J. R. Fagundo,[1] *J. J. Valdes,*[2] *and M. Pulina*[3]

Hydrochemical Investigations in Extreme Climatic Areas: Cuba and Spitsbergen

ABSTRACT: The results of the hydrochemical investigations carried out in the experimental bases installed in the San Marcos river, Sierra de los Organos, Cuba, and Werenskiöld glacier basins and the Hornsund fiord surroundings, in Spitsbergen, are compared.

INTRODUCTION

The studied areas — the San Marcos river and the Werenskiöld glacier basins — are located in tropical and polar regions, respectively.

In the first one is located the Pan de Guajaibon massif, which has been chosen as experimental research polygon of the contemporary karstic processes in tropical conditions in the frame of the PIGEK Program (International Programs for Genesis and Evolution of Karst) of the Physicochemistry and Hydrogeology Comission of the International Union of Speleology, an organization affiliated to UNESCO. Since 1984 hydrochemical and hydrological studies have been performed in this regions by Cuban and Polish scientists (Fagundo et al., 1986b; Rodriguez et al., 1989).

In the polar region the polish experimental polygon is situated, where glaciological (Baranowki, 1977; Jania, 1982), climatic (Pyreyma and Piasecki, 1983) and hydrochemical investigations (Krawcyk and Pulina, 1983; Pulina et al., 1984b) are performed since many years ago.

The objective of this paper is to compare the hydrochemical results obtained in both areas. In the case of the tropical base the hydrochemical data from hydrological year 1985–1985 was taken. In the case of the polar region the data is from the period August–October 1985 in which an international expedition where the authors of this paper participated was carried out (Fagundo et al., 1987). The number of samples was of the same order in both cases.

[1] National Centre of Scientific Research, CENIC, Cuba

[2] Geophysics and Astronomy Institute, Cuba

[3] Silesian University, Poland

MATERIALS AND METHODS

The chemical composition of the water — CO_2, HCO_3, CO_3, Cl, SO_4, Ca, total hardness (Ca and Mg as $CaCO_3$) — was determined by field methods (Markowicz and Pulina, 1979). Mg and Na+K were calculated by difference. Measurement of temperature, pH and electric conductivity were also carried out "in situ". The mineralization expressed as mg/l of the dry residue was determined by empirical relations with the electric conductivity (Markowics and Pulina, 1979). The data was processed by means of statistical and geochemical computation programs. Calcite, dolomite and gypsum saturation indices were calculated by the AGMAR computation program (Fagundo et al., 1986a) based on a water-rock interaction physico-chemical model. The preliminary field hydrochemical information with respect to these areas were previously reported (Fagundo et al., 1986a, 1987; Pulina et al., 1984a; Valdes et al., 1985). The results are graphically presented by means of Stiff diagrams (Stiff, 1951).

In the polar region the physico-chemical behavior of the water of the Ganpassed ad Steinvinkdales river basins; streams and lakes of the Hyttevika road; the Werenskiöld glacier and the Vimsa river, Naambreen glacier and Iskantelva river basins — the latter located at the margin of Torell glacier — were studied. In the other border of the fiord an area near the Treskelen peninsula was also studied. Daily samples were also collected at Glacial and Brattegg rivers in Werenskiöld glacier, as well as other weekly samples from chosen sources at the tongue of the above glacier.

RESULTS AND DISCUSSION

San Marcos River Basin

San Marcos River basin is located in Sierra del Rosario, Pinar del Rio province, Cuba. In this place a complex weathering process occurs in characteristic geologic, hydrogeologic and climatic conditions. Kastifiable limestones, sandstones, clays, sedimentary effusive rocks and ultrabasites crop out in this region with ages ranging from Jurasic to Cretacic intervals. Great amounts of carbonic dioxide and organic acids are released as a result of the intense biological activity. During rain, the former are dragged along by the water and used to dissolve the constitutive minerals of the rocks.

The surface streams from the sedimentary-effusive sequences are of the calcic-alkaline hydrocarbonatic type (see Figure 1, samples 3 and 4), with conductivities of 125 µS/cm in the rainy period and 500 µS/cm in the dry season. These waters have a low CO_2 level and are oversaturated with respect to calcite and dolomite. When these allochtonous waters penetrate the karstic massif, mixing with others of autochtonous origin, the flow increases, but the mineralizaton decreases.

In the karstic massif catchment area the water is of calcic hydrocarbonatic type (see Figure 1, sample 1) with electric conductivities of 300–500 µS/cm and undergo little seasonal fluctuation. This water has a high level of CO_2 and is oversaturated with respect to calcite and dolomite.

In the emergences the waters are of the same hydrochemical type as those above. Electric conductivities are 280, 330 and 470 µS/cm in one resurgence and two exsurgences, respectively (Fig. 1, sample 5). The seasonal fluctuation of the physico-chemical parameter are neglegible. The behaviour of infiltration water inside the caves is similar but with less mineralization (Fig. 1, sample 2). The CO_2 content is poor and the pH values are higher than in other waters in the basin.

In other region of the basin (Mil Cumbres) precipitation infiltrates through terrigenous-carbonatic sediment in a more diffuse way. Emergent waters associated to this system have high levels of CO_2, total hardness and mineralization. The SO_4 contents are relatively higher than in the remaining waters in the basin (see Figure 1, sample 6). Mil Cumbres spring water is unsaturated with respect to calcite, dolomite and gypsum. Along a profile, especially in falls, part of the disolved gas is released and $CaCO_3$ precipitates.

Surface water associated to serpentinites is magnesium hydrocarbonatic type (Figure 1, sample 7) with high pH, total hardness and mineralization values. Mean electric conductivity is of the order of 360 µS/cm. However, a deep well drilled in this sequence has artesian character, water with low pH values, high CO_2, mineralization and total hardness, sodium-magnesium hydrocarbonatic type (Figure 1, sample 8, unsaturated with respect to the reference minerals.

San Marcos river is the main collector of this region. The physico-chemical properties of the water reflect the mixing of different types of water (Figure 1, sample 9).

Rivers and streams outside the basin, with water flows in southern direction and moving over calcareous and terrigenous-carbonatic sequences in Sierra del Rosario, have a similar behavior to those that move in the same lithology to the northern part (Figure 1, sample 10). Water emerging from Pinar fall, at a relatively great depth present a distinctive feature with high temperature, CO_2 contents, total hardness and mineralizaton values, unsaturated respect calcite and dolomite but tend to saturation respect gypsum; belong to the sodium-calcium sulphatic and calcic sulphatic types, with medicinal properties (Figure 1, sample 11).

Werenskiöld glacier basin and its surroundings, near Hornsund fiord

The Polish experimental polygon is located near the Hornsund fiord, at 77° latitude. It belongs to Wedel Jarlsber Earth, in the southern part of Spitsbergen.

In the studied basins the glaciers move slowly over quartzites, amphiboles, marbles and schists of Precambric ages. Many mechanical alterations occur in the rocks due to the friction and temperature changes.

The water coming from the permafrost (Figure 2, sample 6) glaciar ices and fusion of the snow (Figure 2, samples 2–4) show greatchanges in their chemical composition and mineralization levels during the interval summer-beginning of polar winter in which the hydric activity occurs.

According to its origin — supra, en or subglaciar (Figure 2, samples 5, 7) — water reflects the characteristics of the ice, the snow or the geologic medium, respectively. From this mixture the composition of the rivers and streams of the region are deter-

mined (Figure 2, sample 8). Toward the winter, mineralization tends to increase as a result of the cryochemical effect (Pulina, 1984). In these conditions, electric conductivities are of the order of 370 and 162 μS/cm in the waters from the glacier and the permafrost, respectively. This tendency is affected by the relatively hot fohen wine. As a consequence of the last effect, water changes drastically its chemical composition and mineralization level reaching electric conductivities ranging between 60 and 50 μS/cm in glacier and permafrost, respectively (Figure 3). This values are characteristic in water from quartzites. In this case the types changes between magnesium-calcic sulphatic and calcic hydrocarbonatic in the glacier and between sodic hydrocarbonatic and calcic hydrocarbonatic types in the water from permafrost.

The chemical composition of water from marbles is more steady, though is some cases it changes between calcic hydrocarbonate to sodic hydrocarbonate (Figure 2, sample 8).

All waters in this region show very little CO_2 contents. The main biogenic activity is present in water from the tundra. Total hardness is also poor (Figure 4).

The water of the polar region has generally low mineralization, except those from the coastal aquifers affected by marine intrusion, and the water from the lakes in glacier morrains (Figure 2, sample 9). However, in some waters of thermomineral origin, the electric conductivity rises to values near 1000 μS/cm.

In relation to saturation indices, there are the following regularities: all water is generally oversaturated with respect to calcite; in connection with dolomite, the waters from ice, snow, surface streams, supraglaciar and part of the subglaciar sources are unsaturated. There are no waters with high oversaturation level, such as frequently occur in Cuba.

We can remark that while in Cuba the water temperature is 22–25 °C, in Spitsbergen this value is near 0 °C.

CONCLUSIONS

The water sampled in the tropical region of San Marcos river basin and its environs in Sierra del Rosario, Pinar del Rio, show temperatures near 22–25 °C, relatively high CO_2 content, total hardness and mineralization, especially in the autochtonous catchment zone of the karstic massives. Inside the caves and in the emission zone the values of these parameters decrease. In general this water tends to behave as saturated or oversaturated with respect to calcite and dolomite in the dry period and unsaturated with respect to the above minerals in the rainy period. In connection to the gypsum, the water is unsaturated. Deep waters have high CO_2 contents and mineralization and are oversaturated with respect to carbonatic minerals with tendency to saturation with respect to gypsum. These waters change according to the lithology; those associated to the marbles are of the calcic hydrocarbonatic type; those to the sedimentary-effusive rocks, of the sodic-calcic hydrocarbonatic type and those to ultrabasites of the magnesium hydrocarbonatic type. On depth the former tends to be of the sodic-calcic

sulphatic or calcic sulphatic types, meanwhile the latter are of the magnesium-sodium hydrocarbonatic type.

In the polar region near the Hornsund fiord, in Spitsbergen, a large variety of water types with great variation in electric conductivities and mineralization was observed. Along the year (from summer to winter) mineralization tends to increse as a consequence of the cryochemical effect. This tendency was occasionally interrupted by the drastic decrease of the mineralization as a consequence of the ablation of the ice and the fusion of snow due to the fohen wine.

Despite the drastic conditions of the polar environment, the biogenic action was shown in the water from the tundra, where relatively low values of pH and the highest CO_2 level were observed, compared to other polar waters where the disolved gases content is neglegible (Figure 4). Of course, these values are low in relation to those in tropical waters.

According to their hydrochemical type the water reflects the local lithology and how they move or mix with ice or snow. Those waters which cross through marbles have a chemical composition similar to the Cuban karstic waters (calcic hydrocarbonatic). Those that move through quartzites and other minerals tend to behave as sodic hydrocarbonatic similarly to the ice and snow.

With respect to the saturation indices, the studied waters in the polar region are unsaturated respect gypsum with tendency to saturation in the moraine lakes. In relation to calcite and dolomite water from ice, snow, streams and surface flow, supraglaciar sources and part of the subglaciar sources was unsaturated but the waters from the moraine lakes have a tendency to saturation. Water with high degree of oversaturation with respect to carbonatic minerals was not observed.

In general it can be stated that the chemical denudation in tropical areas is more intense, despite the fact that CO_2 dilution in water is higher when temperature is lower. This feature is due to the fact that the production of this gas by the soil is more active in the tropics as a consequence of the higher temperatures and relative humidity. In this condition, waters raise higher levels of mineralization than in a polar region with similar lithology.

On the contrary, the mechanic erosion is more intense in polar regions, as a consequence of friction of the glaciers over the massives and the alternative freezing and melting processes which tend to break and crush the rocks, thus facilitating the subsequent chemical action.

There is more variation in the water type due to the seasons in the polar region than in the tropics. In Cuba, these changes are associated to storm and torrential waters. In Spitsbergen, by the time in which there is hydric activity, the chemical composition changes appreciably according to the occurrence of the antagonistic effects, ablation or ice freezing.

RESUMEN: Se comparan los resultados de investigaciones hidroquímicas realizadas en las bases experimentales instaladas en las cuencas del río San Marcos, Sierra de los Órganos, Cuba y del glaciar Werenskiöld y alrededores del fiordo Hornsund, Spitsbergen.

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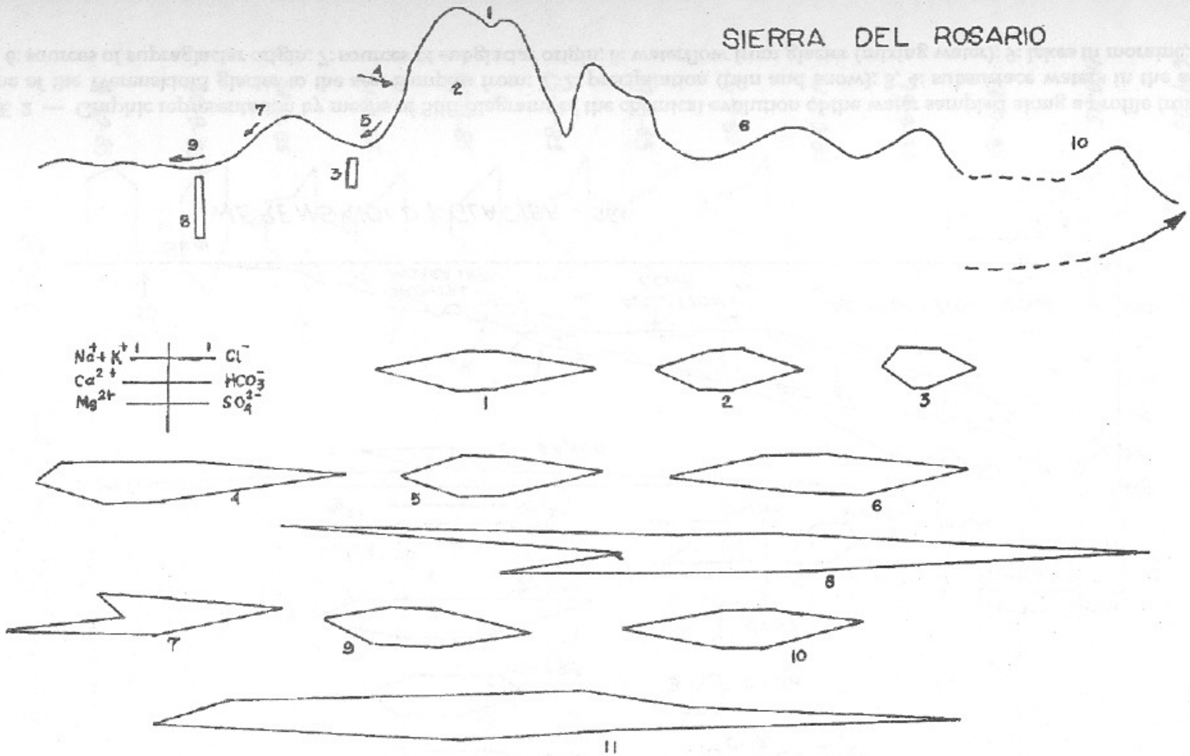


FIGURE 1 — Graphic representation by means of Stiff diagrams of the chemical evolution of the Sierra del Rosario waters along a profile from Sierra de Cajalbana to Sierra de la Guira across the Pan de Guajaibon, Chiquita and Mil Cumbres massives. Samples from: (1) catchment area of the karstic massif; (2) cave; (3) well and (4) stream, in sedimentary-effusive rocks; (5) exsurgence of the karstic massif; (6) spring in the Mil Cumbres region (also in limestone); (7) stream and (8) deep well, in serpentinites; (9) San Marcos river; (10) karstic stream and rivers with water flow to the southern part; (11) mineromedicinal water of deep origin in the karstic region.

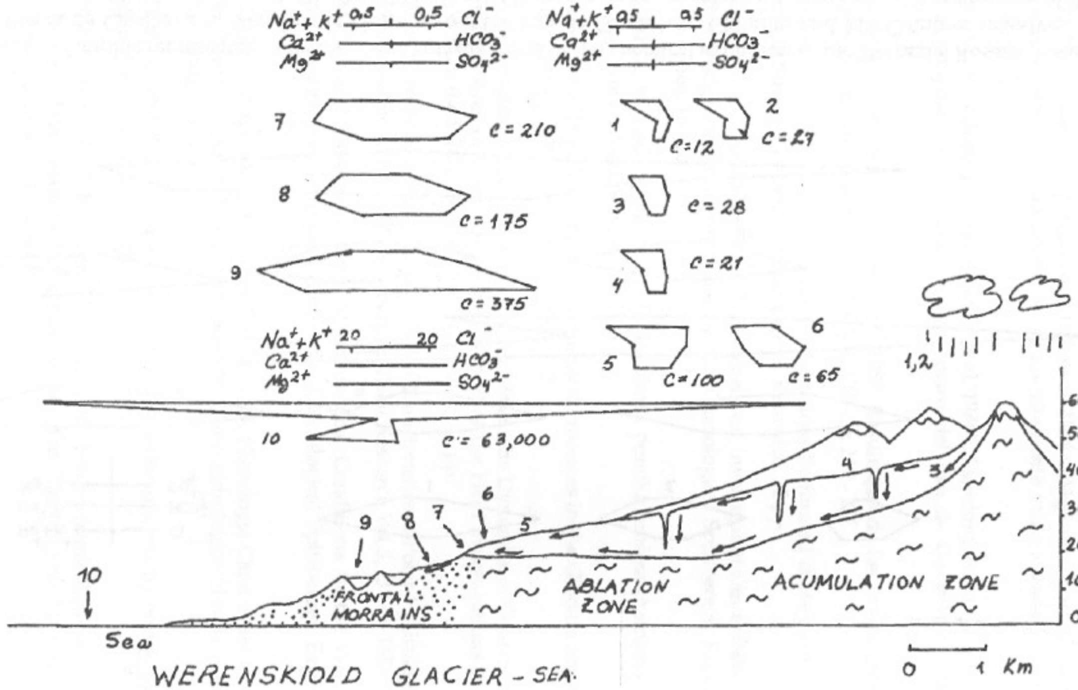


FIGURE 2 — Graphic representation by means of Stiff diagrams of the chemical evolution of the water sampled along a profile from accumulation zone of the Werenskiold glacier to the sea. Samples from: 1, 2: precipitation (rain and snow); 3, 4: subsurface waters in the accumulation zone; 5, 6: sources of supraglaciar origin; 7: sources of subglaciar origin; 8: waterflow from glacier (mixing water); 9: lakes in moraine; 10: sea.

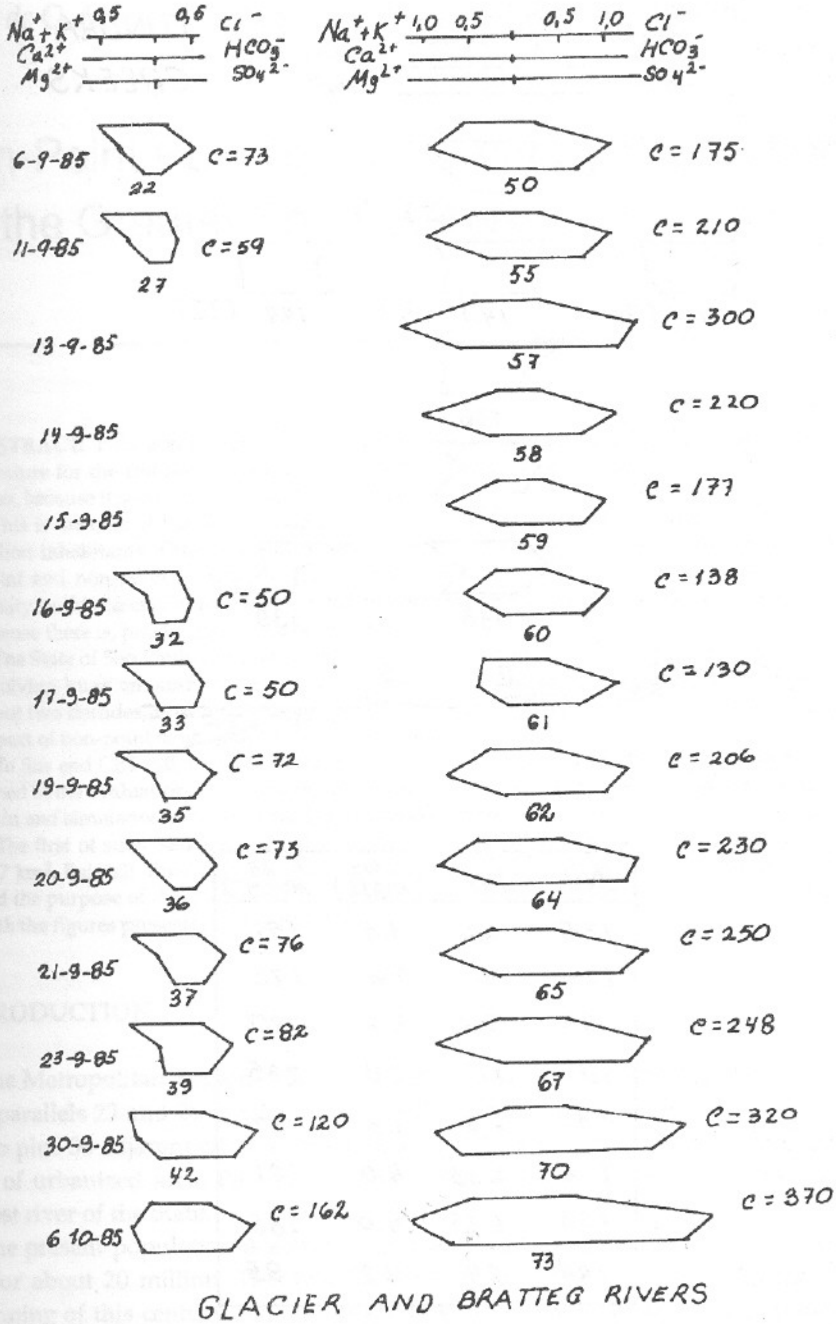
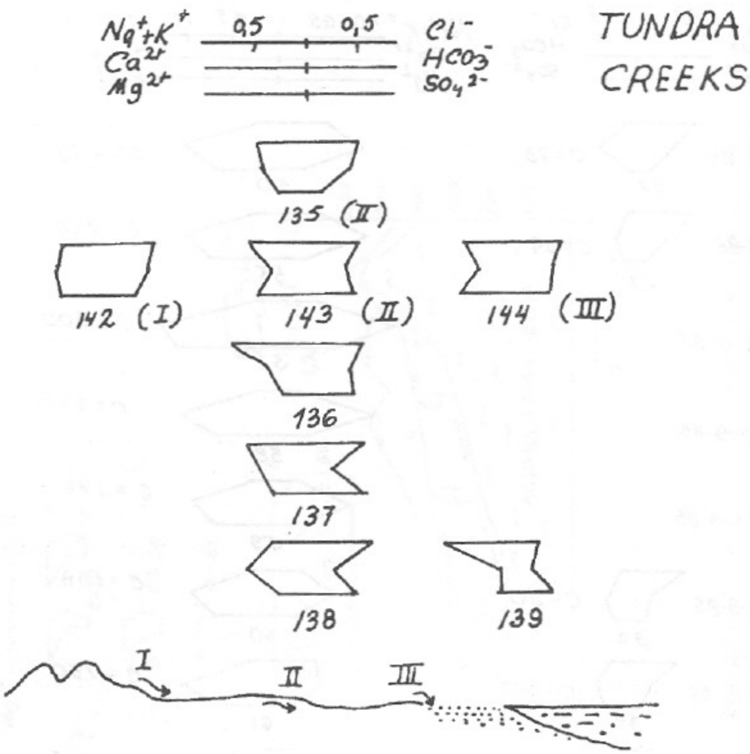


FIGURE 3 — Fluctuation of the chemical composition and electric conductivity of the waters of Bretegg stream (from permafrost) and Glacial river (originated mainly from sub-glaciar type of water).



Nº	pH	CO_2 (mg/l)	C_{25} (µS cm⁻¹)
135	6.6	1.5	157
136	6.4	2.6	175
137	5.4	4.6	180
138	5.1	5.9	235
139	6.2	1.3	57
142	6.55	4.0	181
143	6.35	5.0	185
144	6.4	4.2	185

FIGURE 4 — Graphic representation by means of Stiff diagrams of the chemical composition and behaviour of the Ph, CO_2 content and electric conductivity of the waters from the tundra.