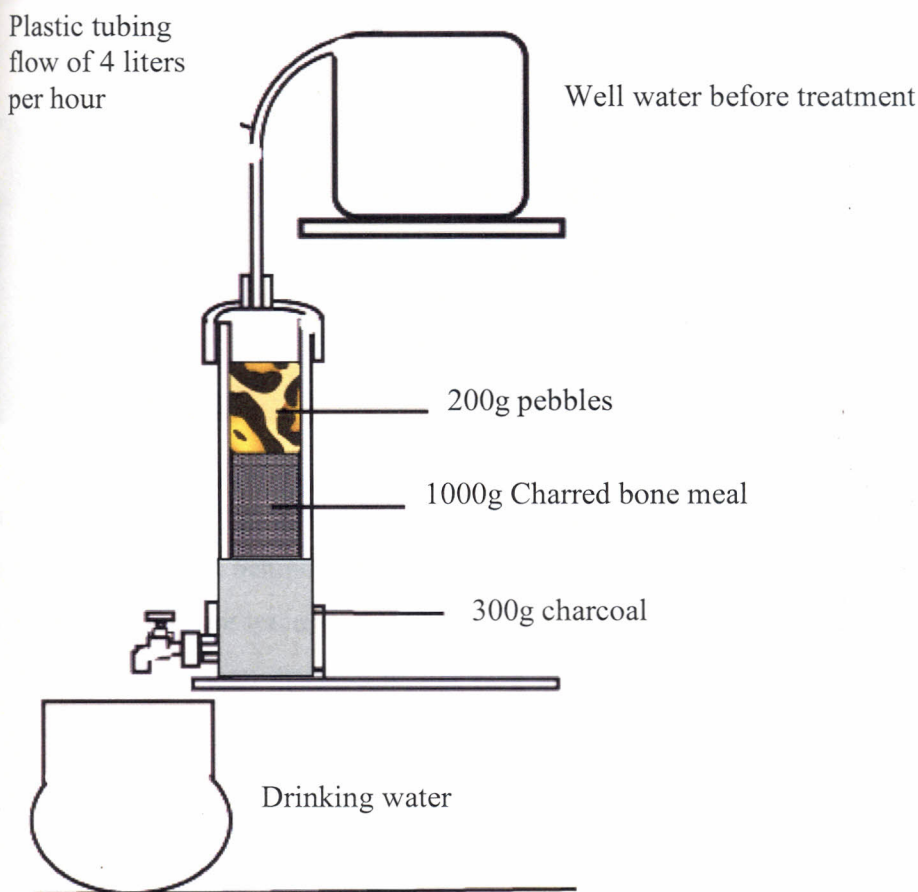


Figure 6.2 ICOH defluoridator (Bone and Charcoal) Phantumvanit et.al.,1988)

This is the same concept that has been adopted by the Catholic Diocese of Nakuru (CDN) defluoridation for its defluoridation filters .

6.41 Bone char

Bone char or bone char gravels are bones, which have been heated to high temperatures (above 400°C) and crushed. They are first burnt in a kiln for 10 days at temperatures strictly between 450°C-500°C to a brown to white coloration, because at low temperatures such as 200°C they become black and cannot be used.

Reasons for burning are;

- Kill all micro- organisms
- Burn down all organic materials
- Make them brittle



Plate. 6.1 Bones drying

Raw bones from the slaughter houses being dried in open air.

In the process all organic material are been removed and only the mineral (apatite) is left. (The major elements left behind include Calcium and Phosphate and they occupy 70% of the bone char material, the rest are traces e.g. Mn, Mg).

The bones are then crushed to increase the surface area, but before they are used they are washed to remove the dust and color in the bone char from 800 units to 15 units in a tank filled with water which contains NaOH 10kg. The Water is circulated for 24 hours then disposed off .



Plate.6.2 Drying bone char

After being crushed the bones are washed spread and dried in the open as shown.

The charred bones are then sprinkled with water to further remove color which drops to 15-25 units. In this state the pH is quite high and the electrical conductivity is between 50-100µm, so its reduced to the low water electrical conductivity which now stands at around 50 units to 8-7 units by adding carbon dioxide gas. Its then ready for use. Due to its porous structure this material is able to absorb high amount of fluoride. The Catholic Diocese of Nakuru water quality program deals with;

House hold filter buckets which contains about 8kg of filter material .It can purify 15-400 litres per day which is enough for a small family unit.

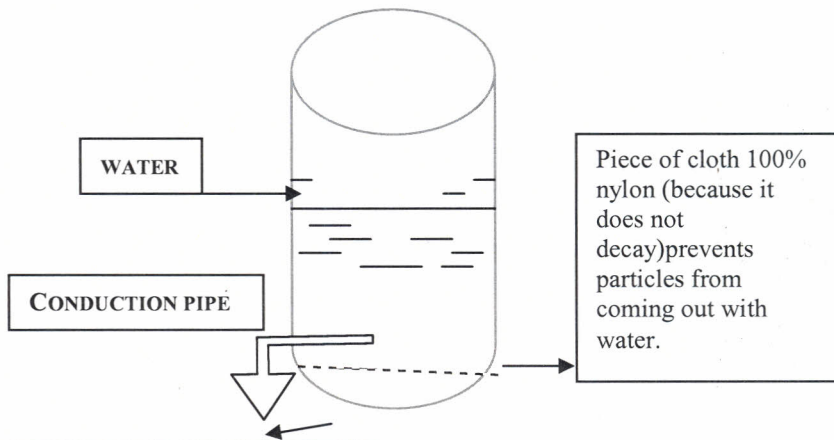


Plate 6.3
CDN household filters

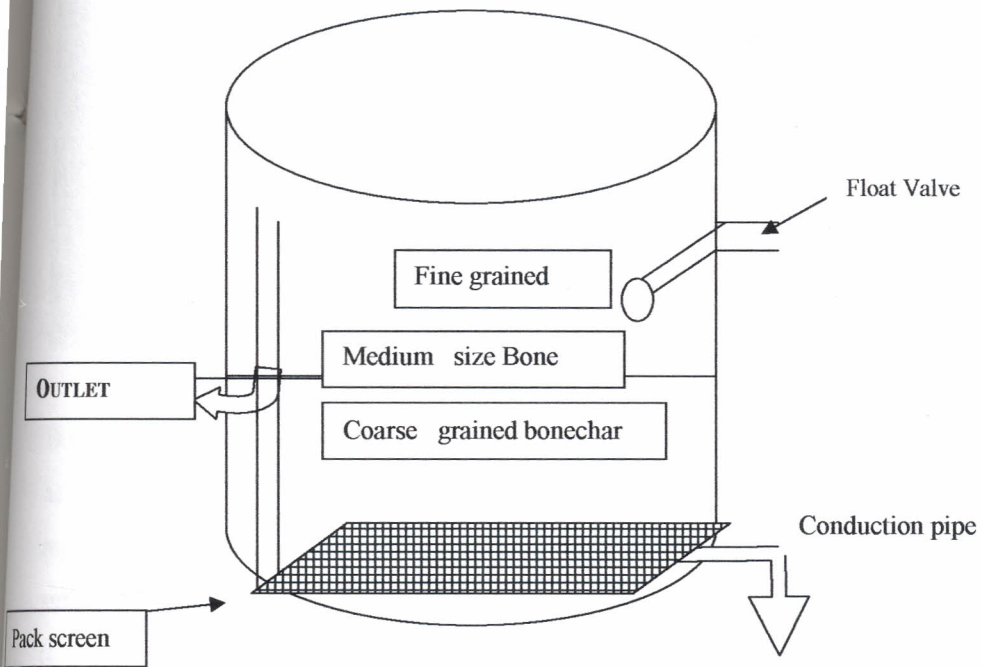


Figure 6.4 Schematic diagram of Community filters which can purify 10,000 litres per day



Plate .6.4 Shows a community filter next to a borehole



Plate 6.5 Defluoridated water

This shows water before and after defluoridation. The water is clear after passing through the bone char and is very suitable for drinking and cooking.

Bone char can be regenerated by raising the pH in a process similar to the regeneration of activated alumina. An alternative method of extending the lifetime of the bone char is with regular interval washing the bone char with a solution of calcium and phosphate (known as surface coating) or continuous adding of small amount of calcium and phosphate the raw water (contact precipitate). As with activated alumina a filter of bone char is simple to operate and have high efficiency, the major problems are connected to the regenerations.

This method is best for our local situation since bones are locally available. If bone char cannot be produced locally the availability of bone char can be a serious problem.

There are only few reported implementations of defluoridation using bone char.

Bone char has been used in a few larger plants in USA (e.g. in Bartlett) and some pilot project with household filters have been implemented in Tanzania and Thailand.



Plate 6.6 Pellets

Bone char is mixed with lime to make small balls (pellets) this is meant to increase the surface area contact with water and therefore increase efficiency in fluoride removal.

This also increases the life span of the bone char; in this method no regeneration of bone char is required.

CHAPTER 7

7.0 SUMMARY AND CONCLUSIONS

The groundwater of area (approximately 6000 km²) which extends from the southern shores of Lake Bogoria which is a few miles South-East of Marigat and to the north of Lake Baringo which lies a few kilometers North east of Marigat. Lying between 35° 45' - 36° 20' E and 1° 00' - 0° 15' N, has been evaluated (Figure 1.1).

For this study random sampling was adopted (samples were taken from different boreholes and a few springs), whereby more than 100 samples were collected. Surface water was recorded to be generally low in fluoride content while in ground water wide differences were noted. The total depth and water table levels were also recorded in order to come up with a reliable groundwater contour map that could be used to delineate ground water discharge and recharge areas. Flow direction as well as geological effects on groundwater flow came out clearly. The direction of ground water flow is generally from west to east, southeast into (Figure 5.1 & 5.2) Lake Baringo, and north-to-north east into Nginyang River in the Lake Turkana basin in the north.

Wide differences were noted in the boreholes within the same vicinity and having approximately the same depth (Figure 4.7) therefore no relationship could be established between borehole depth and fluoride concentration. The ternary diagram shows that most of the waters in the study area are bicarbonate waters.

The geology of the area is composed of tertiary volcanic rocks (tuffs and lavas), which form a thick blanket over massive gneiss of the Mozambique belt. Stratigraphically the formations underlying the study area are tertiary sediments and volcanics; and quaternary sediments.

Tertiary volcanics are represented by basalts, phonolites and trachytes. They consist of several flows which are separated by tuffs and sediments. These rocks in the study area are represented by the Kapchererat basalts in the north and Samburu basalts on the Laikipia escarpment. The phonolites cover large areas in the Tugen hills. The middle and Upper Pliocene volcanics represented by basalts are found in extensive outcrops in the western slopes of the Tugen hills and north of Eldama Ravine.

In general the Baringo area can be divided into three major structural units;

- Tugen hills,
- Baringo-Bogoria basins (central trough) which is intensely faulted,
- Step faulting produced a series of horst and grabens.

The central and northern parts (Baringo basin) is characterized by a series of small faults concentrated especially to the west and north of Lake Baringo.

The flow direction of groundwater is controlled by geology and topography of the area except where faulting may have occurred as was discussed in chapter 5. Recharge of the groundwater bodies in the area is mostly by lateral ground water flow from the Tugen hills where rainfall is higher than the lowland plains. We can therefore attribute the increase in concentration of fluoride ions towards the central part of the study area to this water flow from the flanks to discharges in the rift floor. Lake Baringo recharges groundwater on the rift floor to the north, thus we could also attribute high fluoride concentrations in the north to this.

The fluoride levels in the study have been found to generally exceed the recommended limit of 1.5ppm, except in small isolated pockets. The present study has established that most of the chemical constituents are more concentrated in the central part of the study area i.e. West-East, East-west and also that the concentration of available Ca^{2+} is important in determining the level of dissolved fluoride in this waters. Fluorine is incorporated into the calcium carbonate structure and removed from solution when the latter precipitates. Incorporation of fluorine into calcium phosphates takes place in a similar way, but apparently to a more limited extent (Gaciri and Davies 1992). Literature is replete with accounts of low Ca and Mg contents in waters of Kenya and surrounding areas of the rift system. (Maina, 1982) was able to draw a parallel between areas with high incidence of fluorosis in Kenya and the relatively low levels of Ca^{+2} and Mg^{+2} concentrations (Nanyaro et al., 1984) explained this relationship on the basis the low solubility of fluorides (table 6.3) These findings are consistent with the results of (Chandra et al., 1981) and (Teotia et al., 1981), who maintained that waters with low hardness, i.e. Ca^{2+} and Mg^{2+} contents, and high alkalinity, present the highest risk of fluorosis.

Statistical analysis of concentration levels (Table 4.1) of the data portrays very large standard deviation, most of which exceed the mean value. This alone to a large extent indicates enormous temporal and spatial variations in water composition in the study area. This is attributed to the different stages of weathering that the rocks (basalts, phonolites, trachytes) are undergoing. Some of the parameters also exceed the WHO Standard set standard for drinking water. The mean values for Sodium, Chloride and Fluoride are way above the set standards.

The maximum values observed in this data are from Lake Bogoria which has unique high chemical concentrations, it has the highest recorded fluoride concentration of 1690ppm. This is mainly attributed to geology and the geothermal activity taking place in this area.

The phonolites cover large areas in the Tugen hills these rocks have not been weathered and are somewhat compact and therefore the low concentrations of fluorides in this area

The Quaternary sediments are represented by Kapthurin beds (north of Marigat), which consist of silts and gravel deposits in lacustrine and deltaic environment. Locally, piedmont deposits of silt and clay (Loboi plains sediment), occupy a large area between the lakes. The extension and thickness of the sediments, occupy a large area between the Lakes Baringo–Bogoria Basin. The extension and thickness of the sediments is probably more than 1000m suggesting that Lake Baringo was formerly much bigger than at present and may have been linked to the lenses of course deposits along the major scarps, alluvial deposits in and along the rivers and lacustrine deposits of Lakes Kamnarok, Bogoria, and Baringo. These sediments are highly unconsolidated and therefore susceptible to leaching hence the high concentrations of this ion within the Loboi plains.

There is a complex network of faults and fractures in the south of the study area around Lake Bogoria. This suggests reactivation of tensional strain oblique to the primary rift axis. The occurrences of geothermal manifestations are controlled by these structures. The two main localities with intense hydrothermal activity are at Arus and along the shores of Lake Bogoria. The high concentrations around this area could therefore be attributed to the high in situ temperatures (manifested in form of hydrothermal activity) that result from the tensional strain that may increase the solubility of the minerals containing fluoride ions in the rocks.

Since we have established that water in this area has concentrations of fluoride exceed the set standard of 1.5ppm and that quite a big percentage of the population is suffering from various degrees of fluorosis, there is need for the water to be defluoridated by the cheap available method, which is bonechar in this case, consider;

- Efficiency: Can reduce the fluoride level to acceptable values (typical below 1.5 mgF/l).
- Costs of Defluoridation, both with regard to establishing the plant and the running costs is low ,does not require highly skilled labor and does not require a lot of electricity
- No Possible safety hazards – handling of dangerous chemicals, consequences of wrong dosing of chemicals, inefficient fluoride removal, possible chemical residual in the treated water.

The raw material is generally acceptable to the community, the raw materials not “sacred”

Significance of the study.

The distribution of fluoride has been shown to fall mainly fall within the central part of the study area i.e. on the rift floor. This area is covered by mainly alkaline volcanic rocks i.e. mainly Trachytes, phonolites and Basalts which cover large parts of east African rift system and are thought to contribute to the high concentrations of this ions, when weathered they dissociate to such minerals as micas (phlogopite, adularia, albite), carbonate salts and hydroxides (wolastonite, brucite, dolomite, trona, tremolite), that act as good sinks for fluoride ions. This has been inferred from PCWATEQ 1974(Appendix C). The study has also shown that the area has bicarbonate (Figure 4.5) waters and the pH values fall in the range of 7-10.on the pH scale.

It has been established that the main concern for planners for water resources in this area are mainly the fluoride ion in water which is in excess of the desirable limit of 1.5ppm set by WHO. It has also been shown that an excessive amount of this ions may result in dental fluorosis (Plate 4.1 and 4.2) both in children and adults. If in much higher concentrations, they may cause endemic cumulative fluorosis (Plate 4.3) with resulting skeletal damage in both children and adults. In this regard borehole water, on account of their generally higher fluoride contents, may require defluoridation. It has been shown that a defluoridation method is already in place and accessible to the local communities. Planning and development of the groundwater resources of the area should be carried with the possible health hazards in mind.

Scope for further investigations

- This study calls for detailed mapping showing the levels of fluoride at national level for delineating the problematic zones.
- A follow up action is necessary to study the benefits of Defluoridation pros and cons of proposed defluoridation methods; steps can be taken to evaluate at periodic intervals the general improvement in the dental health of the consumers of deflouridated water.
- Establishment of 'Fluorosis index' for conditions prevailing in Kenya is necessary so that a comprehensive plan for the Defluoridation in areas of endemic fluorosis should be investigated and developed.
- To my knowledge ,it has not been established whether the whole of the study area is one aquifer or many aquifers; whether the aquifer(s) is artesian, confined or unconfined or both .It is important to establish this and demarcate the boundaries of the different aquifers ,if any I order to establish if there is any mixing of the waters from the different waters.

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Internet

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<http://pubs.acs.org/cen80th/fluorine.html> (2005-02-08)

Appendix A

DATA USED TO COME UP WITH THE TERNARY DIAGRAM

Data used to come up with the ternary diagram

Sample Source	HCO ₃	Meq/l	SO ₄	Meq/l	Cl	Meq/l
Tangulbei Mission	170	2.742	45	0.938	130	3.714
Tangulbei commun	252	4.065	30	0.625	30	0.857
Luyeya	1081	17.435	46.4	0.967	101	2.886
Mutaro	178	2.871	16	0.333	12	0.343
Katuwit	1336	21.548	35.2	0.733	88.2	2.520
Komolion community	640	10.323	24	0.500	80	2.286
Komolion dispensary	440	7.097	13	0.271	52	1.486
Nyalilpich	460	7.419	9.6	0.200		0.000
Mkongwo	705	11.371	20.2	0.421	203	5.800
St.Joseph	430	6.935	31	0.646	26	0.743
kiptangwany	230	3.710	5.3	0.110	0.5	0.014
Yatoi	522	8.419	1.2	0.025	9.5	0.271
Sutiechum	317	5.113	115	2.396	9.5	0.271
Kipleshiony	523	8.435	167	3.479	125	3.571
Ngaratuko	345	5.565	63	1.313	99.5	2.843
Naiben	492	7.935	10	0.208	8.5	0.243
Biretuonin	315	5.081	192	4.000	20	0.571
Chebarsiat	390	6.290	13	0.271	95	2.714
Donyasas	1103	17.790	37	0.771	25	0.714
Katkit	233	3.758	21	0.438	40	1.143
Chepkoi II	357	5.758	27	0.563	0.05	0.001
Katolimwa	289	4.661	4.4	0.092	0.1	0.003
Loitip	451	7.274	6.5	0.135	0.1	0.003
Kirim	631	10.177	0.3	0.006	13	0.371
Ngoswe	1211	19.532	93	1.938	36	1.029
SidanNgambo	630	10.161	3944	82.167	0.05	0.001
Iligarua	2503	40.371	2705	56.354	614	17.543
Arusin	291	4.694	30	0.625	26	0.743
KipleshionyII	231	3.726	5	0.104	12	0.343
Barkibi	8.3	0.134	2503	52.146	215	6.143
Salabani(Nasinya)	10.6	0.171	233	4.854	21	0.600
Chepkoi met	309	4.984	20	0.417	14	0.400
Kailer	1813	29.242	215	4.479	130	3.714
kipleshioiog	523	8.435	167	3.479	125	3.571
Ngaratuko	34.5	0.556	63	1.313	100	2.857
Tabarngetyun	556	8.968	7	0.146	16	0.457
Ndonyosas	1103	17.790	37	0.771	25	0.714
Chemeril	323	5.210	27	0.563	27	0.771
Sosiende	630	10.161	3944	82.167	8.4	0.240
Rugus	617	9.952	4	0.083	30	0.857
Kinarok	522	8.419	4	0.083	23	0.657
Cheparsiat	390	6.290	13	0.271	95	2.714
Kipleshionyl	523	8.435	167	3.479	125	3.571
Marigat Div office	4	0.065	7	0.146	4	0.114
Ngambo(logasi)	630	10.161	3944	82.167	804	22.971
Kipleshiony' 2	231	3.726	5	0.104	12	0.343
Arusin	291	4.694	30	0.625	26	0.743
Tabargetuny'	556	8.968	7	0.146	16	0.457
Marigat Sec Sch	143	2.306	4	0.083	7	0.200
Natan	581	9.371	42	0.875	81	2.314
Ramacha 2	617	9.952	4	0.083	30	0.857
Nginyang	3708	59.806	453	9.438	670	19.143

Data used to come up with the ternary diagram

SidanNgambo	581	9.371	42	0.875	81	2.314
Kelewa	244	3.935	0.3	0.006	12	0.343
Kisanana	140	2.258	0.3	0.006	11.81	0.337

Data above was used to come up with the ternary diagram in Grapher.

Meq/l = Concentration in mg/l / RAM

Where ;RAM=Relative Atomic Mass

APPENDIX B
CHEMICAL ANALYTICAL
TECHNIQUES USED

2. Calcium determination

Ion selective electrode method

(Metrohm manual for Ion Selective Electrode ISE)

Reagents:

- Calcium standard solutions (1.00, 10.00, 100.0 mgCa/l)
- Calcium TISAB (Total Ionic Strength Adjustment Buffer)
- Calcium TISAB (1+4) (diluted)
- 3N Ammonium hydroxide
- 1+1 Hydrochloric acid
- Potassium chloride, KCl
- Methyl red indicator

Instruments:

- Ion Selective Electrode (Ca), 6.0504.100
- Reference electrode (Ag/AgCl), 6.0726.100
- pH Meter (with mV readings)
- Magnetic stirrer

Procedure:

1. The electrodes and meter were prepared for measuring the sample. The electrodes were rinsed with distilled water.
2. In a 15 ml plastic beaker, 5.00ml of 1.00 mg/L Calcium standard solution (C1) was added.
3. 5.00ml Calcium TISAB (Use the diluted TISAB on non low ion strength sample) was also added.
4. A stirrer was also added and tip of both electrodes was placed in the solution.
5. The reading on the mV Meter was noted. (The procedure was repeated to get more accurate measurements) (U1).
6. The procedure was then repeated with 10.00 mg Ca/l (U2 and C2 respectively) and 100.0 mg Ca/l (U3 and C3 respectively) in that order
7. It was also repeated with unknown samples (Us). Use Sample R4 (raw sample).

Calculation:

Interval 1 to 10 mg Ca/l:

$$= \text{Antilog} \left\{ \frac{U_s \times (\log C_2 - \log C_1) - (U_1 \times \log C_2) + (U_2 \times \log C_1)}{U_2 - U_1} \right\}$$

Interval 10 to 100 mg Ca/l:

$$\text{mg Ca/l in sample} = \text{Antilog} \left\{ \frac{U_s \times (\log C_3 - \log C_2) - (U_2 \times \log C_3) + (U_3 \times \log C_2)}{U_3 - U_2} \right\}$$

Where:

U1 = measurement in mV for the first standard

C1 = Concentration of Calcium in mg/l of the first standard (1 mg Ca/L)

U2 = measurement in mV for the second standard

C2 = Concentration of Calcium in mg/l of the second standard (10 mg Ca/L)

U3 = measurement in mV for the third standard

C3 = Concentration of Calcium in mg/l of the third standard (100 mg Ca/L)

Us = measurement in mV for the sample

2. pH Value determination

Electrometric Method

(Metrohm 704 pH Meter Instructions for Use)

(Standard methods (1995) 4500-H⁺ A)

Reagents:

- Electrode Storage Solution (3 M Potassium Chloride Solution) (standard reagent)

Instruments:

- pH Meter, Metrohm
- pH Electrode, (Metrohm 6.0220.100)

Procedure:

1. The pH meter had to be calibrated before the analysis is undertaken. (See procedure below).
2. The pH meter and the pH Electrode were assembled. The electrode was checked to see if it contained sufficient 3 M Potassium Chloride solution. It was filled to a depth just before the fill hole. Before use, the electrode from was removed from the storage solution (3 M Potassium Chloride solution), rinsed with distilled water and blot dried with a soft tissue.
3. In a 250-ml Beaker and with stirring, 100-ml of Sample R4 (the raw sample) was added Note that it was stirred gently to minimize Carbon Dioxide Entrainment.
4. The electrode was immersed in the analysis solution until the diaphragm was covered (approx. 2 cm). (Note During measurement, the fill hole should remain open).

5. The pH meter was switched on by pressing the < on / off > key.
6. The < mode > key was pressed once or more until pH appeared in the display. The second line always shows the temperature, as pH values are temperature dependent.
7. The author had to wait for the triangle in the display to disappear. When it disappeared, the measured value was stable.
8. The pH measurement was then recorded.
9. The electrode was then taken out of the beaker and rinsed thoroughly with distilled water and blot dried with a soft tissue, before another sample could be measured.
10. If no other sample was to be analyzed, replace the electrode in the storage solution.

Note: The electrode should never be stored in water or dry, only in 3 M Potassium Chloride Solution.

Reagents:

- Potassium Chloride, KCL
- Buffer Solution pH 4 (Standard reagent)
- Buffer Solution pH 7 (Standard reagent)
- Buffer Solution pH 9 (Standard reagent)

3 M Potassium Chloride Solution

In a 250-ml volumetric flask:

1. Dissolve 55.9133 g of Analytical Grade Potassium Chloride in approx. 150-ml of distilled water.
2. Dilute to mark with distilled water.

Calibration of the pH Meter

1. Two buffer solutions are required for this.
2. Assemble the pH meter and the Electrode. Rinse the electrode with distilled water and blot dry with a soft tissue.
3. Immerse the electrode in the first buffer solution.
4. Press the < pH cal > key.
5. The display shows the temperature. To change the temperature, use the < >>> and < ^ > keys. Select the digit that you want to change with the < >>> key. You will recognize the selected digit by the flashing dot at the bottom right. Then change the number using the < ^ > key by pressing it repeatedly until the desired digit is displayed. When the correct value is set, press < enter > key.
6. The first buffer solution is now measured. After the measurement, the display prompts you to immerse the electrode in the second buffer solution: the buffer beaker flashes. Carry this out and

press < enter >. Remember to rinse and dry the electrode before immersing it into the second buffer.

7. The second buffer solution is now measured.
8. After the calibration, the slope and asymmetry pH (pH as) of the electrode are briefly displayed and the instrument is now ready for pH measurements.

3. Sodium determination

Ion Selective Method

(Metrohm manual for Ion Selective Electrode ISE /a 88.02 Gi/Ti)

Reagents:

- Sodium standard solutions (2.00, 20.00, 200.0 mg Na/l)
- Sodium TISAB (Total Ionic Strength Adjustment Buffer)
- Sodium TISAB (1+4) (diluted)
- Sodium chloride solution (0.1M)
- Potassium chloride solution (3M) (standard reagent)

Instruments:

- Ion Selective Electrode (Na), 6.0501.100
- Reference electrode (Ag/AgCl), 6.0733.100
- pH Meter (with mV readings)
- Magnetic stirrer

Procedure:

1. The electrodes and meter were prepared for measuring the samples. The electrodes were rinsed in distilled water.
2. In a 15 ml plastic beaker, 5.00ml of 2.00 mg/L Sodium standard solution (C_1) was added.
3. 5.00ml Sodium TISAB (Use the diluted TISAB on non acid and low ion strength sample) was also added.
4. A stirrer was added and the tip of both electrodes in the solution was placed in solution.
5. The reading on the mV Meter was noted (The procedure was repeated to get more accurate measurement) (U_1)
6. The procedure was repeated with 20.0 mg Na/l (U_2 and C_2 respectively) and 200.0 mg Na/l (U_3 and C_3 respectively) in that order
7. it was then repeated for all with samples (U_s). Use Sample R4 (raw sample).

Calculation:

Interval 1 to 30 mg Na/l:

$$\text{mg Na/l in sample} = \text{Antilog} \left\{ \frac{U_s \times (\log C_2 - \log C_1) - (U_1 \times \log C_2) + (U_2 \times \log C_1)}{U_2 - U_1} \right\}$$

4. Potassium determination

Ion Selective Method (StdM 1995 3500-K E)

Reagents:

- Potassium standard solutions (1.00, 10.00 mgK/l)
- Potassium ISA (Ionic Strength Adjustment)
- Potassium ISA (1+4) (diluted)
- Sodium chloride solution (0.1M)
- Potassium chloride solution (3M) (standard reagent)
- 6N Sodium hydroxide

Instruments:

- Ion Selective Electrode (K) (Metrohm 6.0504.110 – 0073 0293)
- Sleeve-type, double junction reference electrode (Ag/AgCl) (Metrohm 6.0726.100), with potassium free electrolyte in outer filling (Sodium chloride solution, 0.1M NaCl) and standard Potassium chloride solution (3.0M KCl) in inner filling.
- pH Meter (with 0.1 mV readings)
- Magnetic stirrer

Procedure:

1. The electrodes and meter were prepared for measuring in sample. The electrodes were then rinsed in distilled water.
2. In a 15-ml plastic beaker, 5.00-ml of 1.00 mg/l Potassium standard solution (C_1) was added.
3. 5.00ml Potassium ISA (Use the diluted ISA on low ion strength sample) was also added.
4. The stirrer was then added and the tip of both electrodes was place in the solution.
5. The reading on the mV Meter was recorded (repeat this procedure to get more accurate measurement) (U_1)
6. The procedure was repeated with 10.0 mg/l Potassium standard solution (C_2) (in that order)
7. The reading on the mV Meter was recorded (repeat this procedure to get more accurate measurement) (U_2)

8. This was repeated for all unknown samples (U_s). Use Sample R4 (the raw sample). Note: If Ammonia is present in the sample adjust pH to 11 by adding few drop of 6N Sodium Hydroxide.

Calculation

Interval 0.5 to 20 mgK/l:

$$\text{mg K/l in sample} = \text{Antilog} \left\{ \frac{(U_s \times (\log C_2 - \log C_1)) - (U_1 \times \log C_2) + (U_2 \times \log C_1)}{(U_2 - U_1)} \right\}$$

Where:

C_1 = Concentration in mg K/L of the first standard (1 mg K/L)

U_1 = measurement in mV for the first standard

C_2 = Concentration in mg K/L of the second standard (10 mg K/L)

U_2 = measurement in mV for the second standard

U_s = Measurement in mV for the sample

Reagents :

- Potassium chloride, KCl
- Sodium chloride, NaCl

5. Electrical Conductivity determination

Instrumental Measurement(ELE Paqua lab Operating Instructions)

Instruments:

- Conductivity Meter, ELE Paqua lab

Procedure:

1. Plug the Conductivity cell into the 7 pins DIN Socket at the top of the meter.
2. Set the display to read SET K by use of the MODE keypad.
3. Set the display to read the cell constant (K) value, (1.05). (The SET K control is accessible through a hole in the rear of the meter marked SET K. Adjustments should be made using the small pot adjuster provided with the unit).
4. In 100-ml beaker, add approx. 80 ml of Sample F4.
5. Immerse the conductivity cell in the solution to be measured.
6. Set the display to read in mS or uS corrected to 25°C. Adjust the mode to progressively more sensitive ranges until the highest possible reading is obtained on the display. This reading is the conductivity of the solution directly in mS or uS corrected to 25°.

6. Hardness determination

EDTA Titrimetric Method

(Standard Methods (1995) 2340 C)

Reagents:

- Buffer solution (pH 10.0 for Hardness)
- Indicator (formulation of NaCl and Eriochrome Black T)
- Titrant (0.01 M EDTA)
- Standard Calcium solution (optional)

Instruments:

- 50-ml burette
- Magnetic stirrer

Procedure for soft water:

1. The 0.01M EDTA titrant was diluted to 0.002M and prepared in a 50- ml burette.
2. In a 250-ml beaker and with stirring, 50 ml of sample D3 (Sample D3 is digested and concentrated Twice) was added.
3. 1-ml buffer solution was added to the sample (the titration should be completed within 5 minutes after adding the buffer). At this point, the pH should be 10 \pm 0.1
4. Approximately 0.1 g indicator formulation was added to the sample (sample becomes red)
5. 0.002M EDTA titrant was slowly added with constant stirring until the last reddish tinge disappeared. (the color changed to blue). If more than 50-ml of 0.002 M EDTA solution has been used, use the procedure for hard water.

Procedure for hard water:

1. 0.01-m EDTA titrant was prepared in a 25 ml burette.
2. In a 250-ml beaker and with stirring, 50-ml of the sample D3 was added.
3. 1 ml of the buffer solution was added to the sample (the titration should be completed within 5 minutes after adding the buffer)
4. Approximately 0.1 g indicator formulation was added to the sample (sample becomes red)
5. EDTA titrant was slowly added with constant stirring until the last reddish tinge disappeared. (The color changes to blue)

Calculation of hardness:

Hardness (EDTA) as mg CaCO₃/L = A x B x 1000 / mL sample D3

Where:

A = mL 0.01M EDTA titrant used (when the diluted EDTA titrant is used calculate the amount of 0.01M EDTA titrant used).

B = mg CaCO₃ equivalent to 1.00 ml EDTA titrant (See procedure for EDTA solution).

Note: Remember that sample D3 is concentrated twice, hence to get the concentration in the original sample the result should be divided by 2. Remember to subtract the measurements for the blank (carried through the digestion procedure) from the sample's measurement to get the correct results.

Reagents:

- EDTA disodium salt, C₁₀H₆N₂O₈Na₂ · 2H₂O
- Magnesium sulfate, MgSO₄ · 7H₂O
- Ammonium chloride, NH₄Cl
- Ammonium Hydroxide (25%), NH₄OH, (standard reagent)
- 3N Ammonium Hydroxide, NH₄OH, (standard reagent)
- Sodium Chloride, NaCl
- Eriochrome Black T, C₂₀H₁₂N₃NaO₇S
- Calcium Carbonate, CaCO₃ (Primary grade)
- (1+1) Hydrochloric acid, HCl, (standard reagent)
- Methyl red indicator (standard reagent)

Buffer solution (pH 10.0 for Hardness)

In a 100-ml Erlenmeyer flask with constant stirring:

1. Add 20-ml distilled water
2. Add 0.4716-g EDTA diSodium salt
3. Add 0.312-g Magnesium sulfate
4. Mix
5. Add 6.76-g Ammonium chloride
6. Add 65.1-ml 25% Ammonium hydroxide
7. Mix
8. Transfer to a 100-ml measuring flask and dilute to 100 ml with distilled water.

Store in plastic container with tight lid. (Use two 50-ml PE containers)

The buffer should be used within one month

Indicator (formulation of Sodium Chloride and Eriochrome Black T)

In a mortar:

1. Add 20-g Sodium chloride

2. Add 0.10g Eriochrome Black T
3. Mix using a pestle
4. Store in small glass container with airtight lid.

Standard Calcium solution

Use a 500-ml erlenmeyer flask:

1. Add 1.000-g Calcium carbonate.
2. Use a funnel and add 1+1 Hydrochloric Acid until all Calcium Carbonate is dissolved (the solution becomes clear) (approx. 5-ml)
3. Add 200-ml distilled water
4. Boil for a few minutes (to expel Carbon Dioxide), cool
5. Add a few drop of Methyl red indicator (solution becomes red) (start stirring)
6. Add 3N Ammonium hydroxide until solution becomes yellow (2-4ml)
7. Adjust to the intermediate orange color by adding 1+1 Hydrochloric acid or 3N Ammonium Hydroxide.
8. Transfer to a 1000 ml measuring flask and dilute to 1000-ml with distilled water. Make sure that all the solution is transferred by washing the Erlenmeyer flask with the distilled water used for dilution .
9. Store in a container with airtight lid.

Titrant (0.01 M EDTA)

Use a 1000-ml measuring flask

1. Add 3.723-g EDTA diSodium salt
2. Dilute to 1000-ml with distilled water
3. Add magnetic bar and stir for a few minutes

Store in a 1 L PP plastic bottle with airtight lid.

Standardize regularly against the Standard Calcium Solution, using the following procedure:

Use 20.0 ml of "Standard Calcium Solution" and follow the procedure for titration of hard water (hardness). The "B" in the calculation for hardness is obtained as:

$$B = 20 / \text{ML EDTA TITRANT}$$

8. Sulfate determination

Turbidimetric Method

Standard methods (1995) 4500-SO₄²⁻-E

Reagents:

- Buffer solution A
- Buffer solution B (= buffer solution A + 75-mg $\text{SO}_4^{2-}/\text{L}$)
- Barium chloride (BaCl_2) crystals, 20- 30 mesh
- Standard sulfate solution

Apparatus:

- Spectrophotometer, 420 nm (violet)
- Magnetic stirrer
- Magnetic bar, 3 cm long
- Stop watch.

Procedure for standard curve:

1. A blank was made by mixing 50ml distilled water and 10 ml buffer solution B.
2. The calibration curve was prepared by carrying sulfate standards through the entire procedure for determination of sulfate. The sulfate standards should have been in the range of 10- to 40-mg $\text{SO}_4^{2-}/\text{L}$ at 5-mg/L increments using buffer solution A.

Table 8.1 Sulphate standards preparation

Concentration in $\text{mg SO}_4^{2-} / \text{L}$	Amount in mg SO_4^{2-}	Volume of 100 $\text{mg SO}_4^{2-} / \text{L}$ in 50-ml final volume
10	0.50	5.00
15	0.75	7.50
20	1.00	10.00
25	1.25	12.50
30	1.50	15.00
35	1.75	17.50
40	2.00	20.00

3. Plot absorbance vs. concentration of sulfate in the sample (10 - 40 $\text{mg SO}_4^{2-} / \text{L}$). Refer to Hach DR/2010 Spectrophotometer Instrument Manual for editing of user-entered programs (please see the next page)

Procedure:

1. A blank was made by mixing 50-ml distilled water and 10-ml buffer solution A.
2. In a 250-ml Erlenmeyer flask with constant stirring speed, 50-ml of sample F4 (filtered sample) was added.
3. 10-ml buffer solution A was also added.

4. approx. 0.5-g of Barium chloride crystals was then added one had to wait for exactly one minute.
5. After one minute was over, the solution was poured into an absorption cell of the photo/ turbidity meter and absorbance was measured five minutes after pouring the solution.
6. The amount of sulfate in the sample was estimated by comparing the reading with the calibration curve.
7. If the estimated amount of sulfate was less than 10mg/L, the result was not reliable. and the procedure was repeated but by use of buffer solution B (with 0.75 mg sulfate/10-ml) instead of A. 15 mg /L was subtracted from the readings of the calibration curve.
8. If the reading exceeded 40mg/L, the sample was diluted to the range 10-40 mg/L.

Procedure for Operating the Hach Spectrophotometer:

1. Enter the stored Program number for Sulphate: Press 9 5 1 and then ENTER. The display will show: Dial nm to 420. Rotate the wavelength dial until the small display shows: 420 nm. When the correct wavelength is dialed in, the display will quickly show: Zero sample, then units in mg SO₄²⁻ /L.
2. Fill a sample cell with the blank (zero sample).
3. Fill a second sample cell with the prepared sample.
4. Place the blank into the cell holder and close the light shield.
5. Press Zero. The Display will show: Zeroing ... then mg SO₄²⁻ /L.
6. Place the prepared sample into the cell holder. Close the light shield.
7. Press READ. The display will show Reading ... and then the results in mg SO₄²⁻ /L will be displayed.

Reagents:

- Magnesium chloride (MgCl₂.6H₂O)
- Sodium acetate (CH₃COONa.3H₂O)
- Potassium nitrate (KNO₃)
- Acetic acid (CH₃COOH)
- Anhydrous Sodium sulfate (Na₂SO₄)

Buffer solution A :

In a 500-ml beaker with stirring:

1. Add 250-ml of distilled water.
2. Dissolve 15-g Magnesium chloride.
3. Dissolve 2.5-g Sodium acetate.

4. Dissolve 0.5-g Potassium nitrate.
5. Add 10-ml 99% acetic acid.
6. Transfer to 500-ml volumetric flask and dilute to mark.

Buffer solution B:

In a 500-ml beaker with stirring:

1. Add 250-ml distilled water.
2. Dissolve 15-g Magnesium chloride.
3. Dissolve 2.5-g Sodium acetate.
4. Dissolve 0.5-g Potassium nitrate.
5. Dissolve 0.0555-g Sodium sulfate (exact).
6. Add 10-ml Acetic acid.
7. Transfer to 500-ml volumetric flask and dilute to mark.

Standard sulfate solution :

In a 1000ml volumetric flask:

1. Dissolve 0.1479-g Anhydrous Sodium sulfate in distilled water.
2. Dilute to 1000 ml (500mg/L or 1.00ml=0.100 mg SO₄).

9. Magnesium determination

Calculation Method

(Standard Methods 1995 3500-Mg E)

Magnesium was estimated as the difference between hardness and calcium as CaCO₃ since interfering metals were present in non interfering concentrations in the calcium titration and suitable inhibitors were used in the hardness titration:

$$\text{Mg Mg/L} = [\text{Total hardness as mg CaCO}_3/\text{L} - \text{Calcium hardness as mg CaCO}_3/\text{L}] \times 0.243$$

$$\text{Hardness, mg CaCO}_3/\text{L} = 2.497(\text{Ca, mg/L}) + 4.118 (\text{Mg, mg/L}).$$

10. Chloride determination

Argentometric Method(Standard methods (1995) 4500-Cl—B)

Reagents:

- Potassium chromate indicator solution.
- Standard Silver nitrate titrant [0.0141M]
- Standard Sodium Chloride solution [0.0141M]

Reagents for removal of interference(optional):

- Aluminium hydroxide suspension (for color interference)

- Sodium hydroxide (NaOH), 1 N, standard reagent (for pH adjustment).
- Sulfuric acid (H₂SO₄), 1 N, standard reagent (for pH adjustment).
- Hydrogen peroxide (H₂O₂), 30 %, standard reagent, (for sulfide.... interference).

Apparatus:

- 25ml Burette
- Magnetic stirrer.
- pH meter + pH Electrode (No. 6.0220.100).
- Glass filter (ROBO por-3 and por-4).

Procedure:

1. In a 250-ml beaker with stirring, add a 100-ml of the sample R4 (raw sample) was added.
2. The Standard Silver nitrate titrant was prepared in a 25-ml burette.
3. Removal of interference:
 - 3.1. If the sample was highly colored, 3-ml Aluminium hydroxide suspension was added , mixed left to settle and filtered using micropore glass filter por-3. If the sample still had some precipitate, then micropore glass filter por-4 was used however most of the samples were almost clear and this was not necessary.
 - 3.2. If the sample pH was not in the pH range of 7 to 10, this was adjusted with 1 N Sulfuric acid or 1 N Sodium hydroxide.
4. 1-ml Potassium chromate indicator solution was added.
5. This was then titrated with a Standard Silver nitrate titrant to a pinkish yellow endpoint. The author had to be consistent in end point recognition for all other samples.
6. A reagent blank value had to be established by titrating a sample (100ml) of distilled water using the procedure outlined above (usually 0.2 to 0.3 ml).
7. Calculation for chloride:

$$C, [mgCl/l] = \frac{(A - B) \cdot N \cdot 35450}{sample[ml]}$$

Where:

A = ml titration for sample

B = ml titration for blank

C = mg of Chloride per liter in sample

N = exact normality of AgNO₃ (standardized regularly against Standard Sodium Chloride Solution, see procedure under Standard Silver nitrate titrant)

APPENDIX C

Mineral water chemical equilibrium data for some of the Ground waters of Baringo-Bogoria basin, computed using the programme PCWATEQ.

AIP refers to Inorganic species activity product

KT refers to Equilibrium solubility product at Temp T, the temperature of the sample as measured in the Laboratory

NREACT (I) Name of the i^{th} reaction

NSPEC (I) Name of the species

Z (I) Charge of the species

GFW (I) Gram Formula wt. of i^{th} species

DHA(I) Debye-Huckel a° parameter of the i^{th} species

H_r^o for the i^{th} reaction (Kcal/mole)

EHM "true" Eh of solution to which no temperature correction will be made (volts)

TOT denotes Total

The Debye-Huckel theory considers the effect, on the free energy of a single ion, of electrical interactions with other ions by assuming that oppositely charged ions can be considered as forming a spherical shell around the ion. This assumption is only valid for very dilute solutions, and activity coefficients derived from the theory deviate increasingly from experimental results as concentration increases. Truesdell and Jones, (1974).

Chepkoimet Borehole

INITIAL SOLUTION

TEMPERATURE = 25.00 DEGREES C PH = 7.100
 ANALYTICAL EPMCAT = 6.387 ANALYTICAL EPMAN = 6.290
 CHARGE BALANCE ERROR = .70 %

***** OXIDATION - REDUCTION *****

DISSOLVED OXYGEN = .000 MG/L
 EH MEASURED WITH CALOMEL = 9.9000 VOLTS FLAG CORALK PECALC IDAVES
 MEASURED EH OF ZOBELL SOLUTION = 9.9000 VOLTS 3 0 0 1
 CORRECTED EH = 9.9000 VOLTS
 PE COMPUTED FROM CORRECTED EH = 100.000

*** TOTAL CONCENTRATIONS OF INPUT SPECIES ***

SPECIES		TOTAL MOLALITY	LOG TOTAL MOLALITY	TOTAL MG/LITRE
-----		-----	-----	-----
CA	2	4.74288E-04	-3.3240	1.90000E+01
MG	2	4.11524E-04	-3.3856	1.00000E+01
NA	1	4.43896E-03	-2.3527	1.02000E+02
K	1	1.79108E-04	-3.7469	7.00000E+00
CL	-1	3.95086E-04	-3.4033	1.40000E+01
SO4	-2	2.08303E-04	-3.6813	2.00000E+01
HCO3	-1	5.06666E-03	-2.2953	3.09000E+02
F	-1	2.05383E-04	-3.6874	3.90000E+00
NO3	-1	2.09765E-04	-3.6783	1.30000E+01

*** CONVERGENCE ITERATIONS ***

ITERATION	S1-ANALCO3	S2-SO4TOT	S3-FTOT	S4-PTOT	S5-CLTOT
1	5.570E-05	2.778E-05	4.589E-06	0.000E+00	0.000E+00
2	7.056E-07	2.643E-07	6.762E-08	0.000E+00	0.000E+00
3	-1.875E-08	-8.126E-09	-1.686E-09	0.000E+00	0.000E+00

****DESCRIPTION OF SOLUTION ****

ANAL.	COMP.	PH	ACTIVITY H2O = .9998
EPMCAT 6.39	6.30	7.100	PCO2= 2.407656E-02
EPMAN 6.29	6.20		LOG PCO2 = -1.6184
		TEMPERATURE	PO2 = 0.000000E+00
EH = 9.9000	PE = 100.000	25.00 DEG C	PCH4 = 0.000000E+00
PE CALC S = 100.000			CO2 TOT = 5.878552E-03
PE CALC DOX=100.000		IONIC STRENGTH	DENSITY = 1.0000
PE SATO DOX=100.000		7.276580E-03	TDS = 497.9MG/L
TOT ALK = 5.067E+00 MEQ			CARB ALK = 5.067E+00 MEQ
ELECT = 9.625E-02 MEQ			

DISTRIBUTION OF SPECIES

I	SPECIES		PPM	MOLALITY	ACTIVITY	LOG ACT	GAMMA
1	CA	2	1.7779E+01	4.4380E-04	3.1297E-04	-3.504	7.0521E-01
2	MG	2	9.3544E+00	3.8496E-04	2.7280E-04	-3.564	7.0865E-01
3	NA	1	1.0168E+02	4.4252E-03	4.0485E-03	-2.393	9.1487E-01
4	K	1	6.9934E+00	1.7894E-04	1.6336E-04	-3.787	9.1290E-01
64	H	1	8.7555E-05	8.6904E-08	7.9433E-08	-7.100	9.1403E-01
5	CL	-1	1.4000E+01	3.9509E-04	3.6068E-04	-3.443	9.1290E-01
6	SO4	-2	1.8264E+01	1.9022E-04	1.3369E-04	-3.874	7.0279E-01
7	HCO3	-1	3.0541E+02	5.0078E-03	4.5898E-03	-2.338	9.1654E-01
18	CO3	-2	2.3032E-01	3.8400E-06	2.7098E-06	-5.567	7.0568E-01
86	H2CO3	0	5.0726E+01	8.1824E-04	8.1969E-04	-3.086	1.0018E+00
27	OH	-1	2.3853E-03	1.4032E-07	1.2826E-07	-6.892	9.1403E-01
62	F	-1	3.8207E+00	2.0121E-04	1.8391E-04	-3.735	9.1403E-01
19	MGOH	1	2.5838E-04	6.2563E-09	5.7185E-09	-8.243	9.1403E-01
23	MGSO4 AQ	0	7.5772E-01	6.2979E-06	6.3085E-06	-5.200	1.0017E+00
22	MGHCO3	1	1.3585E+00	1.5929E-05	1.4560E-05	-4.837	9.1403E-01
21	MGCO3 AQ	0	5.9352E-02	7.0423E-07	7.0541E-07	-6.152	1.0017E+00
20	MGF	1	1.5699E-01	3.6265E-06	3.3147E-06	-5.480	9.1403E-01
29	CAOH	1	6.2943E-05	1.1031E-09	1.0083E-09	-8.996	9.1403E-01
32	CASO4 AQ	0	1.1578E+00	8.5086E-06	8.5229E-06	-5.069	1.0017E+00
30	CAHCO3	1	2.0197E+00	1.9988E-05	1.8320E-05	-4.737	9.1654E-01
31	CACO3 AQ	0	1.4370E-01	1.4365E-06	1.4245E-06	-5.846	9.9166E-01
49	CAF+	1	3.2386E-02	5.4847E-07	5.0132E-07	-6.300	9.1403E-01
44	NASO4	-1	3.6977E-01	3.1075E-06	2.8404E-06	-5.547	9.1403E-01
43	NAHCO3	0	8.7575E-01	1.0432E-05	1.0449E-05	-4.981	1.0017E+00
42	NACO3	-1	1.8456E-02	2.2247E-07	2.0335E-07	-6.692	9.1403E-01
94	NACL	0	8.5153E-32	1.4577E-36	1.4602E-36	-35.836	1.0017E+00
46	KSO4	-1	2.2679E-02	1.6788E-07	1.5344E-07	-6.814	9.1403E-01
95	KCL	0	4.3831E-33	5.8820E-38	5.8918E-38	-37.230	1.0017E+00
63	HSO4	-1	1.0938E-04	1.1274E-09	1.0304E-09	-8.987	9.1403E-01
85	NO3	-1	1.3000E+01	2.0977E-04	1.9173E-04	-3.717	9.1403E-01

MOLE RATIOS FROM ANALYTICAL MOLALITY

MOLE RATIOS FROM COMPUTED MOLALITY

LOG ACTIVITY RATIOS

CL/CA	=	8.3301E-01
CL/MG	=	9.6005E-01
CL/NA	=	8.9004E-02
CL/K	=	2.2058E+00
CL/AL	=	3.9509E+26
CL/FE	=	3.9509E+26
CL/SO4	=	1.8967E+00
CL/HCO3	=	7.7978E-02
CA/MG	=	1.1525E+00
NA/K	=	2.4784E+01

CL/CA	=	8.9024E-01
CL/MG	=	1.0263E+00
CL/NA	=	8.9281E-02
CL/K	=	2.2079E+00
CL/AL	=	3.9509E+26
CL/FE	=	3.9509E+26
CL/SO4	=	2.0770E+00
CL/HCO3	=	7.8895E-02
CA/MG	=	1.1529E+00
NA/K	=	2.4730E+01

LOG CA/H2	=	10.6955
LOG MG/H2	=	10.6358
LOG NA/H1	=	4.7073
LOG K/H1	=	3.3131
LOG AL/H3	=	21.3000
LOG FE/H2	=	14.2000
LOG CA/MG	=	.0597
LOG NA/K	=	1.3942

Results

PHASE	IAP	KT	LOG IAP	LOG KT	IAP/KT	LOG IAP/KT
18 ANHYDRIT	4.184E-08	4.130E-05	-7.378	-4.384	1.013E-03	-2.994
22 ARAGONIT	8.481E-10	4.613E-09	-9.072	-8.336	1.839E-01	-.736
151 ARTIN	4.364E-27	3.981E-19	-26.360	-18.400	1.096E-08	-7.960
20 BRUCITE	4.487E-18	3.890E-12	-17.348	-11.410	1.153E-06	-5.938
13 CALCITE	8.481E-10	3.313E-09	-9.072	-8.480	2.560E-01	-.592
12 DOLOMITE	6.269E-19	8.128E-18	-18.203	-17.090	7.713E-02	-1.113
63 FLUOR	1.059E-11	1.096E-11	-10.975	-10.960	9.654E-01	-.015
19 GYPSUM	4.182E-08	2.498E-05	-7.379	-4.602	1.674E-03	-2.776
65 HALITE	1.460E-06	3.819E+01	-5.836	1.582	3.823E-08	-7.418
118 HUNTITE	3.426E-37	3.090E-31	-36.465	-30.510	1.109E-06	-5.955
39 HYDMAG			-53.873	-37.820		-16.053
11 MAGNESIT	7.392E-10	5.754E-09	-9.131	-8.240	1.285E-01	-.891

57	MIRABI	2.187E-09	7.709E-02	-8.660	-1.113	2.836E-08	-7.547
59	NAHCOL	1.858E-05	2.831E-01	-4.731	-.548	6.563E-05	-4.183
61	NATRON	4.432E-11	4.887E-02	-10.353	-1.311	9.070E-10	-9.042
60	NESQUE	7.388E-10	6.152E-06	-9.131	-5.211	1.201E-04	-3.920
66	THENAR	2.191E-09	6.622E-01	-8.659	-.179	3.309E-09	-8.480
62	THRNAT	4.441E-11	1.334E+00	-10.353	.125	3.330E-11	-10.478
60	TRONA	8.250E-16	1.603E-01	-15.084	-.795	5.146E-15	-14.289

Miller Borehole

INITIAL SOLUTION

TEMPERATURE = 25.00 DEGREES C PH = 8.500
 ANALYTICAL EPMCAT = 38.087 ANALYTICAL EPMAN = 38.697
 CHARGE BALANCE ERROR = .78 %

***** OKIDATION - REDUCTION *****

DISSOLVED OXYGEN = .000 MG/L
 MEASURED WITH CALOMEL = 9.9000 VOLTS FLAG CORALK PECALC IDAVES
 MEASURED EH OF ZOBELL SOLUTION = 9.9000 VOLTS 3 0 0 1
 CORRECTED EH = 9.9000 VOLTS
 EH COMPUTED FROM CORRECTED EH = 100.000

*** TOTAL CONCENTRATIONS OF INPUT SPECIES ***

SPECIES		TOTAL MOLALITY	LOG TOTAL MOLALITY	TOTAL MG/LITRE
-----		-----	-----	-----
CA	2	1.00106E-04	-3.9995	4.00000E+00
MG	2	1.23774E-04	-3.9074	3.00000E+00
NA	1	3.76535E-02	-1.4242	8.63000E+02
K	1	1.02610E-04	-3.9888	4.00000E+00
CL	-1	3.67807E-03	-2.4344	1.30000E+02
SO4	-2	2.24501E-03	-2.6488	2.15000E+02
HCO3	-1	2.98040E-02	-1.5257	1.81300E+03
F	-1	6.33569E-04	-3.1982	1.20000E+01
NO3	-1	2.10304E-04	-3.6772	1.30000E+01

*** CONVERGENCE ITERATIONS ***

ITERATION	S1-ANALCO3	S2-SO4TOT	S3-FTOT	S4-PTOT	S5-CLTOT
1	1.174E-03	4.592E-04	2.114E-06	0.000E+00	0.000E+00
2	2.273E-05	3.859E-06	2.492E-07	0.000E+00	0.000E+00
3	-3.332E-07	-3.092E-08	-2.405E-09	0.000E+00	0.000E+00

****DESCRIPTION OF SOLUTION ****

ANAL.	COMP.	PH	ACTIVITY H2O = .9988
EPMCAT 38.09	37.14	8.500	PCO2= 4.818889E-03
EPMAN 38.70	37.76		LOG PCO2 = -2.3171
		TEMPERATURE	PO2 = 0.000000E+00
EH = 9.9000	PE = 100.000	25.00 DEG C	PCH4 = 0.000000E+00
PE CALC S = 100.000			CO2 TOT = 2.900786E-02
PE CALC DOX=100.000		IONIC STRENGTH	DENSITY = 1.0000
PE SATO DOX=100.000		4.043840E-02	TDS = 3057.0MG/L
TOT ALK = 2.980E+01 MEQ			CARB ALK = 2.980E+01 MEQ
ELECT = -6.127E-01 MEQ			

DISTRIBUTION OF SPECIES

I	SPECIES		PPM	MOLALITY	ACTIVITY	LOG ACT	GAMMA
1	CA	2	2.5342E+00	6.3423E-05	3.1627E-05	-4.500	4.9867E-01
2	MG	2	2.0872E+00	8.6112E-05	4.3830E-05	-4.358	5.0899E-01
3	NA	1	8.4413E+02	3.6830E-02	3.0760E-02	-1.512	8.3518E-01
4	K	1	3.9724E+00	1.0190E-04	8.4208E-05	-4.075	8.2637E-01
64	H	1	3.8147E-06	3.7961E-09	3.1623E-09	-8.500	8.3304E-01
5	CL	-1	1.3000E+02	3.6781E-03	3.0394E-03	-2.517	8.2637E-01
6	SO4	-2	1.9511E+02	2.0373E-03	9.9673E-04	-3.001	4.8924E-01
7	HCO3	-1	1.6710E+03	2.7470E-02	2.3075E-02	-1.637	8.4002E-01
18	CO3	-2	4.1118E+01	6.8729E-04	3.4221E-04	-3.466	4.9792E-01
86	H2CO3	0	1.0045E+01	1.6245E-04	1.6406E-04	-3.785	1.0099E+00
27	OH	-1	6.5505E-02	3.8634E-06	3.2183E-06	-5.492	8.3304E-01
62	F	-1	1.1962E+01	6.3157E-04	5.2612E-04	-3.279	8.3304E-01
19	MGOH	1	1.1401E-03	2.7676E-08	2.3055E-08	-7.637	8.3304E-01
23	MGSO4 AQ	0	8.9848E-01	7.4870E-06	7.5570E-06	-5.122	1.0094E+00
22	MGHCO3	1	1.2010E+00	1.4118E-05	1.1761E-05	-4.930	8.3304E-01
21	MGCO3 AQ	0	1.1920E+00	1.4180E-05	1.4313E-05	-4.844	1.0094E+00
20	MGF	1	7.8969E-02	1.8289E-06	1.5236E-06	-5.817	8.3304E-01
29	CAOH	1	1.7468E-04	3.0692E-09	2.5568E-09	-8.592	8.3304E-01
32	CASO4 AQ	0	8.6348E-01	6.3620E-06	6.4215E-06	-5.192	1.0094E+00
30	CAHCO3	1	1.1167E+00	1.1080E-05	9.3075E-06	-5.031	8.4002E-01
31	CACO3 AQ	0	1.9004E+00	1.9045E-05	1.8179E-05	-4.740	9.5451E-01
49	CAF+	1	1.0247E-02	1.7397E-07	1.4493E-07	-6.839	8.3304E-01
44	NASO4	-1	2.2925E+01	1.9315E-04	1.6090E-04	-3.793	8.3304E-01
43	NAHCO3	0	3.3113E+01	3.9545E-04	3.9915E-04	-3.399	1.0094E+00
42	NACO3	-1	1.9380E+01	2.3421E-04	1.9511E-04	-3.710	8.3304E-01
94	NACL	0	5.3968E-30	9.2627E-35	9.3493E-35	-34.029	1.0094E+00
46	KSO4	-1	9.5396E-02	7.0794E-07	5.8975E-07	-6.229	8.3304E-01
95	KCL	0	1.8847E-32	2.5357E-37	2.5595E-37	-36.592	1.0094E+00
63	HSO4	-1	3.5531E-05	3.6716E-10	3.0586E-10	-9.514	8.3304E-01
85	NO3	-1	1.3000E+01	2.1030E-04	1.7519E-04	-3.756	8.3304E-01

MOLE RATIOS FROM ANALYTICAL MOLALITY			MOLE RATIOS FROM COMPUTED MOLALITY			LOG ACTIVITY RATIOS		
CL/CA	=	3.6742E+01	CL/CA	=	5.7992E+01	LOG CA/H2	=	12.5001
CL/MG	=	2.9716E+01	CL/MG	=	4.2713E+01	LOG MG/H2	=	12.6418
CL/NA	=	9.7682E-02	CL/NA	=	9.9866E-02	LOG NA/H1	=	6.9880
CL/K	=	3.5845E+01	CL/K	=	3.6094E+01	LOG K/H1	=	4.4254
CL/AL	=	3.6781E+27	CL/AL	=	3.6781E+27	LOG AL/H3	=	25.5000
CL/FE	=	3.6781E+27	CL/FE	=	3.6781E+27	LOG FE/H2	=	17.0000
CL/SO4	=	1.6383E+00	CL/SO4	=	1.8054E+00	LOG CA/MG	=	-.1417
CL/HCO3	=	1.2341E-01	CL/HCO3	=	1.3389E-01	LOG NA/K	=	2.5626
CA/MG	=	8.0878E-01	CA/MG	=	7.3652E-01			
NA/K	=	3.6696E+02	NA/K	=	3.6143E+02			

Results							
PHASE	IAP	KT	LOG IAP	LOG KT	IAP/KT	LOG IAP/KT	
18 ANHYDRIT	3.152E-08	4.130E-05	-7.501	-4.384	7.632E-04	-3.117	
22 ARAGONIT	1.082E-08	4.613E-09	-7.966	-8.336	2.346E+00	.370	
151 ARTIN	3.532E-24	3.981E-19	-23.452	-18.400	8.873E-06	-5.052	
20 BRUCITE	4.540E-16	3.890E-12	-15.343	-11.410	1.167E-04	-3.933	
13 CALCITE	1.082E-08	3.313E-09	-7.966	-8.480	3.267E+00	.514	
12 DOLOMITE	1.623E-16	8.128E-18	-15.790	-17.090	1.997E+01	1.300	

63	FLUOR	8.754E-12	1.096E-11	-11.058	-10.960	7.984E-01	-.098
19	GYPSUM	3.145E-08	2.498E-05	-7.502	-4.602	1.259E-03	-2.900
65	HALITE	9.349E-05	3.819E+01	-4.029	1.582	2.448E-06	-5.611
18	HUNTITE	3.652E-32	3.090E-31	-31.437	-30.510	1.182E-01	-.927
39	HYDMAG			-46.641	-37.820		-8.821
11	MAGNESIT	1.500E-08	5.754E-09	-7.824	-8.240	2.607E+00	.416
67	MIRABI	9.315E-07	7.709E-02	-6.031	-1.113	1.208E-05	-4.918
59	NAHCOL	7.098E-04	2.831E-01	-3.149	-.548	2.507E-03	-2.601
61	NATRON	3.198E-07	4.887E-02	-6.495	-1.311	6.545E-06	-5.184
150	NESQUE	1.494E-08	6.152E-06	-7.826	-5.211	2.429E-03	-2.615
66	THENAR	9.431E-07	6.622E-01	-6.025	-.179	1.424E-06	-5.846
62	THRNAT	3.234E-07	1.334E+00	-6.490	.125	2.425E-07	-6.615
60	TRONA	2.293E-10	1.603E-01	-9.640	-.795	1.430E-09	-8.845

plelechiog Borehole

INITIAL SOLUTION

TEMPERATURE = 25.00 DEGREES C PH = 8.900
 ANALYTICAL EPMCAT = 14.668 ANALYTICAL EPMAN = 16.990
 CHARGE BALANCE ERROR = 7.11 %

***** OXIDATION - REDUCTION *****

DISSOLVED OXYGEN = .000 MG/L
 EH MEASURED WITH CALOMEL = 9.9000 VOLTS FLAG CORALK PECALC IDAVES
 MEASURED EH OF ZOBELL SOLUTION = 9.9000 VOLTS 3 0 0 1
 CORRECTED EH = 9.9000 VOLTS
 PE COMPUTED FROM CORRECTED EH = 100.000

*** TOTAL CONCENTRATIONS OF INPUT SPECIES ***

SPECIES		TOTAL MOLALITY	LOG TOTAL MOLALITY	TOTAL MG/LITRE
-----		-----	-----	-----
CA	2	1.02418E-04	-3.9896	4.10000E+00
MG	2	2.47088E-04	-3.6071	6.00000E+00
NA	1	1.38488E-02	-1.8586	3.18000E+02
K	1	1.38266E-04	-3.8593	5.40000E+00
CL	-1	3.53002E-03	-2.4522	1.25000E+02
SO4	-2	1.74055E-03	-2.7593	1.67000E+02
HCO3	-1	8.58162E-03	-2.0664	5.23000E+02
F	-1	8.95885E-04	-3.0477	1.70000E+01
NO3	-1	5.21551E-04	-3.2827	3.23000E+01

*** CONVERGENCE ITERATIONS ***

ITERATION	S1-ANALCO3	S2-SO4TOT	S3-FTOT	S4-PTOT	S5-CLTOT
1	3.242E-04	1.704E-04	7.278E-06	0.000E+00	0.000E+00
2	1.193E-05	2.988E-06	6.217E-07	0.000E+00	0.000E+00
3	-1.228E-07	-2.864E-08	-5.230E-09	0.000E+00	0.000E+00

****DESCRIPTION OF SOLUTION ****

ANAL.	COMP.	PH	ACTIVITY H2O =	.9995
EPMCAT 14.67	14.33	8.900	PCO2=	5.480879E-04
EPMAN 16.99	16.65		LOG PCO2 =	-3.2611
		TEMPERATURE	PO2 =	0.000000E+00
EH = 9.9000	PE = 100.000	25.00 DEG C	PCH4 =	0.000000E+00

CALC S = 100.000

CALC DOX=100.000

SATO DOX=100.000

ALK = 8.582E+00 MEQ

ACT = -2.324E+00 MEQ

CO2 TOT = 8.076251E-03

DENSITY = 1.0000

TDS = 1197.8MG/L

CARB ALK = 8.572E+00 MEQ

IONIC STRENGTH

1.781140E-02

DISTRIBUTION OF SPECIES

Table with 7 columns: SPECIES, PPM, MOLALITY, ACTIVITY, LOG ACT, GAMMA. Rows include various chemical species like CA, MG, NA, K, H, CL, SO4, HCO3, CO3, H2CO3, OH, F, MGOH, MGSO4 AQ, MGHCO3, MGCO3 AQ, MGF, CAO, CASO4 AQ, CAHCO3, CACO3 AQ, CAF+, NASO4, NAHCO3, NACO3, NA, KSO4, KCL, HSO4, NO3.

MOLE RATIOS FROM ANALYTICAL MOLALITY

MOLE RATIOS FROM COMPUTED MOLALITY

LOG ACTIVITY RATIOS

Table with 3 columns: Analytical Molarities (e.g., CL/CA = 3.4467E+01), Computed Molarities (e.g., CL/CA = 4.9466E+01), and Log Activity Ratios (e.g., LOG CA/H2 = 13.4327).

PHASE	IAP	KT	LOG IAP	LOG KT	IAP/KT	LOG IAP/KT
18 ANHYDRIT	4.204E-08	4.130E-05	-7.376	-4.384	1.018E-03	-2.992
22 ARAGONIT	1.054E-08	4.613E-09	-7.977	-8.336	2.286E+00	.359
151 ARTIN	2.958E-23	3.981E-19	-22.529	-18.400	7.430E-05	-4.129
20 BRUCITE	7.368E-15	3.890E-12	-14.133	-11.410	1.894E-03	-2.723
13 CALCITE	1.054E-08	3.313E-09	-7.977	-8.480	3.182E+00	.503
12 DOLOMITE	2.914E-16	8.128E-18	-15.535	-17.090	3.586E+01	1.555
63 FLUOR	2.604E-11	1.096E-11	-10.584	-10.960	2.375E+00	.376
19 GYPSUM	4.200E-08	2.498E-05	-7.377	-4.602	1.681E-03	-2.774
65 HALITE	3.699E-05	3.819E+01	-4.432	1.582	9.685E-07	-6.014
118 HUNTITE	2.227E-31	3.090E-31	-30.652	-30.510	7.207E-01	-.142
39 HYDMAG			-44.367	-37.820		-6.547
11 MAGNESIT	2.764E-08	5.754E-09	-7.558	-8.240	4.804E+00	.682
67 MIRABI	1.403E-07	7.709E-02	-6.853	-1.113	1.820E-06	-5.740
59 NAHCOL	7.911E-05	2.831E-01	-4.102	-.548	2.794E-04	-3.554
61 NATRON	3.519E-08	4.887E-02	-7.454	-1.311	7.201E-07	-6.143
150 NESQUE	2.760E-08	6.152E-06	-7.559	-5.211	4.487E-03	-2.348
66 THENAR	1.410E-07	6.622E-01	-6.851	-.179	2.129E-07	-6.672
62 THRAT	3.534E-08	1.334E+00	-7.452	.125	2.650E-08	-7.577
60 TRONA	2.794E-12	1.603E-01	-11.554	-.795	1.743E-11	-10.759

Ngaratuko Borehole

INITIAL SOLUTION

TEMPERATURE = 25.00 DEGREES C PH = 6.900
 ANALYTICAL EPMCAT = 8.108 ANALYTICAL EPMAN = 4.734
 CHARGE BALANCE ERROR = 24.38 %

***** OXIDATION - REDUCTION *****

DISSOLVED OXYGEN = .000 MG/L
 EH MEASURED WITH CALOMEL = 9.9000 VOLTS FLAG CORALK PECALC IDAVES
 MEASURED EH OF ZOBELL SOLUTION = 9.9000 VOLTS 3 0 0 1
 CORRECTED EH = 9.9000 VOLTS
 PE COMPUTED FROM CORRECTED EH = 100.000

*** TOTAL CONCENTRATIONS OF INPUT SPECIES ***

SPECIES		TOTAL MOLALITY	LOG TOTAL MOLALITY	TOTAL MG/LITRE
-----		-----	-----	-----
CA	2	3.74396E-04	-3.4267	1.50000E+01
MG	2	4.11479E-06	-5.3857	1.00000E-01
NA	1	7.09285E-03	-2.1492	1.63000E+02
K	1	2.60957E-04	-3.5834	1.02000E+01
CL	-1	2.82173E-03	-2.5495	1.00000E+02
SO4	-2	6.56083E-04	-3.1830	6.30000E+01
HCO3	-1	5.65632E-04	-3.2475	3.45000E+01
F	-1	2.63282E-05	-4.5796	5.00000E-01
NO3	-1	9.68040E-06	-5.0141	6.00000E-01

*** CONVERGENCE ITERATIONS ***

ITERATION S1-ANALCO3 S2-SO4TOT S3-FTOT S4-PTOT S5-CLTOT

1	4.259E-06	5.777E-05	6.516E-08	0.000E+00	0.000E+00
2	7.310E-08	7.305E-07	1.915E-09	0.000E+00	0.000E+00
3	-1.221E-09	-1.275E-08	-2.706E-11	0.000E+00	0.000E+00

****DESCRIPTION OF SOLUTION ****

ANAL.	COMP.	PH	ACTIVITY H2O =	.9998
MCAT 8.11	8.04	6.900	PCO2=	4.274607E-03
PMAN 4.73	4.67		LOG PCO2 =	-2.3691
		TEMPERATURE	PO2 =	0.000000E+00
		25.00 DEG C	PCH4 =	0.000000E+00
			CO2 TOT =	7.104356E-04
		IONIC STRENGTH	DENSITY =	1.0000
		7.330589E-03	TDS =	386.9MG/L
			CARB ALK =	5.655E-01 MEQ

DISTRIBUTION OF SPECIES

SPECIES	PPM	MOLALITY	ACTIVITY	LOG ACT	GAMMA	
1 CA	2	1.4051E+01	3.5071E-04	2.4705E-04	-3.607	7.0442E-01
2 MG	2	9.4430E-02	3.8856E-06	2.7505E-06	-5.561	7.0787E-01
3 NA	1	1.6259E+02	7.0748E-03	6.4707E-03	-2.189	9.1461E-01
4 K	1	1.0169E+01	2.6017E-04	2.3743E-04	-3.624	9.1262E-01
64 H	1	1.3882E-04	1.3777E-07	1.2589E-07	-6.900	9.1376E-01
5 CL	-1	1.0000E+02	2.8217E-03	2.5752E-03	-2.589	9.1262E-01
6 SO4	-2	5.9267E+01	6.1721E-04	4.3327E-04	-3.363	7.0199E-01
7 HCO3	-1	3.4226E+01	5.6113E-04	5.1416E-04	-3.289	9.1628E-01
18 CO3	-2	1.6299E-02	2.7172E-07	1.9153E-07	-6.718	7.0489E-01
86 H2CO3	0	9.0069E+00	1.4527E-04	1.4553E-04	-3.837	1.0018E+00
27 OH	-1	1.5056E-03	8.8562E-08	8.0925E-08	-7.092	9.1376E-01
62 F	-1	4.9884E-01	2.6267E-05	2.4002E-05	-4.620	9.1376E-01
19 MGOH	1	1.6444E-06	3.9813E-11	3.6379E-11	-10.439	9.1376E-01
23 MGSO4 AQ	0	2.4763E-02	2.0580E-07	2.0615E-07	-6.686	1.0017E+00
22 MGHCO3	1	1.5350E-03	1.7997E-08	1.6445E-08	-7.784	9.1376E-01
21 MGCO3 AQ	0	4.2301E-05	5.0186E-10	5.0271E-10	-9.299	1.0017E+00
20 MGF	1	2.0665E-04	4.7733E-09	4.3617E-09	-8.360	9.1376E-01
29 CAO4	1	3.1362E-05	5.4958E-10	5.0219E-10	-9.299	9.1376E-01
32 CASO4 AQ	0	2.9623E+00	2.1768E-05	2.1804E-05	-4.661	1.0017E+00
30 CAHCO3	1	1.7867E-01	1.7680E-06	1.6200E-06	-5.790	9.1628E-01
31 CACO3 AQ	0	8.0190E-03	8.0150E-08	7.9476E-08	-7.100	9.9160E-01
49 CAF+	1	3.3377E-03	5.6519E-08	5.1645E-08	-7.287	9.1376E-01
44 NASO4	-1	1.9162E+00	1.6102E-05	1.4713E-05	-4.832	9.1376E-01
43 NAHCO3	0	1.5681E-01	1.8677E-06	1.8709E-06	-5.728	1.0017E+00
42 NACO3	-1	2.0858E-03	2.5140E-08	2.2972E-08	-7.639	9.1376E-01
94 NACL	0	9.7183E-31	1.6635E-35	1.6663E-35	-34.778	1.0017E+00
46 KSO4	-1	1.0688E-01	7.9105E-07	7.2283E-07	-6.141	9.1376E-01
95 KCL	0	4.5491E-32	6.1040E-37	6.1143E-37	-36.214	1.0017E+00
63 HSO4	-1	5.6206E-04	5.7925E-09	5.2930E-09	-8.276	9.1376E-01
85 NO3	-1	6.0000E-01	9.6804E-06	8.8456E-06	-5.053	9.1376E-01

MOLE RATIOS FROM ANALYTICAL MOLALITY

MOLE RATIOS FROM COMPUTED MOLALITY

LOG ACTIVITY RATIOS

CL/CA =	7.5367E+00	CL/CA =	8.0457E+00	LOG CA/H2 =	10.1928
CL/MG =	6.8575E+02	CL/MG =	7.2620E+02	LOG MG/H2 =	8.2394
CL/NA =	3.9783E-01	CL/NA =	3.9884E-01	LOG NA/H1 =	4.7110
CL/K =	1.0813E+01	CL/K =	1.0846E+01	LOG K/H1 =	3.2755
CL/AL =	2.8217E+27	CL/AL =	2.8217E+27	LOG AL/H3 =	20.7000

CL/FE = 2.8217E+27	CL/FE = 2.8217E+27	LOG FE/H2 = 13.8000
CL/SO4 = 4.3009E+00	CL/SO4 = 4.5717E+00	LOG CA/MG = 1.9534
CL/HCO3 = 4.9886E+00	CL/HCO3 = 5.0286E+00	LOG NA/K = 1.4354
CA/MG = 9.0988E+01	CA/MG = 9.0260E+01	
NA/K = 2.7180E+01	NA/K = 2.7194E+01	

Results						
PHASE	IAP	KT	LOG IAP	LOG KT	IAP/KT	LOG IAP/KT
18 ANHYDRIT	1.070E-07	4.130E-05	-6.970	-4.384	2.591E-03	-2.586
22 ARAGONIT	4.732E-11	4.613E-09	-10.325	-8.336	1.026E-02	-1.989
151 ARTIN	7.651E-29	3.981E-19	-28.116	-18.400	1.922E-10	-9.716
20 BRUCITE	1.801E-20	3.890E-12	-19.744	-11.410	4.630E-09	-8.334
13 CALCITE	4.732E-11	3.313E-09	-10.325	-8.480	1.428E-02	-1.845
12 DOLOMITE	2.493E-23	8.128E-18	-22.603	-17.090	3.067E-06	-5.513
63 FLUOR	1.423E-13	1.096E-11	-12.847	-10.960	1.298E-02	-1.887
19 GYPSUM	1.070E-07	2.498E-05	-6.971	-4.602	4.282E-03	-2.368
65 HALITE	1.666E-05	3.819E+01	-4.778	1.582	4.363E-07	-6.360
118 HUNTITE			-47.160	-30.510		-16.650
39 HYDMAG			-68.858	-37.820		-31.038
11 MAGNESIT	5.268E-13	5.754E-09	-12.278	-8.240	9.155E-05	-4.038
67 MIRABI	1.810E-08	7.709E-02	-7.742	-1.113	2.348E-07	-6.629
59 NAHCOL	3.327E-06	2.831E-01	-5.478	-.548	1.175E-05	-4.930
61 NATRON	8.003E-12	4.887E-02	-11.097	-1.311	1.638E-10	-9.786
150 NESQUE	5.265E-13	6.152E-06	-12.279	-5.211	8.558E-08	-7.068
66 THENAR	1.814E-08	6.622E-01	-7.741	-.179	2.739E-08	-7.562
62 THRAT	8.018E-12	1.334E+00	-11.096	.125	6.013E-12	-11.221
60 TRONA	2.667E-17	1.603E-01	-16.574	-.795	1.663E-16	-15.779

Tabarngetuny Borehole

INITIAL SOLUTION

TEMPERATURE = 25.00 DEGREES C PH = 8.000
ANALYTICAL EPMCAT = 9.780 ANALYTICAL EPMAN = 9.828
CHARGE BALANCE ERROR = .23 %
***** OXIDATION - REDUCTION *****
DISSOLVED OXYGEN = .000 MG/L
EH MEASURED WITH CALOMEL = 9.9000 VOLTS FLAG CORALK PECALC IDAVES
MEASURED EH OF ZOBELL SOLUTION = 9.9000 VOLTS 3 0 0 1
CORRECTED EH = 9.9000 VOLTS
PE COMPUTED FROM CORRECTED EH = 100.000

*** TOTAL CONCENTRATIONS OF INPUT SPECIES ***

SPECIES		TOTAL MOLALITY	LOG TOTAL MOLALITY	TOTAL MG/LITRE
-----		-----	-----	-----
CA	2	4.99405E-04	-3.3015	2.00000E+01
MG	2	1.23496E-04	-3.9083	3.00000E+00
NA	1	8.18415E-03	-2.0870	1.88000E+02
K	1	3.58327E-04	-3.4457	1.40000E+01
CL	-1	4.51666E-04	-3.3452	1.60000E+01
SO4	-2	7.29288E-05	-4.1371	7.00000E+00
HCO3	-1	9.11953E-03	-2.0400	5.56000E+02
F	-1	9.48214E-05	-4.0231	1.80000E+00
NO3	-1	2.42112E-05	-4.6160	1.50000E+00

*** CONVERGENCE ITERATIONS ***

ITERATION	S1-ANALCO3	S2-SO4TOT	S3-FTOT	S4-PTOT	S5-CLTOT
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1	1.444E-04	8.530E-06	7.805E-07	0.000E+00	0.000E+00
2	1.752E-06	6.406E-08	1.204E-08	0.000E+00	0.000E+00

****DESCRIPTION OF SOLUTION ****

ANAL.	COMP.	PH	ACTIVITY H2O = .9997
EPMCAT 9.78	9.65	8.000	PCO2= 5.297150E-03
EPMAN 9.83	9.70		LOG PCO2 = -2.2760
		TEMPERATURE	PO2 = 0.000000E+00
EH = 9.9000 PE = 100.000		25.00 DEG C	PCH4 = 0.000000E+00
PE CALC S = 100.000			CO2 TOT = 9.214576E-03
PE CALC DOX=100.000		IONIC STRENGTH	DENSITY = 1.0000
PE SATO DOX=100.000		1.034019E-02	TDS = 807.3MG/L
TOT ALK = 9.120E+00 MEQ			CARB ALK = 9.118E+00 MEQ
ELECT = -4.769E-02 MEQ			

DISTRIBUTION OF SPECIES

I	SPECIES		PPM	MOLALITY	ACTIVITY	LOG ACT	GAMMA
1	CA	2	1.7785E+01	4.4409E-04	2.9589E-04	-3.529	6.6629E-01
2	MG	2	2.7201E+00	1.1197E-04	7.5102E-05	-4.124	6.7072E-01
3	NA	1	1.8707E+02	8.1435E-03	7.3412E-03	-2.134	9.0147E-01
4	K	1	1.3996E+01	3.5821E-04	3.2195E-04	-3.492	8.9877E-01
64	H	1	1.1186E-05	1.1106E-08	1.0000E-08	-8.000	9.0039E-01
5	CL	-1	1.6000E+01	4.5167E-04	4.0594E-04	-3.392	8.9877E-01
6	SO4	-2	6.4905E+00	6.7621E-05	4.4836E-05	-4.348	6.6305E-01
7	HCO3	-1	5.4119E+02	8.8767E-03	8.0213E-03	-2.096	9.0364E-01
18	C03	-2	3.3828E+00	5.6418E-05	3.7617E-05	-4.425	6.6677E-01
86	H2CO3	0	1.1149E+01	1.7989E-04	1.8034E-04	-3.744	1.0025E+00
27	OH	-1	1.9226E-02	1.1314E-06	1.0187E-06	-5.992	9.0039E-01
62	F	-1	1.7865E+00	9.4112E-05	8.4738E-05	-4.072	9.0039E-01
19	MGOH	1	5.7334E-04	1.3887E-08	1.2504E-08	-7.903	9.0039E-01
23	MGSO4 AQ	0	6.9891E-02	5.8109E-07	5.8247E-07	-6.235	1.0024E+00
22	MGHCO3	1	6.6332E-01	7.7800E-06	7.0050E-06	-5.155	9.0039E-01
21	MGCO3 AQ	0	2.2660E-01	2.6895E-06	2.6959E-06	-5.569	1.0024E+00
20	MGF	1	2.0209E-02	4.6698E-07	4.2046E-07	-6.376	9.0039E-01
29	CAOH	1	4.7964E-04	8.4087E-09	7.5711E-09	-8.121	9.0039E-01
32	CASO4 AQ	0	3.6674E-01	2.6960E-06	2.7024E-06	-5.568	1.0024E+00
30	CAHCO3	1	3.3837E+00	3.3497E-05	3.0269E-05	-4.519	9.0364E-01
31	CACO3 AQ	0	1.8921E+00	1.8919E-05	1.8695E-05	-4.728	9.8817E-01
49	CAF+	1	1.4317E-02	2.4254E-07	2.1838E-07	-6.661	9.0039E-01
44	NASO4	-1	2.2821E-01	1.9185E-06	1.7274E-06	-5.763	9.0039E-01
43	NAHCO3	0	2.7724E+00	3.3035E-05	3.3114E-05	-4.480	1.0024E+00
42	NACO3	-1	4.7146E-01	5.6849E-06	5.1186E-06	-5.291	9.0039E-01
94	NACL	0	1.7361E-31	2.9730E-36	2.9801E-36	-35.526	1.0024E+00
46	KSO4	-1	1.5213E-02	1.1265E-07	1.0143E-07	-6.994	9.0039E-01
95	KCL	0	9.7129E-33	1.3038E-37	1.3069E-37	-36.884	1.0024E+00
63	HSO4	-1	4.6867E-06	4.8321E-11	4.3508E-11	-10.361	9.0039E-01
85	NO3	-1	1.5000E+00	2.4211E-05	2.1800E-05	-4.662	9.0039E-01

MOLE RATIOS FROM ANALYTICAL MOLALITY		MOLE RATIOS FROM COMPUTED MOLALITY		LOG ACTIVITY RATIOS	
CL/CA	= 9.0441E-01	CL/CA	= 1.0171E+00	LOG CA/H2	= 12.4711
CL/MG	= 3.6573E+00	CL/MG	= 4.0337E+00	LOG MG/H2	= 11.8757
CL/NA	= 5.5188E-02	CL/NA	= 5.5463E-02	LOG NA/H1	= 5.8658
CL/K	= 1.2605E+00	CL/K	= 1.2609E+00	LOG K/H1	= 4.5078
CL/AL	= 4.5167E+26	CL/AL	= 4.5167E+26	LOG AL/H3	= 24.0000
CL/FE	= 4.5167E+26	CL/FE	= 4.5167E+26	LOG FE/H2	= 16.0000
CL/SO4	= 6.1933E+00	CL/SO4	= 6.6794E+00	LOG CA/MG	= .5955
CL/HCO3	= 4.9527E-02	CL/HCO3	= 5.0882E-02	LOG NA/K	= 1.3580

/MG = 4.0439E+00 CA/MG = 3.9660E+00
 /K = 2.2840E+01 NA/K = 2.2734E+01

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	PHASE	IAP	KT	LOG IAP	LOG KT	IAP/KT	LOG IAP/KT
18	ANHYDRIT	1.327E-08	4.130E-05	-7.877	-4.384	3.212E-04	-3.493
2	ARAGONIT	1.113E-08	4.613E-09	-7.953	-8.336	2.413E+00	.383
1	ARTIN	3.414E-24	3.981E-19	-23.467	-18.400	8.576E-06	-5.067
20	BRUCITE	7.793E-17	3.890E-12	-16.108	-11.410	2.003E-05	-4.698
13	CALCITE	1.113E-08	3.313E-09	-7.953	-8.480	3.360E+00	.526
12	DOLOMITE	3.145E-17	8.128E-18	-16.502	-17.090	3.869E+00	.588
63	FLUOR	2.125E-12	1.096E-11	-11.673	-10.960	1.938E-01	-.713
19	GYPHUM	1.326E-08	2.498E-05	-7.878	-4.602	5.306E-04	-3.275
65	HALITE	2.980E-06	3.819E+01	-5.526	1.582	7.802E-08	-7.108
18	HUNTITE	2.510E-34	3.090E-31	-33.600	-30.510	8.122E-04	-3.090
39	HYDMAG			-50.305	-37.820		-12.485
11	MAGNESIT	2.825E-09	5.754E-09	-8.549	-8.240	4.910E-01	-.309
67	MIRABI	2.409E-09	7.709E-02	-8.618	-1.113	3.124E-08	-7.505
59	NAHCOL	5.889E-05	2.831E-01	-4.230	-.548	2.080E-04	-3.682
61	NATRON	2.021E-09	4.887E-02	-8.694	-1.311	4.135E-08	-7.383
50	NESQUE	2.822E-09	6.152E-06	-8.549	-5.211	4.588E-04	-3.338
66	THENAR	2.416E-09	6.622E-01	-8.617	-.179	3.649E-09	-8.438
62	TRNAT	2.027E-09	1.334E+00	-8.693	.125	1.520E-09	-8.818
60	TRONA	1.193E-13	1.603E-01	-12.923	-.795	7.441E-13	-12.128

onyosas Borehole

 INITIAL SOLUTION

TEMPERATURE = 25.00 DEGREES C PH = 8.300
 ANALYTICAL EPMCAT = 21.320 ANALYTICAL EPMAN = 20.288
 CHARGE BALANCE ERROR = 2.42 %

***** OKIDATION - REDUCTION *****

DISSOLVED OXYGEN = .000 MG/L
 EH MEASURED WITH CALOMEL = 9.9000 VOLTS FLAG CORALK PECALC IDAVES
 MEASURED EH OF ZOBELL SOLUTION = 9.9000 VOLTS 3 0 0 1
 CORRECTED EH = 9.9000 VOLTS
 EH COMPUTED FROM CORRECTED EH = 100.000

*** TOTAL CONCENTRATIONS OF INPUT SPECIES ***

SPECIES		TOTAL MOLALITY	LOG TOTAL MOLALITY	TOTAL MG/LITRE
-----		-----	-----	-----
CA	2	1.11962E-03	-2.9509	4.48000E+01
MG	2	4.53202E-04	-3.3437	1.10000E+01
NA	1	1.80814E-02	-1.7428	4.15000E+02
K	1	1.28083E-04	-3.8925	5.00000E+00
CL	-1	7.06328E-04	-3.1510	2.50000E+01
SO4	-2	3.85808E-04	-3.4136	3.70000E+01
HCO3	-1	1.81068E-02	-1.7422	1.10300E+03
F	-1	7.27581E-04	-3.1381	1.38000E+01
NO3	-1	9.69270E-06	-5.0136	6.00000E-01

*** CONVERGENCE ITERATIONS ***

ITERATION	S1-ANALCO3	S2-SO4TOT	S3-FTOT	S4-PTOT	S5-CLTOT
1	7.687E-04	8.655E-05	1.465E-05	0.000E+00	0.000E+00

2 2.858E-05 1.725E-06 7.349E-07 0.000E+00 0.000E+00
 3 -6.330E-07 -4.085E-08 -1.432E-08 0.000E+00 0.000E+00

***DESCRIPTION OF SOLUTION ***

	ANAL.	COMP.	PH	ACTIVITY H2O =	.9993
EPMCAT	21.32	20.62	8.300	PCO2=	4.889676E-03
EPMAN	20.29	19.59		LOG PCO2 =	-2.3107
			TEMPERATURE	PO2 =	0.000000E+00
EH = 9.9000	PE = 100.000		25.00 DEG C	PCH4 =	0.000000E+00
PE CALC S =	100.000			CO2 TOT =	1.783691E-02
PE CALC DOX=	100.000		IONIC STRENGTH	DENSITY =	1.0000
PE SATO DOX=	100.000		2.194953E-02	TDS =	1655.2MG/L
TOT ALK =	1.811E+01	MEQ		CARB ALK =	1.810E+01
ELECT =	1.033E+00	MEQ			

 DISTRIBUTION OF SPECIES

I	SPECIES		PPM	MOLALITY	ACTIVITY	LOG ACT	GAMMA
1	CA	2	3.4784E+01	8.6930E-04	5.0041E-04	-3.301	5.7564E-01
2	MG	2	8.8749E+00	3.6565E-04	2.1314E-04	-3.671	5.8290E-01
3	NA	1	4.1058E+02	1.7889E-02	1.5520E-02	-1.809	8.6756E-01
4	K	1	4.9932E+00	1.2791E-04	1.1030E-04	-3.957	8.6231E-01
64	H	1	5.8250E-06	5.7884E-09	5.0119E-09	-8.300	8.6585E-01
5	CL	-1	2.5000E+01	7.0633E-04	6.0907E-04	-3.215	8.6231E-01
6	SO4	-2	3.2663E+01	3.4059E-04	1.9403E-04	-3.712	5.6971E-01
7	HCO3	-1	1.0331E+03	1.6959E-02	1.4773E-02	-1.831	8.7111E-01
18	CO3	-2	1.4383E+01	2.4007E-04	1.3824E-04	-3.859	5.7582E-01
86	H2CO3	0	1.0253E+01	1.6558E-04	1.6647E-04	-3.779	1.0054E+00
27	OH	-1	3.9844E-02	2.3466E-06	2.0318E-06	-5.692	8.6585E-01
62	F	-1	1.3550E+01	7.1441E-04	6.1857E-04	-3.209	8.6585E-01
19	MGOH	1	3.3720E-03	8.1744E-08	7.0778E-08	-7.150	8.6585E-01
23	MGSO4 AQ	0	8.5536E-01	7.1177E-06	7.1537E-06	-5.145	1.0051E+00
22	MGHCO3	1	3.6023E+00	4.2287E-05	3.6614E-05	-4.436	8.6585E-01
21	MGCO3 AQ	0	2.3549E+00	2.7974E-05	2.8115E-05	-4.551	1.0051E+00
20	MGF	1	4.3499E-01	1.0060E-05	8.7106E-06	-5.060	8.6585E-01
29	CAOH	1	1.6811E-03	2.9496E-08	2.5539E-08	-7.593	8.6585E-01
32	CASO4 AQ	0	2.6747E+00	1.9679E-05	1.9779E-05	-4.704	1.0051E+00
30	CAHCO3	1	1.0924E+01	1.0823E-04	9.4282E-05	-4.026	8.7111E-01
31	CAC03 AQ	0	1.1907E+01	1.1916E-04	1.1619E-04	-3.935	9.7505E-01
49	CAF+	1	1.8364E-01	3.1136E-06	2.6960E-06	-5.569	8.6585E-01
44	NASO4	-1	2.1693E+00	1.8252E-05	1.5804E-05	-4.801	8.6585E-01
43	NAHCO3	0	1.0757E+01	1.2828E-04	1.2893E-04	-3.890	1.0051E+00
42	NACO3	-1	3.8055E+00	4.5926E-05	3.9766E-05	-4.400	8.6585E-01
94	NACL	0	5.4874E-31	9.4049E-36	9.4526E-36	-35.024	1.0051E+00
46	KSO4	-1	2.3435E-02	1.7367E-07	1.5037E-07	-6.823	8.6585E-01
95	KCL	0	4.9750E-33	6.6840E-38	6.7179E-38	-37.173	1.0051E+00
63	HSO4	-1	1.0562E-05	1.0899E-10	9.4367E-11	-10.025	8.6585E-01
85	NO3	-1	6.0000E-01	9.6927E-06	8.3924E-06	-5.076	8.6585E-01

MOLE RATIOS FROM
 ANALYTICAL MOLALITY

MOLE RATIOS FROM
 COMPUTED MOLALITY

LOG ACTIVITY RATIOS

CL/CA =	6.3087E-01	CL/CA =	8.1252E-01	LOG CA/H2 =	13.2993
CL/MG =	1.5585E+00	CL/MG =	1.9317E+00	LOG MG/H2 =	12.9287
CL/NA =	3.9064E-02	CL/NA =	3.9484E-02	LOG NA/H1 =	6.4909
CL/K =	5.5146E+00	CL/K =	5.5221E+00	LOG K/H1 =	4.3426
CL/AL =	7.0633E+26	CL/AL =	7.0633E+26	LOG AL/H3 =	24.9000
CL/FE =	7.0633E+26	CL/FE =	7.0633E+26	LOG FE/H2 =	16.6000
CL/SO4 =	1.8308E+00	CL/SO4 =	2.0739E+00	LOG CA/MG =	.3707
CL/HCO3 =	3.9009E-02	CL/HCO3 =	4.1648E-02	LOG NA/K =	2.1483
CA/MG =	2.4705E+00	CA/MG =	2.3774E+00		

A/K = 1.4117E+02 NA/K = 1.3986E+02

Results

	PHASE	IAP	KT	LOG IAP	LOG KT	IAP/KT	LOG IAP/KT
08	ANHYDRIT	9.710E-08	4.130E-05	-7.013	-4.384	2.351E-03	-2.629
02	ARAGONIT	6.917E-08	4.613E-09	-7.160	-8.336	1.500E+01	1.176
01	ARTIN	1.426E-22	3.981E-19	-21.846	-18.400	3.582E-04	-3.446
00	BRUCITE	8.799E-16	3.890E-12	-15.056	-11.410	2.262E-04	-3.646
03	CALCITE	6.917E-08	3.313E-09	-7.160	-8.480	2.088E+01	1.320
02	DOLOMITE	2.038E-15	8.128E-18	-14.691	-17.090	2.507E+02	2.399
63	FLUOR	1.915E-10	1.096E-11	-9.718	-10.960	1.746E+01	1.242
09	GYPSUM	9.697E-08	2.498E-05	-7.013	-4.602	3.881E-03	-2.411
65	HALITE	9.453E-06	3.819E+01	-5.024	1.582	2.475E-07	-6.606
08	HUNTITE	1.769E-30	3.090E-31	-29.752	-30.510	5.725E+00	.758
39	HYDMAG			-45.180	-37.820		-7.360
01	MAGNESIT	2.946E-08	5.754E-09	-7.531	-8.240	5.120E+00	.709
67	MIRABI	4.643E-08	7.709E-02	-7.333	-1.113	6.022E-07	-6.220
59	NAHCOL	2.293E-04	2.831E-01	-3.640	-.548	8.098E-04	-3.092
01	NATRON	3.308E-08	4.887E-02	-7.480	-1.311	6.769E-07	-6.169
50	NESQUE	2.940E-08	6.152E-06	-7.532	-5.211	4.780E-03	-2.321
66	THENAR	4.673E-08	6.622E-01	-7.330	-.179	7.057E-08	-7.151
62	THRAT	3.327E-08	1.334E+00	-7.478	.125	2.495E-08	-7.603
60	TRONA	7.624E-12	1.603E-01	-11.118	-.795	4.755E-11	-10.323

Meril Borehole

INITIAL SOLUTION

TEMPERATURE = 25.00 DEGREES C PH = 7.100
 ANALYTICAL EPMCAT = 6.327 ANALYTICAL EPMAN = 6.394
 CHARGE BALANCE ERROR = .49 %

***** OXIDATION - REDUCTION *****

DISSOLVED OXYGEN = .000 MG/L
 EH MEASURED WITH CALOMEL = 9.9000 VOLTS FLAG CORALK PECALC IDAVES
 MEASURED EH OF ZOBELL SOLUTION = 9.9000 VOLTS 3 0 0 1
 CORRECTED EH = 9.9000 VOLTS
 EH COMPUTED FROM CORRECTED EH = 100.000

*** TOTAL CONCENTRATIONS OF INPUT SPECIES ***

SPECIES		TOTAL MOLALITY	LOG TOTAL MOLALITY	TOTAL MG/LITRE
-----		-----	-----	-----
CA	2	3.49481E-04	-3.4566	1.40000E+01
MG	2	3.29225E-05	-4.4825	8.00000E-01
NA	1	5.30943E-03	-2.2750	1.22000E+02
K	1	2.55873E-04	-3.5920	1.00000E+01
CL	-1	2.37055E-04	-3.6252	8.40000E+00
SO4	-2	2.81214E-04	-3.5510	2.70000E+01
HCO3	-1	5.29630E-03	-2.2760	3.23000E+02
F	-1	2.36984E-04	-3.6253	4.50000E+00
NO3	-1	6.45442E-05	-4.1901	4.00000E+00

*** CONVERGENCE ITERATIONS ***

ITERATION S1-ANALCO3 S2-SO4TOT S3-FTOT S4-PTOT S5-CLTOT

1 3.566E-05 2.226E-05 8.745E-07 0.000E+00 0.000E+00
 2 3.819E-07 1.846E-07 1.449E-08 0.000E+00 0.000E+00

****DESCRIPTION OF SOLUTION ****

	ANAL.	COMP.	PH	ACTIVITY H2O = .9998
PMCAT	6.33	6.27	7.100	PCO2= 2.531504E-02
PMAN	6.39	6.34		LOG PCO2 = -1.5966
			TEMPERATURE	PO2 = 0.000000E+00
H = 9.9000	PE = 100.000		25.00 DEG C	PCH4 = 0.000000E+00
PE CALC S = 100.000				CO2 TOT = 6.151106E-03
PE CALC DOX=100.000		IONIC STRENGTH		DENSITY = 1.0000
PE SATO DOX=100.000		6.916846E-03		TDS = 513.7MG/L
TOT ALK = 5.296E+00 MEQ				CARB ALK = 5.296E+00 MEQ
ELECT = -6.705E-02 MEQ				

 DISTRIBUTION OF SPECIES

I	SPECIES	PPM	MOLALITY	ACTIVITY	LOG ACT	GAMMA
1	CA	2 1.2967E+01	3.2369E-04	2.3001E-04	-3.638	7.1060E-01
2	MG	2 7.4074E-01	3.0484E-05	2.1763E-05	-4.662	7.1391E-01
3	NA	1 1.2157E+02	5.2908E-03	4.8500E-03	-2.314	9.1668E-01
4	K	1 9.9868E+00	2.5554E-04	2.3376E-04	-3.631	9.1480E-01
64	H	1 8.7378E-05	8.6729E-08	7.9433E-08	-7.100	9.1587E-01
5	CL	-1 8.4000E+00	2.3706E-04	2.1686E-04	-3.664	9.1480E-01
6	SO4	-2 2.5550E+01	2.6611E-04	1.8848E-04	-3.725	7.0828E-01
7	HCO3	-1 3.2050E+02	5.2554E-03	4.8259E-03	-2.316	9.1828E-01
18	CO3	-2 2.4033E-01	4.0070E-06	2.8492E-06	-5.545	7.1106E-01
86	H2CO3	0 5.3339E+01	8.6040E-04	8.6185E-04	-3.065	1.0017E+00
27	OH	-1 2.3804E-03	1.4004E-07	1.2826E-07	-6.892	9.1587E-01
62	F	-1 4.4846E+00	2.3617E-04	2.1630E-04	-3.665	9.1587E-01
19	MGOH	1 2.0570E-05	4.9809E-10	4.5619E-10	-9.341	9.1587E-01
23	MGSO4 AQ	0 8.5231E-02	7.0842E-07	7.0955E-07	-6.149	1.0016E+00
22	MGHCO3	1 1.1372E-01	1.3334E-06	1.2212E-06	-5.913	9.1587E-01
21	MGCO3 AQ	0 4.9787E-03	5.9075E-08	5.9169E-08	-7.228	1.0016E+00
20	MGF	1 1.4700E-02	3.3958E-07	3.1101E-07	-6.507	9.1587E-01
29	CAOH	1 4.6165E-05	8.0908E-10	7.4101E-10	-9.130	9.1587E-01
32	CASO4 AQ	0 1.1998E+00	8.8172E-06	8.8313E-06	-5.054	1.0016E+00
30	CAHCO3	1 1.5577E+00	1.5416E-05	1.4156E-05	-4.849	9.1828E-01
31	CAACO3 AQ	0 1.1100E-01	1.1096E-06	1.1007E-06	-5.958	9.9207E-01
49	CAF+	1 2.7937E-02	4.7313E-07	4.3333E-07	-6.363	9.1587E-01
44	NASO4	-1 6.2328E-01	5.2381E-06	4.7974E-06	-5.319	9.1587E-01
43	NAHCO3	0 1.1032E+00	1.3141E-05	1.3162E-05	-4.881	1.0016E+00
42	NACO3	-1 2.3200E-02	2.7966E-07	2.5613E-07	-6.592	9.1587E-01
94	NACL	0 6.1338E-32	1.0501E-36	1.0518E-36	-35.978	1.0016E+00
46	KSO4	-1 4.5665E-02	3.3802E-07	3.0959E-07	-6.509	9.1587E-01
95	KCL	0 3.7715E-33	5.0613E-38	5.0694E-38	-37.295	1.0016E+00
63	HSO4	-1 1.5390E-04	1.5863E-09	1.4528E-09	-8.838	9.1587E-01
85	NO3	-1 4.0000E+00	6.4544E-05	5.9114E-05	-4.228	9.1587E-01

MOLE RATIOS FROM
 ANALYTICAL MOLALITY

MOLE RATIOS FROM
 COMPUTED MOLALITY

LOG ACTIVITY RATIOS

CL/CA = 6.7831E-01	CL/CA = 7.3236E-01	LOG CA/H2 = 10.5618
CL/MG = 7.2004E+00	CL/MG = 7.7765E+00	LOG MG/H2 = 9.5377
CL/NA = 4.4648E-02	CL/NA = 4.4805E-02	LOG NA/H1 = 4.7857
CL/K = 9.2646E-01	CL/K = 9.2768E-01	LOG K/H1 = 3.4688
CL/AL = 2.3706E+26	CL/AL = 2.3706E+26	LOG AL/H3 = 21.3000
CL/FE = 2.3706E+26	CL/FE = 2.3706E+26	LOG FE/H2 = 14.2000
CL/SO4 = 8.4297E-01	CL/SO4 = 8.9081E-01	LOG CA/MG = 1.0240

CL/HCO3 = 4.4759E-02 CL/HCO3 = 4.5107E-02 LOG NA/K = 1.3170
 CA/MG = 1.0615E+01 CA/MG = 1.0618E+01
 NA/K = 2.0750E+01 NA/K = 2.0705E+01

	PHASE	IAP	KT	LOG IAP	LOG KT	IAP/KT	LOG IAP/KT
18	ANHYDRIT	4.335E-08	4.130E-05	-7.363	-4.384	1.050E-03	-2.979
22	ARAGONIT	6.554E-10	4.613E-09	-9.184	-8.336	1.421E-01	-.847
151	ARTIN	2.478E-27	3.981E-19	-26.606	-18.400	6.224E-09	-8.206
20	BRUCITE	3.580E-19	3.890E-12	-18.446	-11.410	9.202E-08	-7.036
13	CALCITE	6.554E-10	3.313E-09	-9.184	-8.480	1.978E-01	-.704
12	DOLOMITE	4.064E-20	8.128E-18	-19.391	-17.090	4.999E-03	-2.301
63	FLUOR	1.076E-11	1.096E-11	-10.968	-10.960	9.815E-01	-.008
19	GYPSUM	4.333E-08	2.498E-05	-7.363	-4.602	1.734E-03	-2.761
65	HALITE	1.052E-06	3.819E+01	-5.978	1.582	2.754E-08	-7.560
118	HUNTITE			-39.806	-30.510		-9.296
39	HYDMAG			-59.277	-37.820		-21.457
11	MAGNESIT	6.201E-11	5.754E-09	-10.208	-8.240	1.078E-02	-1.968
67	MIRABI	4.424E-09	7.709E-02	-8.354	-1.113	5.739E-08	-7.241
59	NAHCOL	2.341E-05	2.831E-01	-4.631	-.548	8.266E-05	-4.083
61	NATRON	6.687E-11	4.887E-02	-10.175	-1.311	1.369E-09	-8.864
150	NESQUE	6.197E-11	6.152E-06	-10.208	-5.211	1.007E-05	-4.997
66	THENAR	4.434E-09	6.622E-01	-8.353	-.179	6.695E-09	-8.174
62	TRNAT	6.701E-11	1.334E+00	-10.174	.125	5.025E-11	-10.299
60	TRONA	1.568E-15	1.603E-01	-14.805	-.795	9.780E-15	-14.010

Sosiente boreholes

 INITIAL SOLUTION

TEMPERATURE = 25.00 DEGREES C PH = 10.500
 ANALYTICAL EPMCAT = 149.167 ANALYTICAL EPMAN = 94.537
 CHARGE BALANCE ERROR = 22.32 %

***** OXIDATION - REDUCTION *****

DISSOLVED OXYGEN = .000 MG/L
 EH MEASURED WITH CALOMEL = 9.9000 VOLTS FLAG CORALK PECALC IDAVES
 MEASURED EH OF ZOBELL SOLUTION = 9.9000 VOLTS 3 0 0 1
 CORRECTED EH = 9.9000 VOLTS
 PE COMPUTED FROM CORRECTED EH = 100.000

*** TOTAL CONCENTRATIONS OF INPUT SPECIES ***

SPECIES		TOTAL MOLALITY	LOG TOTAL MOLALITY	TOTAL MG/LITRE
CA	2	1.38345E-03	-2.8590	5.50000E+01
MG	2	1.32696E-04	-3.8771	3.20000E+00
NA	1	1.46862E-01	-.8331	3.34900E+03
K	1	4.89874E-04	-3.3099	1.90000E+01
CL	-1	2.38867E-04	-3.6218	8.40000E+00
SO4	-2	4.13920E-02	-1.3831	3.94400E+03
HCO3	-1	1.04092E-02	-1.9826	6.30000E+02
F	-1	6.89852E-04	-3.1612	1.30000E+01
NO3	-1	1.18693E-03	-2.9256	7.30000E+01

*** CONVERGENCE ITERATIONS ***

ITERATION S1-ANALCO3 S2-SO4TOT S3-FTOT S4-PTOT S5-CLTOT

1	1.807E-02	2.545E-02	1.175E-06	0.000E+00	0.000E+00
2	1.339E-03	1.634E-03	1.445E-06	0.000E+00	0.000E+00
3	5.502E-06	1.357E-06	1.939E-08	0.000E+00	0.000E+00

****DESCRIPTION OF SOLUTION ****

ANAL.	COMP.	PH	ACTIVITY H2O =	.9968
MCAT 149.17	137.60	10.500	PCO2=	1.105330E-06
MAN 94.54	83.15		LOG PCO2 =	-5.9565
		TEMPERATURE	PO2 =	0.000000E+00
H = 9.9000	PE = 100.000	25.00 DEG C	PCH4 =	0.000000E+00
E CALC S = 100.000			CO2 TOT =	5.356269E-03
E CALC DOX=100.000		IONIC STRENGTH	DENSITY =	1.0000
E SATO DOX=100.000		1.470403E-01	TDS =	8094.6MG/L
TOT ALK = 1.041E+01 MEQ			CARB ALK =	9.988E+00 MEQ
LECT = 5.489E+01 MEQ				

DISTRIBUTION OF SPECIES

I	SPECIES	PPM	MOLALITY	ACTIVITY	LOG ACT	GAMMA	
1	CA	2	2.3741E+01	5.9716E-04	2.0877E-04	-3.680	3.4960E-01
2	MG	2	1.6062E+00	6.6607E-05	2.4554E-05	-4.610	3.6865E-01
3	NA	1	3.1225E+03	1.3693E-01	1.0406E-01	-.983	7.5995E-01
4	K	1	1.7680E+01	4.5585E-04	3.3504E-04	-3.475	7.3497E-01
64	H	1	4.1590E-08	4.1597E-11	3.1623E-11	-10.500	7.6022E-01
5	CL	-1	8.4000E+00	2.3887E-04	1.7556E-04	-3.756	7.3497E-01
6	SO4	-2	3.1551E+03	3.3112E-02	1.0800E-02	-1.967	3.2616E-01
7	HCO3	-1	4.1897E+01	6.9225E-04	5.2929E-04	-3.276	7.6460E-01
18	CO3	-2	1.3671E+02	2.2967E-03	7.8494E-04	-3.105	3.4177E-01
86	H2CO3	0	2.2343E-03	3.6316E-08	3.7631E-08	-7.424	1.0362E+00
27	OH	-1	7.1278E+00	4.2252E-04	3.2121E-04	-3.493	7.6022E-01
62	F	-1	1.2955E+01	6.8749E-04	5.2264E-04	-3.282	7.6022E-01
19	MGOH	1	6.9524E-02	1.6963E-06	1.2896E-06	-5.890	7.6022E-01
23	MGSO4 AQ	0	5.2947E+00	4.4345E-05	4.5872E-05	-4.338	1.0344E+00
22	MGHCO3	1	1.6825E-02	1.9879E-07	1.5113E-07	-6.821	7.6022E-01
21	MGCO3 AQ	0	1.4871E+00	1.7780E-05	1.8392E-05	-4.735	1.0344E+00
20	MGF	1	4.7913E-02	1.1153E-06	8.4788E-07	-6.072	7.6022E-01
29	CAOH	1	1.2552E-01	2.2166E-06	1.6851E-06	-5.773	7.6022E-01
32	CASO4 AQ	0	5.9957E+01	4.4399E-04	4.5928E-04	-3.338	1.0344E+00
30	CAHCO3	1	1.8482E-01	1.8431E-06	1.4092E-06	-5.851	7.6460E-01
31	CACO3 AQ	0	3.2366E+01	3.2601E-04	2.7524E-04	-3.560	8.4427E-01
49	CAF+	1	7.3254E-02	1.2501E-06	9.5031E-07	-6.022	7.6022E-01
44	NASO4	-1	9.1614E+02	7.7581E-03	5.8979E-03	-2.229	7.6022E-01
43	NAHCO3	0	2.4944E+00	2.9941E-05	3.0972E-05	-4.509	1.0344E+00
42	NACO3	-1	1.6395E+02	1.9915E-03	1.5140E-03	-2.820	7.6022E-01
94	NACL	0	1.0238E-30	1.7660E-35	1.8269E-35	-34.738	1.0344E+00
46	KSO4	-1	4.4837E+00	3.3443E-05	2.5424E-05	-4.595	7.6022E-01
95	KCL	0	4.2049E-33	5.6861E-38	5.8819E-38	-37.230	1.0344E+00
63	H2SO4	-1	4.1973E-06	4.3593E-11	3.3140E-11	-10.480	7.6022E-01
85	NO3	-1	7.3000E+01	1.1869E-03	9.0233E-04	-3.045	7.6022E-01

MOLE RATIOS FROM
ANALYTICAL MOLALITY

MOLE RATIOS FROM
COMPUTED MOLALITY

LOG ACTIVITY RATIOS

CL/CA =	1.7266E-01	CL/CA =	4.0000E-01	LOG CA/H2 =	17.3197
CL/MG =	1.8001E+00	CL/MG =	3.5862E+00	LOG MG/H2 =	16.3901
CL/NA =	1.6265E-03	CL/NA =	1.7445E-03	LOG NA/H1 =	9.5173
CL/K =	4.8761E-01	CL/K =	5.2400E-01	LOG K/H1 =	7.0251
CL/AL =	2.3887E+26	CL/AL =	2.3887E+26	LOG AL/H3 =	31.5000
CL/FE =	2.3887E+26	CL/FE =	2.3887E+26	LOG FE/H2 =	21.0000
CL/SO4 =	5.7708E-03	CL/SO4 =	7.2139E-03	LOG CA/MG =	.9295

CO3 = 2.2948E-02 CL/HCO3 = 3.4506E-01 LOG NA/K = 2.4922
 MG = 1.0426E+01 CA/MG = 8.9654E+00
 NA = 2.9980E+02 NA/K = 3.0038E+02

Results

PHASE	IAP	KT	LOG IAP	LOG KT	IAP/KT	LOG IAP/KT
ANHYDRIT	2.255E-06	4.130E-05	-5.647	-4.384	5.459E-02	-1.263
ARAGONIT	1.639E-07	4.613E-09	-6.785	-8.336	3.553E+01	1.551
ARTIN	3.496E-18	3.981E-19	-17.456	-18.400	8.782E+00	.944
BRUCITE	2.533E-12	3.890E-12	-11.596	-11.410	6.512E-01	-.186
CALCITE	1.639E-07	3.313E-09	-6.785	-8.480	4.947E+01	1.694
DOLOMITE	3.158E-15	8.128E-18	-14.501	-17.090	3.886E+02	2.589
FLUOR	5.703E-11	1.096E-11	-10.244	-10.960	5.201E+00	.716
GYPSUM	2.240E-06	2.498E-05	-5.650	-4.602	8.967E-02	-1.047
HALITE	1.827E-05	3.819E+01	-4.738	1.582	4.783E-07	-6.320
HUNTITE	1.173E-30	3.090E-31	-29.931	-30.510	3.797E+00	.579
HYDMAG			-42.462	-37.820		-4.642
MAGNESIT	1.927E-08	5.754E-09	-7.715	-8.240	3.349E+00	.525
MIRABI	1.133E-04	7.709E-02	-3.946	-1.113	1.469E-03	-2.833
NAHCOL	5.508E-05	2.831E-01	-4.259	-.548	1.945E-04	-3.711
NATRON	8.233E-06	4.887E-02	-5.084	-1.311	1.685E-04	-3.773
NESQUE	1.909E-08	6.152E-06	-7.719	-5.211	3.103E-03	-2.508
THENAR	1.169E-04	6.622E-01	-3.932	-.179	1.766E-04	-3.753
THRAT	8.472E-06	1.334E+00	-5.072	.125	6.353E-06	-5.197
TRONA	4.652E-10	1.603E-01	-9.332	-.795	2.901E-09	-8.537