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Subduction Zones of the Caribbean: the sedimentary, magmatic, metamorphic and ore-deposit records

UNESCO/IUGS IGCP Project 546 Subduction Zones of the Caribbean

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The International Union of Geosciences (IUGS) and UNESCO IGCP project 546 *Subduction Zones of the Caribbean* (http://www.ugr.es/~agcasco/igcp546/) was launched in 2007 and scheduled to be completed by the end of the current year 2011. It was set up with the aim of gathering researchers interested in the geological evolution of the Caribbean realm. The development of this region is largely controlled by a number of subduction zones that formed along its margins from the break-up of Pangea during the Jurassic until Present. The current setting is characterized by a very complex plate-tectonic configuration dominated by subduction zones, large-scale strike-slip faults, volcanic arcs and collision belts (Figure 1). The project was built upon previous developments of IGCP project 433 *Caribbean Plate Tectonics* (2000-2005), of which the Special Volume 4 (Issue 1-2) of Geologica Acta *Caribbean Plate Tectonics. Stratigraphic, Magmatic, Metamorphic and Tectonic Events* (Iturralde Vinent and Lidiak, 2006) deserves mentioning.

Since 2007, Project IGCP 546 *Subduction Zones of the Caribbean* has set up or participated in the organization of several events together with other institutions and agencies, such as field trips, seminars for students, and workshops in Cuba (2007, 2009), Guatemala (2007, 2010), San Francisco (2007, 2009), Dominican Republic (2008), Spain (2008, 2010), Houston (2008), Stanford (2009), United Kingdom (2009), Panama (2010), Venezuela (2010) and Colombia (2009, 2011). This has attracted the interest of researchers and students from a large number of countries including Australia, Austria, Canada, Chile, China, Colombia, Costa Rica, Cuba, France, Germany, Guatemala, Italy, Jamaica, Japan, Malaysia, Mexico, Netherlands, Nicaragua, Panama, Puerto Rico, Spain, Switzerland, United Kingdom, USA and Venezuela, who have produced field-trip guides, abstracts, papers and books dealing with different aspects of the Geology of the whole Caribbean region (see http://www.ugr.es/~agcasco/igcp546/ for details).

This special issue of Geologica Acta, containing fourteen papers, is representative of the aims of IGCP 546, for it covers most of the cutting-edge topics pertaining to the Caribbean's geological development from the Jurassic to the Neogene in the whole Caribbean region (Guatemala, Cuba, Hispaniola, Puerto Rico, Venezuela, Colombia, the isthmus of Panama, Costa Rica, and the offshore Nicaraguan rise). The issue was conceived during the workshop *Subduction Zones of the Caribbean* and associated field trip *Subduction and arc complexes of central Cuba* organized by IGCP 546 in the III Cuban Convention in Earth Sciences, held in Havana, Cuba, during March 2009. The study cases presented in the workshop and contained in this volume are indicated in Figure 1 and briefly commented below.

Both the 2009 Havana workshop and this volume are dedicated to Wayne Travis Jolly, who passed away on February 9, 2008. As noted in his **memorial** (Edward Lidiak, this issue), **Wayne Jolly** was an enthusiastic and valuable petrologist of the Caribbean community. He devoted much of his career to studying the petrogenesis of Puerto Rican, Virgin Islands and other northeastern Antilles ancient island arc volcanic rocks, associated peridotite sources, and subducted sediments (see the references listed by Edward Lidiak in the memorial). Based on firm stratigraphic, regional and geochemical constraints, his work enabled the refining of the tectonic evolution of the northeastern Caribbean, with special emphasis on the evolution of the Mesozoic-Tertiary subduction systems. In his contributions, he suggested a persistent southwest-dipping Cretaceous convergence in the northeast Antilles and a subduction flip (from NE-dipping to SW-dipping) by the Aptian or even earlier (e.g., Pindell and Kennan, 2009; Pindell et al., in press, and references therein), challenging those

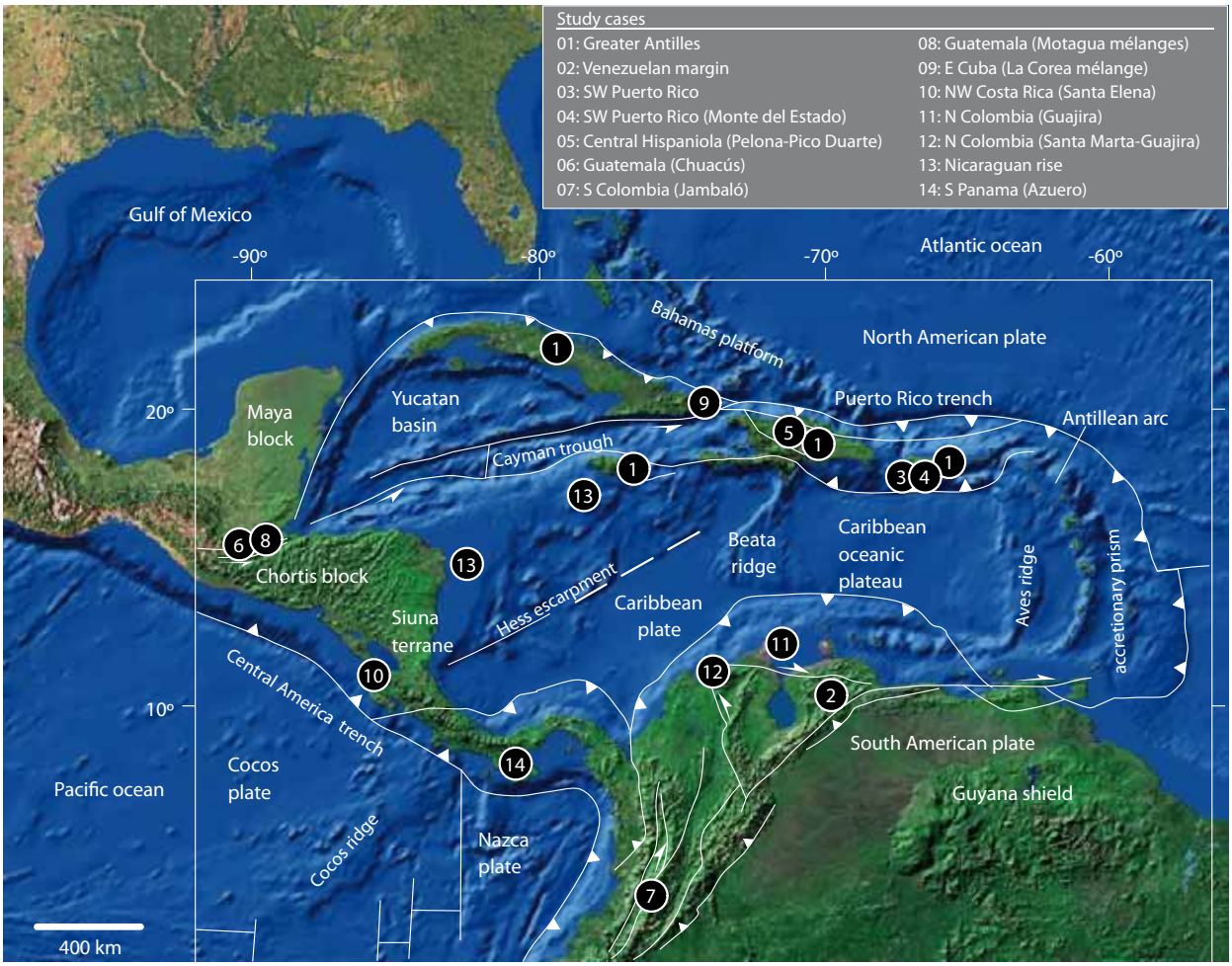

FIGURE 1 | **Plate tectonic configuration of the Caribbean region showing the location of the study cases presented in this issue (numbers refer to papers, arranged as in the issue), and other important geological features of the region (compiled from several sources).**

portraying a subduction flip during the Late Cretaceous (e.g., Kerr et al., 2003, and references therein) .

ORE DEPOSITS OF THE GREATER ANTILLES AND THEIR PLATE TECTONIC SETTINGS OF FORMATION

The first paper of this issue (C.E. Nelson, J.A. Proenza, J.F. Lewis and J. López-Kramer) presents a different approach to that suggested by W. Jolly for evaluating plate tectonic models. This article offers comprehensive maps and descriptions of ore deposits and evaluates **the record of metallogenesis in the Greater Antilles** in relation to the tectonic environment of formation of ore deposits, including (from Jurassic to Recent): rift, platform, volcanic arc, fore-arc and back-arc, syn-orogenic (subduction/ collision) and post-orogenic environments. These authors consider that ore formation in the Greater Antilles can be reconciled with plate tectonic models of SW-dipping subduction of the Atlantic since -at least- the Aptian, and in particular with the model proposed by García-Casco et al. (2008) for the Greater Antilles.

PASSIVE MARGINS

Mesozoic passive margins developed in the northern and southern margins of South and North America respectively upon the Jurassic rifting of Pangea. The zircon **provenance study of Early Cretaceous platform sediments of northern Venezuela** by M.I. Noguera, J.E. Wright, F. Urbani and J. Pindell confirms the Guyana shield provenance of Archean, Paleoproterozoic and early Mesoproterozoic detrital zircon grains, though a prominent age population (ca. 0.95-1.2Ga) suggests a western source (Venezuelan and/or northern Colombian Andes). In addition to previous zircon provenance studies (e.g., Rojas-Agramonte et al., 2008), these data allow for the constraint of the paleogeography of the Caribbean region prior to the breakup of Pangea and the longevity of continental scale river systems.

OCEANIC BASINS

The nature of **pre-volcanic arc basement rocks and volcanic arc rocks of western Puerto Rico**, by E.G. Lidiak, W.T. Jolly and A.P. Dickin, help to constrain the nature of the oceanic basement of the Cretaceous-Tertiary volcanic arc crust in Puerto Rico. This basement is formed by serpentinized peridotites, a sequence of Jurassic to mid-Cretaceous pelagic chert, blocks of N-MORB-type amphibolites, and tholeiite and associated trondhjemite fractionates also of N-MORB affinity. The basement is overlain by a younger sequence of pre-arc plateau basaltic and andesitic lava flows having E-MORB and OIB geochemical characteristics. A geochemical analysis of the arc lavas overlying these geologic units was carried out considering the potential effects of subducted pelagic and chert deposits from the Pacific/Caribbean and of pelagic sediments from the Atlantic/Proto-Caribbean on the enrichment of the ultramafic source. This analysis allowed the authors to conclude that the formation of the Late Cretaceous to Eocene (85 to 45Ma) island arc strata was related to the N-dipping subduction of the Caribbean, and not to the earlier (from 125Ma) SW-dipping subduction system that formed the volcanic arc of central Puerto Rico. Such a complex evolution of the Antillean arc, with multiple subduction zones of -possibly- limited lateral extent, are to be expected in the highly mobile/dynamic tectonic environment of oceanic volcanic arc systems. Similar complex histories, with the formation and consumption of back-arc basins, double arcs, reversals of arc polarity and episodic subduction are recorded in other oceanic arc regions, such as the Tertiary-Present arcs of the western Pacific (e.g., Honza, 1991). As a corollary, it could be added that rapid changes (in space and time) of tectonic arrangements should be the rule, rather than the exception in the Mesozoic-Tertiary oceanic evolution of the Caribbean arc. In a related paper, C. Marchesi, W.T. Jolly, J.F. Lewis, C.J. Garrido, J.A. Proenza and E.G. Lidiak give insight on the **origin and evolution of mantle peridotites from the Monte del Estado massif of southwest Puerto Rico**. They are interpreted as a section of lithospheric mantle which underwent several stages of partial melting in the garnet and spinel stability fields, probably during the Jurassic-Early Cretaceous spreading of the Atlantic/Proto-Caribbean oceanic basin. This conclusion is important for it follows that this fragment of the Atlantic/Proto-Caribbean lithosphere should have been tectonically incorporated to the fore-arc region of the Greater Antilles arc within a tectonic scenario of subduction polarity reversal during the Aptian-Albian as proposed by Mattson (1979).

J. Escuder-Viruete, A. Pérez-Estaún, M. Joubert and D. Weis examine the volcanism related to the Late Cretaceous **Caribbean large igneous province** emplaced in the Caribbean volcanic arc. Based on new geological, geochemical and geochronologic data from the **Pelona-Pico Duarte basalts Formation of Central Hispaniola**, these authors find fundamental changes in the mantle sources of Late Cretaceous lavas that fed the volcanic-arc region. This suggests that the Late Cretaceous Caribbean plume flowed toward the mantle wedge region of the Caribbean island-arc in response to back-arc opening induced by the rollback of the SW-directed subduction of the proto-Caribbean slab.

SUBDUCTION ZONE-RELATED COMPLEXES

The nature and age of **metamorphic complexes** documenting the deep tectonic evolution of the convergent margins of the Caribbean realm is considered in detail by L.A. Solari, A. Gómez-Tuena, F. Ortega-Gutiérrez and C. Ortega-Obregón. These authors provide new geochemical and zircon-age data of the **Chuacús Metamorphic Complex of central Guatemala**. They describe a long-lasting evolution which includes three stages of metamorphism of Paleozoic (post-Ordovician/pre-Triassic), Late Triassic, and Late Cretaceous ages, in line with recent developments in the complex North American–Caribbean Plate boundary region of Mexico–Guatemala–Honduras (Ratschbacher et al., 2009). Subduction-related eclogite facies conditions (perhaps reaching ultra-high pressure conditions) were reached during the Paleozoic stage, and a high-P/low-T event -at eclogite-amphibolite facies conditions- also occurred in a Late Cretaceous stage. Such a history, not shared by adjacent continental blocks (e.g., Maya and Chortís blocks) points to an allochthonous character of the Chuacús complex. That is, rather than being a fragment of the Maya block, the Chuacús evolved independently from the Paleozoic until the Late Cretaceous, when it was accreted to the former. In any case, the latest Cretaceous high-pressure event indicates subduction and collision of the Caribbean arc with the margin of the Maya block, followed by accretion and exhumation. This is similar to what has been inferred from other high-pressure rocks of Guatemala (e.g., Brueckner et al., 2009) and the Yucatan basin-Cuba-Dominican Republic-Puerto Rico-Virgin Islands belt (García-Casco et al., 2008). It may not be causal, but the oceanic subduction-related **blueschists of Jambaló, Central cordillera of Colombia** were also exhumed during the latest Cretaceous-earliest Tertiary, as documented by the first Ar-age data available for these rocks provided by A. Bustamante, C. Juliani, C.M. Hall and E.J. Essene. Though the history of the Central Cordillera of Colombia is rather complex (Villagómez et al., 2011a), the data provided suggest that exhumation was caused by the collision of an intra-oceanic arc (rather than the Caribbean plateau; e.g., Kerr and Tarney, 2005) with the continental margin of South America. This collisional event is considered unrelated to synchronous arc-continent collisions in the Northern Andes (and the Antilles and Guatemala) and provides evidence for the possible existence of multiple arc-continent collisions along the margins of the Caribbean plate.

Petrological-geochemical processes occurring in the subduction environment do not only generate blueschists and eclogites. Locally, hydrothermal/metasomatic jadeitite and related rocks such as those from Guatemala are produced, as reported by G.E. Harlow, V.B. Sisson and S.S. Sorensen. These authors provide textural and mineral data of **jadeitite blocks in serpentinite mélanges from distinct settings on opposite sides of the Motagua fault**, and conclude that a contrasting petrologic nature of jadeitite characterize the two districts. Such contrast has to do with different thermal, mechanical and geochemical conditions during slab subduction and development of the subduction channel. It is also related to the ensuing tectonic history, which may include metamorphic reworking, likely related to the complex Cretaceous evolution of the margin of the Caribbean plate and adjacent blocks (*sensu* Brueckner et al., 2009; Pindell et al., in press). The complexities of long-lasting subduction channels are also attested by ultramafic rocks of the related mélanges. I. Blanco-Quintero, J.A. Proenza, A. García-Casco E. Tauler and S. Galí provide petrological and geochemical data of **serpentinite-matrix and -blocks from the Antillean subduction channel, Eastern Cuba**. Antigorite-serpentinites correspond to upper plate peridotites serpentinized at depth in the subduction channel due to dehydration of the subducting slab, whereas antigorite-lizardite serpentinites are lower plate abyssal serpentinized peridotites accreted to the channel, in what seems a regular picture of subduction-related serpentinite-melanges (e.g., Saumur et al., 2010). The authors emphasize that hydration of the upper plate mantle wedge is critical for exhumation of subducted material (e.g., Guillot et al., 2009). The geodynamic settings of formation of these serpentinites and their ultramafic protoliths, however, contrast with that of variably chromitite-bearing serpentinized ultramafic rocks of obducted ophiolitic sheets. In Eastern Cuba these ophiolites (i.e., Mayarí-Baracoa ophiolite belt) have been interpreted as formed in a back-arc/arc region (Marchesi et al., 2006, 2007). Similarly, F. Zaccarini, G. Garuti, J.A. Proenza, L. Campos, O.A.R. Thalhammer, T. Aiglsperger and J.F. Lewis conclude that the **Santa Elena ultramafic nappe of Costa Rica** formed in a suprasubduction zone environment, as indicated by the first systematic geochemical description of chromite and platinum group minerals from Santa Elena chromitites. This work suggests formation of chromitite due to fractional crystallization of boninitic magma and strengthens the view that the ultramafic nappe was formed in a suprasubduction environment (e.g., Geldmacher et al., 2008) rather than at a mid-ocean rift or a hotspot setting. It also illustrates the use of ophiolitic chromitite as a petrogenetic and geodynamic indicator, which is particularly useful when related ultramafic-mafic rocks are moderately to strongly altered.

VOLCANIC ARCS

Ocasionally, suprasubduction zone rocks formed far away from oceanic trenches enter a subduction zone. Complex tectonic scenarios, involving subduction erosion and/or the interplay of several subduction zones

are commonly envisaged to explain these occurrences, as described by M. Weber, A. Cardona, V. Valencia, U. Altenberger, M. López-Martinez, M. Tobón, S. Zapata, G. Zapata and E. Concha for the **eclogites of the Guajira Peninsula, northern Colombia**. The geochemistry of these rocks is similar to that of the Early-to-Late Cretaceous basalts and basaltic andesites of the oceanic island arc tholeiitic series of the Caribbean realm and their Late Cretaceous metamorphic ages are comparable to those of other high-pressure rocks of the southern margin of the Caribbean plate from Venezuela. A generalized stage of volcanic-arc subduction in the southern branch of the Caribbean plate margin points to a complex plate tectonic scenario involving the approach of the volcanic arc to the continental margin of South America. A major question left open by the authors is whether the high-pressure belts of northern South America represent a single continuous subduction zone through time or are part of multiple subduction zones that were modified by a strike-slip system during their approach to the margin (Maresch et al., 2009). Collision and accretion of the Caribbean Cretaceous volcanic arc to the northern margin of South America during the latest Cretaceous-early Tertiary caused orogenesis. Further development of topography resulted from the onset of subduction of the Caribbean plate below South America. Renewed magmatism constrains the evolution of exhumation and tectonic stages during the Cenozoic, as exemplified by the paper by A. Cardona, V. Valencia, M. Weber, J. Duque, C. Montes, G. Ojeda, P. Reiners, K. Domanik, S. Nicolescu, and D. Villagómez on **U-Th/He thermochronology and barometry of Eocene plutonic rocks of the Santa Marta massif and the Guajira Peninsula, northern Colombia**. Several major exhumation events from up to ca. 20 km in Santa Marta and 10 km in Serranía de Guajira are identified since the Eocene, though both complexes experienced independent histories since the late Oligocene. The control of exhumation in this active subduction/strike-slip plate margin is considered essentially tectonic, including post-Eocene changes in plate convergence obliquity and rate. These changes caused the South American margin to override the Caribbean plate, in agreement with fission track thermochronology (Villagómez et al., 2011b).

The paper by J. Lewis, G. Kysar Mattietti, M. Perfit and G. Kamenov deals with the geochemistry of **granitoids recovered from the basement of the northern Nicaraguan Rise**. This will certainly attract the scientific community, for the geology of this important part of the Caribbean is poorly known and controversial. According to this study, the elemental and Pb, Nd and Sr isotope systematics of granitoids indicate that basement rocks of the northern Nicaraguan Rise have a mature oceanic arc affinity and show no evidence for a continental component. Furthermore, these granitoids are similar to the possibly related Late Cretaceous-Paleocene oceanic volcanic-arc granitoid intrusions of Above Rocks (Jamaica) and Terre Neuve (Haiti). Hence, the authors propose that the basement of the northern Nicaraguan Rise in the investigated region corresponds to a Caribbean oceanic arc, probably related to the Siuna terrane (or the Mesquito Composite Oceanic Terrane of Baumgartner et al., 2008, which includes the Siuna terrane) rather than to the Paleozoic-Precambrian continental crust of the Chortís block (e.g., Rogers et al., 2007). This oceanic arc was formed during Cretaceous-Paleocene subduction of the Caribbean lithosphere and the subduction could have been active until the thick Caribbean large igneous province arrived at the trench during the Eocene.

Another case of Late Cretaceous-Tertiary arc-derived rocks, though related to a different subduction zone, is that of the Panamá arc. I. Corral, A. Griera, D. Gómez-Gras, M. Corbella, À. Canals, M. Pineda-Falconett and E. Cardellach present a study of the volcaniclastic **Río Quema Formation of the Azuero Peninsula, Panamá, and the associated gold and copper mineralization**. These authors conclude that the volcano-sedimentary rocks of the Cerro Quema area and associated Au-Cu mineralization were formed in the Panama arc/fore-arc basin during the late Cretaceous-Eocene. Rather than an accreted exotic oceanic terrane, the basement is confirmed to be part of the Caribbean large igneous province (in line with Buchs et al., 2010; Wegner et al., 2011) and is considered autochthonous. This allows the characterization of arc development and maturation since the onset of subduction of Farallon below the Caribbean large igneous province.

As shown, the papers presented in this issue cover a wide spectrum of Caribbean rock complexes in terms of space, time and geologic origin, and add new data and far-reaching ideas that will fruitfully contribute to the current debate on the evolution of the Caribbean and adjacent plates.

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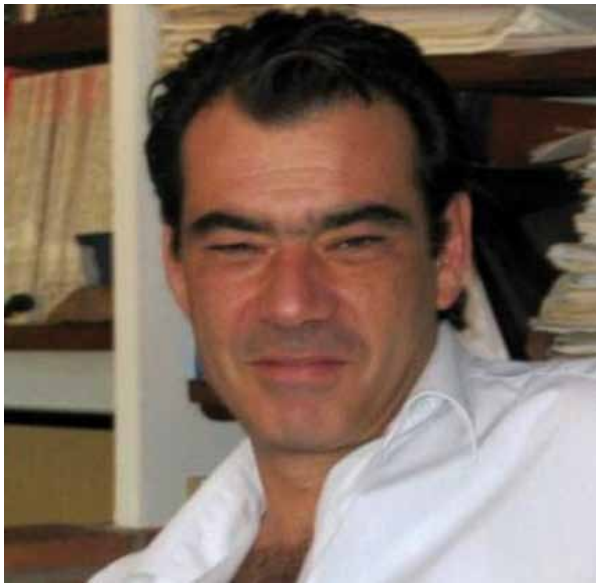

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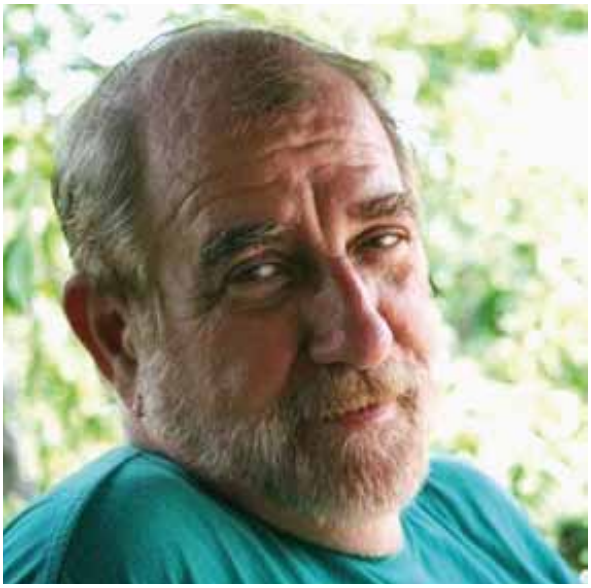

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