Chapter 25
Geochemistry of Waters from Tropical Karst Mountain of Western Cuba

J.M. Pajón and J.R. Fagundo

Abstract The studies on geochemistry of the karstic waters, especially, those related to the classic system of chemical reactions CO_2-H_2O-$CaCO_3$, have been fully developed in different karstic areas around the world, many of them to disembowel the mechanism and processes of the karstification. Some significant contributions, among others, developed in the tropical mountain karst of western Cuba are: studies about the chemico-physical behavior of the karstic waters of different hydrogeological natures and their typologies; studies about the chemical evolution of the karstic waters and the empiric relations among variables, parameters and physico-chemical indexes; quantitative estimations about the chemical denudation; the "prompt" work of hydrogeologic, chemico-physical and isotopic monitoring of the karstic waters in different hydrodynamic zones of the karst. This work offers information and brief analyses about the above mentioned, and pay attention to some cardinal problems, totally or partially not yet solved.

Keywords Karst waters • Geochemistry • Isotopic monitoring • Cuba

25.1 Introduction

The researches on geochemistry of the karstic waters, especially those related to the classical system of chemical reactions CO_2-H_2O-$CaCO_3$ and the governing processes and mechanisms of karstification, have been adequately studied (Garrels and

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Christ 1965; Back et al. 1966; Langmuir 1971; White 1977; Stumm and Morgan 1981; Boegli 1972; Miserez 1973; Fagundo and Valdés 1975; Wigley 1977; Bakalowicz 1979; Ford 1988). New contributions have been developed in recent decades, among others, White (2000), Klimchouk et al. (2000), Dreybrodt (2000) and Plummer (2002).

Some contributions to the geochemistry of the karstic waters in the tropical karst mountains of western Cuba are: studies on the chemical behavior of waters of differing karst hydrogeology, the influence of geodynamic factors on the properties of the waters and its types (Fagundo et al. 1981a; Valdés et al. 1981; Molerio 1995); the studies of the chemical evolution in karst waters and the empirical relationships between variables, parameters and physico-chemical indices (Fagundo et al., 1986a; Pajón et al., 1990; Fagundo, 1990; Fagundo et al., 1991; Fagundo et al., 1992); the quantitative estimates of chemical denudation in experimental sites in karst areas (Pulina et al., 1984; Fagundo et al., 1986b; Rodríguez 1995; Rodríguez and Fagundo 1995); work "point" monitoring of hydrogeological, chemical, physical and isotopic karst water in different areas of karst hydrodynamics (Fagundo et al. 1987; Arellano et al. 1992; Molerio 1992; Pajón et al. 2009, 2010).

Despite the efforts mentioned above, some basic problems remain unresolved, in whole or in part, such as: continuing to conduct monitoring of isotopic, chemical-physical, hydrological and climates suitable for hydrological cycles in loading zones stations across the hydrodynamic karst zones; performing multi-parametric monitoring stations of the aeration zone of the karst (hypodermic flow), especially designed for recording rainfall and drip into the study of speleothems; palaeoclimate and palaeoenvironmental studies during the Late Pleistocene-Holocene; to obtain quantitative estimates of global denudation of the karst mountain areas; to study the problem of seawater intrusion in the coastal karst connected to the mountain area, related to human activity and climate change, and chemical denudation taking into account the effect of salt and water mixture on the equilibrium of carbonates. Some of these actions have already been identified earlier by Molerio and Valdes (1975) ("The Problem") and Molerio (1981).

25.2 Results and Discussions

25.2.1 Monitoring Behaviors of Chemical-Physical and Hydrogeological Karst Waters

25.2.1.1 Types and Characterization

Fagundo et al. (1981a, c) studied the behavior of the main parameters and physico-chemical indexes in 35 sites representing different types of waters of the Cuyaguateje River Basin in the Sierra de los Organos Mountains (Pinar del Río Province, Cuba). The variables and physical-chemical parameters were determined in situ using the techniques of Markowics and Pulina (1979), which were previously implemented and adjusted to the natural water conditions in Cuba (Pajón and Fagundo

1978, 1983). The data obtained, which characterized the rainy and dry periods 1978–1989, reflected patterns of sequence variation characteristic of the different types of natural waters that occur in the region. The results were analyzed on the basis of geological and hydrogeological characteristics of the basin, which fairly represents the zoning of karst hydrodynamics.

To establish a classification of karst waters of the Cuyaguateje River Basin and to study the relationship between the type of waters, defined by geomathematics methods and those defined by geological and hydrogeological criteria, Valdés et al. (1981) applied methods of numerical classification and factor analysis to the chemical and physical data of the karstic waters for six geochemical testing cycles developed between 1978 and 1979, by sampling and characterizing the winter and summer periods for the years in question. From the analysis and interpretation of the dendrogram (Cluster Analysis), five groups of waters were defined. A Factor Analysis of the results of the karst water hydrochemistry testing of the Cuyaguateje River Basin August 1979 results were conducted. The results demonstrate that the chemical and physical properties of these waters are effectively linked to the two main geological formations in the region, the non-karst rocks (slate, sandstone, shale, etc.) and the karst rocks (limestone and dolomitized limestone).

A hydrogeochemical study (Fagundo et al. 1981b) was developed in the Fuentes Cave System (Sierra de Mesa, Sierra de los Órganos), which showed the occurrence of two mechanisms of water-rock interaction. The first mechanisms where along watercourses that lose CO_2 and carbonates are precipitated in the form of travertine. The second mechanism tends to dissolve these, from the rainwater and allochthonous streams not influenced by the environment karst. De la Cruz and Valdés (1985) studied karst waters of the Sierra del Pan de Guajaibón and its surroundings using mathematical methods of exploratory data analysis. Molerio (1995) conducted a hydrogeochemical regionalization of groundwater in the Sierra de Quemados, Pinar del Rio, Cuba, which evaluates the patterns of movement of groundwater. Rodríguez M (2005) applied principles and methods of physical chemistry and mathematical modelling to characterize the flow system and hydrogeochemical processes that cause the chemical composition of natural and mineral waters in the Sierra del Rosario. A complete catalogue of the natural waters of Sierra del Rosario was realized by González et al. (2005). Arellano et al. (1992) performed an interesting study to clarify aspects of the regional flow dynamics and the origin of recharge in the area of articulation of the criptokarstic plain with karst mountain of the Sierra del Rosario (Pinar del Rio, Cuba), particularly in areas related to the Santa Cruz, San Cristobal and Taco Taco rivers.

25.2.1.2 Chemical Evolution and Empirical Relationships in Karst Waters

The process of the dissolution of limestone by waters passing through the zone of aeration takes a certain amount of CO_2, ionic and molecular species of the system CO_2-H_2O-$CaCO_3$ concentrations will vary depending on the time nonlinear way. The relationship between the pH or the CO_2 with the concentration of Ca^{2+}, HCO_3, as well

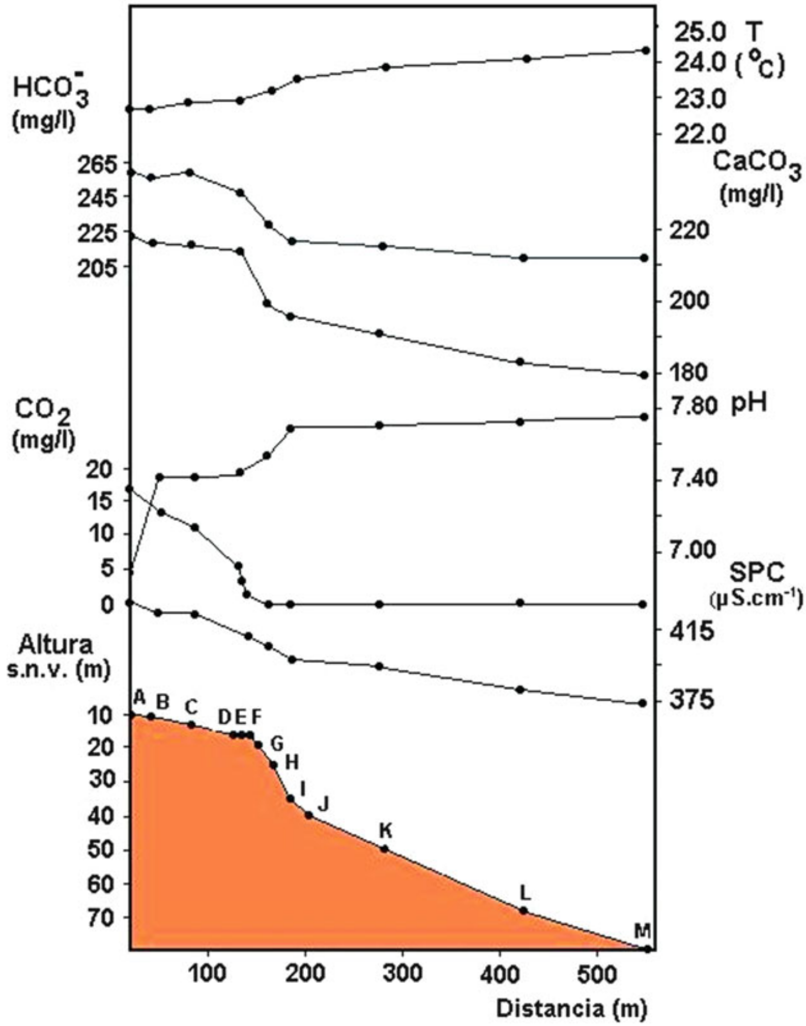

Fig. 25.1 Variation of some parameters and physico-chemical indices of the karstic waters of the Mil Cumbres stream (Sierra del Rosario, Pinar del Río, Cuba). Sampling of the profile realized the 20.09.1985 (Pajón et al. 1990)

as the hardness (expressed as, mg/l de $CaCO_3$), are not linear. To cite a few examples, this behavior is observed in the laboratory work carried out by Picknett (1964), Fagundo and Pajón (1985) and González (1997) in saturated conditions. Fagundo (1985) found that if relationships were determined between ion concentrations and electrical conductivity of waters (SPC) at 25 °C, it is possible to automate the quality control of waters (macrocomponent) by simple measurements of in situ temperature, pH and electrical conductivity. These principles were applied in the karst waters of Pan de Guajaibón with satisfactory results (Fagundo and Pajón 1985).

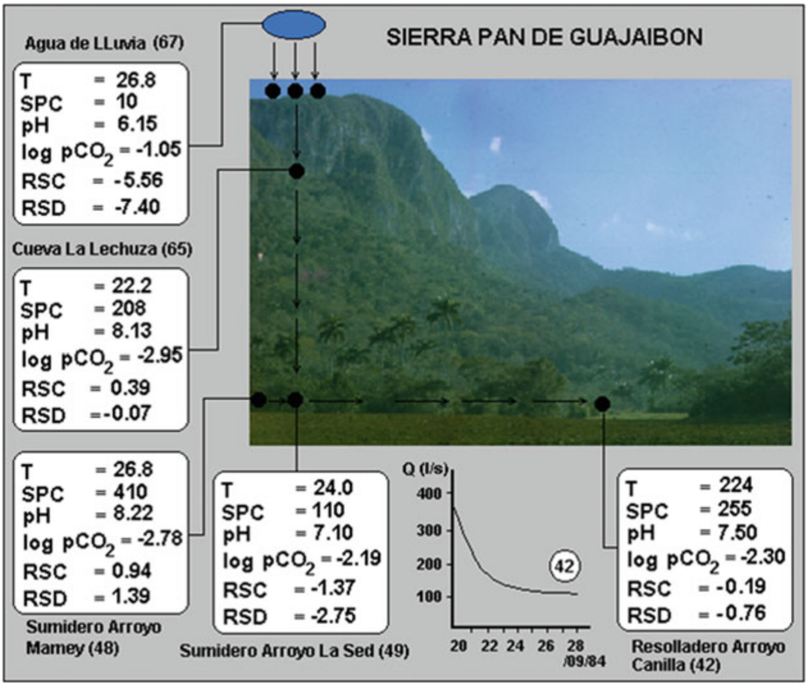

Fig. 25.2 Representative diagram of the model dissolution (spot) Guajaibón karst massif (Campaign 2 September 1984) (Pajón 1990)

Pajón et al. (1990) evaluated as a first approximation, the kinetics of the precipitation of carbonates in the form of travertine along 600 m of the Mil Cumbres stream (Sierra del Rosario, Pinar del Rio, Cuba). They studied pH variation, SPC (25 °C), the concentrations of major ionic species macrocomponent, the CO_2 and $CaCO_3$ as well as some chemical and physical indices, to experience the waters from the upwelling to the level of the valley (Fig. 25.1). Pajón (1986) presents a representative diagram of the model dissolution (spot) Guajaibón karst massif, based on the seasonal variations of parameters and physico-chemical indices of waters associated with the main entrances, inside and out sectors of the massif, which represent the areas of food, intermittent aeration and saturation (Fig. 25.2). Fagundo et al. (1991) studied using mathematical modelling, chemical evolution and the empirical relations existing in natural waters of the San Marcos River watershed, Sierra del Rosario, Pinar del Rio, Cuba.

25.2.2 Chemical Denudation

A comprehensive assessment of chemical denudation processes for the seasonally humid tropical karst Pan de Guajaibón can be seen in Pulina et al. (1984), Fagundo et al. (1987) and Rodriguez (1995). The karst denudation hyperannual values for wet and dry periods, in the Ancon and Canilla karstic systems are as follows:

Ancon System: an average value was obtained for the hydrological cycle of 107 m^3/km^2.year, with 37 m^3/km^2.181 days for dry period and 70 m^3/km^2.184 days for the rainy season. The average values of the order of the highest recorded globally, as in the case of: Gnong Mulu, Indonesia, with 120–200 m^3/km^2.year (Tropical Climate Zone); SW Caucasus, Georgia, 114–139 m^3/km^2.year (Mediterranean climatic zone); Picos de Europa, Spain, 148 m^3/km^2.year (Temperate-Transitional Climatic Zone).

Canilla System: The estimated average chemical denudation for Canilla system was 49 m^3/km^2. year, with 19 m^3/km^2.181 days for dry period and 37 m^3/km^2.184 days for the rainy season. These results are consistent with those reported for other areas of tropical, Mediterranean, temperate and polar climates (Pulina 1977; Garay and Morell 1989; Rodriguez 1995).

The direct linear correlation between denudation and the rainfall has been extensively studied by various researchers for different climatic areas of the world (Pulina (1971); Garay and Morell 1989). Taking into account the values of palaeoprecipitation (up to 6,000 mm) obtained for the karst region of the Sierra de San Carlos during the Sangamon Interglacial (Pajón et al. 2001), replacing them in the equation for calculating the denudation, estimates of chemistry paleodenudation order of those found today in Papua New Guinea can be obtained, where Maire (1981) gave values of chemical denudation in the order of 270–760 m^3/km^2.year, and where ranging from 5,700 to 12,000 mm rainfall annually. Farfán (2005) makes an evaluation processes considering karstification of polycyclic and polygenic natures conducted by the analysis of the age through karstification geoindicators.

25.3 Some Problems and Approaches to the Study of Karst Processes in the Tropical Karst Mountains of Western Cuba

Molerio and Valdés (1975), in a pioneering study ahead of its time, raised some problems and cardinal prospects for the karstological and geospeleological studies in Cuba. They noted, among other things, the importance of hydrochemical investigations in Cuba. Molerio (1981) also noted earlier some problems related to the hydrogeology of the karst mountains of Cuba in general, and Pinar del Rio in particular. The work carried out over several decades in the karst mountain of western Cuba, some of them mentioned in the text, providing various data and assessments that contribute to the understanding of karst processes in this region.

As was mentioned above, monitoring is needed to continue with physical-chemical, isotopical, hydrogeological and climatic stations throughout the zoning of karst hydrodynamics during hydrological cycles appropriate to characterize not only the basic “steady conditions” of karst systems, but also the conditions attached climate-hydrological events diverse and extreme. A notable example in this regard was Project PIGEK (Pulina et al. 1984). Special attention should be paid to the realization of multiparametric monitoring stations in the aeration zone of the karst (hypodermic flow), especially designed to record rainfall and drip in the speleothems. A remaining problem is to obtain quantitative estimates of Global Denudation (DG) in the karst areas, whether mountain or other terrestrial ecosystems in karst. Although there are good estimates of chemical denudation for karst areas (e.g. Pan de Guajaibón), virtually no estimates of mechanical denudation, therefore, has not been possible to have even an estimate of the DG. Moreover, although some efforts have been made, it is important to study the chemical denudation (quantitative estimates) in the coastal karst connected to the karst mountain, taking into account the effect of saline and mixing water on the balance of the carbonate. Of current and capital importance is the continuation of studies related to paleoclimatic and paleoenvironmental reconstructions during the Late Pleistocene-Holocene, from natural paleorecords high resolution, as is the case of speleothems.

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References

Arellano AM, Molerio FL, Suri HA (1992) Efecto de la actitud del ^{18}O en zona de articulación de llanura criptocársica con carso de montaña. In: Llanos HJ, Antigüedad I, Morell I, Eraso A (eds) Taller Internacional sobre Cuencas Experimentales en el Karst. Libro de Comunicaciones, Matanzas, pp 29–42

Back W, Cherry RN, Hanshaw BB (1966) Chemical equilibrion between the water and minerals of a carbonate aquifer. Nat Speleol Soc Bull 28(3):119–126

Bakalowicz M (1979) Contribution de la Geochimie des eaux a la connaissance de L'aquifere karstique et de la karstification. These Doct. es sciences, Paris, 269pp

Boegli A (1972) La Corrosione per miscela d'acque. Atti del Seminario di Speleogenesi. Vorenna. Le Grotte d'Italia IV(4):333–352, 5–8 Otobre 1972

de la Cruz AV, Valdés JJ (1985) Estudio de las aguas kársticas de la Sierra del Pan de Guajaibón y sus inmediaciones mediante métodos matemáticos de análisis exploratorio de los datos. Revista Vol. Hidráulica 68. Año XXII 68:25–34

Dreybrodt W (2000) Equilibrium chemistry of karst water in limestone terranes. In: Klimchouk BA, Ford DC, Palmer AN, Dreybrodt W (eds) Speleogenesis evolution of karst aquifers. National Speleological Society, Huntsville, pp 126–135

Fagundo JR (1985) Caracterización de acuíferos mediante relaciones entre contenidos iónicos y parámetros químico-físicos. Revista CENIC Ciencias Químicas 16(2):321–325

Fagundo JR (1986) Caracterización de acuíferos mediante relaciones entre contenidos iónicos y parámetros químico-físicos. Revista CENIC Ciencias Químicas 16(2):321–325

Fagundo JR (1990) Evolución química y relaciones empíricas en aguas naturales. I- Estudio mediante simulación química del efecto de la litología. Voluntad Hidráulica 82:28–37

Fagundo JR, Pajón JM (1985) Contribución al estudio de las relaciones lineales entre contenidos iónicos y parámetros químico-físicos. Efecto de la litología. Rev Ingeniería Hidráulica VI(1):12–29, ISPJAE, Ciudad de La Habana

Fagundo JR, Valdés JJ (1975) Estudio químico-físico del comportamiento de las aguas kársticas de la región de San Antonio de los Baños, mediante el uso de modelos matemáticos. Ann Speleol 30(4):643–653

Fagundo JR, Pajón JM, Valdés JJ, y Rodríguez JE (1981a) Comportamiento químico-físico de las aguas kársticas de la cuenca del Río Cuyaguateje. Rev Ingeniería Hidráulica 11(3):251–274, ISPJAE, Ciudad de La Habana

Fagundo JR, Pajón JM, Spasov K (1981b) Estudio Hidrogeoquímico de la Cueva Fuentes y sus Alrededores durante la Expedición Espeleológica Búlgaro-Cubana 1981. Revista Voluntad Hidráulica 75(1986):3–8

Fagundo JR, Valdés JJ, Pajón JM (1981c) Estudio Hidroquímico de las Aguas Kársticas de la Cuenca del Río Cuyaguateje. Libro Coloquio Internacional sobre Hidrología Cársica de la Región del Caribe, UNESCO. C, Habana, Dic. 1982, pp 374–401

Fagundo JR, Pajón JM, Valdés JJ, Rodríguez J, Arellano M (1987) Naturaleza de los procesos de disolución de los minerales calcita, dolomita y yeso en las aguas naturales de la región occidental de Cuba. Revista Voluntad Hidráulica 76:30–42

Fagundo JR, Valdés JJ, Cardoso ME, y de la Cruz A (1986a) Algoritmo para el cálculo de parámetros e índices químico-físicos y geoquímicos en aguas naturales altamente mineralizadas. Revista CENIC Ciencias Químicas 12(1/2):72–76

Fagundo JR, Valdés JJ, Rodríguez JE, Pajón JM, de la Cruz A, García A, Pulina M (1986b) Estudio preliminar sobre el proceso de denudación cársica en el polígono cubano-polaco del Pan de Guajaibón. Voluntad Hidráulica 70/71:11–15

Fagundo JR, Pajón JM, Valdés JJ, Rodríguez J, Arellano M (1987) Naturaleza de los procesos de disolución de los minerales calcita, dolomita y yeso en las aguas naturales de la región occidental de Cuba. Revista Voluntad Hidráulica 76:30–42

Fagundo JR, Rodríguez J, Pajón JM, Franco E, Álvarez E, Vinardell J, Vega J, Benítez G (1991) Evolución Química y Relaciones Empíricas en Aguas Naturales. III. Cuenca del Río San Marcos. Sierra del Rosario, Pinar del Río, Cuba. Revista Voluntad Hidráulica No. 85, Año XXVIII, 1991, pp 8–18

Fagundo JR, Rodríguez JE, Pajón JM, Franco E, Benítez G, Rodríguez AC, Güerón J, y Abelló I (1992) Caracterización hidroquímica de las aguas del Pan de Guajaibón y otras áreas cársicas cercanas a la Sierra del Rosario. In: Llanos HJ, Antigüedad I, Morell I, Eraso A (eds) Libro de Comunicaciones I Taller sobre Cuencas Experimentales en el Karst, Matanzas. Universitat Jaume I, Castelló (España), pp 43–53, ISBN: 84-8021-036-2

Ford DC (1988) Characteristics of dissolution cave systems in carbonate rocks. In: James NP, Choauette PW (eds) Paleokarst. Springer, New York, p 601pp

Garay P, Morell I (1989) Tasas de disolución en regiones kársticas españolas. El Karst en España, Madrid, pp 257–264

Garrels RM, Christ CL (1965) Solutions, minerals and equilibria. Harper and Row, New York, p 437pp

González P (1997) Estudio a escala de laboratorio de los procesos de interacción agua-roca. Tesis en opción al título de Maestro en Ciencias del Agua. CNIC, La Habana

González P, Fagundo JR, Antigüedad I, Hernández R, LLanes AJ, Blanco D, Suarez M, Melian C (2005) Catalogo de aguas naturales de la Sierra del Rosario. Banco de Datos del Centro Nacional de Medicina Natural y Tradicional, 44pp

Klimchouk BA, Ford DC, Palmer AN, Dreybrodt W (2000) Speleogenesis. Evolution of karst aquifers. Published by the NES, USA, p 527pp

Langmuir D (1971) The geochemistry of some carbonate ground waters in Central Pennsylvania. Geochim Cosmochim Acta 35(10):1023–1045

Markowics M, y Pulina M (1979) Ilosciowa Polmikroanaliza Chemiczna Wod Wobszarach Krasu Weglanowego. Universytet Slaski, Katowice, pp 67

Miserez JJ (1973) Geochimie des eaux du karst Jurassien. Contribution physico-chimique a l'etude des alterations. These Doct. és sciences. Neuchatel, 313pp

Molerio LF (1981) Problemas hidrogeológicos del Karst de Montaña de Cuba. Voluntad Hidráulica XVIII(56):37–40, La Habana

Molerio LF (1992) Técnicas Estadísticas y de la Teoría de la Información para el Diseño y control de las redes de Monitoreo de las Aguas Subterráneas en el Carso. 1er Taller Iberoamericano de Informática y Geociencias, Acad. Cienc, Cuba, La Habana, p 32

Molerio LF (1995) Regionalización Hidrogeoquímica de las Aguas Subterráneas en la Sierra de Quemados, Pinar del Río, Cuba. Congreso Internacional LV Aniversario de la Sociedad Espeleológica de Cuba y Primera Reunión Iberoamericana, La Habana, pp 92–93

Molerio LF, Valdés JJ (1975) Problemas y perspectivas de la investigación geoespeleológica en Cuba. Revista Tecnológica, 3/75, XIII, pp 34–37

Maire R (1981) Karst and hydrogeology synthesis of Papua-New Guinea. Spelunca 3:7–8

Pajón JM (1986) Geoquímica de las Aguas Kársticas de la Sierra de los Órganos y el Pan de Guajaibón, Pinar del Río, Cuba. Tesis de Grado de Licenciatura en Química, Universidad de La Habana y Centro Nacional de Investigaciones Científicas, 226pp

Pajón JM, Fagundo JR (1978) Aplicación e instrumentación de las técnicas de análisis químico-físico de campo de Markowicz y Pulina a las condiciones de las aguas naturales del karst de la Sierra de los Órganos. Manuscrito Inédito, 50pp

Pajón JM, Fagundo JR (1983) Optimización de métodos analíticos de campo para el estudio de la interacción de las aguas naturales con el medio geológico. Informe Científico-Técnico. Biblioteca BTJ Nacional, 73pp

Pajón JM, García A, Cruz C, de la Cruz A (1990) Evolución Química de las Aguas Kársticas del Arroyo Mil Cumbres (Área Protegida Mil Cumbres), S. del Rosario, Cuba (I). Libro Programa y Resúmenes, Cong. Int. 50 Aniv. de la SEC, pp 114 (25pp)

Pajón JM, Hernández I, Macle J, y Ortega F (2001) Periods of wet climate in Cuba: evaluation of expression in karst of Sierra de San Carlos. In: Markgraf V (ed) Interhemispheric climate linkages (present and past interhemispheric climate linkages in the Americas and their societal effects). Academic, New York, pp 217–226

Pajón JM, Mangini A, Fensterer C, Schroeder-Ritzrau A, Scholz D, Otero V, García G, Chávez O (2009) Monitoreo químico-físico e isotópico de las aguas de flujo hipodérmico de la cueva Dos Anas (Sierra de San Carlos) y la cueva Antorcha (Sierra de Quemados), Sierra de los Órganos, Pinar del Río, Cuba. Informe Científico-Técnico. ICAN, Universidad de Heidelberg, Alemania, 45pp

Pajón JM, Mangini A, Fensterer C, Schroeder-Ritzrau A, Scholz D (2010) Dripwaters Monitoring in cave systems of Western karstic area of Cuba. A preliminary contribution to understanding isotopic composition of speleothems, karst hydrochemistry and kinetic of carbonate dissolution. Part I. Interdynamik project “Caribclim” – Heidelberg – Havana Project. Informe Científico-Técnico (ICT). Banco de Proyectos del ICAN, 20pp

Plummer NL (2002) Geochemical and isotopic studies of paleowaters and recent recharge in parts of the Floridian aquifer system of Florida and Georgia. In Martin JB et al (eds) Hydrogeology and biology of post-paleozoic carbonate aquifers. Proceedings of the symposium karst frontier, Florida and related environments, Gainesville 6–10 Mar 2002, pp 69–72

Pulina M (1971) Observations of the chemical denudation of some karst areas of Europe and Asia. Studia Geomorph Carpatho-Balcanica 5:79–92

Pulina M (1977) Uwagi o zjawiskach krasowyeh w poludniowej czesci Spitsbergenu. Kras i Speleologia, 1, 27pp

Picknett RG (1964) A study of calcite solution at 10°C. Trans Cave Res Group Great Britain 7(1):40–50

Pulina M, Fagundo JR, Valdés JJ, Rodriguez J, Kosik A, Leszkiewicz J, Glowacki P, Pajón JM, de la Cruz AV, García AE (1984) The dynamic of the contemporary karstic processes in the tropical area of Cuba. Preliminary Report of the field investigations performed by the Expedition Guajaibón’84 in the winter season 1984. Universytet slaski, Sosnowiec, Polonia, 42pp

Rodríguez JE (1995) Hidrología y dinámica del karst tropical de montaña de Cuba (Contribución al conocimiento de los sistemas kársticos a partir del ejemplo del Pan de Guajaibón). Tesis para la opción al grado de Doctor en Ciencias Geográficas, La Habana, 150pp

Rodríguez JE, Fagundo JR (1995) Hydrology and dynamics of tropical karst processes in Cuba. Studia Carsologica (Brno) 4: 99–55; (1992). Newsletters 1992, IGCP-299, Guilin (China), pp 46–51

Rodriguez M (2005) Aplicaciones de la Química Física en la caracterización del sistema de flujos de la Sierra del Rosario, Pinar del Río, Cuba. Maestría en Medio Ambiente y Desarrollo. Facultad de Química. La Habana

Stumm W, Morgan JJ (1981) Aquatic chemistry. An introduction emphasizing chemical equilibria in natural waters. Wiley Interscience, New York, p 583pp

Valdés JJ, Fagundo JR, Pajón JM (1981) Aplicación de métodos numéricos al estudio hidroquímico de la cuenca del Río Cuyaguateje. Rev Ingeniería Hidráulica II(3):275–286, ISPJAE, Ciudad de La Habana

White WB (1977) The role of solution kinetics in the development of karst aquifers. In Tolson JS, Doyle FL (eds) Karst hydrogeology (vol 12). International Association Hydrogeology, Memoir, pp 503–517

White WB (2000) Dissolution of limestone form field observation. In: Klimchouk AB (ed) Speleogenesis. Evolution of karst aquifers. Published by the NES, Huntsville, pp 149–155

Wigley TML (1977) WATSPEC: a computer program for determining the equilibrium speciation of aqueous solutions. Brit Geomorph Res Group Tech Bull 20:48pp