A FIELD GUIDE TO CRETACEOUS FACIES AND SEQUENCE STRATIGRAPHY OF NORTHEASTERN VENEZUELA

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by

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INTRODUCTION

This field trip will specifically examine the high-resolution stratigraphy, depositional facies, and sequence stratigraphy of Cretaceous strata in northeastern Venezuela.

Three stratigraphic intervals, representing a broad spectrum of depositional settings, will be visited. Day one will be spent examining the upper Venados, Moro Blanco, and lower Picuda Members (Middle Valanginian - Middle Hauterivian) of the Barranquin Formation In the vicinity of Cantera la Rosa, near Cumana. Special attention will be focused on third-order stratigraphic sequences, representing relative sea-level fluctuations, in mixed carbonate-siliciclastic platform facies.

Day two will be spent traversing the Late Albian - Late Maastrichtian Cretaceous section along the banks of the Rio Querecual, near Bergantin. Here we will examine predominantly fine-grained siliciclastic and pelagic carbonate facies of outer shelf, slope and basinal environments in the Querecual, San Antonio and Vidono formations - the major source rocks of this region. We will also study coarser siliclastic lowstand wedges of the lower San Antonio and San Juan formations. River sections will allow a complete traverse of these formations, relatively uncomplicated by regional folding and faulting.

Day three will be spent on Isla Borracha off the coast of Puerto la Cruz. Starting with the third-order sequence stratigraphy of mixed carbonate-siliciclastic facies of the Borracha Formation (Aptian-Albian: partially equal to the El Cantil Formation of the interior), with its well preserved rudistid reefs, we will traverse a major karst surface and sequence boundary on top of the Borracha, overlain by a condensed Albian glauconitic marl/claystone sequence of the lower Chimana Formation, and proceed through the basinal, cyclically bedded facies of the Querecual Formation, representing the highest second-order global sealevel highstand of the Cretaceous. We will proceed upsection to a thin fine-grained sandstone unit representing the global second-order sequence boundary and lowstand deposit at the Middle Turonian - Upper Turonian boundary..

We are pleased to have the opportunity to take this field trip with you, and to exchange ideas on the Cretaceous stratigraphy and depositional environments of northeastern Venezuela.

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AN INTEGRATED CRETACEOUS RADIOMETRIC - BIOSTRATIGRAPHIC TIME SCALE FOR THE WESTERN INTERIOR BASIN OF NORTH AMERICA
(Kauffman, Obradovich, and Cobban, in manuscript, 1993)

CRETACEOUS WESTERN INTERIOR BIOZONATION AND GEOCHRONOLOGY

STAGE		AMMONITE ZONES	AGE (MYBP)	
				88.7
TURONIAN	UPPER	S. corvensis, P. germari	88.84	
		Scaphites nigricollensis	89.11	
		Scaphites whitfieldi	• 89.39	
		Scaphites ferronensis	89.66	
		Scaphites warreni	89.94	
		P. macombi, C. colleti	** 90.21	
				90.35
	MIDDLE	Prionocyclus hyatti	**90.51	
		Prionocyclus percarinatus	90.97	
		Collignoniceras woollgari regulare	91.42	
		Collignoniceras woollgari woollgari	91.88	
				92.11
	LOWER	Mammites nodosoides	92.34	
		Vascoceras birchbyi	92.8 (***93.4)	
		Pseudaspidoceras flexuosum	**93.25	
		Watinoceras devonense	93.35	
				93.40
CENOMANIAN	UPPER	Nigericeras scotti	93.46	
		Neocardioceras juddii	** 93.56	
		Burroceras clydense	93.67	
		Euomphaloceras septemseriatum	93.78(***93.49)	
		Vascoceras diartianum	** 93.90	
		Duvenganoceras conditum	94.08	
		Duvenganoceras albertense	94.27	
		Dunveganoceras problematicum	94.45	
		C. canituarinum, D. pondi	** 94.63	
				94.71
	MIDDLE	Plesiacanthoceras wyomingense	94.78	
		Acanthoceras amphibolum	** 94.93	
		Acanthoceras bellense	95.14	
		Acanthoceras muldoonense	95.36	
		Acanthoceras granerosense	95.57	
		Conlinoceras tarrantense	**95.78	
				95.98
	LOWER □	Beattonoceras beattonense	96.18	
		Irenicoceras bahani	96.58	
		Neogastroplites septimus	96.97 **	
(1)				97.17
		Neogastroplites macleami	*97.36	
		Neogastroplites americanus	**97.75	
		Neogastroplites muelleri	98.14	
(2)				98.33
ALBIAN	UPPER	Neogastroplites cornutus	**98.52	
		Neogastroplites haasi	**98.54	
		Unzoned (with Eopachydiscus?)	*99.61	
		Inoceramus bellvuensis	100.68	
		Inoceramus comancheanus	101.75	
		Unzoned	102.82	
				103.36
	MIDDLE □	Stelckiceras liardense	103.89	
		Gastroplites sp.cf. cantianus	104.96	
		Gastroplites canadensis	106.03	
		Pseudopulchellia pattoni	**107.10	
		UNNAMED	107.75	
				108.08
	LOWER □	Arcthoplites macconnelli	108.41	
		Arcthoplites irenense	109.06	
		Arcthoplites belli	109.71	
		Lemuroceras sp.cf. L. indicum	110.37	
		Cleoniceras sp.cf. C. subbaylei	111.02	
		Sonneratia sp.cf. S. kitchini	111.67	
				112.0

(1) Traditional A-C boundary; (2) New A-C boundary proposed by Cobban and Kennedy (1989). Radiometric ages from *Kauffman (1977; corrected to 89.59), Obradovich and Cobban (1975, corrected to 96.2), and Odin (1982, corrected to 99.4), but because these levels are now being redated by Obradovich (1992, personal communication), interpolated ages between newly dated levels (**) are used herein. ** New Ar39-Ar40 ages from Obradovich (1992, this volume); remaining values interpolated between dated levels based on assignment of equal time durations to biozones.

□ Marine zones known only from Canada

*** New ages in parentheses (Obradovich, this volume) are incompatible with new bounding dates and appear next to a calculated value based on new bounding dates: e.g., 92.8 (***93.4)

CRETACEOUS WESTERN INTERIOR BIOZONATION AND GEOCHRONOLOGY

STAGE		AMMONITE ZONES	AGE (MYBP)	
Paleocene				**65.4
MAASTRICHTIAN ***	UPPER ***	Unnamed or Triceratops ← **66.8	65.95	
		D. cheyennensis, D. nebrascensis	67.17	
		Discoscaphites roanensis, H. nicolleti	67.92	
		Hoploscaphites sp.aff. H. nicolleti	68.67	*69.05
	LOWER	Baculites clinolobatus	**69.42	
		Baculites grandis	*69.91	
		Baculites baculus	*70.40	
		Baculites eliasi	70.89	71.38
CAMPANIAN ◎	UPPER	Baculites jenseni	71.87	
		Baculites reesidei	*72.36	
		Baculites cuneatus	*72.85	
		Baculites compressus	**73.35	
		Didymoceras cheyennense	74.06	
		Exiteloceras jenneyi	**74.76	
		Didymoceras stevensoni	75.33	
		Didymoceras nebrascense	**75.89	76.15
	MIDDLE	Baculites scotti	76.41	
		Baculites gregoryensis, B. reduncus	76.92	
		Baculites perplexus (late form)	77.44	
		Baculites gilberti	77.96	
		Baculites perplexus (early form)	78.47	
		Baculites sp. (smooth 2)	78.99	
		Baculites asperiformis	79.51	
		Baculites mclearni ← **79.8	80.03	
		Baculites obtusus	**80.54	80.57
	LOWER	Baculites sp. (weak flank ribs)	*80.60	
		Baculites sp. (smooth 1) ← **+/-81.0	80.64	
		Scaphites hippocrepis III	81.17	
		Scaphites hippocrepis II	**81.71	
		Scaphites hippocrepis I ← **81.76	82.44	
		Scaphites leei	83.17	83.54
SANTONIAN	UPPER	Desmoscaphites bassleri	**83.91	
		Desmoscaphites erdmanni	84.51	84.81
	MIDDLE	Clioscaphites choteauensis	85.11	
		Clioscaphites vermiformis	85.72	86.02
	LOWER	Clioscaphites saxitonianus	86.32	86.62
CONIACIAN	UPPER	Scaphites depressus	**86.92	87.27
	MIDDLE	Scaphites ventricosus	87.63	
		Scaphites preventricosus, F. alluaudi	**88.34	88.47
	LOWER	Forresteria peruana	88.59	**88.70

* Radiometric ages for these levels are cited in Obradovich and Cobban (1975) and Folinsbee et al. (1961, 1966), but because these levels are now being redated by Obradovich (1992, personal communication), interpolated ages between newly dated levels (**) are used herein.

** New Ar39-Ar40 ages from Obradovich (1992, this volume); remaining values interpolated between dated levels based on assignment of equal time durations to biozones.

*** Boundary from Kennedy and Cobban (in press)

◎ Three-fold division of the Campanian after Cobban (1992, in press).

HIGH-RESOLUTION ANALYSIS OF STRATIGRAPHY, CHRONOLOGY, AND SEA LEVEL HISTORY IN CRETACEOUS STRATA OF NORTHEASTERN VENEZUELA

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INTRODUCTON

The Cretaceous strata of northeastern Venezuela (Fig. 1) comprise a diverse sequence of fluvial, paludal-lagoonal, siliciclastic shoreface and platform, carbonate platform, slope and basinal facies deposited across a stable passive margin. Stratigraphic studies, to date, comprise generalized documentaton and regional correlation of major lithologic units based on scattered outcrops (Fig. 2), mainly in river valleys, road-cuts, and poorly vegetated hill tops. Paleontologic and biostratigraphic analyses are equally generalized. Published Venezuelan macrofaunal studies are limited to major biota of a few formations (e.g. Macsotay, et al, 1985) with the outstanding exception of Renz's systematic work on the ammonites (1982). Renz, however, does not present detailed biostratigraphic range data, thus the correlation potential of ammonites is limited. Older published Venezuelan microfaunal data are generalized and do not allow detailed correlation with the new global oceanic plankton standard; newer data generated by various Energy Companies are largely unpublished and unavailable at present. Macsotay et al (1985) have compiled the only comprehensive modern biostratigraphy for the region based largely on macrofossils, but the limited amount of data available to him has resulted in a biostratigraphic resolution averaging only 2.6 Ma/biozone (compared to 0.12 - 0.33 Ma/biozone in comparable strata of the North American Western Interior Basin: Kauffman, 1970, 1975, Kauffman et al, 1976, 1992 in press).

Modern stratigraphic analysis of the Cretaceous sequence in northern Venezuela, and meaningful correlation of this sequence to Cretaceous strata, sequence stratigraphy, sealevel history, ocean/climate history, and biological evolution/ecology on a global scale will depend upon establishing a new, high-resolution (cm-m scale, Ka-100 Ka scale) stratigraphic and chronologic standard for northern Venezuela. This is the principal directive for the University of Colorado Basin Analysis Research Group as part of the current project to study the passive margin history of northeastern Venezuela.

The current study, reported herein, represents a first and as yet incomplete effort to achieve these goals. Building on a general stratigraphic survey of the sequence by Kauffman

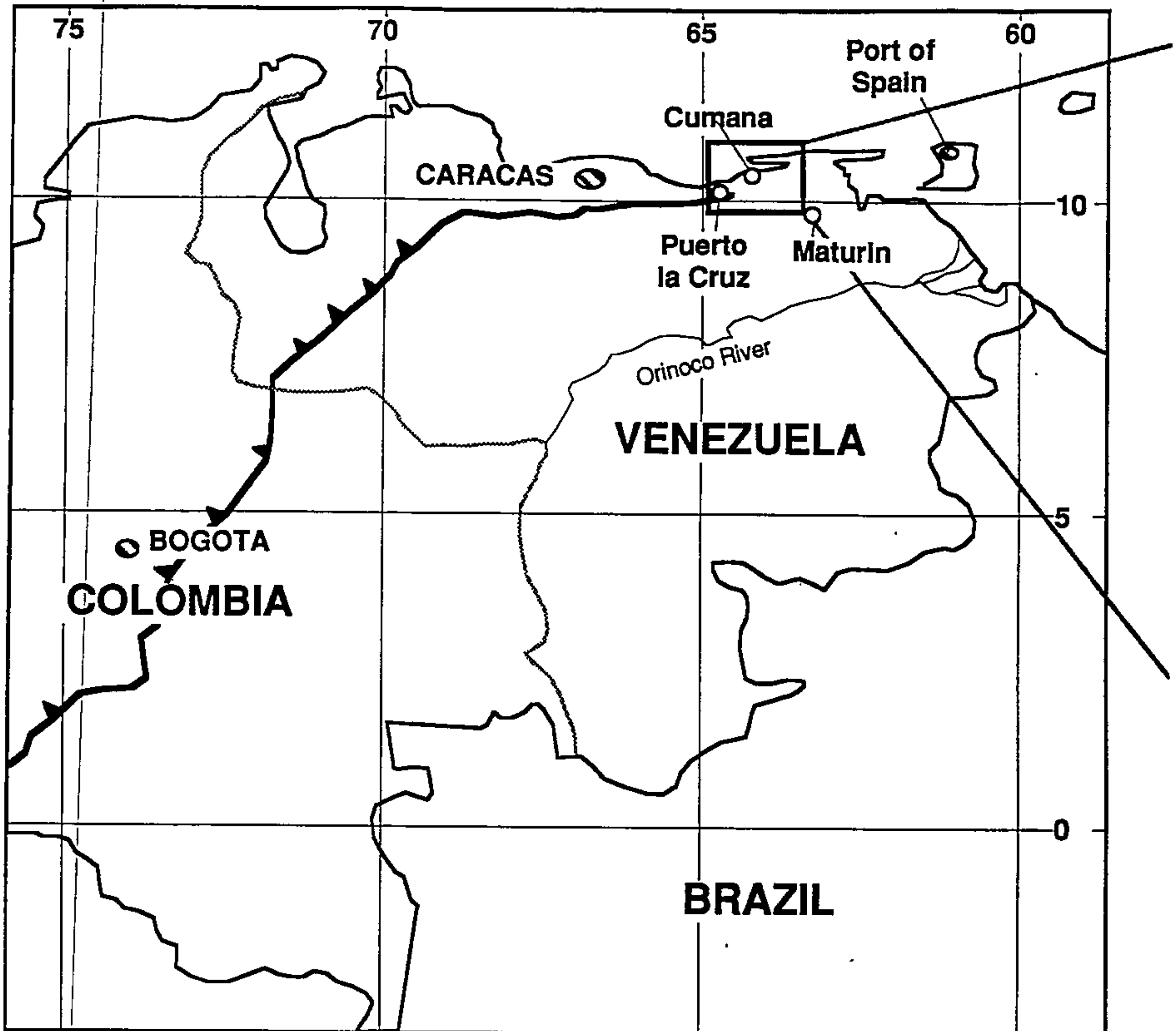


FIGURE 1 - MAP OF VENEZUELA SHOWING THE STUDY AREA (IN BOX)

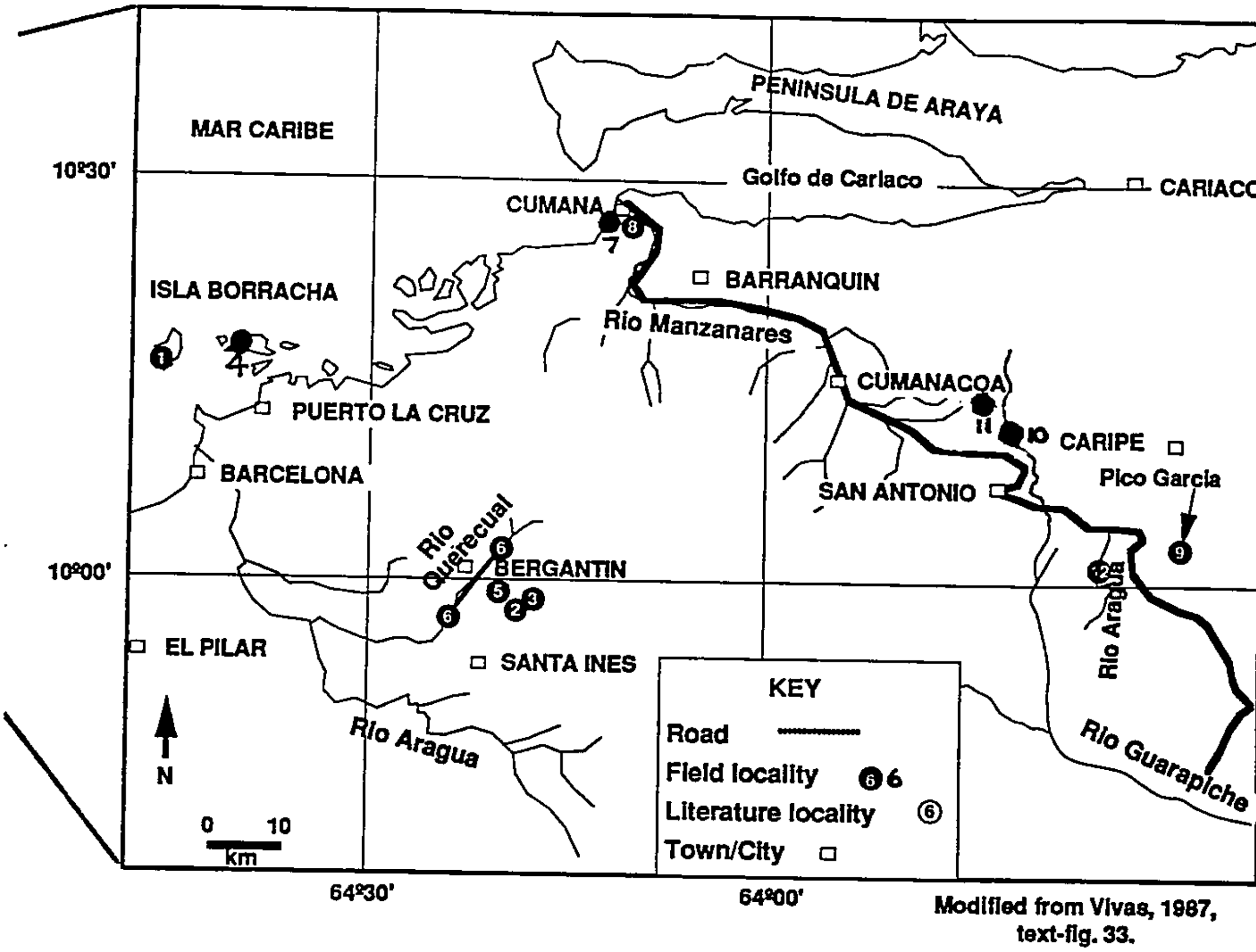


FIGURE 2 - MAP OF NORTHEASTERN VENEZUELA SHOWING LOCATIONS OF SECTIONS JKV-92-1 THROUGH JKV-92-12 (KEYED TO LAST NUMBER OF LOCALITY), STUDIED BY THE AUTHORS DURING THE PERIOD 1989 - 1992.

and Johnson in 1989 in cooperation with Snrs. Oliver Macsotay and Jose Ortega of the Corpoven Company at Puerto La Cruz, two additional weeks were spent in the field in January, 1992, for the purpose of establishing a high-resolution, composite stratigraphic and biostratigraphic data base for the Cretaceous sequence near the northern and southern margins of the study area (Fig. 2), interpreting the temporal evolution of depositional environments, and developing a sequence stratigraphic framework from 2nd- to 5th-order scale (9 Ma to 100 Ka average durations, respectively). This sequence stratigraphy can then be tested against the global cycles of Haq et al (1988), and the Cretaceous sequence stratigraphy and sealevel history of Colombia (Villamil, in progress, 1992; Fig. 3 herein), Western Europe (Hancock, in press), and the Western Interior United States (Kauffman, 1985; Kauffman and Caldwell, 1992 in press). These tests of correlation will, in turn, allow assessment of the relative roles of eustatic sealevel change versus tectonics in regulating the evolution of sedimentary sequences in northeastern Venezuela.

To the degree that limited outcrop availability, structural complications, lack of pre-existing detailed stratigraphic data, and an insufficient fossil record for some parts of the sequence would allow, the principal goals of this research have been achieved. This report presents a new and more detailed composite biostratigraphy for the Cretaceous of northeastern Venezuela than previously available. Numerous microfossil analyses (foraminifers, dinoflagellates, palynomorphs, radiolarians) are still under way, slowed by the difficulties of extraction from siliceous and diagenetically altered fine-grained rocks, and poor preservation. Also presented are the first high-resolution stratigraphic sections made for parts of the Barrenquin (Morro Blanco, Picuda, and Taguaruma members), El Cantil, Garcia, Chimana, Querecual, San Antonio, and basal Vidono formations, and new paleoenvironmental interpretations. Many of these detailed field studies have turned up new, biostratigraphically important fossil biotas, including some in levels where precise biostratigraphic dating was not previously possible. Finally, a first detailed sequence stratigraphic interpretation, to 5th-order of resolution (100 Ka) where possible, has been completed and regionally correlated to Cretaceous sequences worldwide. New sequence stratigraphic models for some facies have resulted.

We envision this work as only a first step in establishing a broad-scale, high-resolution Cretaceous stratigraphy, sequence stratigraphy, and chronology for all of Venezuela. More work needs to be done in northeastern Venezuela to refine this stratigraphy, fill in still poorly known gaps, and to establish a final Cretaceous stratigraphic standard for this region. The next critical north-south transect across the passive margin should be to the west, possibly in

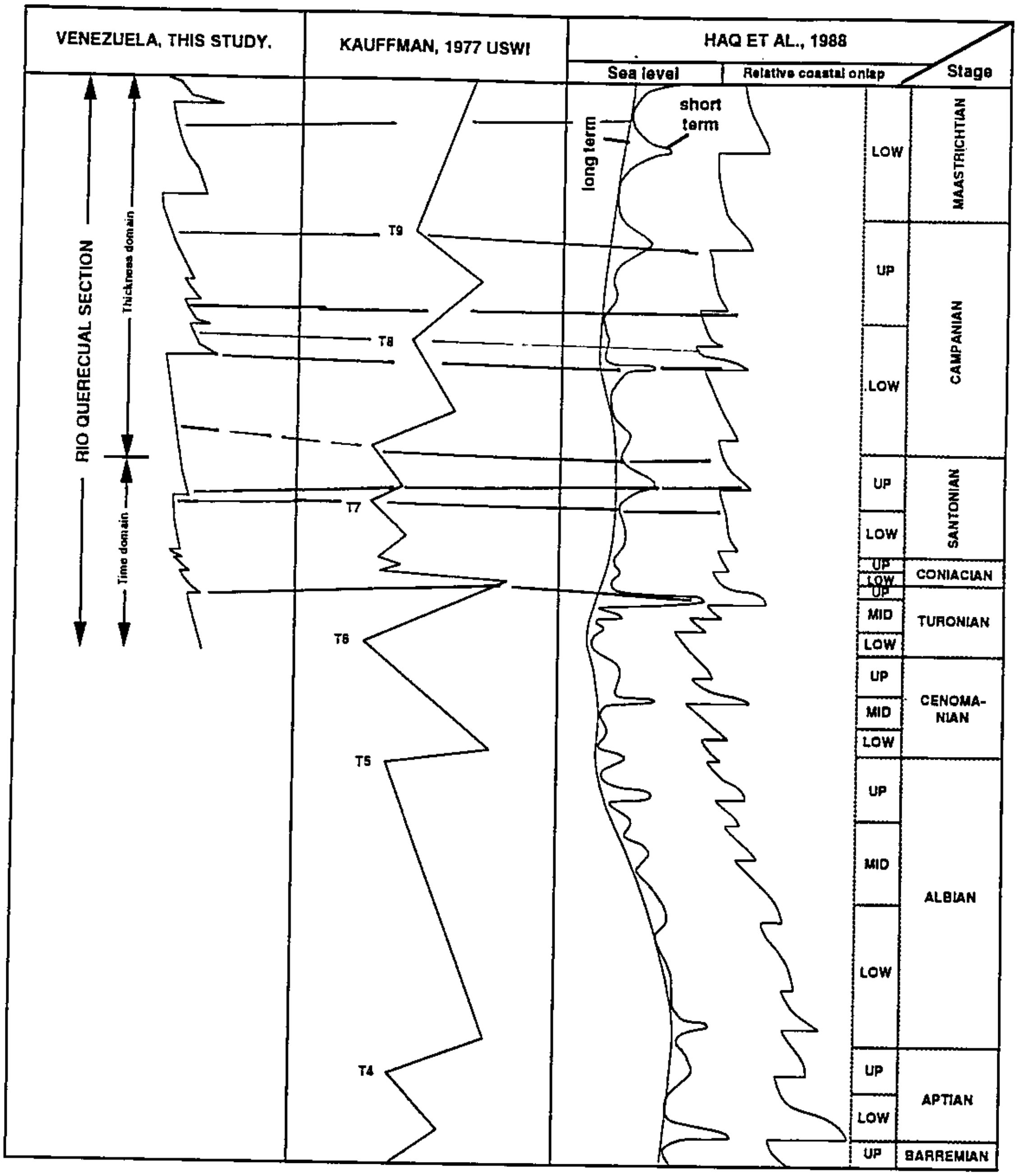
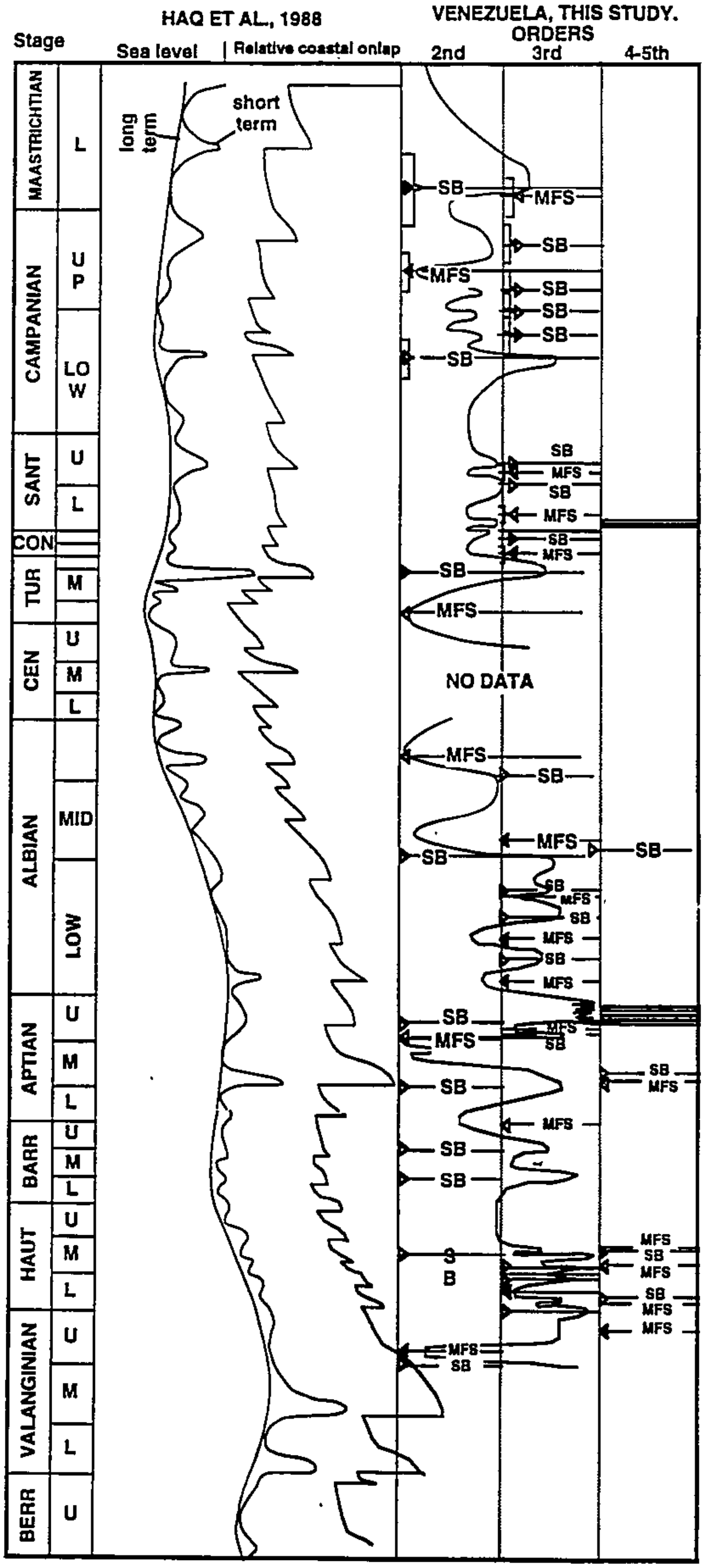
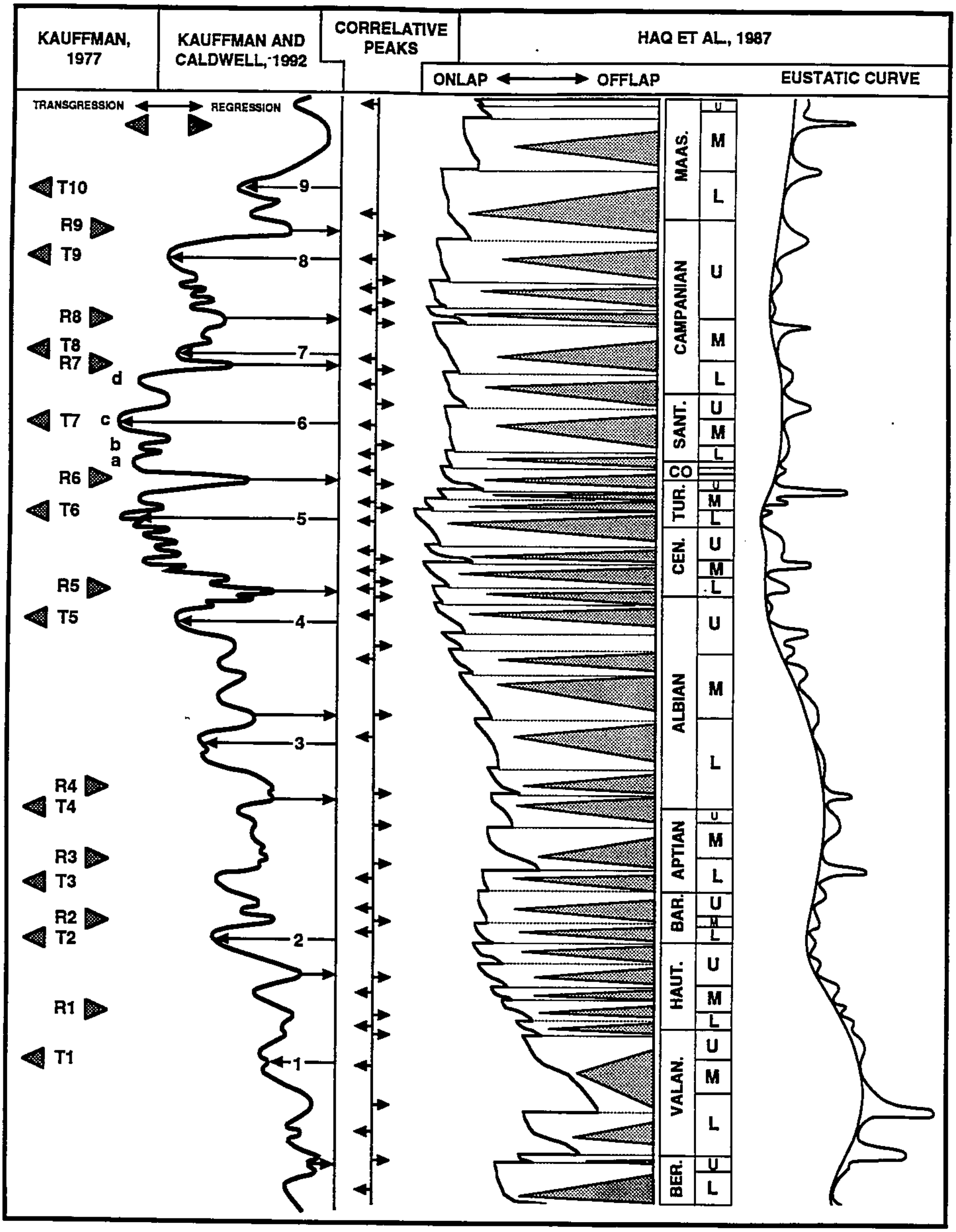


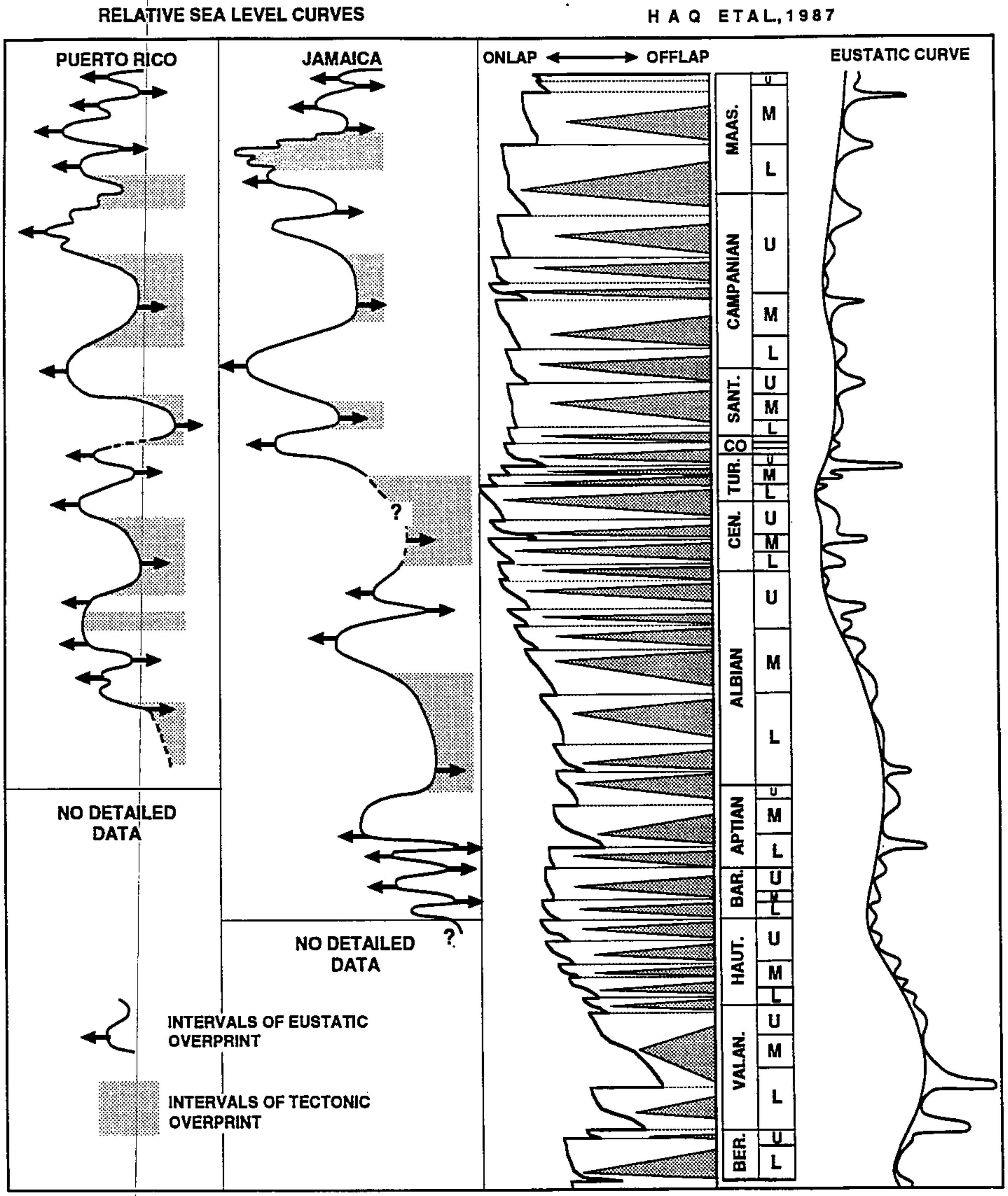
FIGURE 3 - COMPARISON OF RELATIVE SEALEVEL CHANGES BETWEEN THE COASTAL ONLAP AND GLOBAL SEALEVEL CURVES OF HAQ ET AL (1988) (RIGHT), KAUFFMAN'S TRANSGRESSIVE-REGRESSIVE CURVE FOR THE WESTERN INTERIOR OF NORTH AMERICA (CENTER), AND THE ONLAP CURVE FOR THE CRETACEOUS OF THE RIO QUERECUAL, NORTHEASTERN VENEZUELA. CLOSE CORRELATIONS OF SEQUENCE BOUNDARIES AND MAXIMUM FLOODING SURFACES (HORIZONTAL LINES) SUGGEST EUSTATIC REGULATION FOR CERTAIN CYCLES.

A PROPOSED SECOND- THROUGH FOURTH-ORDER SEQUENCE STRATIGRAPHY FOR THE CRETACEOUS OF NORTHEASTERN VENEZUELA, COMPARED TO THE HAQ ET AL. (1987) GLOBAL CYCLE CHART





A SEALEVEL CURVE FOR THE CRETACEOUS OF THE WESTERN INTERIOR OF NORTH AMERICA, COMPARED TO THE HAQ ET AL. (1987) GLOBAL CYCLE CHART (From Kauffman and Caldwell, in press, 1993)



A CRETACEOUS SEALEVEL CURVE FOR THE ANTILLEAN ARC ISLANDS OF JAMAICA AND PUERTO RICO, COMPARED TO THE HAQ ET AL. (1987) GLOBAL CYCLE CHART (From Kauffman, 1993, in manuscript) the Miracaibo Region; this would then allow close linkage to seven highly detailed stratigraphic sections spanning the Cretaceous basins of Colombia and Ecuador which were completed in 1991. Collectively these data will provide a new Cretaceous stratigraphic standard for northern South America which will be critical to new exploration ventures.

METHODOLOGY

Modern stratigraphic analysis of basin and platform history requires a high-resolution system of chronology which will allow local, regional and global correlation of short-term historical even9ts such as sequence boundaries (regressive peaks), transgressive surfaces, maximum flooding surfaces (transgressive peaks), major geochemical fluctuations (e.g. regional and global anoxic/dysoxic events resulting in source rock generation; trace element enrichment intervals); and short-term tectonic/volcanic events. This chronology must have a resolution finer than the 1 Ma or greater level of many current systems, preferably at a scale of 10's to 100's of Ka as already developed for the Western Interior Cretaceous Basin of North America (Kauffman, 1988; Kauffman, et al, 1991; 1992 in press), Western Europe, and Colombia, S.A. (Villamil, manuscript in preparation).

Without such a refined chronology, modern basin analysis integrating tectonic, eustatic, sedimentologic, climatic, paleoceanographic and biological factors into a series of dynamic interpretations and interactive models, is not possible. The reasons are obvious: during the last two decades, stratigraphers have become increasingly aware of the fact that sedimentological, geochemical, and biological units/surfaces critical to understanding basin and platform history are predominantly short-term (<500 Ka, and mainly under 100 Ka) events, or reflect predictable short-term depositional rhythms such as Milankovitch Climate Cycles. For example, the critical data for analyzing relative sealevel changes and sequence stratigraphy in a region, and testing its correlation to other regions and the global cycle chart of Haq et al (1987), are the precise ages of the sequence boundaries, transgressive/marine flooding surfaces, and the point/interval of maximum flooding (peak highstand of authors). These are all surfaces or thin stratigraphic intervals that Vail et al (1977) and Haq et al (1988) consider as "chronostratigraphic surfaces" of correlation. (In the sense of standard sequence stratigraphic usage, a chronostratigraphic surface consistently separates older rocks below from younger rocks above, throughout its extent, and implies that the surface represents a short interval of geologic time rather than being absolutely isochronous, in contrast to the original usage of The American Code of Stratigraphic Nomenclature. Kauffman (1988), Kauffman et al (1991, and in press) and various papers in Einsele et al (1991) review the new science of event and cycle chronostratigraphy and its critical role in modern basin/platform analysis. For many Cretaceous sections of the world, including Venezuela and Colombia, the great majority of the stratigraphic column is dominated by deposits reflecting short-term (<100 Ka) events and cycles (e.g. the Querecual and San Antonio formatons). These will form a primary basis for local and regional correlation in a new system of chronology for northern South America.

Similarly, the field of biostratigraphy has changed dramatically in recent years as biochronologists seek finer levels of resolution in zonation and correlation (100's of Ka as opposed to the 0.5 - 3 Ma zonal durations of many currently used systems). For the Cretaceous, Kauffman (1970, 1988) has demonstrated that three advanced methods of biostratigaphic analysis greatly improve zonal resolution: (1) Population systematic analysis of single lineages normally leads to taxonomic refinement and greater zonal resolution; (2) use of evolutionary events among characters or character suites within lineages, as opposed to species, may greatly improve biozonal resolution, at least locally, because characters evolve at different rates and times in the evolutonary history of a species plexus; and (3) the application of composite assemblage zone techniques in which diverse, biostratigraphically useful macrofossil and microfossil species data (first, last occurrence points and and total range) are integrated from each section into multitaxic assemblage zones (commonly using graphic correlation techniques). Only the last method (3) can be practically applied to zonation of the Venezuelan Cretaceous section at present because of limitations in existing paleontologic data. Composite assemblage zonation works to improve biostratigraphic resolution because different groups evolve at different rates and times within a single depositional basin, reflecting varying adaptive ranges and stress limits among different lineages, as well as different rates of genetic experimentation. Thus, integration of biostratigraphic data from many coeval groups provides many more first and last occurrence points for taxa, at many more stratigraphic levels, than other biostratigraphic systems based on single groups or lineages. Kauffman (1970) achieved over 100 percent increase in biozonal refinement for the Western Interior Cretaceous Basin of North America using this system, as compared to previous biozonations based only on ammonites or calcareous plankton.

Establishment of a new Cretaceous chronology for northern South America, integrating modern systems of composite assemblage biostratigraphy with high-resolution event chronostratigraphy (Kauffman, 1988), and fine-scale sequence stratigraphy (2nd-7th-order: Haq et al, 1988), requires a new, much greater level of stratigraphic documentation and analysis than is currently available from past work in Venezuela. This, in turn, also requires a different

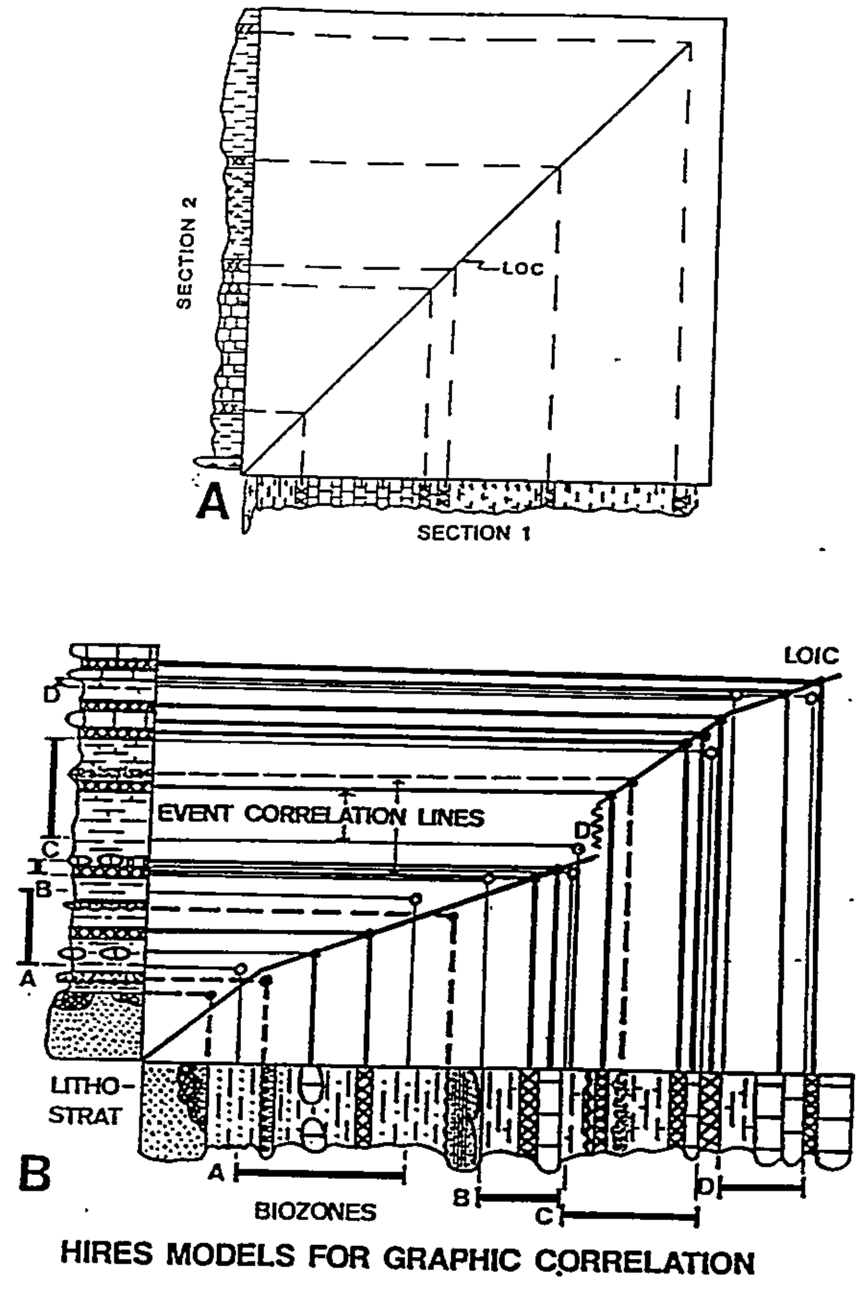


Figure 4.–(*A*) Simple model of graphic correlation to develop an isochron event correlation line from volcanic ash beds in two sections [X's and dashed lines; LOC is solid diagonal line (from Barlow 1985)]. (*B*) Detailed model for graphic correlation of high-resolution event stratigraphic data from two sections (after Kauffman 1986) showing development of line of isochron correlation (LOIC) from event units (ash layers and climate cycle beds), near-correlation of mass flow deposits to this line, and position of biozone first and last occurrence points (open circles), which are close but not isochronous.

philosophy in field and laboratory stratigraphy: Field observation, data collecton, and laboratory analyses are focused at the centimeter scale on the discovery and documentation of short-term event and cycle deposits or surfaces, rather than on broader scale lithologic similarities or differences within the observed stratigraphic sequences.

Kauffman (1970) provides a detailed description of the methodology utilized in composite assemblage biostratigraphy, and similar reviews of the concepts and methods of high-resolution event chronostratigraphy (HIRES) may be found in Kauffman (1988) and Kauffman et al (1991, and in press).

Graphic correlation (Miller, 1979; Edwards, 1984) provides a powerful analytical tool for correlation and integration of diverse data among a series of coeval stratigraphic sections. This tool is being applied to analyses of the Venezuelan sections and their comparison to those of Colombia, the Western Interior United States, and to the global cycle chart and sealevel curve of Haq et al (1987). Graphic correlation, as originally proposed and still largely used, establishes a calculated line of correlation between sections based on first and last occurrence data of diverse, biostratigraphically useful fossil taxa. The line of correlation (LOC) (Fig. 4) is thus a composite biostratigraphic correlation and is especially useful in developing a composite set of taxa ranges for assemblage zone biostratigraphy.

Kauffman (1988) introduced a new application of graphic correlation to chronostratigraphy by developing lines of isochronous correlation (LOIC) based on high-resolution event and cyclic stratigraphic data (especially volcanic ash layers, climate cycle deposits, geochemical spikes), and then independently comparing biostratigraphic data (and thus the LOC) against this LOIC in order to integrate and test components of each system. An integrated chronology results from this analysis which provides a more powerful tool for regional correlation. This technique is applied herein to correlations between northeastern Venezuela and the Cretaceous basins of Colombia, and between Venezuela and the Western Interior United States. When sufficient data are collected from a broader area within Venezuela as an extension of this work, this new system can be used effectively to composite and correlate data throughout northern South America.

The present study is a first attempt at high-resolution stratigraphic and biostratigraphic analysis of the Cretaceous sequences in northeastern Venezuela, and their integration into a graphic correlation matrix. These data have then been applied for the first time to the dating, regional correlation, and analysis of 2nd - 5th-order Cretaceous depositional sequences and their comparison to the global cycle chart and eustatic sealevel curve of Haq et al (1988).

Several workers have collectively provided an excellent stratigraphic framework for the Cretaceous of northeastern Venezuela, especially Hedberg (1937, 1950), Macsotay et al (1985), Vivas (1987) . As is characteristic of pioneer stratigraphic analysis of an area, these works have focused primarily on the definition and broad lithologic characterization of Cretaceous strata, formal establishment of formations and members, and documentation of the most common fossil taxa. Few of the previously measured and published Cretaceous sections for northeastern Venezuela provide sufficient detail for either high-resolution event and cycle chronostratigraphy, or for refined biozonation. It was therefore necessary for our group to re-measure and re-describe sections of the Morro Blanco Member of the Barranquin Formaton, and of the Taguaruma, El Cantil, Garcia, Chimana, Querecual, San Antonio, San Juan, and lower Vidono formations in much greater detail than previous authors, with observations consistently to the centimeter to at least the meter scale of resolution. Unfortunately because of logistic and time constraints, and lack of fresh outcrop for some intervals, the best resolution of data obtained is still not ideal for high-resolution stratigraphy, and only 50 - 75 percent as refined as that available for coeval strata of North America and western Europe. Nevertheless, the new sections represent a considerable refinement over past work, and reveal many new and important details of sequence stratigraphy, depositional environments, and regional stratigraphic relationships for most units.

All new sections were measured with either Jacob Staff or Brunton Compass traverse methods to meter scale, and well exposed outcrops were further described at the cm - m scale utilizing a calibrated tape. No attempts were made to reconstruct detailed stratigraphic relationships across major faults or tightly folded sequences because of time constraints. All rock types were described and sampled within each stratigraphic unit, and representative photographs taken for facies analysis. The outcrops were thoroughly searched for macrofossils, and all concretion horizons broken and searched extensively. For micropaleontologic and geochemical analyses, samples were taken at meter intervals (finer sampling across intervals of special interest, e.g. condensed horizons) and bagged in inert plastic. All sequence boundaries, transgressive marine flooding surfaces, condensed horizons, and maximum flooding surfaces were identified and characterized in the field after discussion among members of the field team. Fossils which could not be successfully removed from the outcrop were identified to the finest possible taxonomic level in the field, and photographed.

Laboratory analysis at the University of Colorado involved splitting and dispersal of sample sets to various specialists in Geochemistry (Lisa M. Pratt, Indiana University) and Micropaleontology (Don L. Eicher, Foraminifera; Charles Blome, Radiolarians; Douglas Nichols, Palynomorphs including dinoflagellates), detailed lithologic descriptions, fossil preparation and identification, drafting and annotation of sections, and final sequence stratigraphic analysis.

All data have been entered and analytically tested in the MacIntosh Computer files (Basin Analysis Research Group) at the University of Colorado. A library sample set for each section, and all identified macrofossils and rock types, are curated in the Department of Geological Sciences at the University of Colorado. Small sample sets (as long as they last) and diskette copies of stratigraphic data are available upon request to Erle G. Kauffman, Department of Geological Sciences, CB-250, University of Colorado, Boulder, CO 80309, USA.

Research still in progress includes additional work on the carbon geochemistry by Pratt, the majority of new micropaleontological analyses, and continued evaluation of published macrofossil data from Venezuela. Completion of this work is essential before a final sequence stratigraphy, biostratigraphy, integrated chronology, and composite graphic correlation matrix can be constructed for the northeastern Venezuelan Cretaceous, and before detailed facies relationships can be determined across this passive margin.

LITHOSTRATIGRAPHY

Macsotay, Vivas, de Bellizzia and Bellizia (1985) have most recently summarized the Cretaceous stratigraphy and much pertinent biostratigraphic data for northeastern Venezuela. The reader is referred to this excellent piece of work, and the references therein, for details on the historical development of stratigraphic nomenclature, type sections, regional facies relationships, and relevant tectonic history of the region. In general, somewhat distinct systems of stratigraphic nomenclature and facies development exist north and south of the El Naranjo - Los Borrachos Fault Zone of Macsotay et al (1985).

During the course of our field studies, it was hoped that two new high-resolution stratigraphic sections and sample sets would be developed for the entire sequence of the Barrenquin, El Cantil, Garcia, Chimana, Querecual, San Antonio, San Juan, and Vidono formations; one composite section near the northeast coast (seaward passive margin) and one inland (central to landward passive margin) on the north edge of the Orinoco River drainage. This plan was not fully achieved for various logistical reasons: (a) field studies and data collecting on the offshore islands (e.g. Isla La Borracha) were cut short by National Park officials' refusal to allow collecting or access to certain sections; only the Borracha (El Cantil, in part) and Chimana formations were observed in detail here, and a full northern section for the Cretaceous could not be established; (b) Inland, the fine-grained facies of the lower and middle Barrenquin Formation (e.g. at Pica Garcia), important parts of the lower Querecual Formation (basal Late Albian sequences, and most of the Cenomanian), and portions of the upper San Antonio Formation were not exposed and could not be excavated at the sections visited; (c) severe structural complications (tight folding and faulting) omitted or repeated portions of the secton studied, especially for the Querecual and San Antonio formations, e.g. along the Rio Aragua section. Neither outcrop extent nor time in the field allowed solution of these structural problems, and thus true thicknesses or missing section to be restored.

Nevertheless, valuable new data were collected from all formations: these data, and interpretations made from them, are summarized below.

BARRENQUIN FORMATION

Macsotay et al (1985) reviewed the regional stratigraphy of the Barrenquin Formation of Liddle (1928) and noted that it contained three members in the study area, in ascending order: The Venados Member (Late Berriasian - Middle Valanginian), Morro Blanco Member (Middle? and Late Valanginian - Lower Hauterivian), and Picuda Member (Middle to middle Late Hauterivian). In addition the overlying Taguarumo Formation (latest Hauterivian - Middle Barremian) was initially included in the Barrenquin Formation (Von Der Osten, 1957) but has subsequently been elevated to formational rank (Guillaume et al, 1972; Macsotay et al, 1985). Readers are referred to these sources, and references therein, for information concerning general stratigraphy and regional facies relationships of these formations and members.

Our field research covered only the upper Venados Member, the Morro Blanco Member, a small portion of the Picuda Member, a predominantly fluvial facies of the "upper Barranquin Formation" undifferentiated, and the upper part of the Taguaruma "Member" (now a discrete formation). Lack of sufficient exposures and a poor fossil record that would not serve our main purpose of creating a refined Cretaceous chronology gave low priority to the study of the remaining parts of the Barranquin Formation.

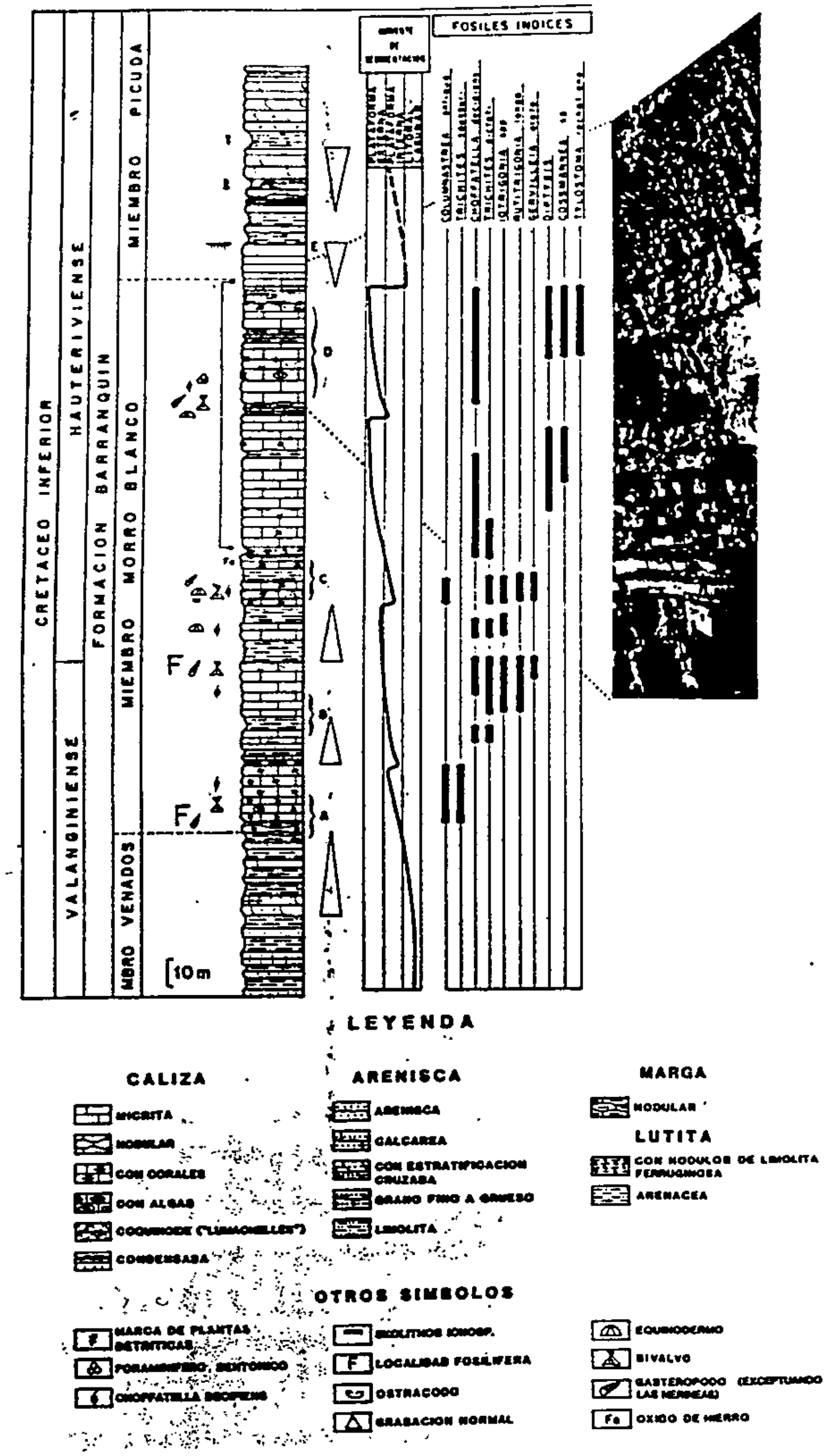


FIGURE 5 - GENERALIZED STRATIGRAPHIC SECTION OF THE UPPER VENADOS MEMBER AND THE MORO BLANCO MEMBER AT CANTERA LOS ANDES, CANTERA LA ROSA, NEAR CUMANA, NORTHEASTERN VENEZUELA (FROM VIVAS AND MACSOTAY, 1988).

VENADOS MEMBER.- This predominantly fluvial sequence of varicolored cross-bedded orthoquartzites, subconglomerates, arkosic and subarkosic sandstones, and thick-bedded mudstones averages 375 m in thickness in the study area (Macsotay et al, 1985). The unit has not previously yielded fossils other than simple traces (Planolites) which do not indicate any specific facies.

The upper 59 m of the upper Venados Member were measured and described in detail at Cantera La Rosa, and a sequence stratigraphy constructed (Fig. 6). At the base of the exposure, a brown sandy soil interval is overlain abruptly by 3.8 m of thin- to thick-bedded, argillaceous grayish-brown limestones 0.3 - 1.2 m thick, separated by thinner buff to tan marls. These strata are fossiliferous (corals, foraminifers, molluscan shell fragments) - the first marine faunas reported from the member. These are still under study, but the corals appear to be similar to those of the Middle Valanginian, lower Moro Blanco Member. This limestone comprises a first failed attempt at establishing a carbonate platform in this region; its base is a transgressive surface, and the thick (1.2 m) limestone at the top of the sequence most likely represents a maximum flooding surface. The highstand systems tract is apparently contained in a 30.7 m, predominantly covered interval overlying the limestone unit; this interval contains scattered thin brown slabby sandstone beds and both sandstone and limestone float blocks; the lack of exposure suggests that it is predominantly mudstone and soft sandstone.

Near the top of the Venados Member, a third-order (?) sequence boundary marks the base of a 13 m thick, channelized, thick bedded arkosic sandstone unit (Unit 12; Fig. 6) which represents an abrupt return to coastal fluvial conditions. This sandstone, and 5.5 m of overbank deposits (silty shales, mudstones and thin sandstones) above it, comprise the lowstand systems tract. The top of the exposed Venados Member at Cantera La Rosa consists of 6 m of sandy iron-stained mudstone with abundant siderite concretions and beds, representing partially stagnant swamp, marsh, and/or lagoon facies. This upper unit suggests initial marine invasion of the coastal plain, establishment of a paludal-lagoonal facies complex, and thus initial transgression. The initial transgressive surface is placed at the sharp base of this unit (Unit 18; Fig. 6), and the sideritic mudstone is interpreted as comprising the early transgressive systems tract. A sharp erosional surface with moderate relief cuts the top of the Venados Member (marine flooding surface: TS; Fig. 6), and is directly overlain by 0.5 m of nodular glauconitic marls (transgressive lag; Unit 19, Fig. 6) at the base of the Moro Blanco Member.

MORRO BLANCO MEMBER.- The Morro Blanco Member of the

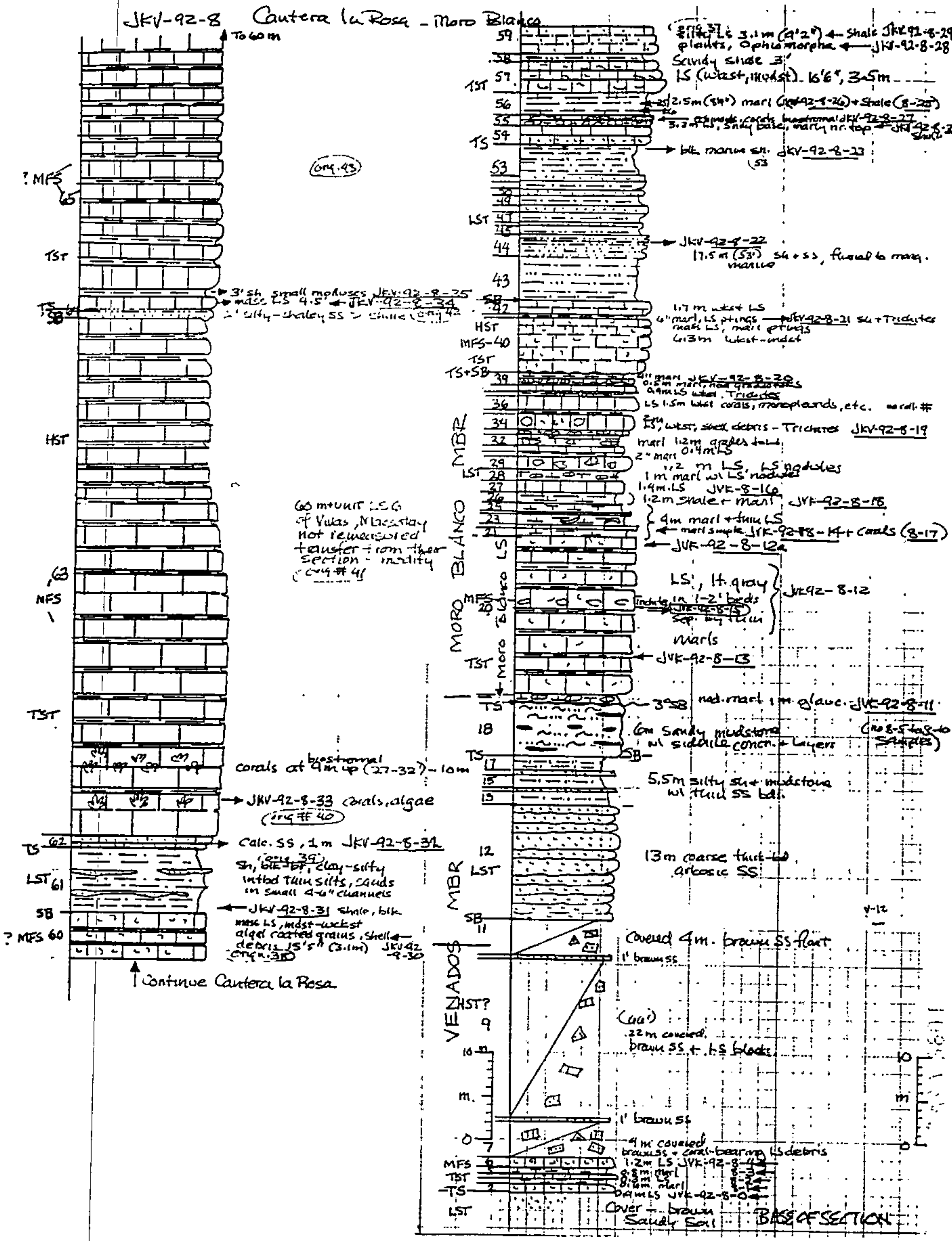


FIGURE 6 - DETAILED STRATIGRAPHIC SECTION, WITH SEQUENCE STRATIGRAPHIC INTERPRETATIONS, FOR THE UPPER VENADOS AND MORO BLANCO MEMBERS, BARRANQUIN FORMATION, AT CANTERA LA ROSA, NORTHEASTERN VENEZUELA (MEASURED BY KAUFFMAN, JOHNSON, AND VILLAMIL, 1992).

Barrenquin Formation (Rosales, 1960) is described by Macsotay et al (1985) as consisting mainly of nodular to massive limestones (75%) with intercalations of calcareous and clay shales; some of the massive carbonate units in the lower part of the member are biostromal with corals; the relative abundance of nodular chalks and limestones increases up-section. Intervals of siliciclastic fluvial facies occur at several levels within the carbonate platform sequence. The contact with the overlying Picuda Member is sharp and paraconformable, comprising a sequence boundary; the Morro Blanco and underlying Venados member are reported to have a gradational contact by these authors.

The most completely exposed section of the Morro Blanco Member in the Serrania, representing middle to inner carbonate platform deposition, occurs at Cantera La Rosa, (Fig. 6) just south of the El Naranjo-Los Borrachos Fault Zone. Vivas and Macsotay's (1988) generalized section for this member is shown in Figure 5, and the newly measured, high-resolution section from this study is shown in Figure 6, with sequence stratigraphic interpretations. Five 3rd- to 4th-order sequences can be defined in the Moro Blanco Member at Cantera La Rosa, and the member itself represents a 2nd-order maximum flooding interval above a 2nd-order sequence boundary in the upper Venados Member, and below a similar sequence boundary which cuts the top of the Moro Blanco Member.

At Cantera La Rosa, the Moro Blanco Member lies abruptly on an erosional marine flooding surface developed at the top of paludal-lagoonal facies (early TST) in the uppermost Venados Member (Unit 18, Fig. 6), and is not transitional as reported by Macsotay et al (1985). A 0.5 m thick nodular glauconitic marl bed at the base of the Moro Blanco Member comprises the transgressive lag, and is abruptly overlain by 17.5 m of planar-laminated, massive to thick-bedded, light gray, fossiliferous limestone beds separated by thin buff marls. Corals, small molluscs, algae and larger foraminifers comprise this fauna, which suggested to Wells (1944) a Valanginian age. The maximum flooding surface lies within this sequence of massive limestones, probably at the 5th bed above the base which is more massive and fossiliferous than the rest (Fig 6). A 3rd-order highstand systems tract comprises progressively thinning limestone units at the top of Unit 20, and 18-19 m of thinner bedded limstones, nodular limestones and marls, soft marls and calcareous shales which overlie it (units 21 - 39; Fig. 6). Condensed and eroded horizons become most common at the top of this highstand sequence, and it is capped by an erosional surface (3rd-order sequence boundary) at the top, below an 8 m thick series of massive to thick-bedded fossiliferous limestones with very thin marl partings (Units 40-42; Fig. 6). These massive carbonates comprise a late TST, maximum flooding (near the middle of Unit 40) and early HST complex of systems tracts, and are abruptly overlain at a 3rd-order boundary by a 17.5 m thick fluvial lowstand systems tract of variegated overbank shales, mudstones, and thin tan to brown channel sandstones (Units 43-53; Fig. 6).

A very similar 3rd to 4th-order sequence overlies the previous one in the middle Moro Blanco Member. Sandy glauconitic limestones (transgressive lag; Unit 54, Fig. 6) are overlain by biostromal coral-algal structures in marly limestones and nodular marls (condensed sedimentation; Units 55,56; Fig. 6) during early transgression (TST). A series of massive fossiliferous limestones, some of them silty, separated by thinner marl units (Units 57-60; Fig. 6) represent parasequences formed during late transgression and maximum flooding. An erosional 3rd-order sequence boundary cuts these limestones, and is overlain by a 7.5 m thick succession of small meandering channel sandstones interbedded with silty and sandy overbank mudstones (Unit 61; Fig. 6).

Two 50 - 60 m thick massive limestone units, separated by a thin silty sandstone (Unit 64, Fig. 6), comprise the final two 3rd-4th-order sequences of the upper Morro Blanco Member. The lowest of these massive limestones, 58.5 m thick, overlies a 1.5 m thick calcareous sandstone (Unit 62; transgressive lag) on top of a sharp marine flooding surface across lowstand fluvial facies. The thick limestone unit contains coral-algal biostromes and small mounds in the lower 10 m, suggesting mid-platform depths. A maximum flooding interval probably lies within the lower, more massive 25 m of Unit 63 limestones (Fig. 6). Upward thinning of limestone beds, and thickening of intercalated marls, suggest early highstand deposition on the inner platform. The sequence boundary that cuts these limestones is sharp but planar, and is overlain by 0.7 m of silty and shaley sandstone of fluvial to marginal marine origin (Unit 64; Fig. 6). This sandstone is truncated by another marine flooding surface at the base of Unit 65, overlain by another 60 m thick sequence of massive limestones representing TST, MFS, and early HST as in the underlying sequence.

Facies analysis suggests that the entire Morro Blanco Member represents middle and inner carbonate platform facies, cut by fluvial systems during lowstand deposition. No shelf margin or slope facies were recognized. The top of the Morro Blanco Member is cut by a 2nd-order, paraconformable to broadly erosional sequence boundary overlain by upper shoreface and foreshore sandstones and orthoquartzites of the basal Picuda Member.

PICUDA MEMBER.- Macsotay et al (1985) described the Picuda Member as up to 425 m of orthoquartzites and subarkoses in units up to 10's of m thick, intercalated with micaceous mudstones and siltstones with poorly developed stratification, and containing a few sandy rhythmites. Planar cross-stratification is the dominant sedimentary structure. The basal 10 - 50 m contain surfaces which have been intensly burrowed by Skolithos; a prominent Skolithos horizon near the base of the member can be regionally traced and correlated. The upper contact with the Taguarumo Formation is transitional; the basal contact with the Morro Blanco Member is sharp to erosional, and comprises a possible second-order sequence boundary. The Middle to middle Late Hauterivian age range of the member is determined by its stratigraphic position between well dated units; no body fossils have been found in the Picuda Member.

At Cantera La Rosa, an outcrop of the lower Picuda Member was examined: thick- bedded, relatively pure quartz sandstones and orthoquartzites up to a meter thick are separated in some cases by very thin sandy claystone beds. Several horizons are densely burrowed by vertical Skolithos tubes up to 0.75 m deep. Infilling of the burrows with a finer sand than the matrix suggests periods of sediment bypass at the top of the burrowed sandstone cycles, as does the density of the burrows themselves. These are interpreted as middle to inner shoreface and lower foreshore facies with storm-dominated deposition.

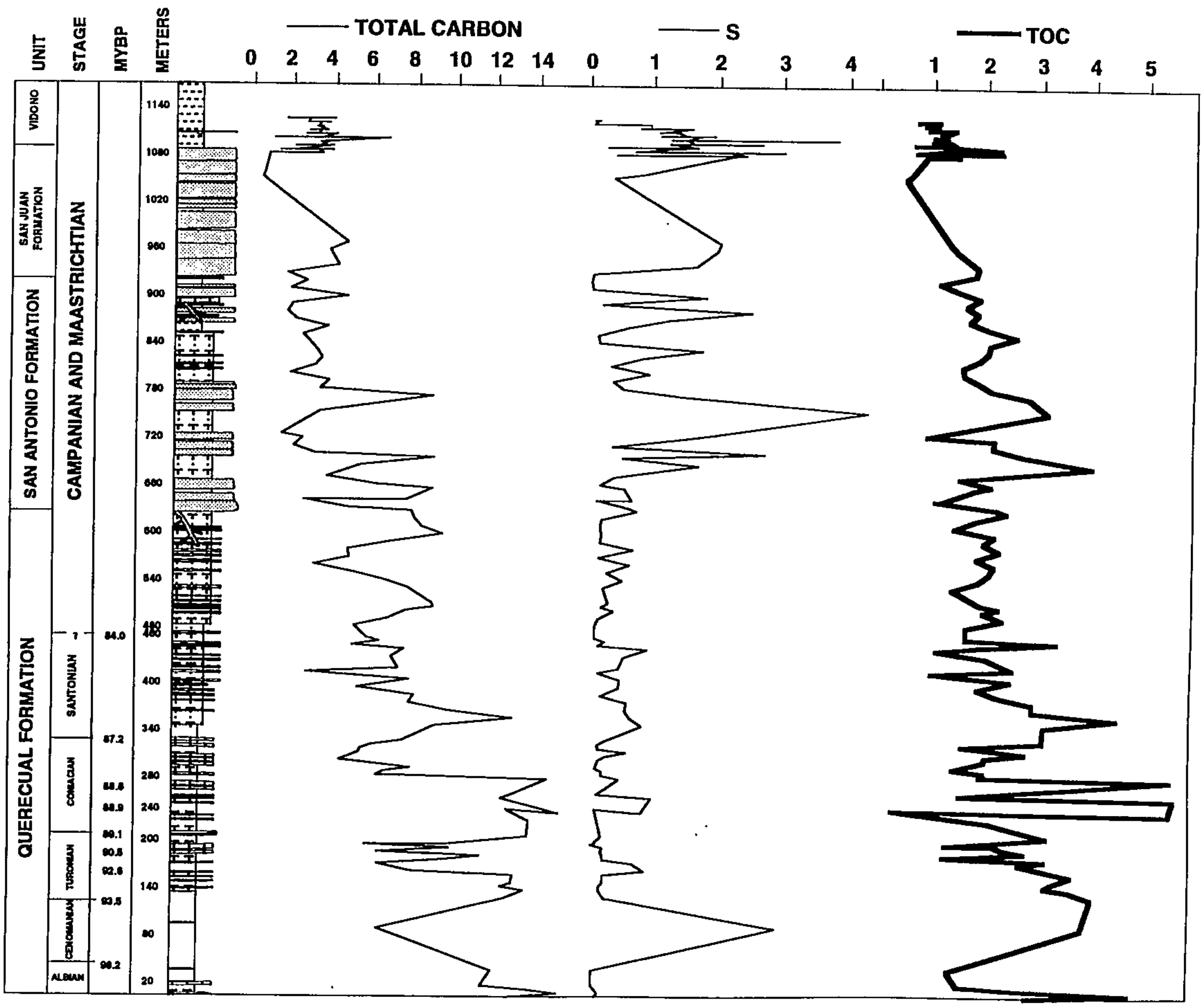
DAY 2; RIO QUERECUAL SECTION

QUERECUAL FORMATION

The Late Albian - Campanian Querecual Formation (Hedberg, 1937) has been generally described (e.g. Macsotay et al, 1985) as a monotonous sequence of dark gray to black, rhythmically bedded, organic-rich calcareous shales and argillaceous limestones, and siliceous shales (increasing upward), containing numerous horizons of ovate to discoidal concretions. In general the Formation has been interpreted as representing maximum flooding of Cretaceous seas across the northeast Venezuelan passive margin. The latest Albian (Vraconian) through Late Coniacian age of the Querecual Formation proposed by various authors (in Macsotay et al, 1985) has been modified by this study which found Santonian Inoceramidae (Bivalvia) 330 m above the base of the formation at the Rio Querecual section, and Late Santonian - Early Campanian inoceramids in the upper, more siliceous Querecual at the Rio Aragua section. Macsotay gives an average thickness of 650 m for the formation. The Rio Querecual section, measured in high-resolution stratigraphic detail, is 636 m thick (assuming no significant bedding faults) and lacks much of the basal, Late Albian part of the section (covered and faulted out).

The Rio Querecual section (Fig 14), which spans the lower Querecual (Late Albian) through lower Vidono formations (late Maastrichtian), has yielded the greatest amount of high-resolution stratigraphic data, to date, for our northeastern Venezuela project. This and all following lithologic analyses draw heavily from this section. Attempts to replicate these data in the Rio Aragua section (Fig. 15) were hindered by many structural complications - tight folds and faults which extensively cut the Querecual and San Antonio formations and prohibited accurate stratigraphic measurement and complete section descriptions to be made.

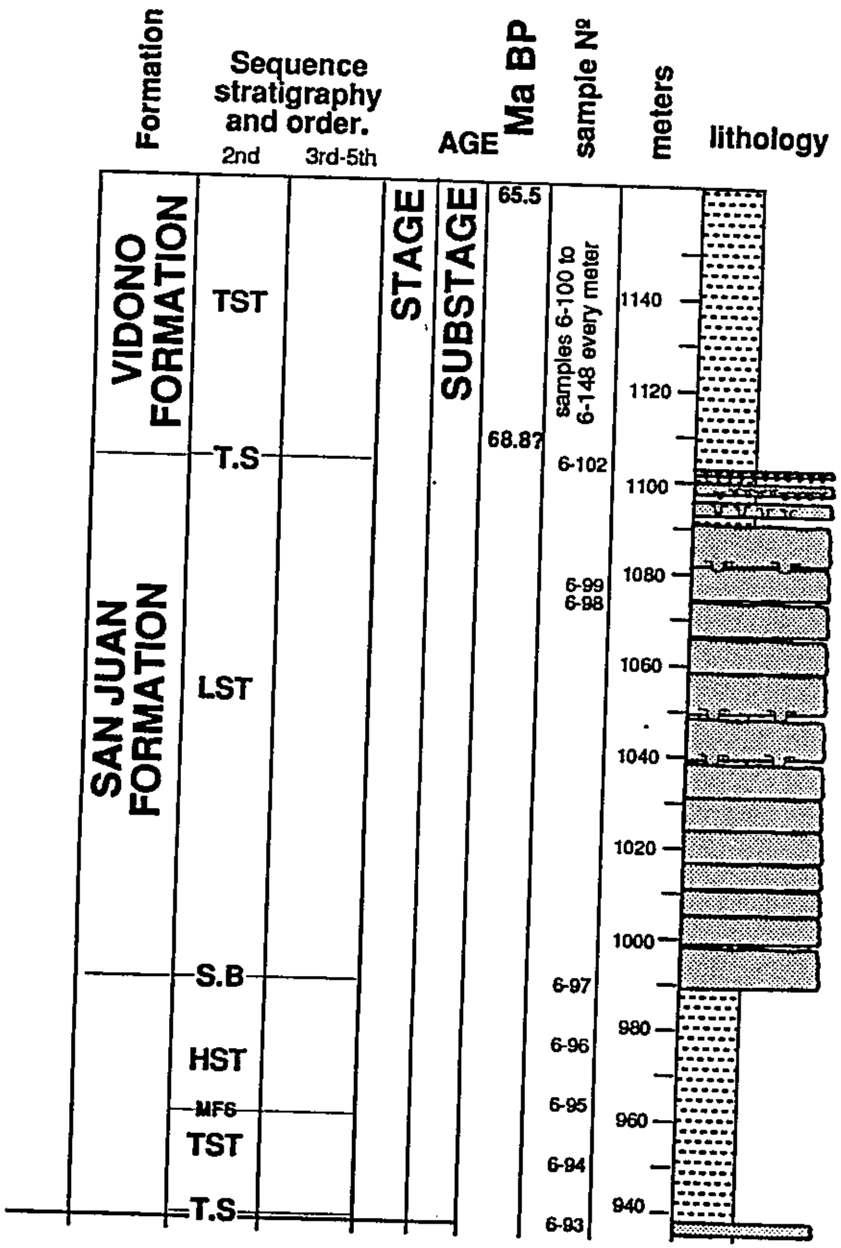
On the Rio Querecual, the 636 m section of Querecual Formation is far from lithologically uniform, as previously supposed. Although the Querecual represents one major first or extended second-order sequence, with maximum flooding in the highly condensed Turonian - Coniacian stage boundary interval (basalmost Coniacian), lithologic variations within the Querecual Formation allow definition of nine second and



UNIT
STAGE
MYBP
METERS
TOTAL CARBON
0 2 4 6 8 10 12 14
S
0 1 2 3 4
TOC
1 2 3 4 5
VIDONO
SAN JUAN FORMATION
SAN ANTONIO FORMATION
QUERECUAL FORMATION
CAMPANIAN AND MAASTRICHTIAN
SANTONIAN
CONIACIAN
TURONIAN
CENOMANIAN
ALBIAN
84.0
87.2
88.8
88.9
89.1
90.5
92.6
93.5
98.2
1140
1080
1020
960
900
840
780
720
660
600
540
480
460
400
340
280
240
200
140
80
20

FIGURE 14a

RIO QUERECUAL SECTION MEASURED BY THE UNIVERSITY OF COLORADO BASIN ANALYSIS RESEARCH GROUP



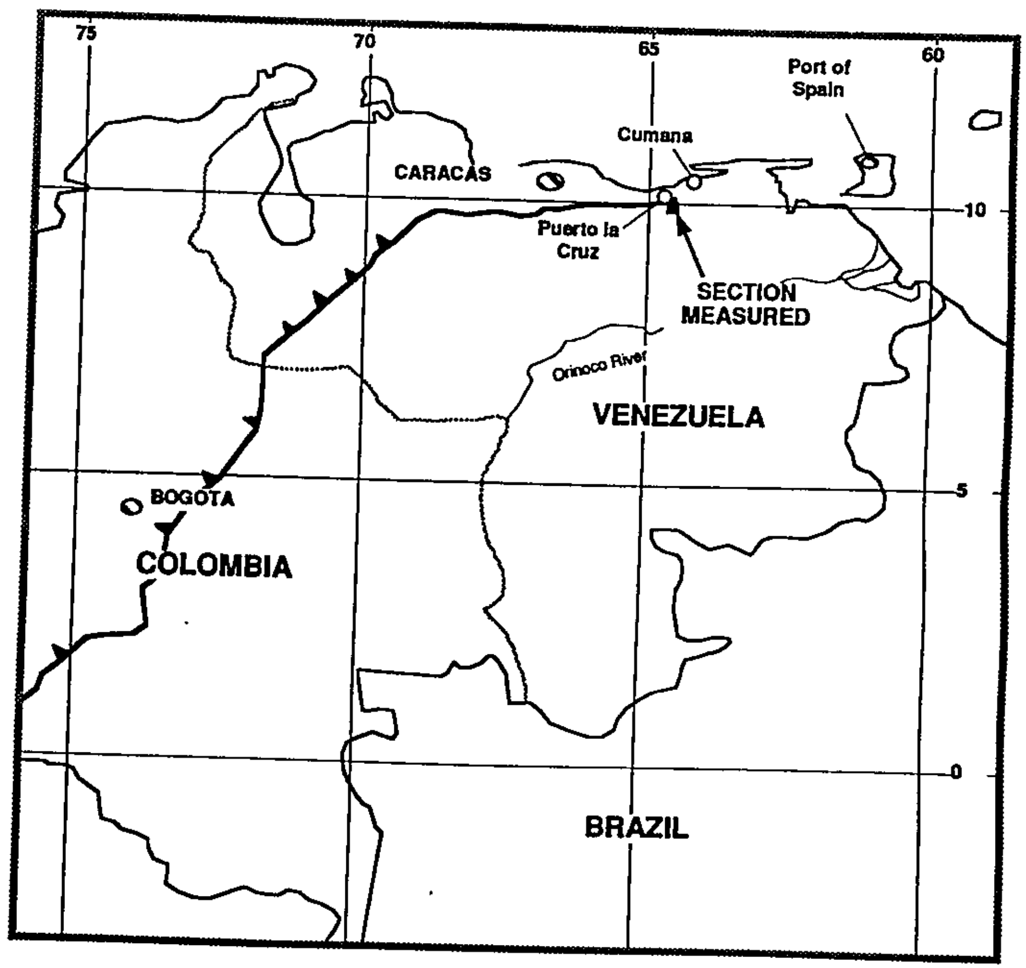
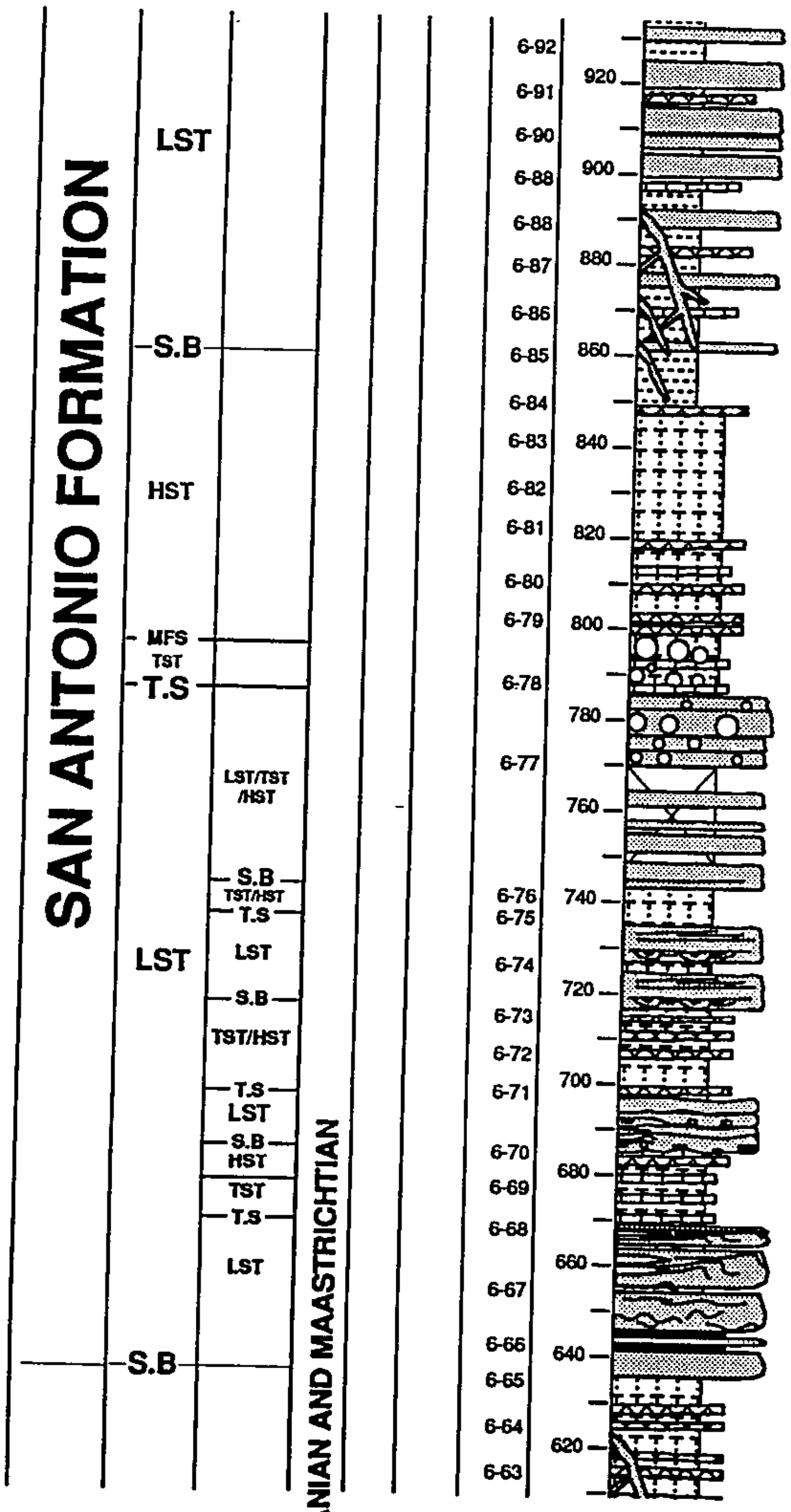
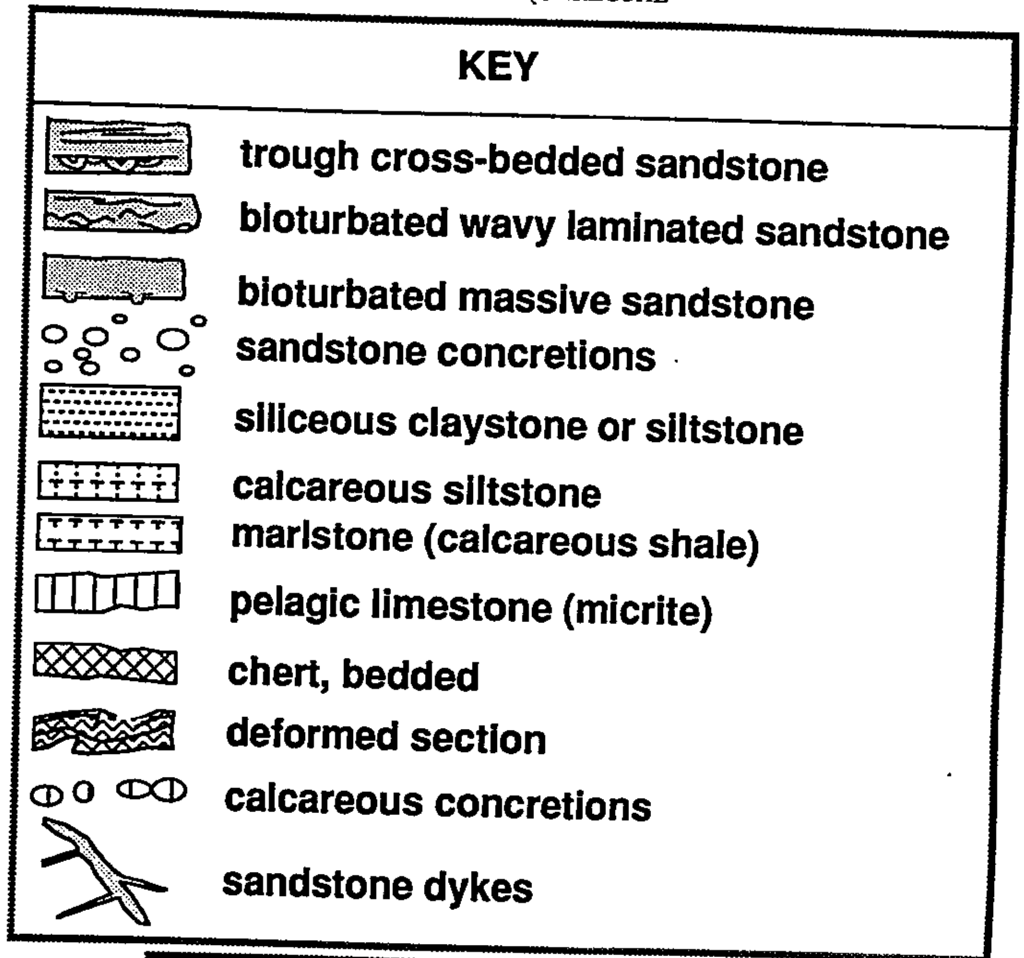


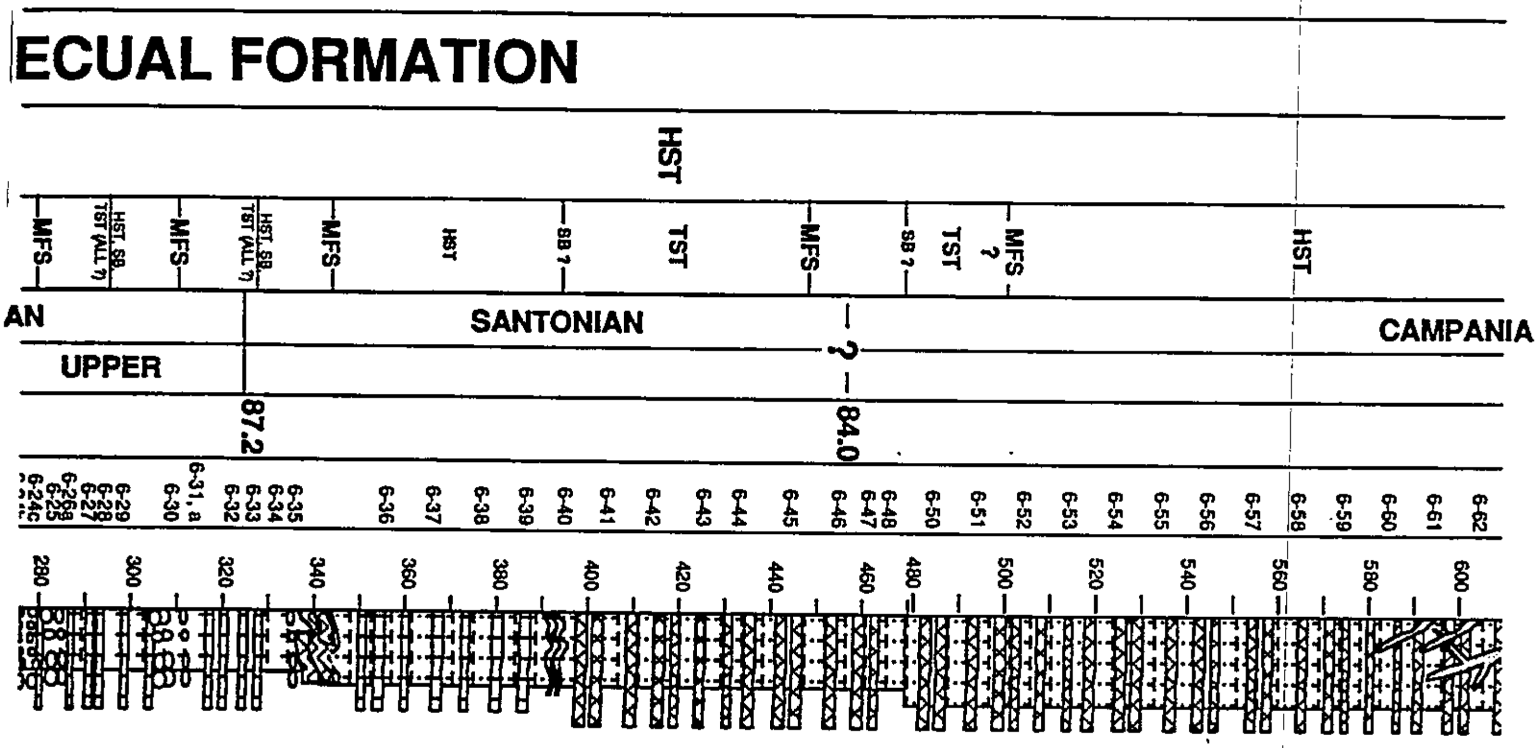
FIGURE 14b: RIO QUERECUAL





Ma B. P.	Thickness, m.
98.2-93.5	80
93.5-92.6	40
92.6-90.5	20
90.5-89.1	25
89.1-88.8	60
88.8-87.2	60
87.2-84	130 ?
84-68.8	1110 ?
68.8-65.5	60 ?

Kauffman, Johnson, and Villamil, 1992.



Sergipia sp. 2 (cf Col.)
oniceras sp. nov. (early stage of genus)
Gautherlceras sp. cf. G. bajuvaricum
Gauthericeras bajuvaricum
Subprionotropis sp.
Forresteria sp.
Hauericeras sp. aff. H. gardeni
Fish scales >>
Platyceramus sp. aff. P. platinus

. aff. M. incertus
). 2

jealatus (fine ribs)
s guayabanum
.) sp. aff. B. onilahyense
cobi
tus
mbophora sp.

leversi

FIGURE 14c: RIO QUERECUAL
KAUFFMAN, JOHNSON, AND VILLAMIL 1992

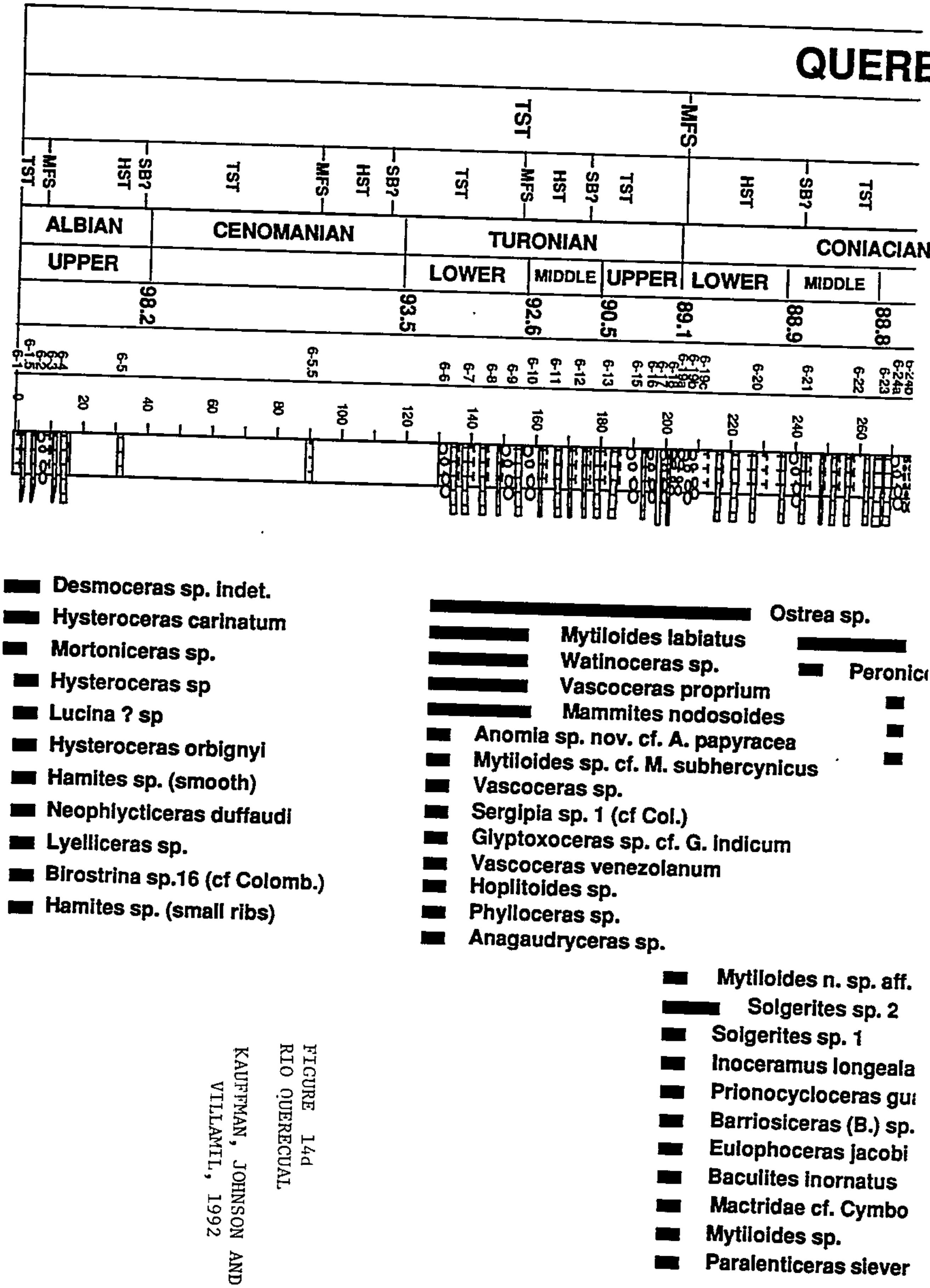


FIGURE 14d
RIO QUERECUAL
KAUFFMAN, JOHNSON AND VILLAMIL, 1992

third-order sequences, utilizing new models for sequence stratigraphy developed by Kauffman and Cole (in manuscript) and Kauffman and Sageman (1992, in press) for the Western Interior Cretaceous sequence of North America. Further, a rich fossil record of ammonites and inoceramid bivalves in the Albian - Santonian part of the section allows close biostratigraphic correlation to Colombia and the Western Interior Basin of North America, and from this designation of the position of stage and substage boundaries as well as integration of radiometric dates from the Western Interior at key levels. This, in turn, allows close comparisons of the sealevel history between these three areas, and analysis of the effects of eustasy vs. tectonics in regulating the sequence stratigraphy of northeastern Venezuela (subsequently discussed).

The basalmost undeformed Querecual Formation in the Rio Querecual section (JKV-92-6; Fig. 14) represents a condensed sequence of concretions and calcareous shales (Samples 6-1 - 6-4; Fig. 14) characteristic of maximum flooding in basinal facies. A covered interval extending from the latest Albian through the basal Turonian omits the record of the subsequent sequence boundary, and of the great Late Cenomanian global transgression. Cyclically interbedded argillacous, organic rich pelagic limestone and calcareous shale facies comprise the next major TST, which reaches maximum flooding in the late Early Turonian (the most extensive Cretaceous global eustatic highstand). The maximum flooding surface is characterized by a condensed horizon with numerous fossiliferous concretions (Sample 6-9, 6-10; Fig. 14). HST deposits are similar to those of TST; silty and sandy carbonate beds in the late Middle Turonian (between samples 6-12 and 6-13; Fig. 14) possibly represent the position of another 2nd- or 3rd-order sequence boundary with global expression. A transgressive systems tract characterized by interbedded pelagic limestones, calcareous shales, and scattered concretion levels (partially condensed) culminates in a maximum 1st, 2nd, and 3rd-order flooding in the basal Coniacian; this MFS is marked by a highly condensed sequence of fossiliferous concretions (samples 6-19a-c: Fig. 14). Increasing amounts of calcareous shale and diminishing limestone content mark the ensuing HST, which may be terminated by a conformable sequence boundary in the vicinity of sample 6-21.

Middle and Late Coniacian transgression (TST) is marked, as before, by increasing percentages of pelagic limestone and diminishing percentages of calcareous shale, suggesting deepening and some condensation, with two maximum flooding surfaces, separated by about 20 m of interbedded shale and limestone, marked in the middle and late Late Coniacian, respectively, by condensed horizons with closely spaced fossiliferous concretions (Samples 6-25 and 6-30, respectively). A return to interbedded limestone and shale, and eventually to mostly shale in the Coniacian-Santonian boundary interval characterizes 3rd-order HST, with a sequence boundary projected for the abrupt limestone to shale contact (base of Sample 6-34; Fig. 14). Subsequent Early Santonian maximum flooding is marked by a highly condensed, pyrite and carbon-rich interval (Sample 6-35 and above; Fig 14), overlain by cyclically bedded pelagic limestones and calcareous shales during highstand (HST), and an erosional Middle Santonian sequence boundary (Sample 6-40). This sequence boundary marks a major shift in sedimentation within the upper Querecual Formation from predominantly limestone-shale bedding cycles (probably Milankovitch climate cycle deposits: see Fischer et al, 1985), to equivalent size or thinner cycles of chert/shaley chert and shale bedding cycles, announcing the onset of San Antonio style sedimentation and increased nutrient upwelling across the northeastern Venezuela passive margin.

In the upper Querecual Formation, a Late Santonian transgression (TST) is marked basinally by decreasing silt and chert content, and increasing calcareous content in the shale facies (Samples 6-40 to 6-45: Fig. 14), with the maximum flooding tentatively placed in the middle of the carbonate-rich cherty shale interval (at and below sample 6-46). Subsequent highstand is marked by chert-shaley chert bedding cycles without significant carbonate, and a sequence boundary picked at the base of a 2 m sandstone-sandy shale interval (480 m; Fig 14). A final third-order Querecual transgression (TST) is marked by another increase in pelagic carbonate content in the Early Campanian, culminating at maximum flooding (Sample 6-52; Fig. 14) in a condensed sequence of cherts interbedded with highly calcareous shales. The upper 135 m of the Querecual is characterized by alternating cherts and siliceous shales, which become increasing silty and sandy upward, describing highstand conditions.

The Querecual - San Antonio formation contact is sharp and marks a major 2nd-order sequence boundary of probable Late Campanian age (Sample 6-65 and above). The boundary is marked by the top of a zone of deeply penetrating sandstone dikes, and the base of a 35 m lowstand sequence of medium-to coarse-grained turbiditic sandstones with mass flow deformation structures.

The Querecual Formation thus shows enough lithologic differentiation to allow detailed sequence stratigraphy down to at least 4th-order of resolution. TST's are commonly characterized by increasing pelagic carbonate content and condensation, associated with diminishing relative shale and/or chert content. Condensed sequences marking maximum flooding have the highest relative carbonate content and are commonly associated with closely spaced, fossiliferous concretion levels. Highstand systems tracts are marked by increasing silt, sand, and/or clay content associated with diminishing carbonate. Sequence boundaries may be conformable or slightly erosional, condensed, and commonly have an abruptly appearing increase in sand and silt content of the shales. These interpretations are compatible with basinal sequence stratigraphic models in Cretaceous rocks of North America and Europe. The commonly held view that chert deposition represents the deepest water conditions is rejected; chert content actually diminshes near maximum flooding surfaces/intervals. Chert deposition in the Querecual and overlying San Antonio Formations is probably most strongly dependent on paleobathymetric and oceanographic conditions that promote slope to platform upwelling of nutrients.

SAN ANTONIO FORMATION

The San Antonio Formation (Hedberg, 1937) as summarized in Macsotay et al (1985), is characterized by thick sandstone layers (many of them mass flow deposits) intercalated with thinner sandy and silty black shales at the base of the section; sandstone beds diminish in size, and shales become more prominent, more siliceous and more calcareous upsection, where they are cyclically bedded in a manner similar to that of the upper Querecual Formation. The type section is in the Rio Querecual, where it was re-measured during the course of this study. The base and top of the San Antonio Formation are 2nd-order sequence boundaries marked by an abrupt erosional contact between massive sandstone beds above (basal San Antonio sandstones, basal San Juan sandstones), and thin, cyclically bedded shales and cherts below (Fig. 14).

The San Antonio Formation was documented in detail only at the type section during this study, where it is measured as 355 m thick; faulting may have modified its true thickness in several places. In the Rio Querecual the San Antonio Formation contains four major lithologic divisions: (a) a lower 150-m-thick sequence of dominantly thick-bedded sandstones showing mass flow characteristics near the base, and more even bedding upward, interbedded with thinner units of silty clay and calcareous clay shales (Fig. 14: m 635 - m 785); (b) a 105-m-thick sequence of predominantly shale, more calcareous at the base, and more siliceous and cherty at the top, interbedded with thin chert and (upward) brown sandstone beds (Fig. 14; m 785 - m 890); (c) an upper 45 m interval characterized by relatively thick, flat bedded brown sandstones (probably slope flow events) with secondary amounts of clay and silty clay shale, and rare chert beds; (d) and an upper clay shale unit, without significant sand or silt except near the top, where it is truncated by the first massive sandstones of the San Juan Formation (sequence boundary).

Two second-order sequences characterize the San Antonio and relate to these four facies suites. The lower 150 m sandstone sequence represents lowstand deposition at the base of the platform slope, mainly through mass flow, during a major drop in sealevel. This is condensed upward, with increasing numbers of concretionary layers, possibly announcing early transgression. A major marine flooding surface at m 785 (Fig. 14) is characterized by abrupt truncation of sandstone deposition and development of a condensed sequence of pelagic limestones and concretions in calcareous shale (m 785 -m 798), representing a shortened TST and maximum flooding surface/interval (MFS). Above this, the shale sequence becomes less calcareous and more siliceous, marking the highstand systems tract (HST) up to meter 860 (Fig. 14), where another sequence boundary is marked by a level of sandstone dikes and the base of the first thick, massive sandstone slope deposit (m-862; Fig.14). The interval between meter 862 and meter 938 (Fig. 14) is characterized by an upward thickening sequence of massive to thick-bedded sandstones, mostly slope flow deposits, marking the lowstand systems tract. The uppermost shale interval (m 938 to m 990; Fig. 14) of clay shale represents a final TST and maximum flooding just below the point it begins to get silty and sandy upward (m 960), above which it represents early HST.

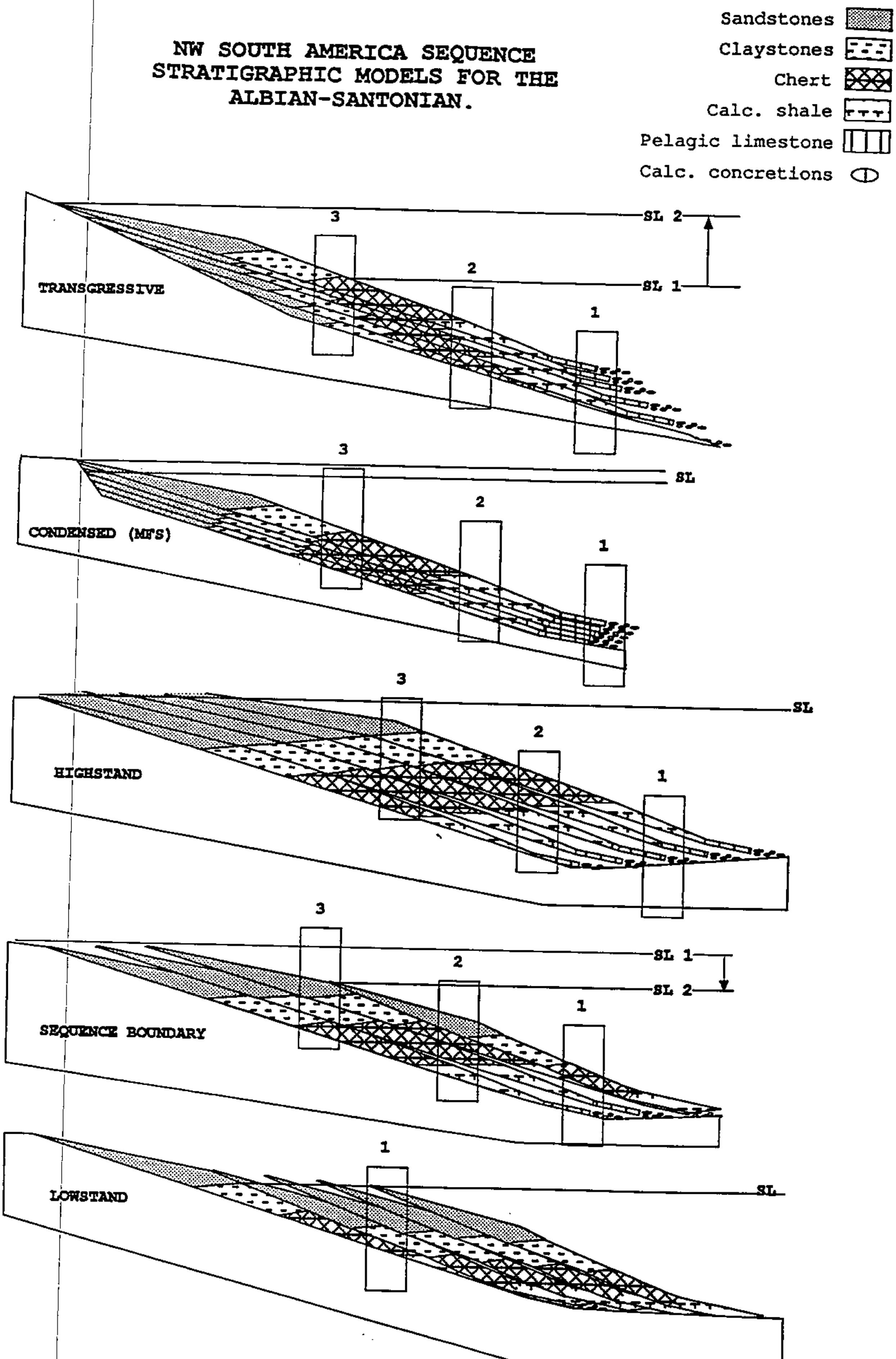
The 2nd-order sequence boundary at the San Antonio-San Juan contact is sharp, paraconformable to broadly scoured, and marks an abrupt change from basinal clay shales of the San Antonio, to massive shoreface? or upper slope sandstones of 2the San Juan Formation. Macrofossils are so rare in the San Antonio Formation that no revision of its age is now possible; ongoing micropaleontological analyses, especially among radiolarians, will help to resolve this in the near future.

SAN JUAN FORMATION

The San Juan Formation (Hedberg, 1937), as summarized by Macsotay et al (1985), consists of a thick sequence of massive to thick-bedded orthoquartzites and relatively pure quartz sandstones with very thin sandy clay intercalations. Sedimentary structures other than weakly defined trough beds and rare trace fossils, are not well developed. Individual sandstone beds are <1 m to 3 m thick and generally flat bedded. Thinner sandstone beds incalated with carbonaceous shales and sandy mudstones characterize the upper 8 - 10 m of the formation.

The San Juan Formation represents, except at the very top, a stacked lowstand sequence of shoreface or upper slope sandstones. At the top, thinner bedding, and greater amounts of shale and plant material, may reflect onset of coastal transgression, and thus early TST. But the top of the San

NW SOUTH AMERICA SEQUENCE STRATIGRAPHIC MODELS FOR THE ALBIAN-SANTONIAN.



Juan Formation displays a well defined, bioturbated marine flooding surface (TS) overlain by rapidly deepening shales of the Vidono Formation (Fig. 14) . The San Juan Formation was not studied in detail during the course of this research.

VIDONO FORMATION

The Vidono Formation (Hedberg and Pyre, 1944) represents rapid flooding and deepening of the platform following San Juan sealevel lowstand, and consists in the basal 50 m of thin-bedded calcareous and clay shale with a few thin bioturbated sandstone beds near the base. The entire measured sequence (Fig. 14) comprises a transgressive systems tract which becomes progressively more calcareous and finer-grained up-section. The shales to 50 m above the base contain a very rich and well preserved Late Maastrichtian foraminifer fauna. The Cretaceous-Tertiary boundary must lie close to the top of our measured section along the Rio Querecual.

Macsotay et al (1985) note that the thickness of the Vidono Formation is variable in the study area, reaching 300 m and crossing the Cretaceous-Tertiary boundary, as indicated by microfaunas. The upper Vidono Formation was not well exposed along the Rio Querecual, and therefore not studied in detail.

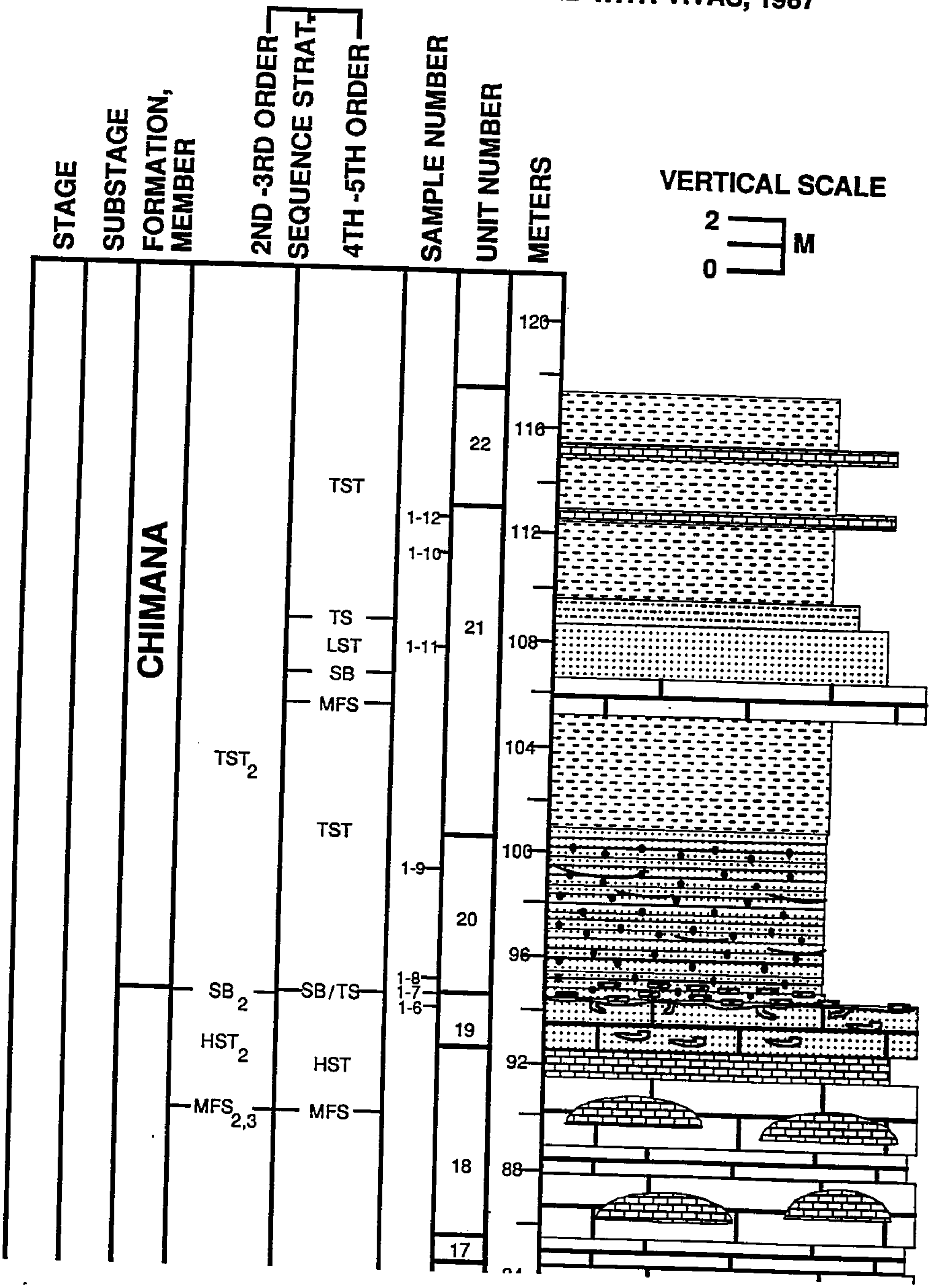
DAY 3; ISLA BORRACHA SECTION

BORRACHA FORMATION

North of the El Naranjo-Los Borrachos fault zone, on the offshore islands of northeastern Venezuela, the massive limestone unit that lies between the Garcia and Chimana formations is called the Borracha Formation (Macsotay et al, 1985), subsequently studied and measured in detail by Vivas (1987). Macsotay et al (1985) note that the Borracha is temporally equivalent to, and at the top younger than the El Cantil Formation south of the fault zone. The top may be equivalent to the Guacharo Limestone Member of the Chimana Formation in the Serrania.

FIGURE 13a

EL CANTIL AND LOWER CHIMANA FORMATIONS, ISLA BORRACHA, JKV-92-1, ANNOTATED WITH VIVAS, 1987



Kauffman, Johnson & Villamil 1992

FIGURE 13b : ISLA BORRACHA

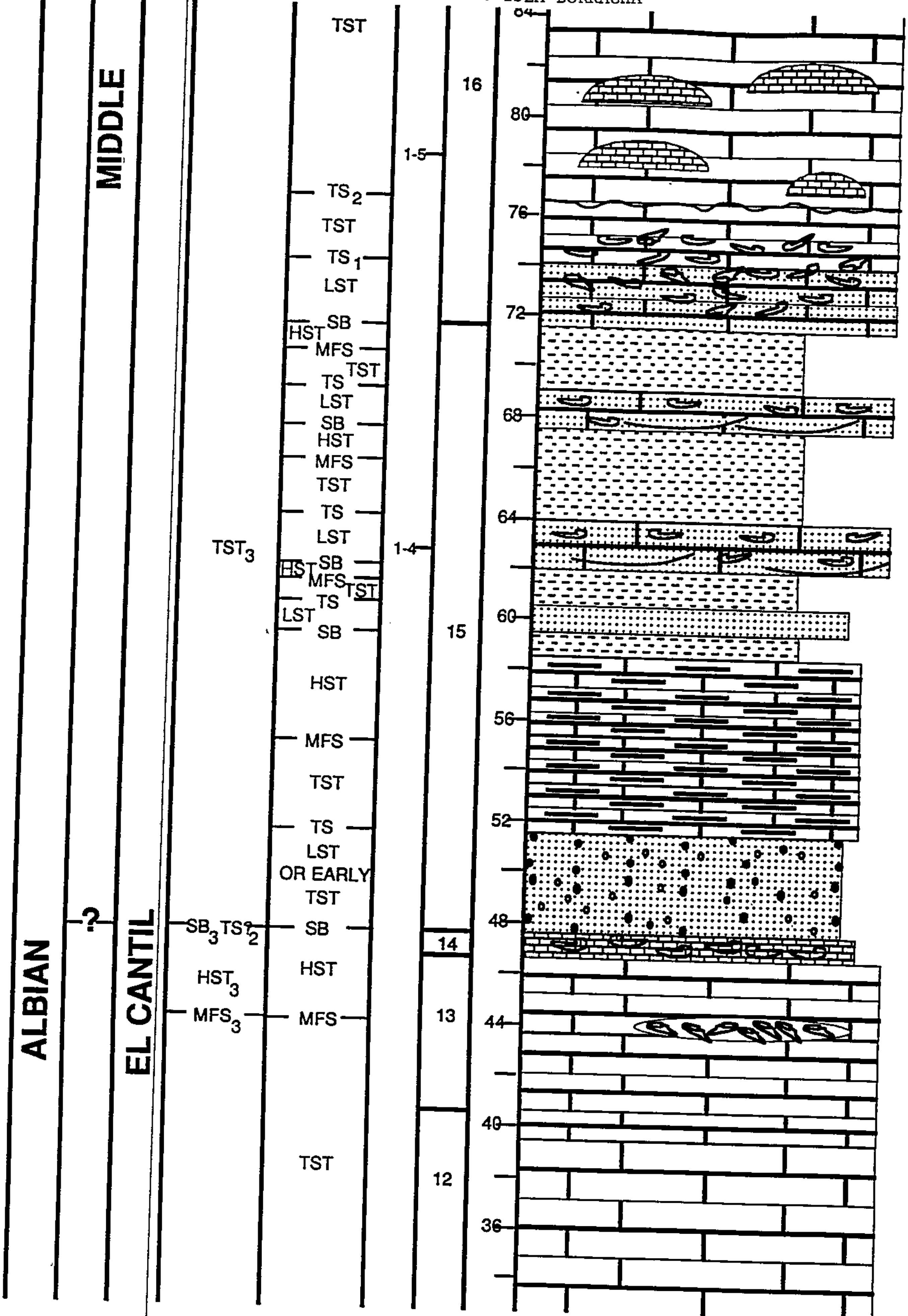
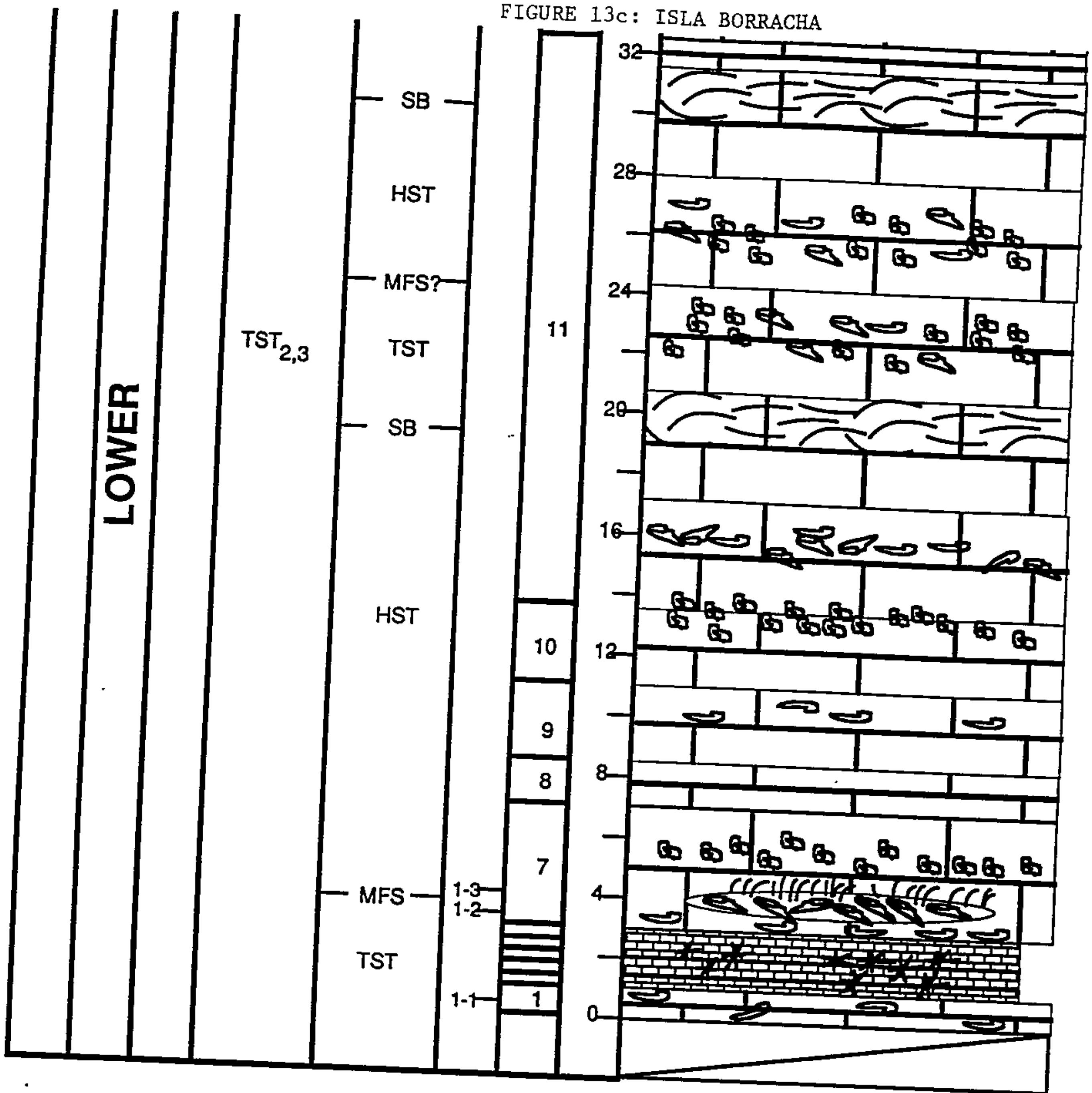


FIGURE 13c: ISLA BORRACHA



Key to Lithologies and Weathering Profiles

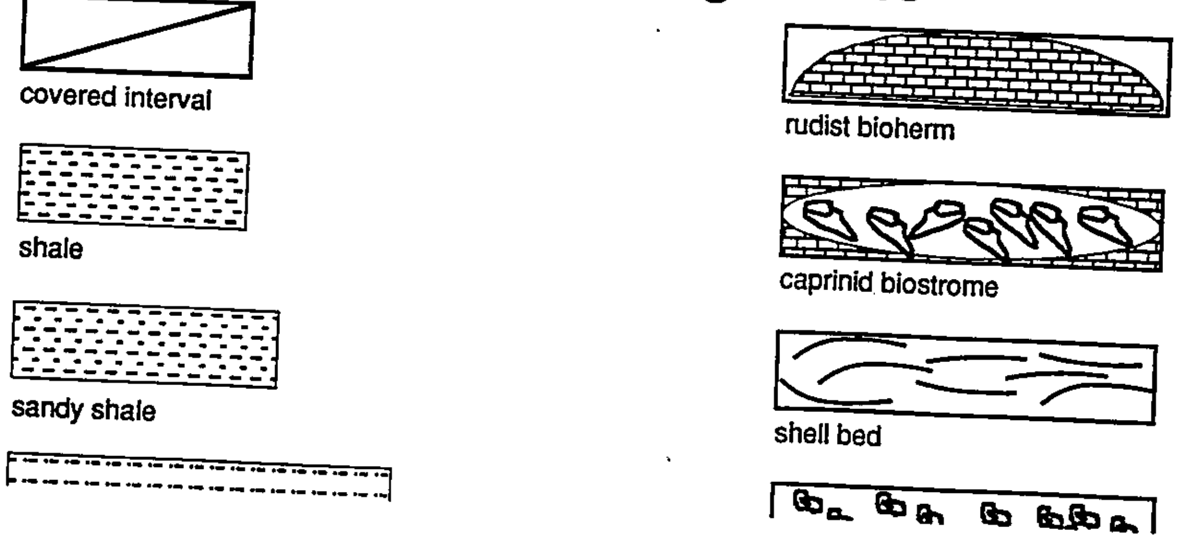


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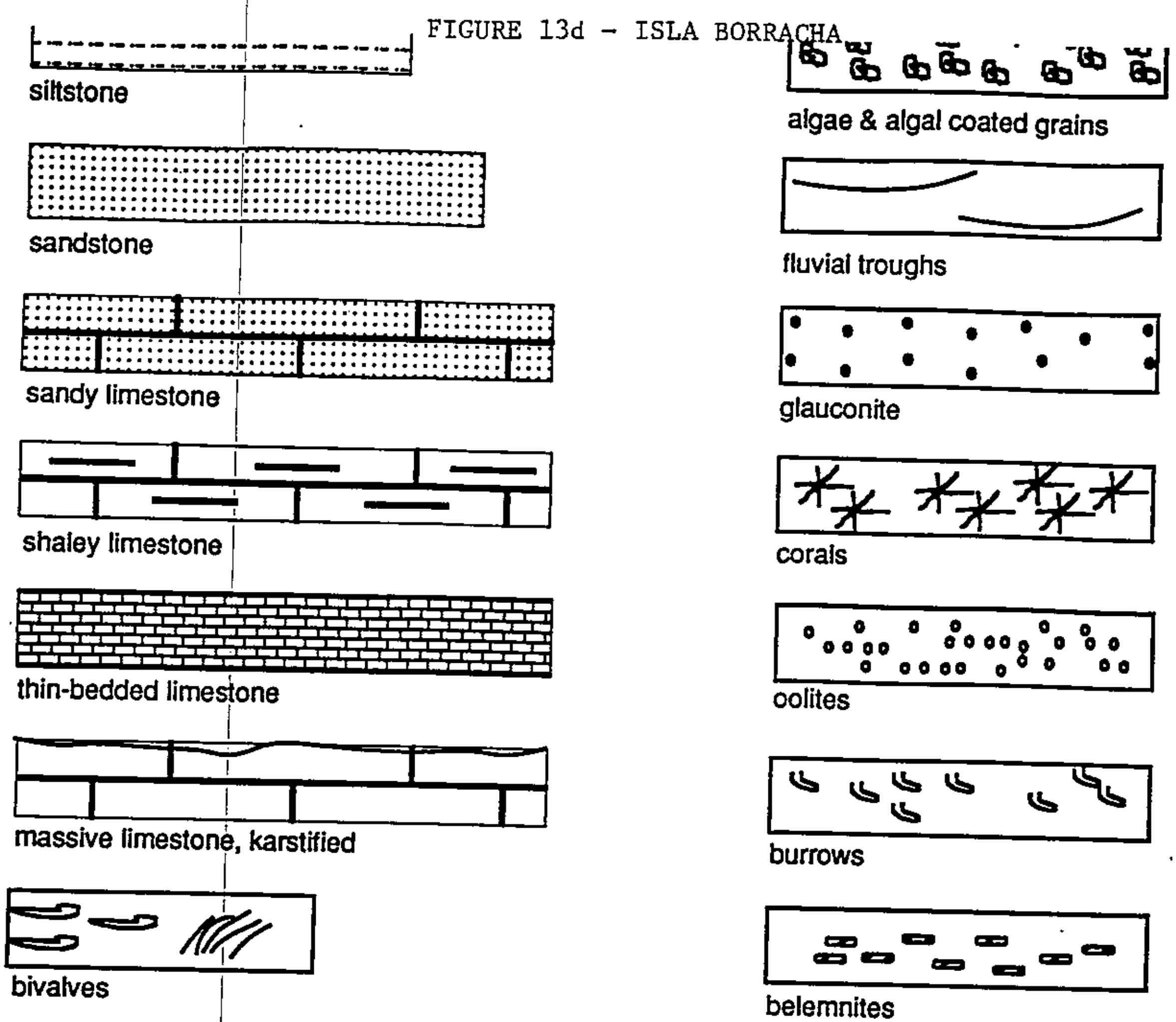
FIGURE 13d - ISLA BORRACHA



Kauffman, Johnson, and Villamil
1992

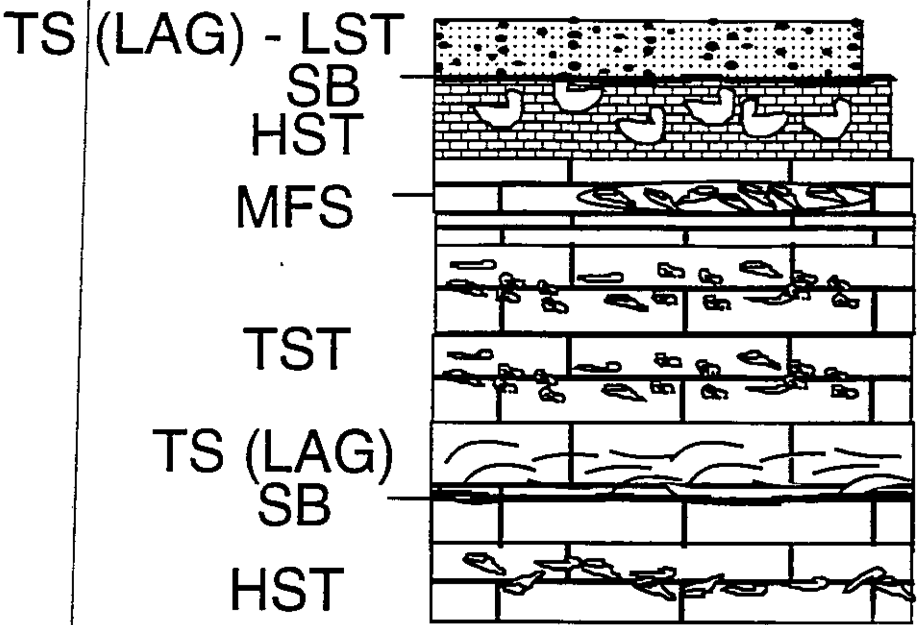
The biostratigraphic evidence for these age relationships has been re-examined by the authors and found to be questionable, and largely based on rudistid bivalves near the tops of these limestones whose ranges are now known to be largely coeval. Because of the possible age equivalency of these limestones throughout northeastern Venezuela (middle? and Late Aptian through Early Albian), and their basic lithologic similarity, including the expression of third-order sequences, we believe that all of these units should be included in the El Cantil Formation.

The upper 93 m of the Borracha Formation (upper El Cantil) was studied on Isla Borracha, north of the fault zone, where it is capped by a 2nd-order sequence boundary (Borracha - Chimana formation contact), and internally contains at least one 3rd-order sequence and numerous 4th and 5th-order parasequences, as shown in Figure 13. Upper El Cantil facies in this area extend from shallow subtidal to platform margin depositional settings.

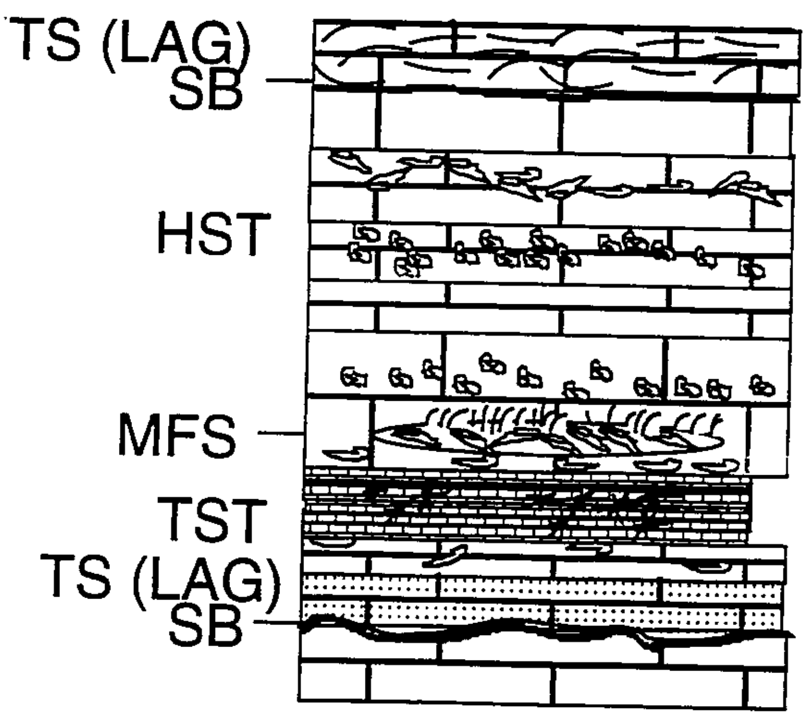
At Isla Borracha, the middle Borracha (El Cantil) Formation exposed on the ridge crest represents late 4th-order TST and maximum flooding in the lower 4 meters. These are thin to thick-bedded limestones with, upsection, delicate coral thickets and small requieniid and caprinid rudistid biostromes and thickets (Units 1-7; Fig. 13). Above this, the next 43 m of section contains a series of cyclically bedded, thick-bedded light to medium gray, fine-grained limestones representing inner and middle shelf facies, and a 2nd- and 3rd-order transgressive systems tract. Maximum third-order flooding is at the development of caprinid rudist frameworks (Unit 13), possibly representing platform edge environments, 3 m below the top of the limestone sequence which spans Units 7-13 (Fig. 13). This interval contains many 4th-order parasequences (Fig. 13) represented by repetitive cycles of bivalve shell debris (base of cycle; SB), micritic limestone with algal-coated grains, and biostromes of requieniid and scattered caprinid rudistids (TST and MFS), overlain during HST by limestone with algal coated grains and scattered small requieniid rudistids. These 4th-order cycles are superimposed over a finer scale of cycles represented by the 1 - 2.5 m thin marl - thick limestone bedding couplets, pssibly representing a 5th order (100 Ka) Milankovitch climate cycle. The 2nd and 3rd-order HST lies at the top of unit 13 and in Unit 14 and shows a return to inner shelf conditions, thin-shelled requieniid rudist biostromes, and more marly facies. A 3rd-order erosional to paraconformable sequence boundary caps this limestone (top of Unit 14), and is overlain by 4 m of glauconitic calcareous sandstone - an amalgamated lowstand systems tract and transgressive lag (Unit 15, base; Fig. 13).

DEPOSITIONAL CARBONATE SEQUENCE MODELS FOR THE MIDDLE AND UPPER BORRACHA FORMATION, ISLA BORRACHA, NE VENEZUELA

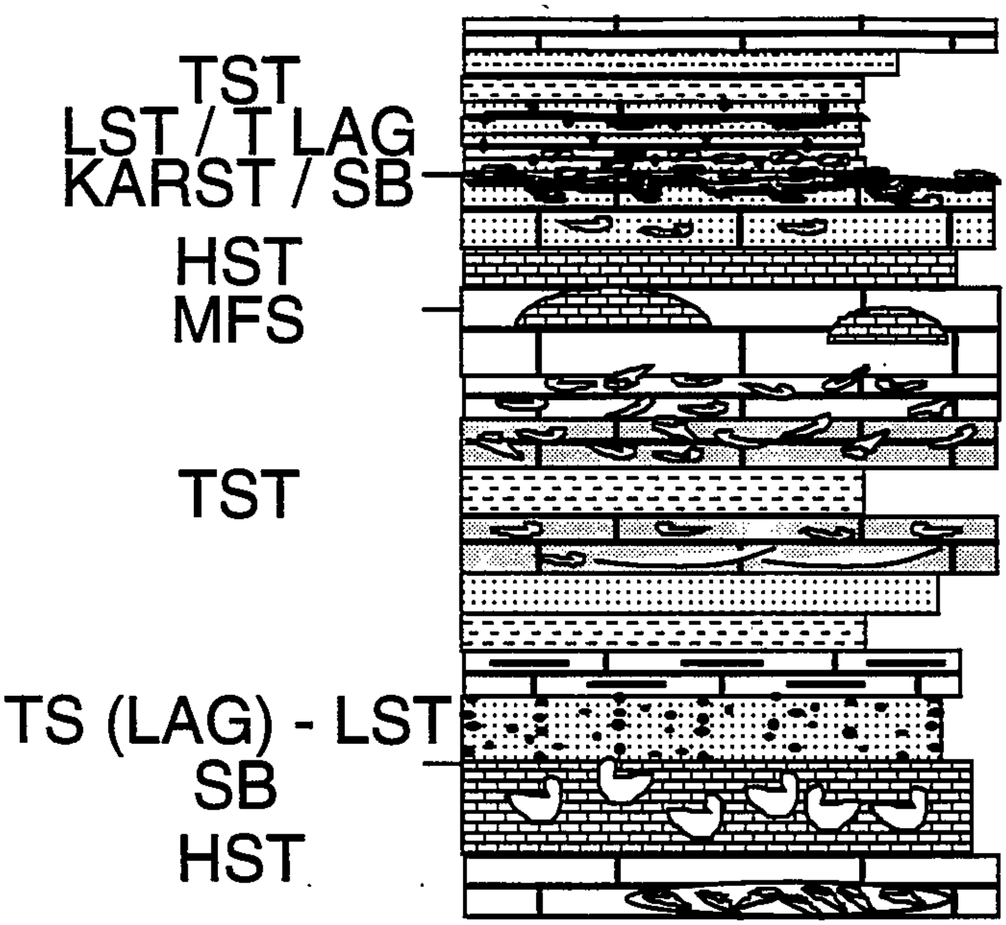
JKV-92-1 UPPER BORRACHA FORMATION



JKV-92-1 MIDDLE BORRACHA FM.



JKV-92-1 UPPER BORRACHA-LOWER CHIMANA FMS.



In the upper Borracha Formation, the final 3rd-order sequence is represented by a transgressive systems tract consisting of, at the base, alternating thin quartzose marine sandstones and thicker interbedded shale and calcareous shale units, which themselves describe 4th and 5th-order parasequences (Units 15, basal 16; Fig. 13). Above this, 18.5 m of massive thick-bedded gray limestones containing abundant rudistid (mainly caprinid) bioherms and biostromes 1 - 3 m across comprise late TST and the maximum flooding interval expressed in outer platform and platform-edge facies (Units 16-18; Fig. 13). A thin 3rd-order HST is developed in the upper 4 m of the Borracha Formation, as represented by thinner-bedded limestones and, at the top, large oyster and rudist-bearing sandy limestone.

The Borracha (El Cantil) - Chimana contact is a second-order sequence boundary, and is characterized on Isla Borracha by a karstic surface on a sandy limestone hardground (encrusted), indicating subaerial exposure before subsequent drowning by Chimana transgression. Karst voids are primarily along fractures, and are filled with glauconitic sandy shales of the Chimana Formation (Unit 19 - 20 contact; Figure 13). All observed contacts between the El Cantil and overlying strata south of the fault zone were faulted, but appeared to have been equally abrupt.

CHIMANA FORMATION

Macsotay et al (1985) described the Chimana formation as being of Early to Late Albian age south of the fault zone, and Middle to Late Albian age north of the zone on the coastal islands. Ammonites from the uppermost Borracha (El Cantil) and lower Chimana formations on Isla Borracha suggest a late Middle Albian age for the contact. Macsotay et al (1985) described the Chimana in the study areas as 150 m of quartz and quartz-feldspathic sandstones, calcareous sandstones and shales, and clay shales bearing diverse fossils. In general, the Chimana Formation comprises a second- or third-order sequence, with glauconitic and quartzose sandstones at the base (transgressive lag and early TST), grading upward to clay shales and calcareous shales with limestone lenses and concretions (Late TST and maximum flooding surface/interval), and at the top coarsening upward to fossiliferous sandy shales and argillaceous calcareous sandstones representing HST. A major sequence boundary cuts the top of the Chimana, superimposed on the martine flooding surface of the Querecual Formation.

The lower part of the sequence, representing the early to late transgressive systems tract, was studied in detail on Isla Borracha (Fig. 13). The second-order sequence boundary at the base is a karstified and encrusted limestone hardground on top of the Borracha Formation (=El Cantil), with karst holes filled with basal Chimana greensands. The basal transgressive lag and condensed horizon (Unit 20, Figure 13) is a 7 meter thick phosphatic and glauconitic greensand with relatively abundant fossils, especially belemnites and bivalves. This grades upward into dark gray clay shales with thin limestone and calcareous sandstone lenses and beds, becoming less prominent upward (Units 21, 22; Figure 13). These strata collectively comprise the 2nd-order transgressive systems tract; 3rd - 5th-order cycles are reflected by the thin sandstone beds, with sequence boundaries at their bases (e.g. Fig. 13; Unit 21).

BIOCHRONOLOGY

Of the four major stratigraphic tools for establishing age and correlation of the northeast Venezuelan Cretaceous sections (magnetostratigaphy, geochronology, event chronostratigraphy, and biostratigraphy), only biostratigraphy provides a reliable base at present. Paleomagnetic data are scattered in northern South America, and much of the Cretaceous is a quiet interval. Rare volcanic ashes were encountered in the Cretaceous, and these were too altered for geochronologic analysis. For those individual sections where high-resolution stratigaphic analysis was completed (e.g. the Rio Querecual), several hundred event surfaces have been identified, mainly among climate cycle and mass flow deposits, concretion horizons, and on a larger scale, among 3rd - 5th-order sequence and parasequence boundaries and marine flooding or highstand surfaces.

But the present event and cycle chronostratigraphy for this region represents only a testable hypothesis inasmuch as most event data for each formation was collected from only a single stratigraphic section. This powerful new system of stratigraphy now remains to be tested by similar studies in other areas of Venezuela, and then correlated to the already highly refined Cretaceous stratigraphy of the Colombia marine Cretaceous basins (Villamil, in progress). We propose that this be the next critical step of future research.

The Cretaceous strata of northeast Venezuela have yielded rich fossil biotas from several levels, mainly molluscs, corals, and calcareous microplankton, but including such groups as ammonites, inoceramid bivalves, planktonic foraminifers, radiolarians, and coccoliths that are mainstays of the global Cretaceous biochronology. Our hope at achieving an initial high-resolution chronology for this sequence lies first in refining the biostratigraphic data base and applying it to modern techniques of zonation and correlation, previously discussed.

As a first step in this process, all published biostratigraphic data with relatively trustworthy stratigraphic occurrences, were compiled for the Lower Cretaceous (ammonites, bivalves, gastropods, corals, foraminifers, etc.) of northeastern Venezuela and plotted against stage and substage divisions (Fig. 16). Only the ammonite data of Renz (1982) were plotted for the Upper Cretaceous, where other groups are more poorly studied. Besides Renz (1982) additional main sources of data were Macsotay, et al (1985 and references therein; molluscs; foraminifers), Wells (1944; corals), Rossi (1985 and references therein: algae, molluscs, foraminifers), Vivas (1987, and references therein; molluscs, foraminifers); Macsotay (1980; and personal communication, 1989), Kauffman, Johnson, and Sohl (Caribbean biostratigraphic chart; manuscript in prep.) and the collections of the authors between 1989 and 1992.

Figure 16 shows the published ranges of most known fossils from the Lower Cretaceous of northeastern Venezuela, and the Upper Cretaceous ammonite ranges of Renz (1982). These ranges and the composite assemblage zones that can be made from them provide a broad scale system of dating and correlation, but only at the stage and substage level.

These data allow the derivation of 18 composite assemblage zones, many with one or more ammonite or bivalve species restricted to the zone, between the Hauterivian and the top of the Coniacian (about 47 Ma), giving a current biostratigraphic resolution of 2.6 Ma/biozone. This is extremely coarse compared to modern biozonal systems developed for Colombia (0.5 - 1 Ma/biozone) and the Western Interior of North America (0.12 - 0.33 Ma/biozone), suggesting the need for an intensive program of paleontological research in northeastern Venezuela to further refine ranges of known taxa, and add new data to the zonations. For example the diverse ammonites of Renz (1982), potentially the most powerful first tool of correlation and dating, are not precisely located stratigraphically as published, and many rudistid species

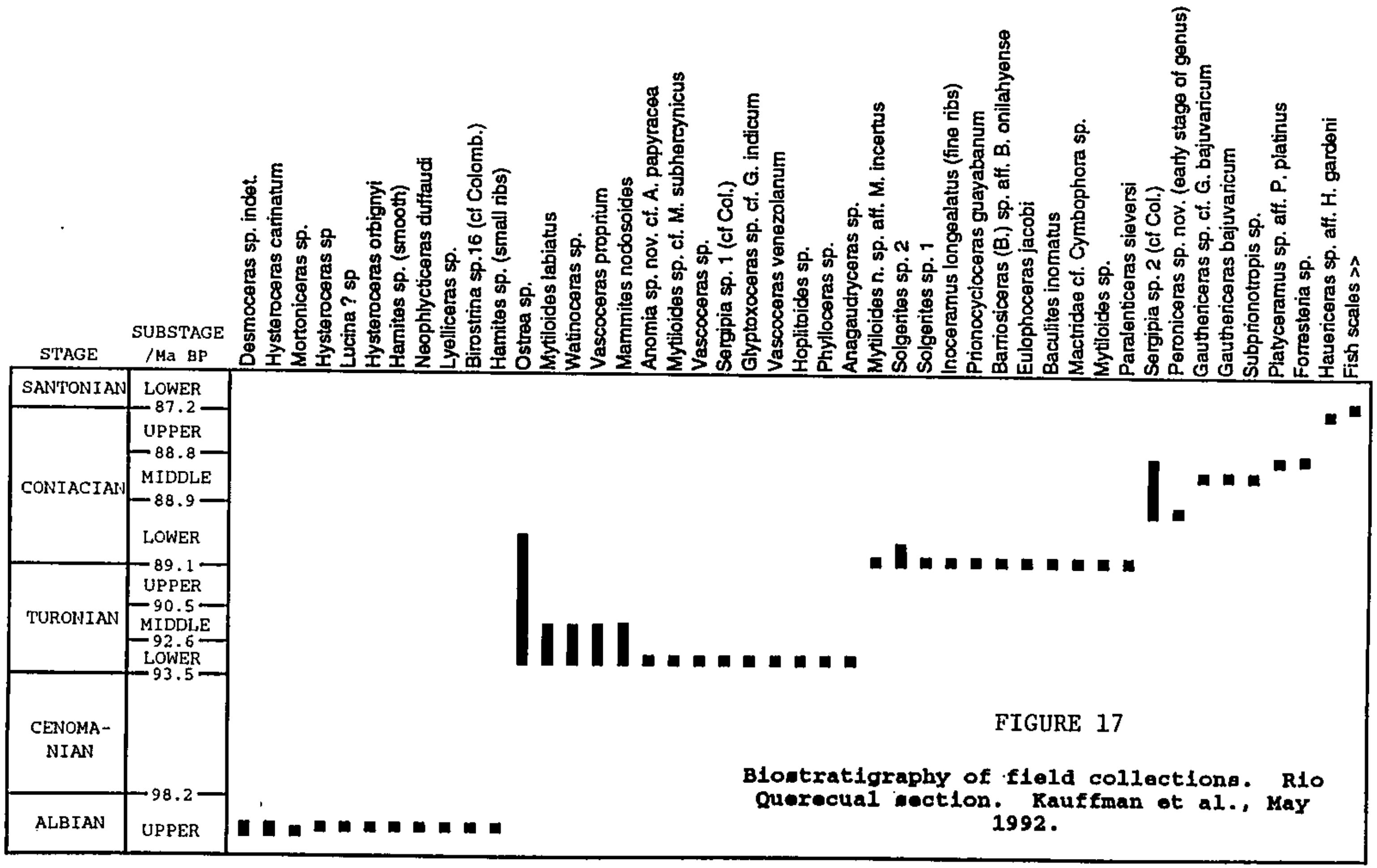


FIGURE 17

Biostratigraphy of field collections. Rio Querecual section. Kauffman et al., May 1992.

Kauffman, Johnson, and Villamil, 1992

used in dating carbonate platform facies are now known to have different and more restricted ranges in the Caribbean Province elsewhere (Kauffman, Johnson, and Sohl, in manuscript).

As an example of the biostratigraphic improvement that can result from high-resolution stratigraphic analysis, the ammonites and bivalves retrieved from the lower Querecual Formation on the Rio Querecual during the course of our research are plotted in Figure 17; not only are the ranges more restricted than those generally cited by Renz (1982) and others, but the resultant zonation achieves a resolution of 0.63 Ma/biozone, nearly four times more refined than existing systems summarized on Figure 16.

At present we expect to add a large microfossil data base to this zonation when work is completed by various specialists on the radiolarians, foraminifers, and palynomorphs, and thin-section work is completed on some macrofossils in carbonate facies. But the main need in order to establish a new and more refined biostratigraphy for northeastern Venezuela is a great deal of more focused high-resolution field collecting along a series of Cretaceous transect between the Miracaibo Basin and the northeastern margin of Venezuela.

CRETACEOUS BIOSTRATIGRAPHY OF VENEZUELA AND COLOMBIA

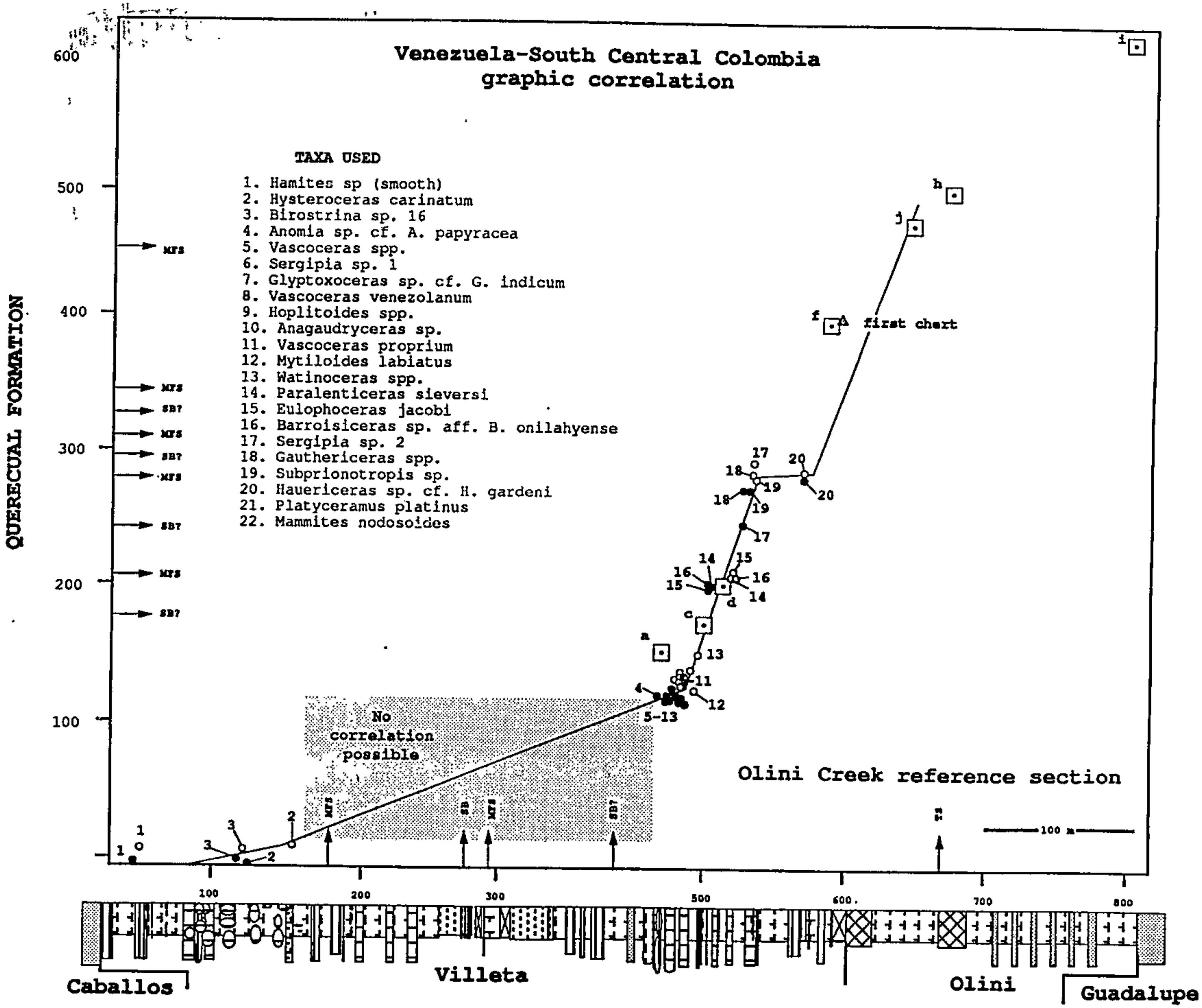
In an attempt to establish a new biostratigraphic zonation for the Cretaceous of northern South America, we have collated all published data, as well as our new field observations, into a series of biostratigraphic charts for foraminifera, ammonites, and other macroinvertebrates. Copies of these charts are attached on the following pages; they may be removed from the guidebook and assembled into single wall charts for your convenience.

These are "state-of-the-art" diagrams, and represent only data that are published or personally observed. Based on experience learned during our development of a highly refined Cretaceous biostratigraphic system in the Western Interior of North America, we believe that this preliminary zonation for northern South America can be considerably improved. We ask you help in correcting range zones and adding new data to these charts for our mutual benefit.

REGIONAL CORRELATIONS OF SEQUENCE STRATIGRAPHY; A FIRST TEST

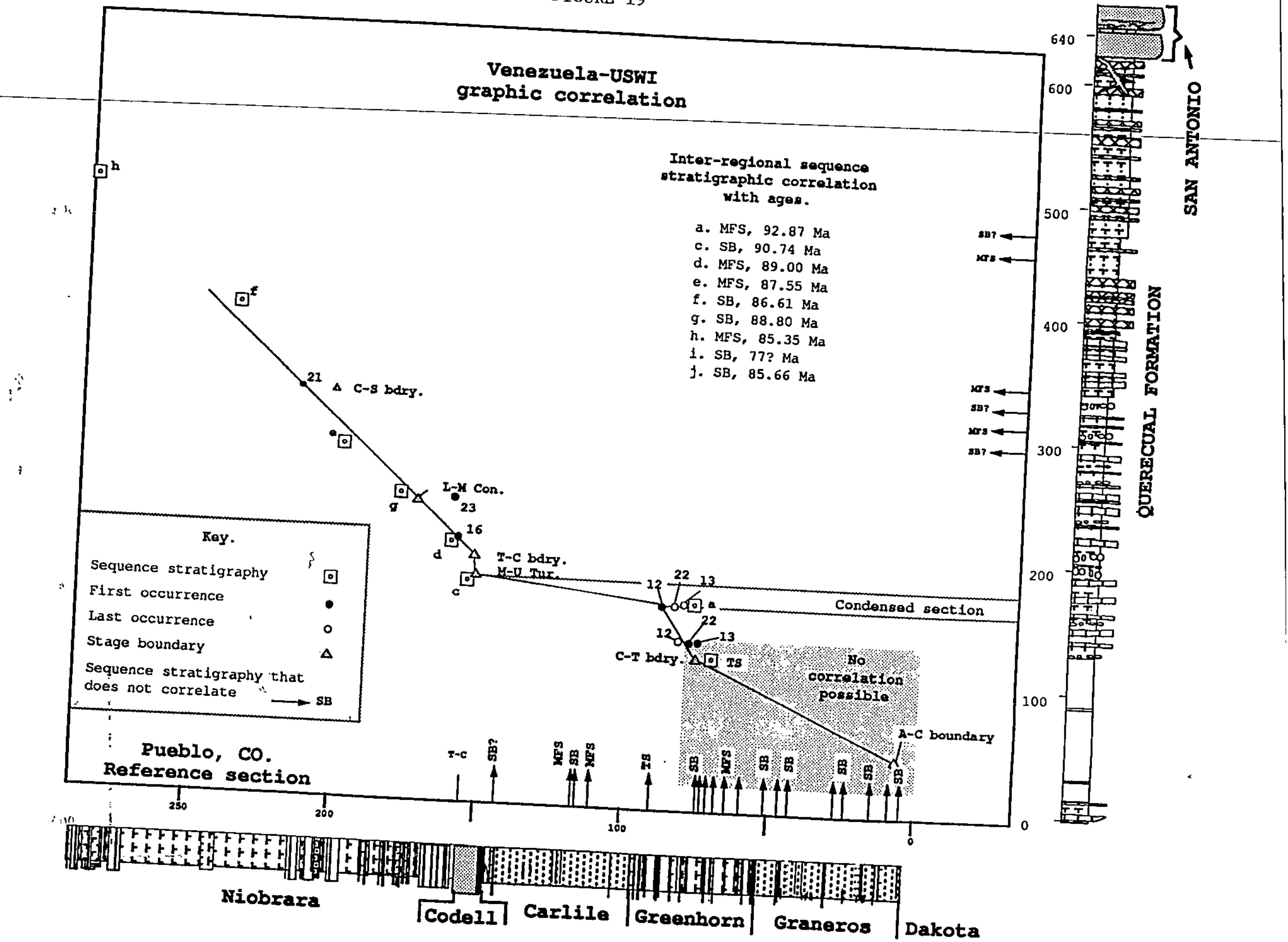
The major 2nd and 3rd-order sequence stratigraphic divisions of the Cretaceous strata in northeastern Venezuela have been presented in text, and are summarized on Figure 3. As a first test of controls on the development of these sequences (eustatic vs tectonic, etc.), graphic correlations (Edwards, 1984) based on comparable Cenomanian - Santonian biostratigraphy of northeastern Venezuela, the Magdalena Basin of Colombia (Olini Creek Reference Section for the Villeta Group), and Pueblo, Colorado (the Greenhorn and Niobrara Cyclothem reference sections for the Western Interior Basin of North America), have been completed. Figure 18 correlates the Venezuela and Colombia sections, and Figure 19 the Venezuelan and Colorado sections. The line of correlation is drawn strictly on biostratigraphic range terminations, following the methodology of Miller (1979) and Edwards (1984). These biostratigraphic zones have been correlated to the new geochronologic time scale for the Western Interior Basin (Obradovich, in press; Kauffman et al, in press) and the ages integrated into the correlation matrix. Changes in the slope of the line of correlation (LOC) denote differences in sedimentation rate between correlated sections; flat lines usually mean omission or severe condensation of section at one locality. Note that due to very great differences in total thickness of the compared sections, different scales had to be used on the graphic axes in plotting. A strong biostratigraphic

FIGURE 18



Kauffman, Johnson, and Villamil, 1992

FIGURE 19



Kauffman, Johnson, and Villamil, 1993

correlation matrix exists between the three sections, even though only a relatively small percentage of fossil taxa found in any one section are shared between sections.

As a second step, sequence boundaries and maximum flooding surfaces identified for the three sections were then tested against the biostratigraphic line of correlation to determine which surfaces correlated, and which did not. On Figures 18 and 19 the square boxes with central dots and letters beside them refer to those sequence stratigraphic surfaces that correlate within one standard deviation to the biostratigraphic line of correlation. Arrows on the axes of the graph denote those that did not correlate at 2nd - 4th order.

It is significant that, where correlation was possible because of a well developed data base (but not in the shaded area of each graph), about 40 percent of the sequence boundaries or maximum flooding surfaces in the Rio Querecual section can be correlated rather precisely to the Villeta group of Colombia (77, 85.35, 85.66, 86.61,89, 90.74, and 92.87 Ma surfaces). Between the Querecual Formation and the Western Interior Basin of North America (Colorado), about 58 percent of the surfaces correlate (77, 85.35, 86.61,87.55, 88.8, 89, 90.74, and 92.87 Ma surfaces). Five Cenomanian - Santonian surfaces graphically correlate between all three regions.

This clearly establishes the probability that about half of the sequence boundaries and maximum flooding surfaces found in Venezuela during the course of this study are primarily eustatically regulated, and have global correlation significance. This conclusion needs to be tested further in different areas, and with a more precise Venezuelan data base. Precise biostratigraphic dating of the Albian, earlier Cenomanian, and Campanian-Maastrichtian sequences in Venezuela which will result from future work, and analyses in progress, will doubtless allow more precise interpretations for the driving forces behind relative sealevel fluctuations across the northeastern Venezuela passive margin.

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