

Thesis presented to the University of Oxford for the degree of Doctor of
Philosophy.

THE SEDIMENTATION, TECTONICS AND STRATIGRAPHY OF THE CRETACEOUS/TERTIARY
SEQUENCE OF NORTHWEST SANTANDER, NORTHERN SPAIN.

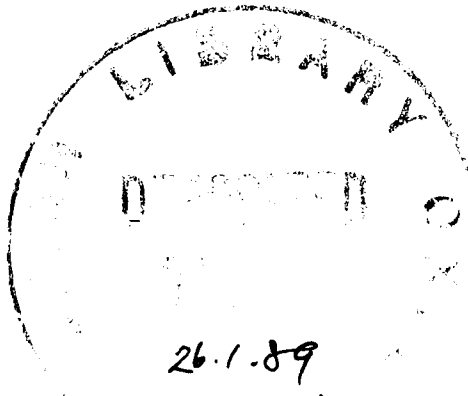
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VOLUME 2 : FIGURES.



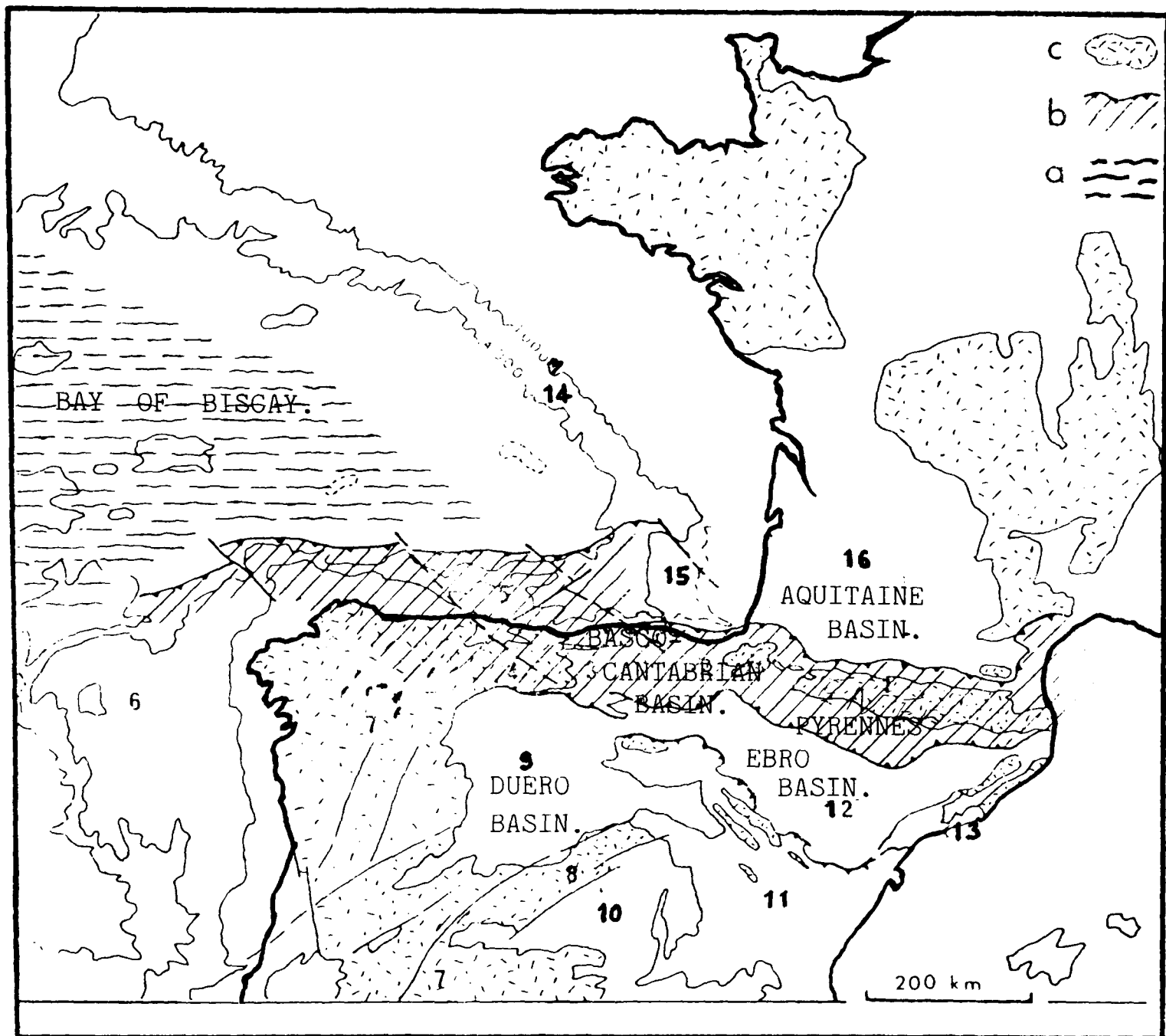


FIGURE 1-1

Geological/structural subdivision of central Western Europe (after Derognaucourt, 1981).

Shading a : Oceanic crust of the Bay of Biscay.

b : Pyreneo-Cantabrian chain with frontal thrusts to the north and south.

c : Hercynian basement.

Numbering :

- 1 : Pyrenean chain.
- 2 : Basque arc.
- 3 : Cantabrian domain of the Basco-Cantabrian basin.
- 4 : Asturian palaeozoic massif.
- 5 : Northern Iberian continental margin.
- 6 : Galicia bank.
- 7 : Hercynian basement of Iberia.
- 8 : Central cordillera of Iberia.
- 9 : Old Castille Tertiary basin (=Duero basin).
- 10 : New Castille Tertiary basin (=Tagus basin).
- 11 : Iberian chain (=Celtiberian chain).
- 12 : Ebro basin.
- 13 : Catalan chain.
- 14 : Armorican continental margin.
- 15 : Landes plateau.
- 16 : Aquitain basin.

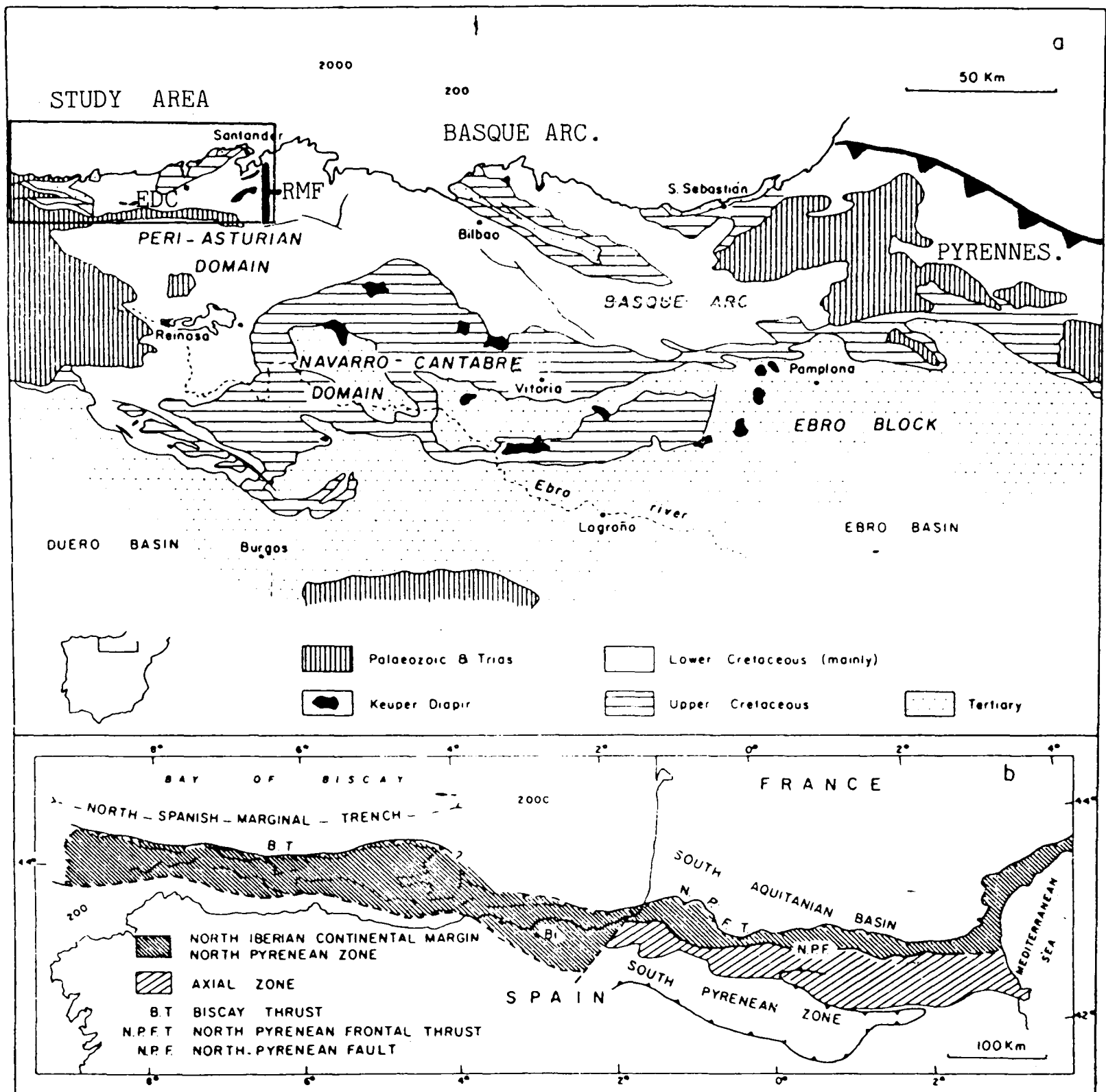
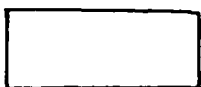


FIGURE 1-2 (Upper figure "a")

Tectono-sedimentary domains of the Basco-Cantabrian basin (from Garcia Mondejar, Hines et al., 1985). Offshore bathymetry in metres.



Location of study area.

NEAR THE NW SANTANDER STUDY AREA THESE TECTONIC LINEAMENTS EXIST : RMF = RIO MIERA FLEXURE, ESC = ESCUDO DE CABUERNIGA

FIGURE 1-3 (Lower figure "b")

Sketch map of the main structural features of the Pyrenean belt and it's continuation into the Basco-Cantabrian basin and then offshore.

(from Garcia Mondejar, Hines et al., 1985).

Bi = Bilbao.

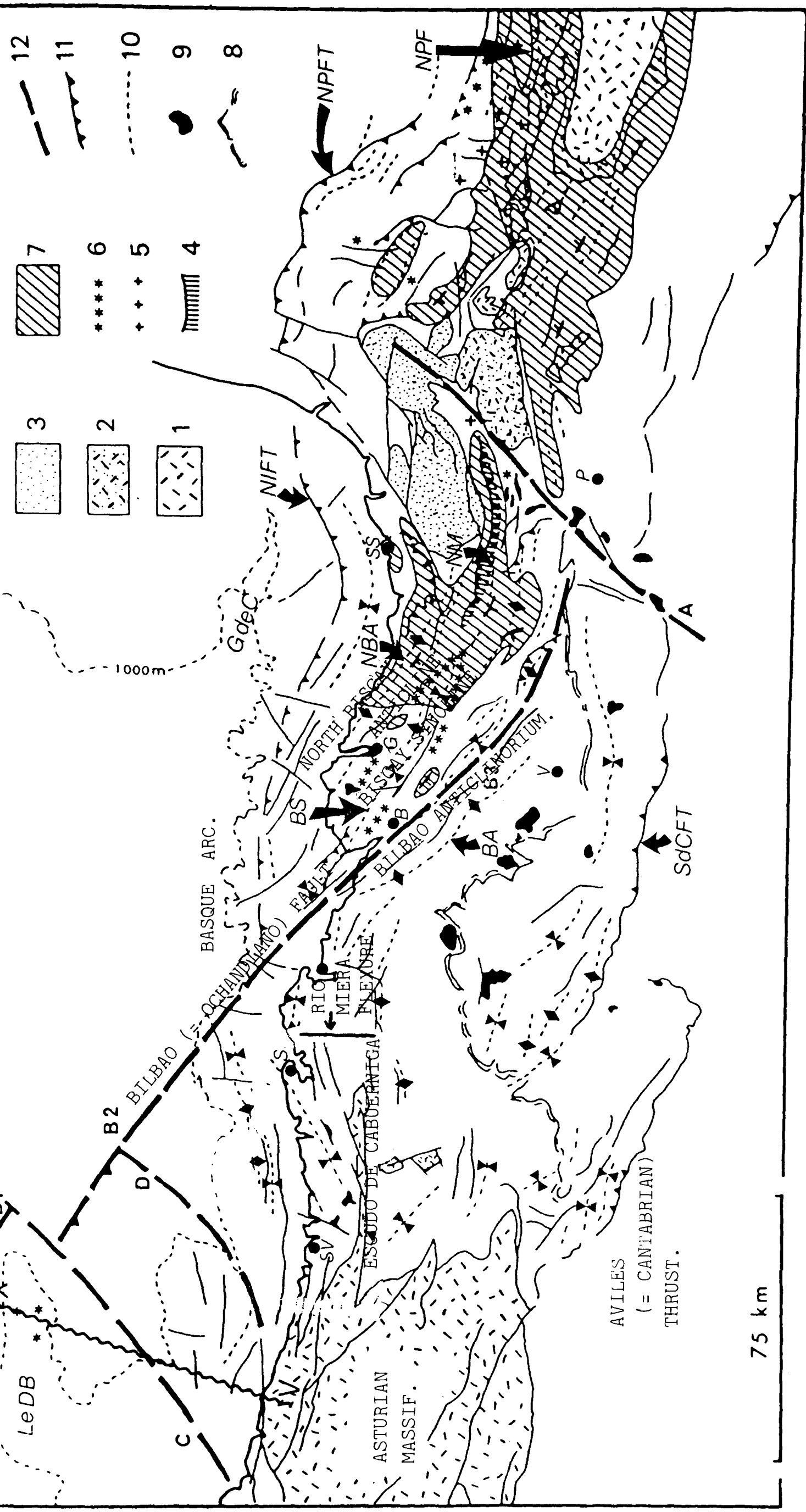


FIGURE 1- 4. (for caption see opposite).

FIGURE 1-4

Structural map of the Basco- Cantabrian basin showing the westward continuation of the Pyrenees into the Basco-Cantabrian basin.

Key to the basement (top right hand corner) ; 1 : Iberian Hercynian basement (for the Pyrenees s.s. from Souquet et al., 1982), 2 : European Hercynian basement, 3 : Hercynian basement of Aldudes (origin still under discussion), 4 : Metamorphism of the Nappe de Marbres, 5 : Lherzolites, 6 : Upper Cretaceous volcanics of the Basque arc, 7 : Schistosity.

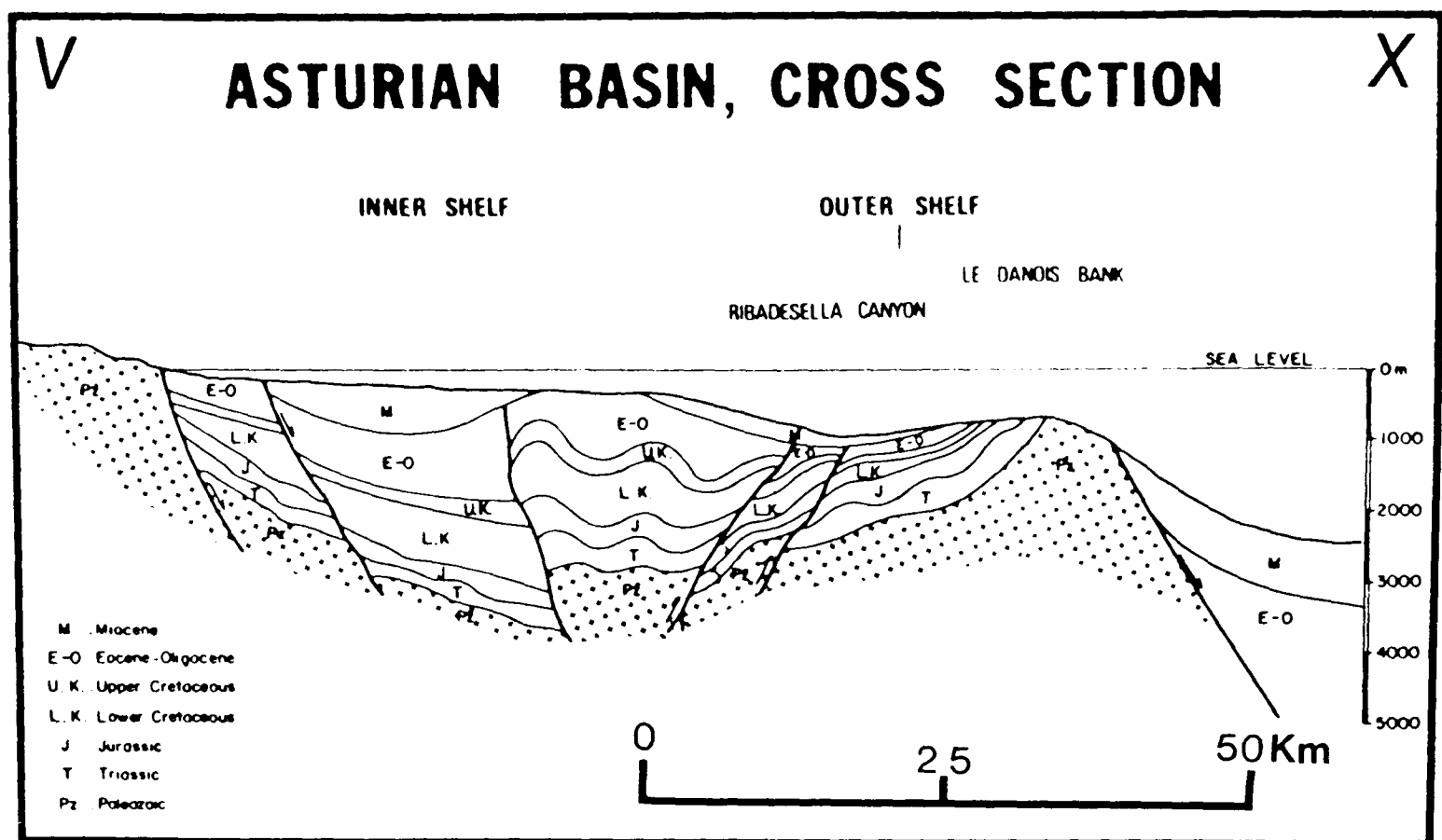
Key to morphology and structure ; 8 : Navro-Cantabrian domain (= Alavais block), 9 : Keuper diapirs, 10 : Axes of principal folds (with anticlines and synclines indicated), 11 : Principal thrusts, 12 : Axes of major, deep-seated lineaments (A : Navarro diapiric lineament, B : Bilbao fault - B1: To the north of the Le Danois bank, B2: On the continental margin, after Derogaucourt, 1981, B3: Biscay anticlinorium, C : Lastres canyon, D : Llanes canyon).

Structural features (initialled in italics) ; -from east to west- NPF : North Pyrenean Fault, NPFT : North Pyrenean Frontal Thrust, NM : Nappe de Marbres, NBA : North Biscay Anticline BS : Biscay Syncline, BA : Biscay Anticlinorium, SdCFT : Sierra de Cantabria Frontal Thrust, GdeC : Gouf de Capbreton, LeDB : Le Danois Bank, NIFT : Northern Iberian Frontal Thrust.

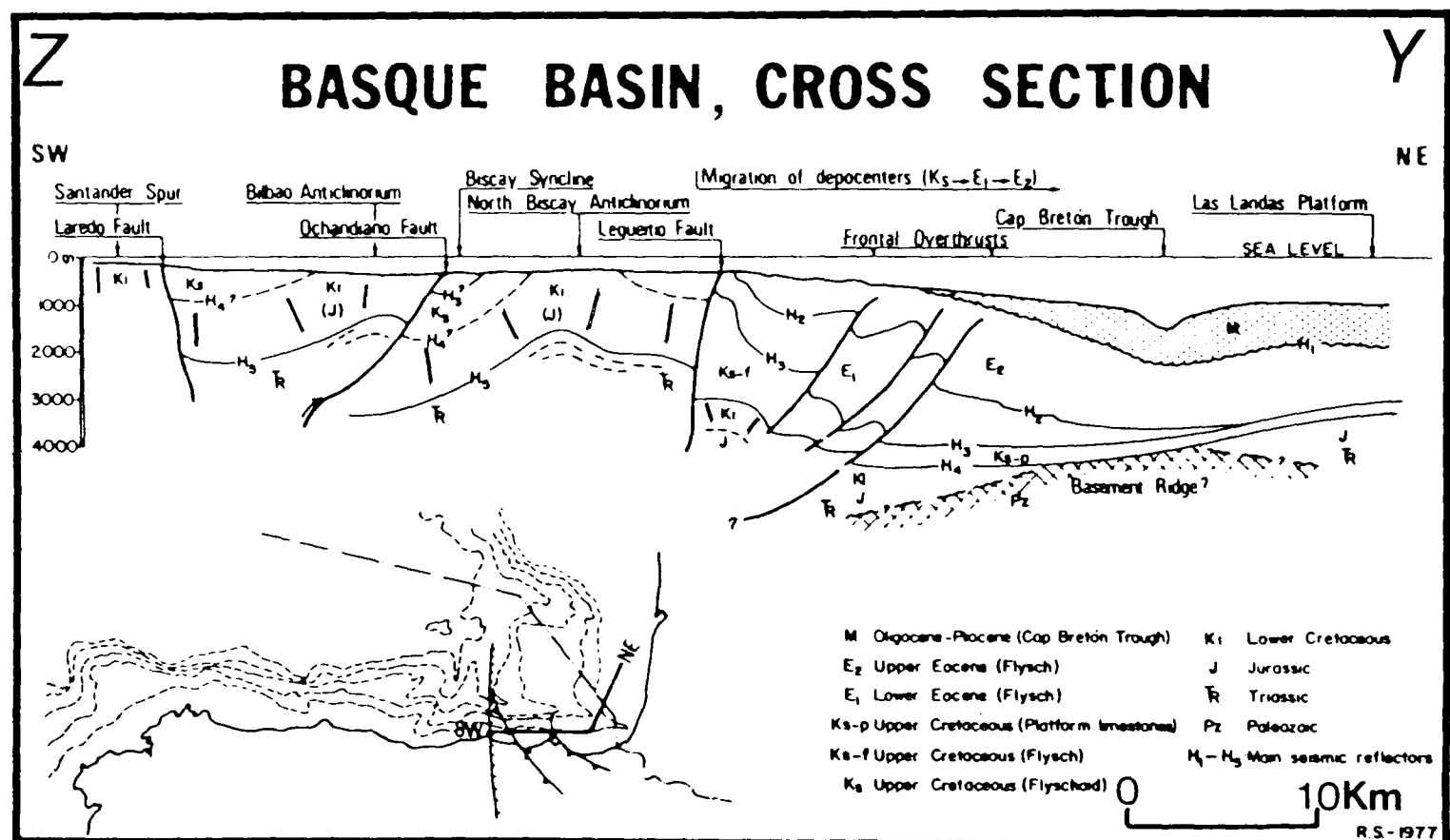
Towns ; (in italics), B : Bilbao, G : Guernica, P : Pamplona, S : Santander, SS : San Sebastian, SV : San Vicente de la Barquera, V : Vitoria.

Seismic line V-X from the Asturian massif to the Le Danois bank is shown in the upper part of Figure 1- 5.

(extensively adapted from Rat, 1983).



Asturian basin, cross-section.



Basque basin, cross-section.

FIGURE 1- 5.

Seismically-derived cross-sections of the Basco-Cantabrian basin from Soler et al., 1981. The upper section shows a section from the Asturian massif northward to the Le Danois bank (section V-X). Its location is shown in Figure 1-3.

The lower section is of the Basque arc taken offshore (see insert for location).

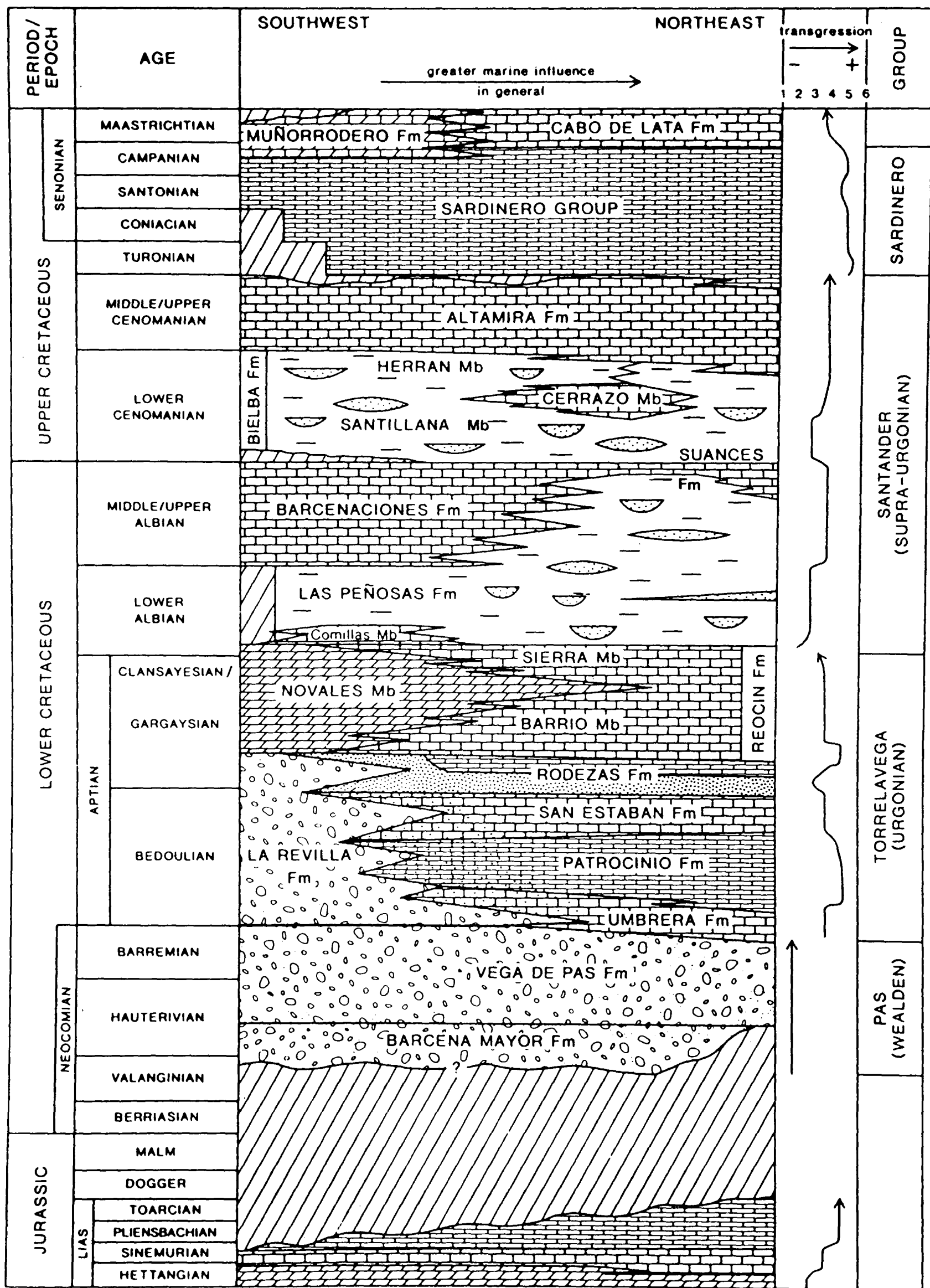


FIGURE 1-9.

Lithostratigraphic column for the Cretaceous of northwest Santander. See Figure 1-10 for key.

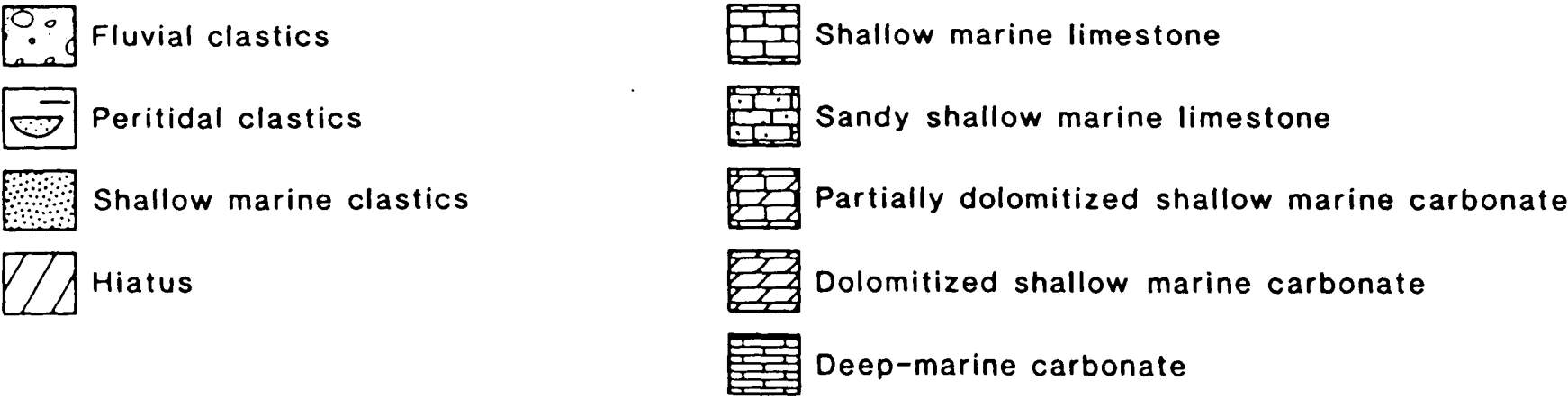
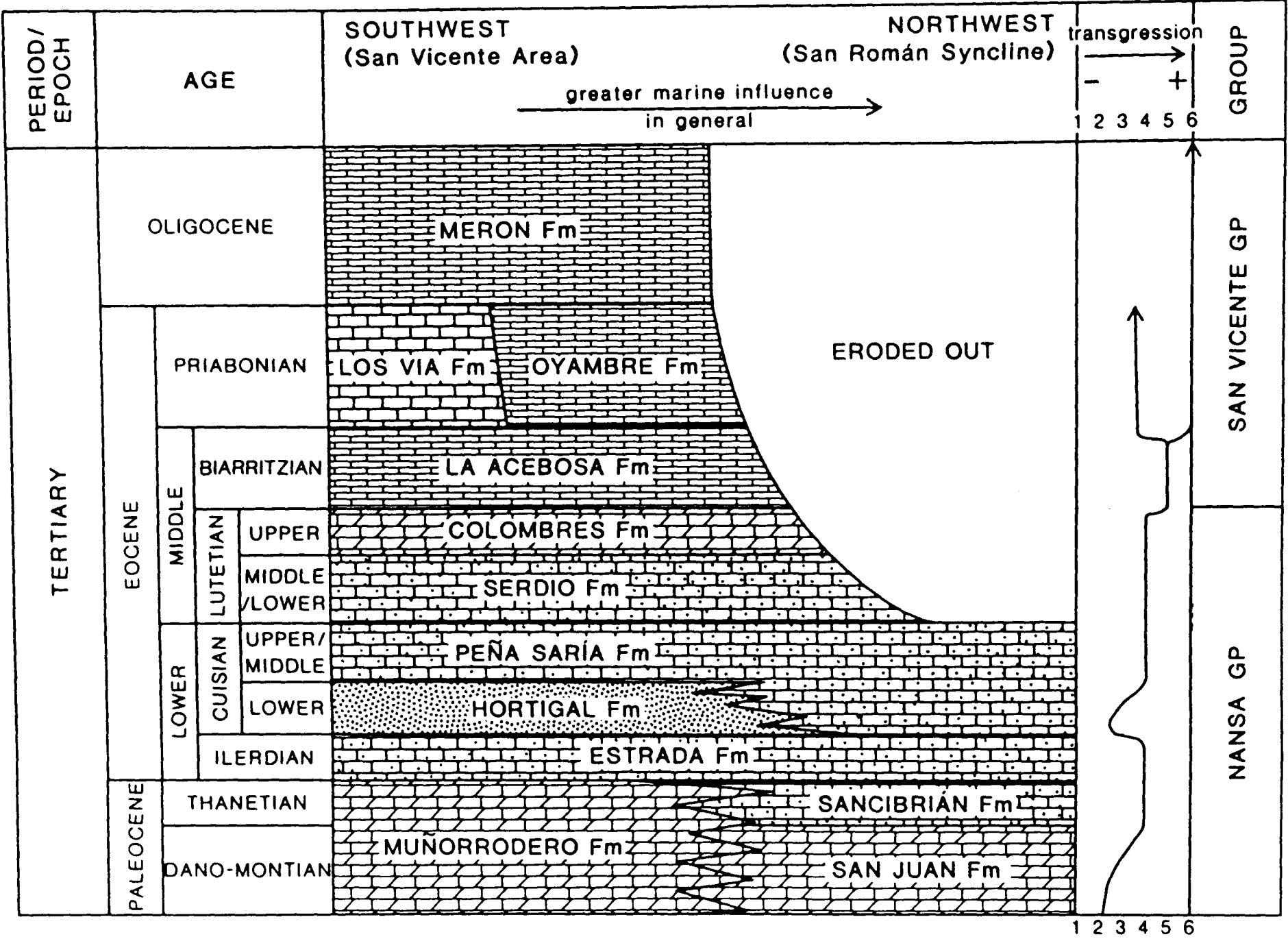


FIGURE 1-10.

Lithostratigraphic column for the Tertiary of northwest Santander. The column furthest to the right but one gives a general indication of the environment of deposition. Key : 1-Subaerial exposure, 2-Fluvial, 3-Peritidal, 4-Internal platform, 5-External platform, 6-Flysch.

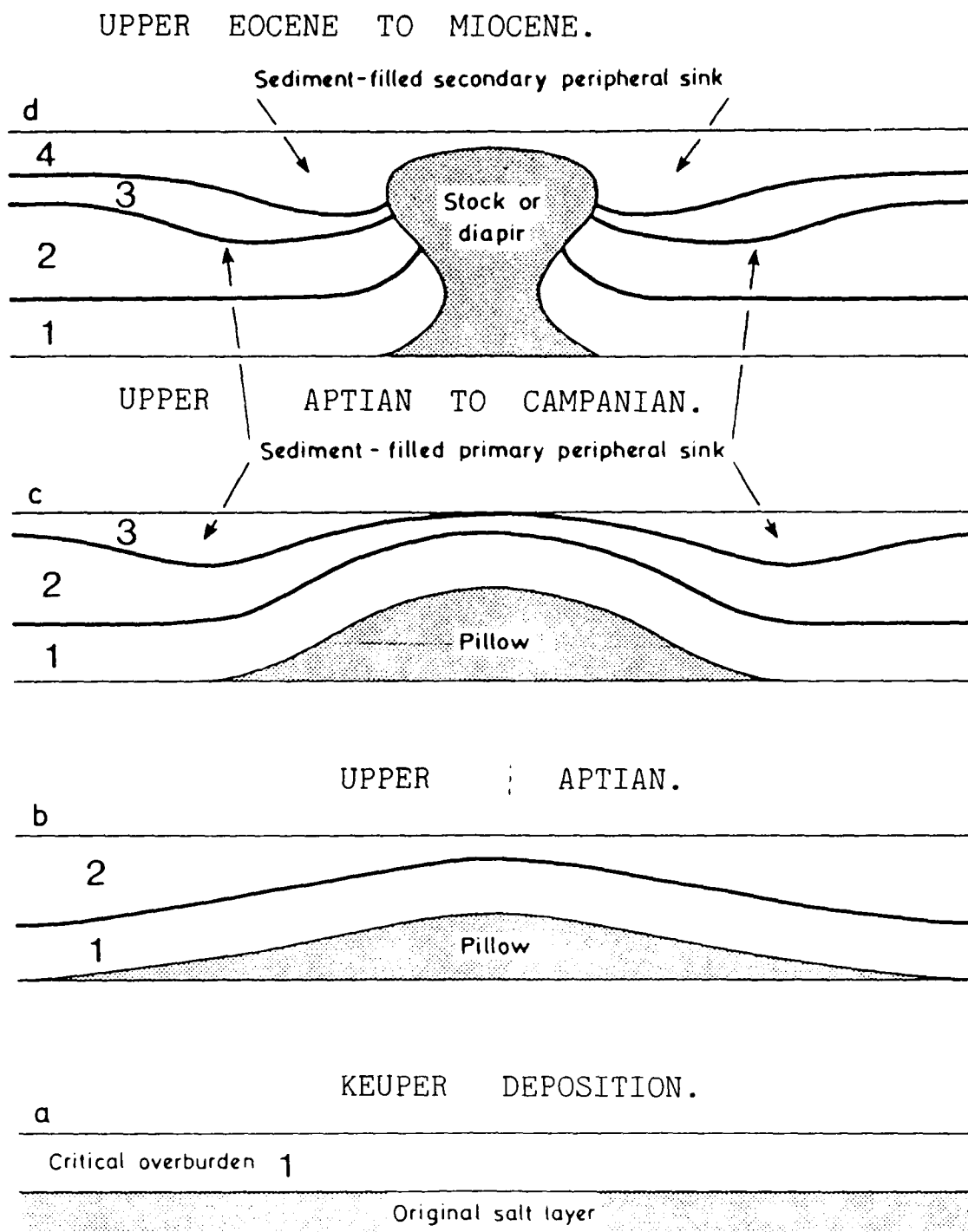


FIGURE 1-11.

Stages in the development of salt pillows and stocks, modified after Trusheim (1960) and taken from Taylor (1984).

- a. State immediately before movement of diapir.
Generally pre-Upper Aptian in NW Santander.
- b. With increasing overburden, salt has flowed inwards to form a gentle pillow. Once initiated, the imbalance of sediment load between flanks and crest accentuates the action. In NW Santander there was most probably a tectonic trigger to diapirism during the Upper Aptian.
- c. As salt withdraws from the flanks a rim syncline or peripheral sink forms. Becoming infilled with young "rim syncline" sediments (3) it continues to drive the migration of salt inwards. In NW Santander this generally occurs during the Upper Aptian to Campanian.
- d. The buoyant salt mass finally breaks through the overlying sediments to form a diapiric plug or stock, or an elongated wall, which may take a variety of cross-sections. The continued withdrawal from the original salt layer forms a secondary peripheral sink inwards from the primary sink. Such secondary peripheral sinks are not developed in NW Santander but the pillow is pierced during the Pyrenean orogeny

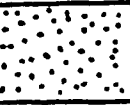
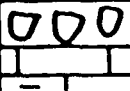
AGE	STAGE		LITHOLOGY	FAUNA
CRETACEOUS	UPPER PURBECK	CLASTIC WEALDEN	 900m cross bedded sandstone oncolite beds	No fauna
	MIDDLE PURBECK	AGUILAR FORMATION Unit 3	 Interbedded limestone and sandstone	Charophytes are very common, ostracods gastropods and algae
UPPER JURASSIC	LOWER PURBECK		800m micrite, brecciated, veined, abundant intra-clasts	
			700m conglomerate with oncolites	
MIDDLE JURASSIC	CALLOVIAN	MARINE LIMESTONE	 600m thick bedded slightly argillaceous	Fauna less common in particular ammonites
	BATHONIAN			
	BAJOCIAN		 500m sponge bioherms	siliceous sponges, serpulids
			fossiliferous marly limestone well-bedded	Chondrites; Zoophycas
LIAS	TOARCIAN	MARINE LIMESTONE	400m alternating beds of marly limestone and marl, becomes bituminous shale	Ammonites are common. brachiopods, bivalves occasionally burrows
	PLIENSCHACHIAN			
	UPPER SINEMURIAN		300m	
	LOWER SINEMURIAN		sandy calcarenite, ooides, pellets, skeletal frag, algal lamination	
TRIASSIC	HETTANGIAN	CARNIOLAS MIDDLE	 No bedding. Brecciated limestone and dolomite. Vuggy crystalline. Evaporite pseudomorphs	No fauna
	RHAETIAN	LOWER	Micrite	Moulds of bivalves ?
	KEUPER		0 Dolomite with gypsum and anhydrite pseudomorphs Clay with gypsum & salt	No fauna

FIGURE 1-12

Generalised log of the Jurassic sequence as seen in Aguilar de Campoo in the very SW part of the Basco-Cantabrian basin. The sequence in NW Santander develops the Keuper and the Carniolas generally. The marine Jurassic (Sinemurian to Callovian) is only rarely represented but is much more extensively developed south of the Escudo de Cabuerniga where this log was taken. After Sbeta, (1976).

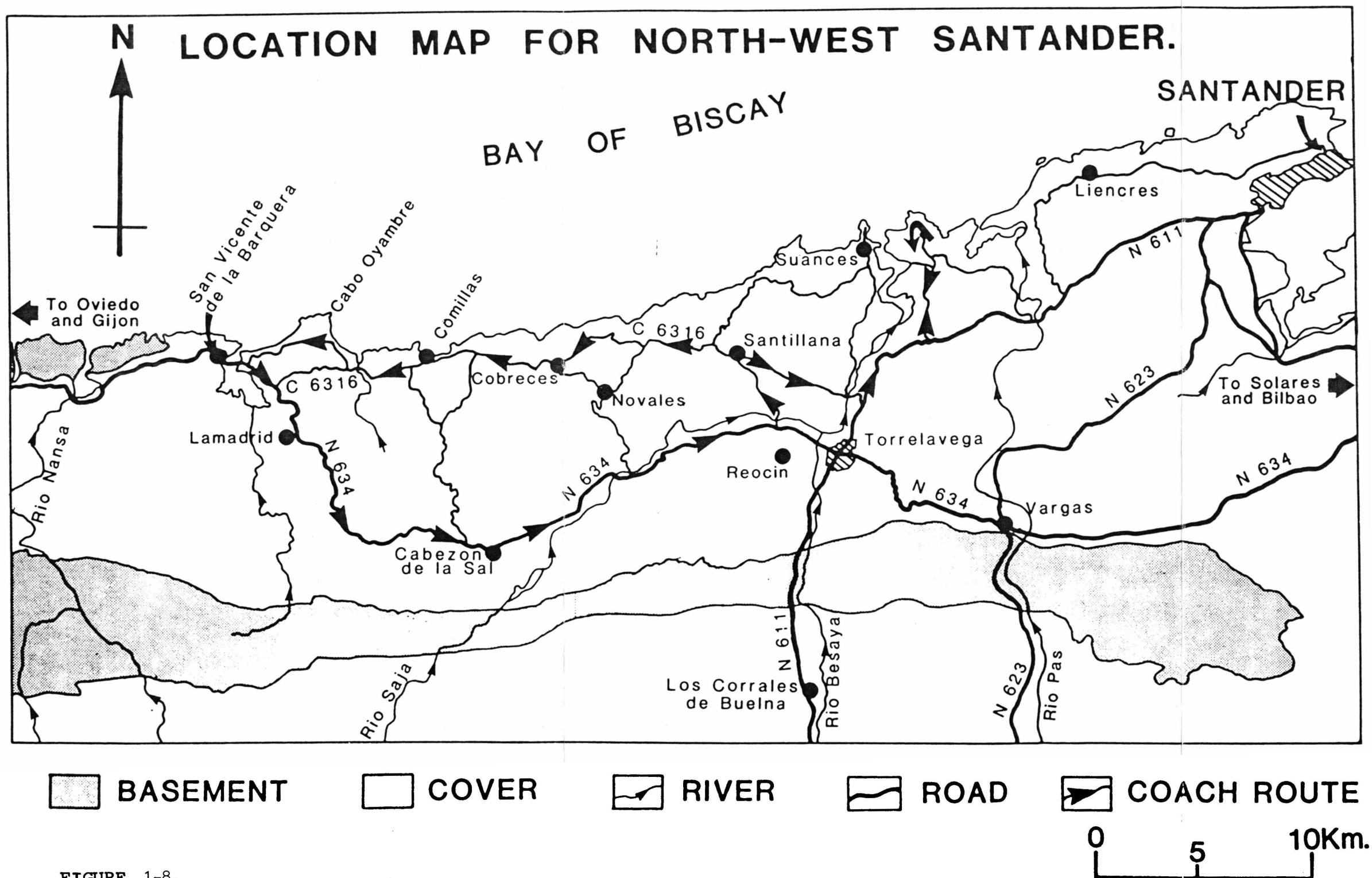
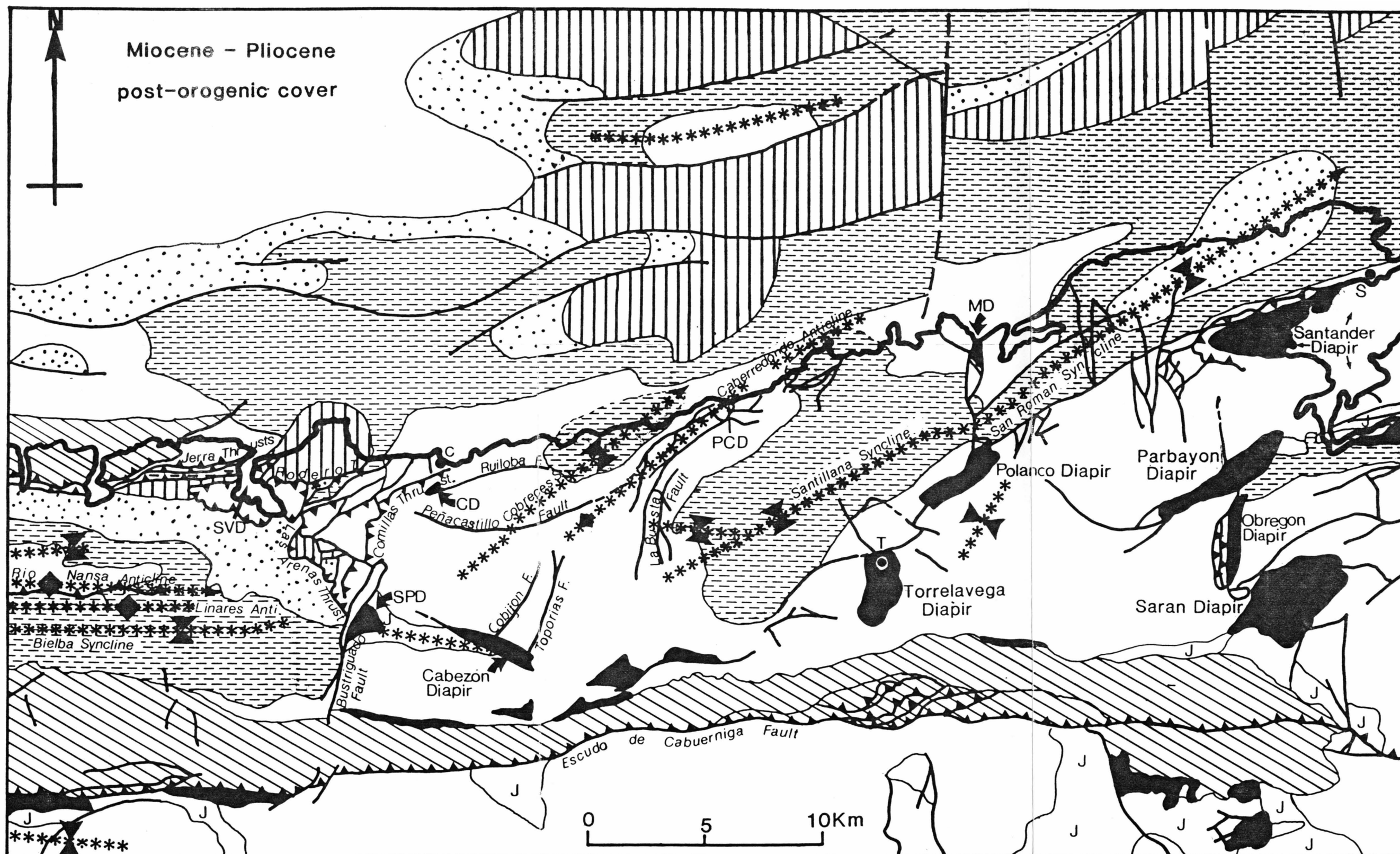


FIGURE 1-8.

Location map for northwest Santander showing the major road system. Disregard the "coach route". Taken from Hines, (1985)a.



STRUCTURAL MAP OF NORTH-WEST SANTANDER

Basement

Keuper Diapir

Jurassic

Lower Cretaceous

Upper Cretaceous

Paleocene-Middle Eocene

Upper Eocene- Oligocene

Fault

Thrust

Anticline

Syncline

Plunging fold

Town

Coast

FIGURE 1-7.

Structural map of northwest Santander. Offshore geology from Boillot et al., (1976). Diapires : CD-Comillas Diapir, MD-Miengo Diapir, PCD-Punta Calderon Diapir, SPD-San Pedro Diapir, SVD-San Vicente de la Barquera Diapir. Towns : C-Comillas, S-Santander, T-Torrelavega.

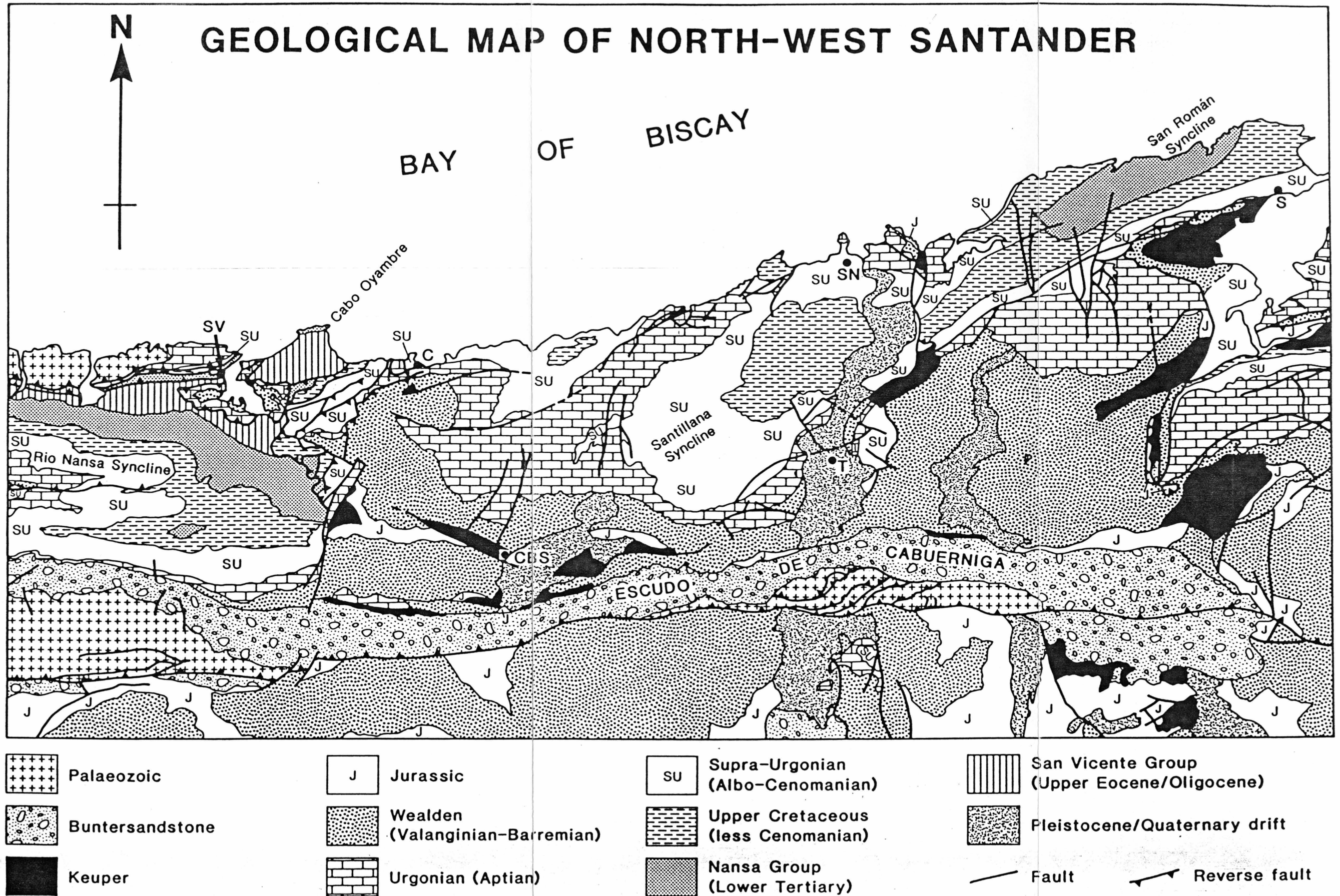


FIGURE 1-6.

A geological map of NW Santander, showing the main Group stratigraphy of the area. Key:- SV : San Vicente de la Barquera.

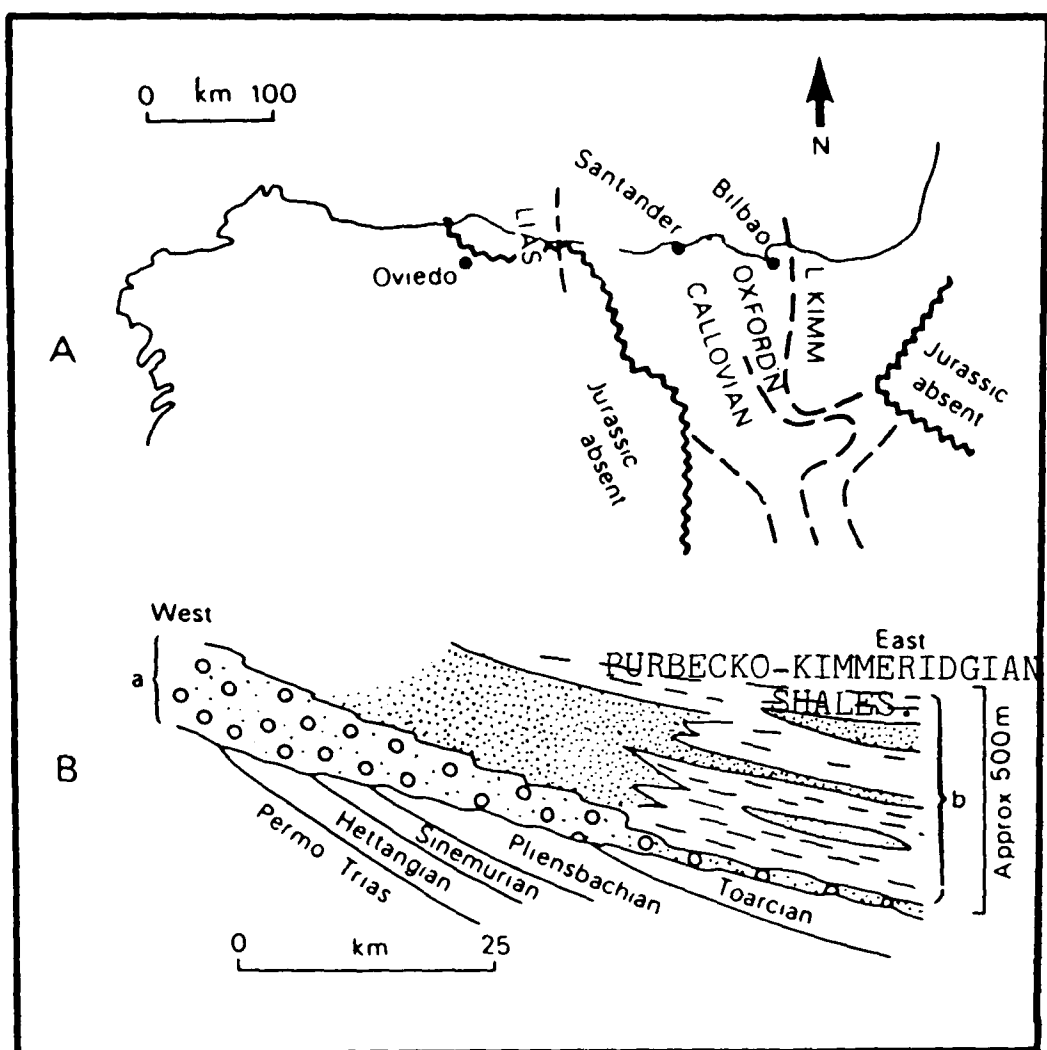


FIGURE 1-13.

The westward overstep of the Wealden facies in northern Spain. Upper figure A shows the age of the uppermost marine Jurassic underlying the Purbecko-Wealden complex, mainly after Querol, 1969. Lower figure B shows the overstep of clastics beneath the Kimmeridgian shales in the area north and west of Oviedo. The line of the section starts in the west from a point due north of Oviedo. Key : circles and stipple : fining upwards cycles of conglomerates, red sandstones and siltstones; fine stipple : sandstones, mostly marine; dashes : black shales with brackish and restricted marine faunas. The continental, fluvial sequence a is contemporaneous with the marine sequence (b) in the east. From Wilson, 1975.

AGE	IGME SYMBOL	LITHOSTRATIGRAPHIC NAME USED IN THIS THESIS.
Oligocene	T ₃ ^A	Meron Formation.
Upper Eocene	T ₂ ^{Ac}	Oyambre Formation.
Upper Eocene/ Oligocene	T ₂ ^{Ac}	Los Via Formation.
Biarritzian (= uppermost Middle Eocene)	T ₂₂ ^{Ab}	La Acebosa Formation.
Upper Lutetian	T ₂₁ ^{Ab3}	Colombres Formation.
Middle/Lower Lutetian	T ₂₁ ^{Ab12}	Serdio Formation.
Upper/Middle Cuisian	T ₂₂ ^{Aa23}	Pena Saria Formation.
Lower Cuisian	T ₂₂ ^{Aa1}	Hortigal Formation.
Ilerdian	T ₂₁ ^{Aa}	Estrada Formation.
Upper Campanian/ Maastrichtian/ Palaeocene.	C ₂₅ ³ -T ₁ ^A	Munorrodero Fm.
Thanetian	T ₁₃ ^A	Sancibrian Formation.
Dano-Montian	T ₁₁₋₁₂ ^A	San Juan Formation.
Santonian-Middle Campanian.	C ₂₄₋₂₅ ^{O-2}	Cabo Menor Formation.
Turonian/ Coniacian.	C ₂₂₋₂₃	Pedruquios Formation.
Upper/Middle Cenomanian	C ₂₁ ²³	Altamira Formation.
Lower Cenomanian	C ₂₁ ¹	Bielba Formation.
Upper/Middle Albian	C ₁₆ ²³	Barcenaciones Fm.
Lower Albian	C ₁₆ ¹	Las Penosas Formation.
Upper Gargasian/ Clansayesian.	C ₁₅ ²³	Reocin Formation.
Lower Gargasian	C ₁₅₃ ¹	Rodezas Formation.
Basal Gargasian/ uppermost Bedoulian	C ₁₅₂ ¹	San Esteban Formation.
Bedoulian	C ₁₅₁ ¹	Patrocinio Formation.
Basal Bedoulian/ Upper Barremian	C ₁₅₁ ¹	Umbrera Formation.
Barremian / Upper Valanginian.	C _{W12-14} ³⁻⁰	Vega de Pas Fm. and Barcena Mayor Fm.

FIGURE 2-1.

A correlation diagram of the IGME map symbols with their ages and the formation names used in this thesis.

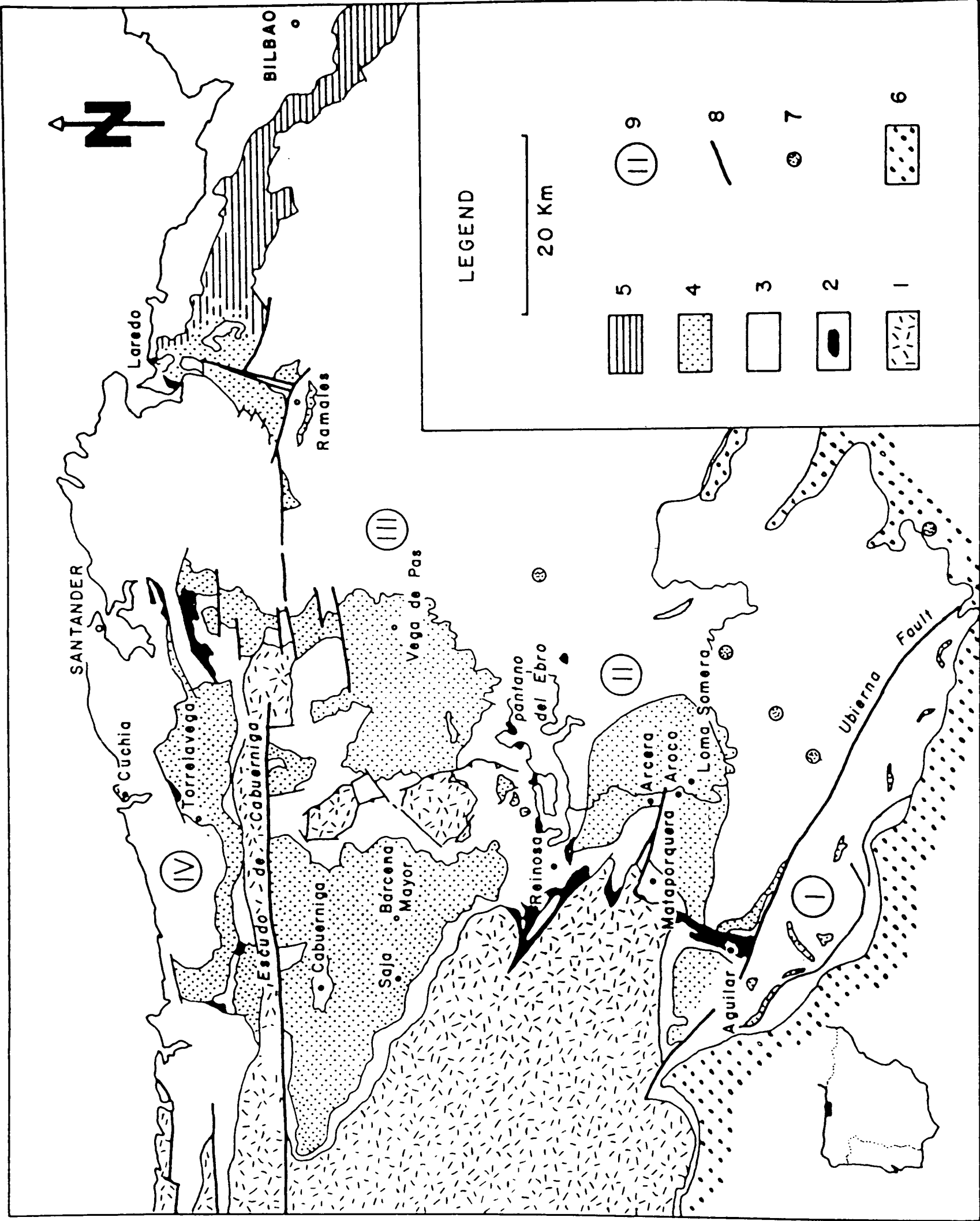


FIGURE 4-1. (diagram)

FIGURE 4-1. (caption).

Simplified geological map of the Santander area showing the Wealden outcrops.

Legend:

- 1 : Palaeozoic and Buntersandstone (Lower Triassic).
- 2 : Upper Triassic Keuper.
- 3 : Liassic and Dogger (= "Marine Jurassic") plus undifferentiated post-Aptian strata.
- 4 : Wealden outcrops of the Santander basin.
- 5 : Wealden outcrops of the Bilbao anticlinorium (mostly black, brackish-water shales).
- 6 : Tertiary of the Duero basin.
- 7 : Wealden rocks proved in boreholes.
- 8 : Principal faults that were active during sedimentation.
- 9 : Tectono-stratigraphic sector numbers used in this chapter.

The NW Santander area lies to the north of the Escudo de Cabuerniga fault .
Adapted from Pujalte, (1985).

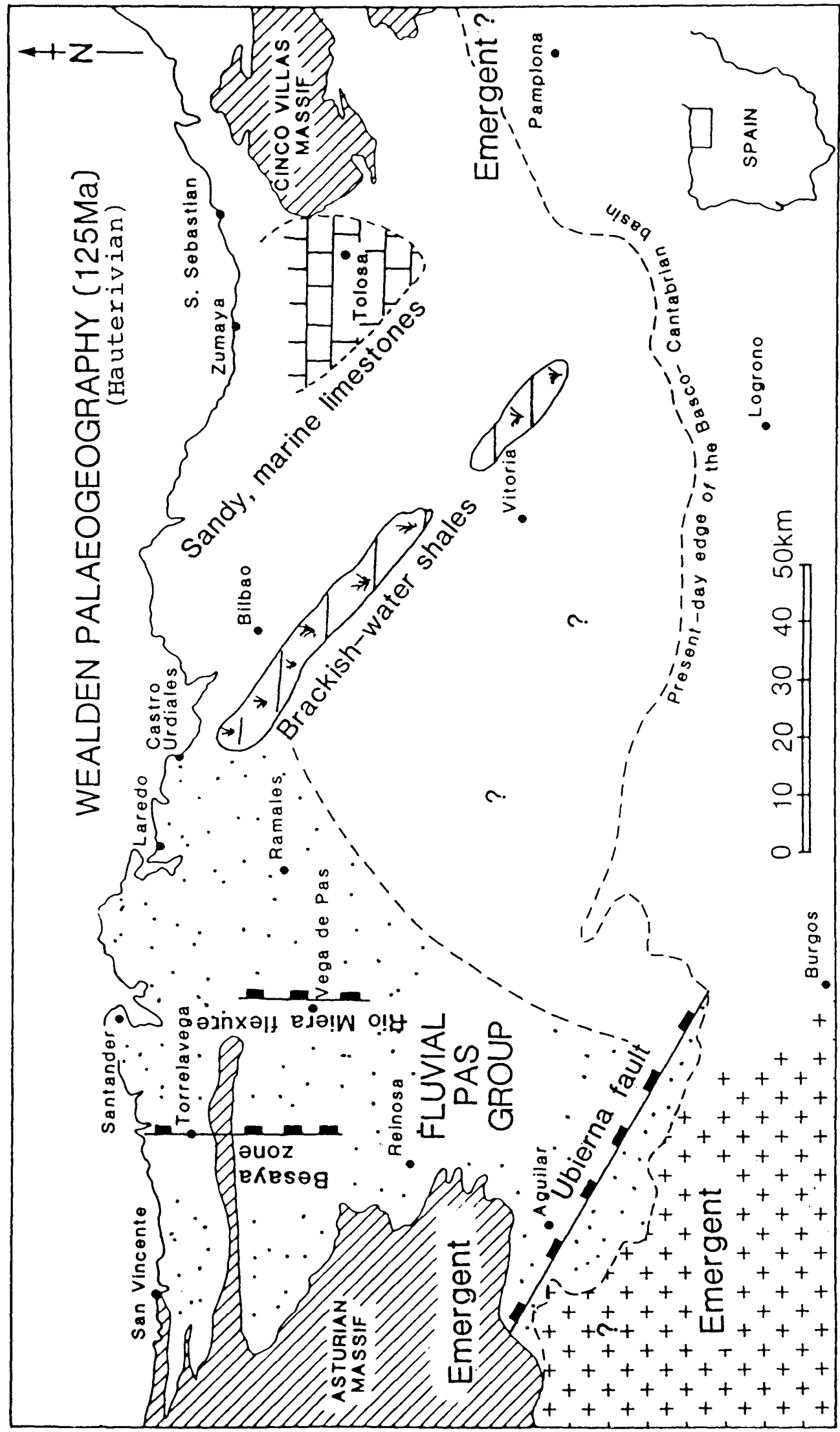


FIGURE 4-2.

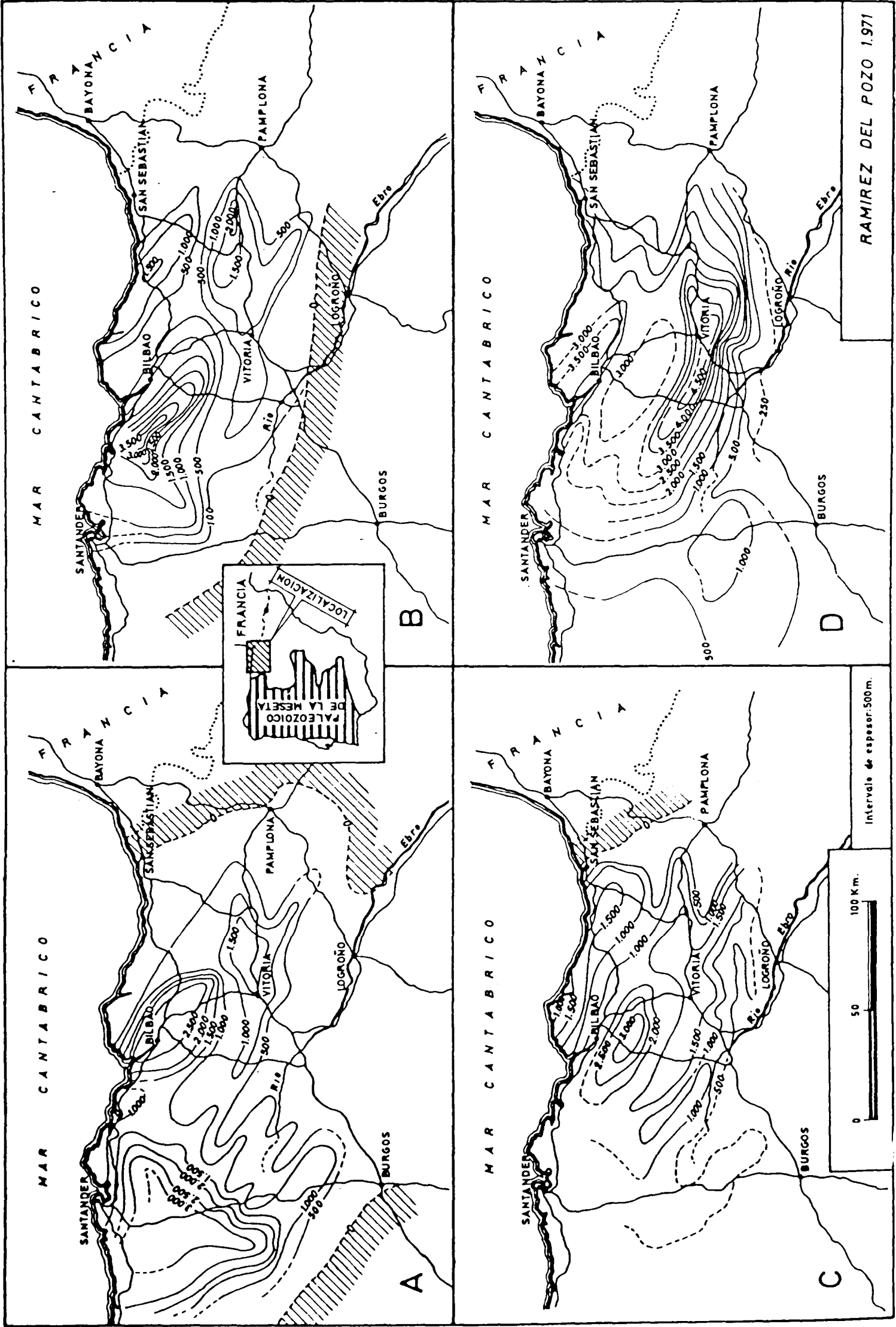
Generalised palaeogeography of the Wealden of the Basco-Cantabrian basin showing the dominantly fluvial Santander basin in the western Peri-Asturian domain, the brackish-water shales around Bilbao and the sandy, marine limestones around Tolosa in the east. Adapted from Rat, (1959) and Mangin & Rat, (1962).

FIGURE 4-3.

Isopach map of the Basco-Cantabrian basin.

- A : The Upper Jurassic/Lower Cretaceous Purbecko-Wealden
- B : Aptian - Lower Albian Urganian.
- C : Albo-Cenomanian Supra-Urganian complex.
- D : Upper Cretaceous

Isopachs in 500m intervals unless otherwise marked.
After Ramirez del Pozo, 1971a.



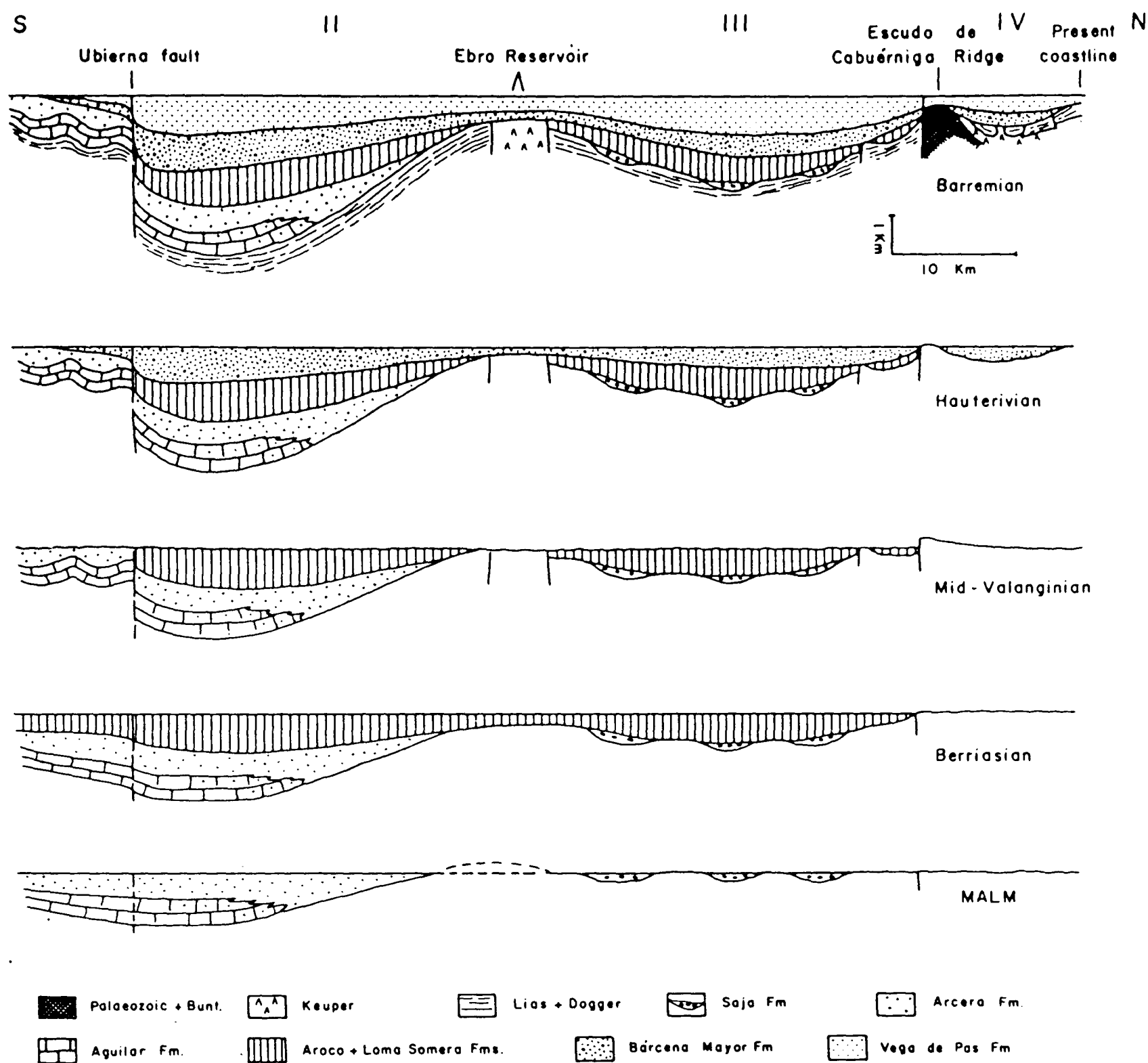


FIGURE 4-4.

Generalised cross-section of the Santander basin from the north around Cuchia (Fig. 4-1) via the Ebro Reservoir to Aguilar de Campoo in the south. See Fig. 4-7 for the stratigraphy. Adapted from Pujalte, 1985. NW Santander is sector IV shown on the top line.

FIGURE 4-5

Stratigraphic correlation for the Purbecko-Wealden of the Santander basin.
Correlation with other parts of Spain and Europe is also given.

SE FRANCE				SWITZERLAND NW GERMANY SE ENGLAND				N O R		T H E		N		S P A I N		IBERIAN CHAIN SIERRA DE LOS CAMEROS		Santander stratigraphy.	
				RAMALES				REOCIN		AGUILAR		SAJA		N OF BURGOS E OF SANTANDER		BISCAY		TOLOSA	
CRETACEOUS				APTIAN				URGO-APTIAN LST. etc.		and		clays		in		WEALDEN FACIES		WEALDEN FACIES	
APTIAN				APT				WEALD CLAY		GAP ?		sands		GAP ?		URGO-APTIAN LST. etc.		APTIAN	
BARREMIEN				BARREMIEN				BARREME		GAP ?		GAP ?		GAP ?		GAP		BLACK SERPULA LIMESTONES	
HAUTERVIEN				HAUTERVIEN				HAUTERIVE		HASTINGS BEDS		HASTINGS BEDS		HASTINGS BEDS		HASTINGS BEDS		BLACK CLAYS	
VALANGINIEN				VALANGINIEN				VALANGINIEN		VALANGINIEN		VALANGINIEN		VALANGINIEN		VALANGINIEN		BLACK CLAYS	
BERRIASIEN				BERRIASIEN				BERRIASIEN		BERRIASIEN		BERRIASIEN		BERRIASIEN		BERRIASIEN		BLACK CLAYS	
PURBECKIEN				PURBECKIEN				PURBECKIEN		PURBECKIEN		PURBECKIEN		PURBECKIEN		PURBECKIEN		BLACK CLAYS	
PORTLANDIEN				PORTLANDIEN				PORTLANDIEN		PORTLANDIEN		PORTLANDIEN		PORTLANDIEN		PORTLANDIEN		BLACK CLAYS	
JURASSIC				JURASSIC				JURASSIC		JURASSIC		JURASSIC		JURASSIC		JURASSIC		JURASSIC	
a				b				c		d		e		f		g		h	
i				j				k		l		m		n		o		p	
q				r				s		t		u		v		w		x	
y				z				aa		ab		ac		ad		ae		af	
ag				ah				ai		aj		ak		al		am		an	
ao				ap				aq		ar		as		at		au		av	
aw				ax				ay		az		ba		bb		bc		bd	
be				bf				bg		bh		bi		bj		bk		bl	
bm				bn				bo		bp		bq		br		bs		bt	
bu				bv				bw		bx		by		bz		ca		cb	
cc				cd				ce		cf		cg		ch		ci		cj	
ck				cl				cm		cn		co		cp		cq		cr	
cs				ct				cu		cv		cw		cx		cy		cz	
da				db				dc		dd		de		df		dg		dh	
di				dj				dk		dl		dm		dn		do		dp	
dq				dr				ds		dt		du		dv		dw		dx	
dy				dz				ea		eb		ec		ed		ee		ef	
eg				eh				ei		ej		ek		el		em		en	
eo				ep				eq		er		es		et		eu		ev	
ew				ex				ey		ez		fa		fb		fc		fd	
fg				fh				fi		fj		fk		fl		fm		fn	
fo				fp				fq		fr		fs		ft		fu		fv	
fw				fx				fy		fz		ga		gb		gc		gd	
ge				gf				gg		gh		gi		gj		gk		gl	
gm				gn				go		gp		gq		gr		gs		gt	
gu				gv				gw		gx		gy		gz		ha		hb	
hv				hw				hx		hy		hz		ia		ib		ic	
ia				ib				ic		id		ie		if		ig		ih	
ib				ic				id		ie		if		ig		ih		ii	
id				ie				if		ig		ih		ii		ij		ik	
ie				if				ig		ih		ii		ij		ik		il	
if				ig				ih		ii		ij		ik		il		im	
ig				ih				ii		ij		ik		il		im		in	
ih				ii				ij		ik		il		im		in		io	
ii				ij				ik		il		im		in		io		ip	
ij				ik				il		im		in		io		ip		iq	
ik				il				im		in		io		ip		iq		ir	
il				im				in		io		ip		iq		ir		is	
im				in				io		ip		iq		ir		is		it	
in				io				ip		iq		ir		is		it		iu	
io				ip				iq		ir		is		it		iu		iv	
ip				iq				ir		is		it		iu		iv		iw	
iq				ir				is		it		iu		iv		iw		ix	
ir				is				it		iu		iv		iw		ix		iy	
is				it				iu		iv		iw		ix		iy		iz	
it				iu				iv		iw		ix		iy		iz		ja	
iu				iv				iw		ix		iy		iz		ja		jb	
iv				iw				ix		iy		iz		ja		jb		jc	
iw				ix				iy		iz		ja		jb		jc		jd	
ix				iy				iz		ja		jb		jc		jd		je	
iy				iz				ja		jb		jc		jd		je		jf	
iz				ja				jb		jc		jd		je		jf		jg	
ja				jb				jc		jd		je		jf		jg		jh	
jb				jc				jd		je		jf		jg		jh		ji	
jc				jd				je		jf		jg		jh		ji		jj	
jd				je				jf		jg		jh		ji		jj		jk	
je				jf				jg		jh		ji		jj		jk		jl	
jf				jg				jh		ji		jj		jk		jl		jm	
jg				jh				ji		jj		jk		jl		jm		jn	
jh				ji				jj		jk		jl		jm		jn		jo	
ji				jj				jk		jl		jm		jn		jo		jp	
jj				jk				jl		jm		jn		jo		jp		jq	
jk				jl				jm		jn		jo		jp		jq		jr	
jl				jm				jn		jo		jp		jq		jr		js	
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js				jt				ju		jv		jw		jx		jy		jz	
jt				ju				jv		jw		jx		jy		jz		ka	
ju				jv				jw		jx		jy		jz		ka		kb	
jv				jw				jx		jy		jz		ka		kb		kc	
jw				jx				jy		jz		ka		kb		kc		kd	
jx				jy				jz		ka		kb		kc		kd		ke	
jy				jz				ka		kb		kc		kd		ke		kf	
jz				ka				kb		kc		kd		ke		kf		kg	
ka				kb				kc		kd		ke		kf		kg		kh	
kb				kc				kd		ke		kf		kg		kh		ki	
kc				kd				ke		kf		kg		kh		ki		kj	
kd				ke				kf		kg		kh		ki		kj		kl	
ke				kf				kg		kh		ki		kj		kl		km	
kf				kg				kh		ki		kj		kl		km		kn	
kg				kh				ki		kj		kl		km		kn		ko	
kh				ki				kj		kl		km		kn		ko		kp	
ki				kj				kl		km		kn		ko		kp		kq	
kj				kl				km		kn		ko		kp		kq		kr	
kl				km				kn		ko		kp		kq		kr		ks	
km				kn				ko		kp		kq		kr		ks		kt	
kn				ko				kp		kq		kr		ks		kt		ku	
ko				kp				kq		kr		ks		kt		ku		kv	
kp				kq				kr		ks		kt		ku		kv		kw	
kq				kr				ks		kt		ku		kv		kw		kx	
kr				ks				kt		ku		kv		kw		kx		ky	
ks				kt				ku		kv		kw		kx		ky		kz	
kt				ku				kv		kw		kx		ky		kz		la	
ku				kv				kw		kx		ky		kz		la		lb	
kv				kw				kx		ky		kz		la		lb		lc	
kw				kx				ky		kz		la		lb		lc		ld	
kx				ky				kz		la		lb		lc		ld		le	
ky				kz				la		lb		lc		ld		le		lf	
kz				la				lb		lc		ld		le		lf		lg	
la				lb				lc		ld		le		lf		lg		lh	
lb				lc				ld		le		lf		lg		lh		li	
lc				ld				le		lf		lg		lh		li		lj	
ld				le				lf		lg		lh		li		lj		lk	
le				lf				lg		lh		li		lj		lk		ll	
lf				lg				lh		li		lj		lk		ll		lm	
lg				lh				li		lj		lk		ll		lm		ln	
lh				li				lj		lk		ll		lm		ln		lo	
li				lj				lk		ll		lm		ln		lo		lp	
lj				lk				ll		lm		ln		lo		lp		lq	
lk				ll				lm		ln		lo		lp		lq		lr	
ll				lm				ln		lo		lp		lq		lr		ls	
lm				ln				lo		lp		lq		lr		ls		lt	
ln				lo				lp		lq		lr		ls		lt		lu	
lo				lp				lq		lr		ls		lt		lu		lv	
lp				lq				lr		ls		lt		lu		lv		lw	
lq				lr				ls		lt		lu		lv		lw		lx	
lr				ls				lt		lu		lv		lw		lx		ly	
ls				lt				lu		lv		lw		lx		ly		lz	
lt				lu				lv		lw		lx		ly		lz		ma	
lu				lv				lw		lx		ly		lz		ma		mb	
lv				lw				lx		ly		lz		ma		mb		mc	
lw				lx				ly		lz		ma		mb		mc		md	
lx				ly				lz		ma		mb		mc		md		me	
ly				lz				ma		mb		mc		md		me		mf	
lz				ma				mb		mc		md		me		mf		mg	
ma				mb				mc		md		me		mf		mg		mh	
mb				mc				md		me		mf		mg		mh		mi	
mc				md				me		mf		mg		mh		mi		mj	
md				me				mf		mg		mh		mi		mj		mk	
me				mf				mg		mh		mi		mj		mk		ml	
mf				mg				mh		mi		mj		mk		ml		mn	
mg				mh				mi		mj		mk		ml		mn		mo	
mh				mi				mj		mk		ml		mn		mo		mp	
mi				mj				mk		ml		mn		mo		mp		mq	
mj				mk				ml		mn		mo		mp		mq		mr	
mk				ml				mn		mo		mp		mq		mr		ms	
ml				mn				mo		mp		mq		mr		ms		mt	
mn				mo				mp		mq		mr		ms		mt		mu	
mo				mp				mq		mr		ms		mt		mu		mv	
mp				mq				mr		ms		mt		mu		mv		mw	
mq				mr				ms		mt		mu		mv		mw		mx	
mr				ms				mt		mu		mv		mw		mx		my	
ms				mt				mu		mv		mw		mx		my		mz	
mt																			

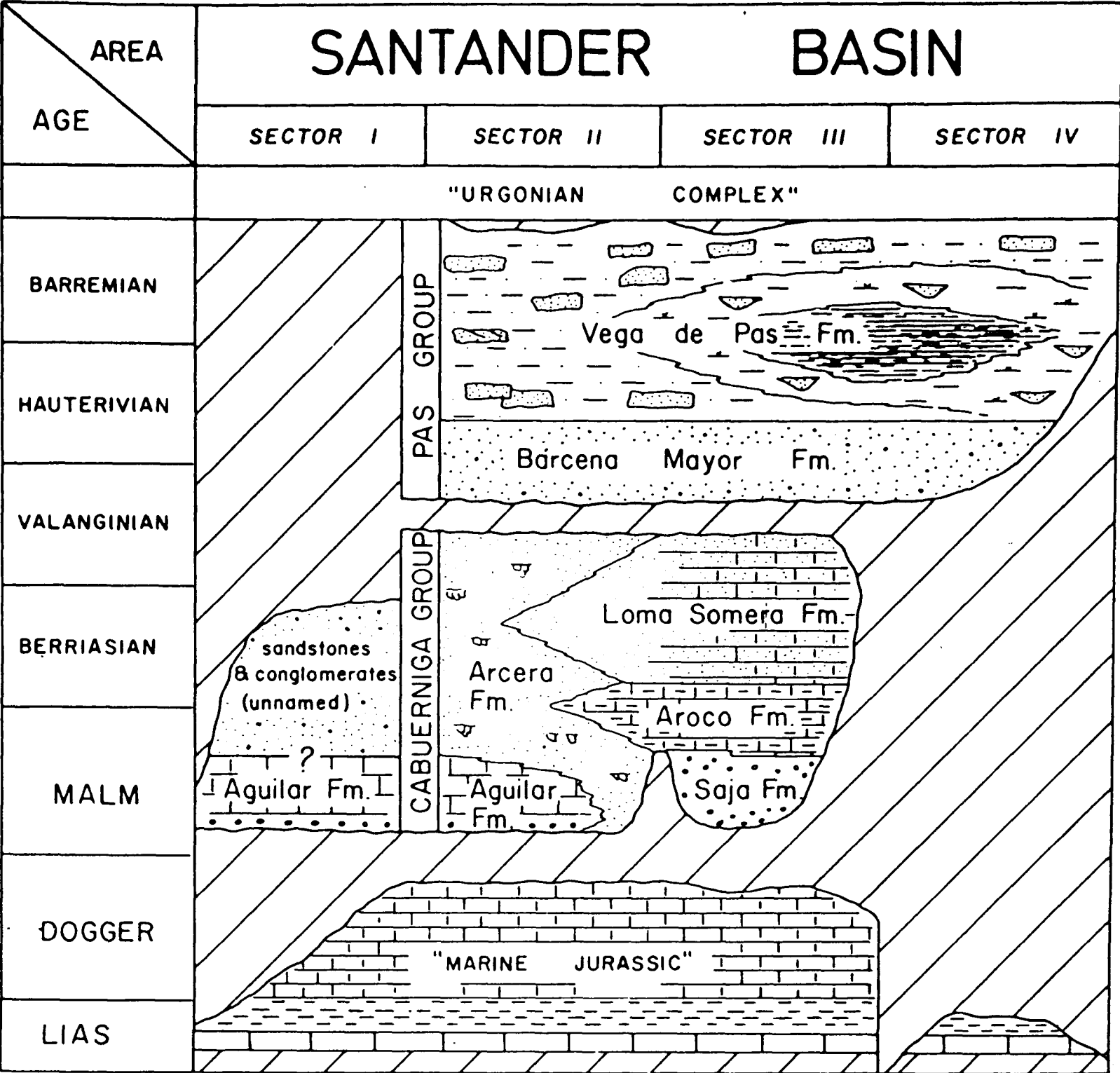


FIGURE 4-6. Upper Jurassic and Lower Cretaceous litho-stratigraphy of the Santander basin. From Pujalte, 1985. Oblique lines indicate hiatus and the sectors mentioned at the top of the diagram are those shown in Fig. 4-1.

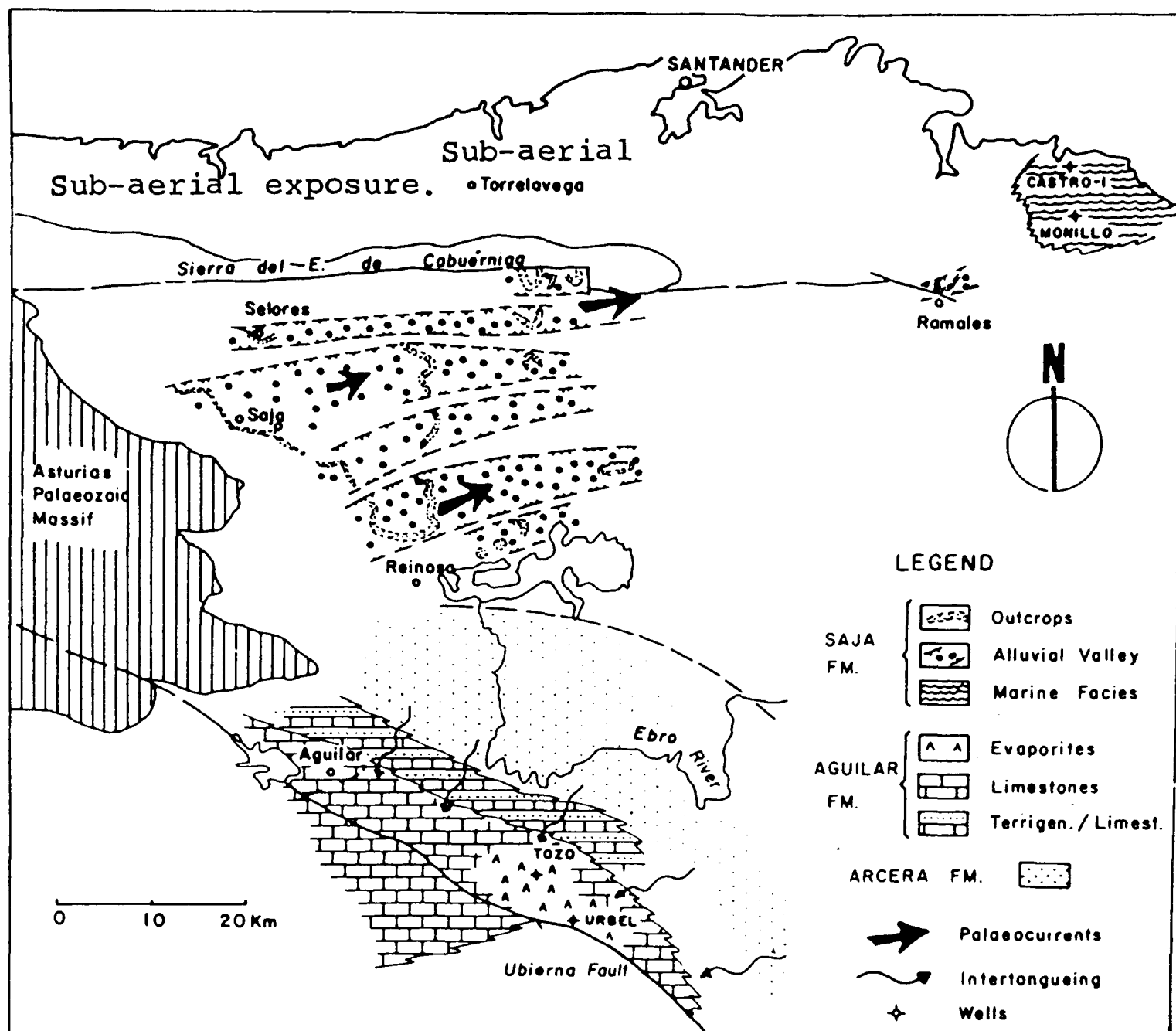


FIGURE 4-7.

Upper Jurassic palaeogeography of the Santander basin showing the alluvial vallies of the Saja Fm. and the non-marine limestones of the Aguilar Fm.. NW Santander was a zone of sub-aerial exposure at this time. Composed after Pujalte, 1985 and IGMEn. The evaporites south of Tozo have only been proved in boreholes.

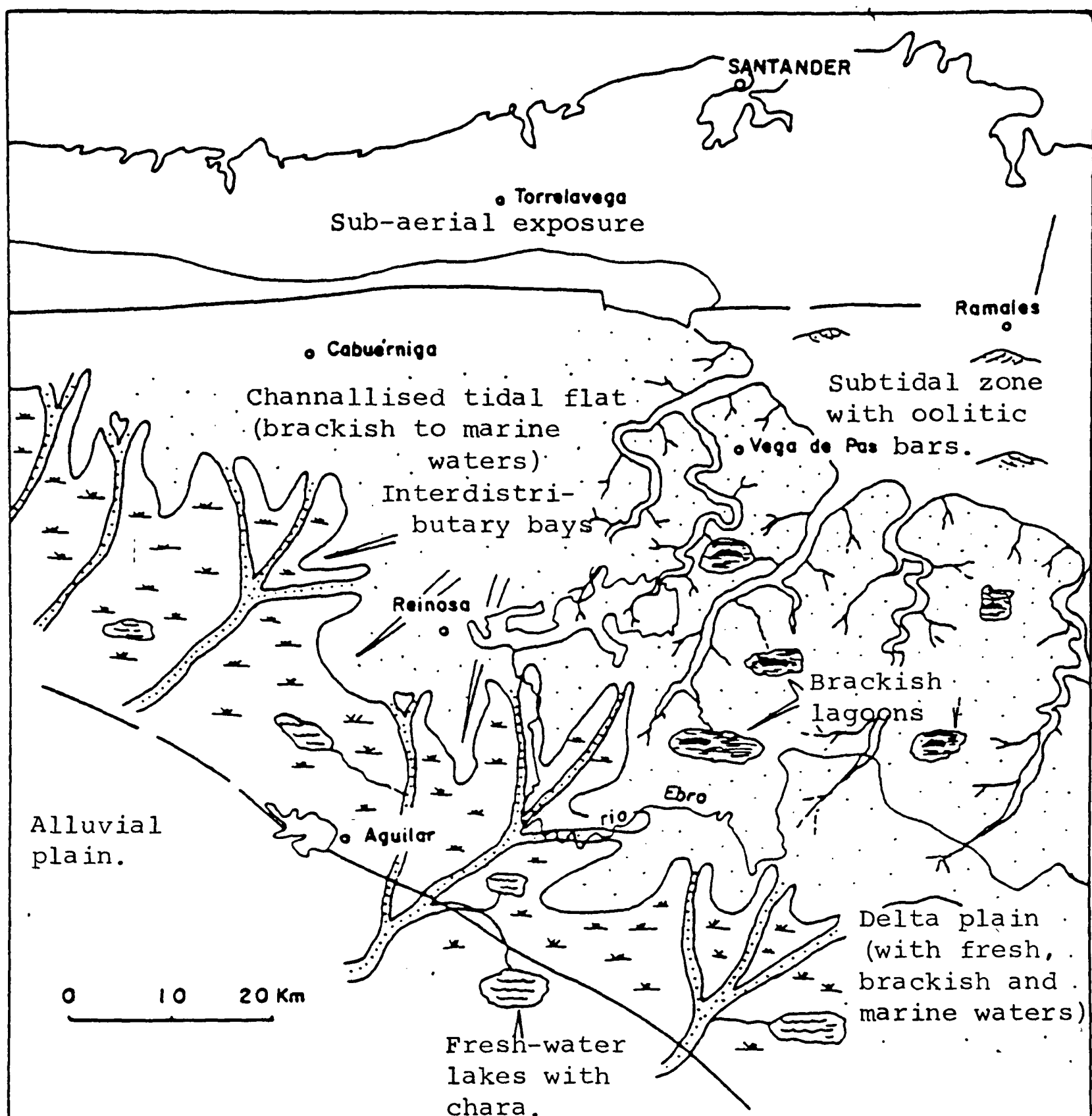


FIGURE 4-8

Palaeogeography for the Loma Somera Fm. (the "capas de bryozoos" of Garcia Mondejar & Pujalte, 1981 or the Bryozoan beds member of Pujalte, 1981) of the Cabuerniga Group. NW Santander was an area of sub-aerial exposure at this time. Adapted from Garcia Mondejar & Pujalte, 1981.

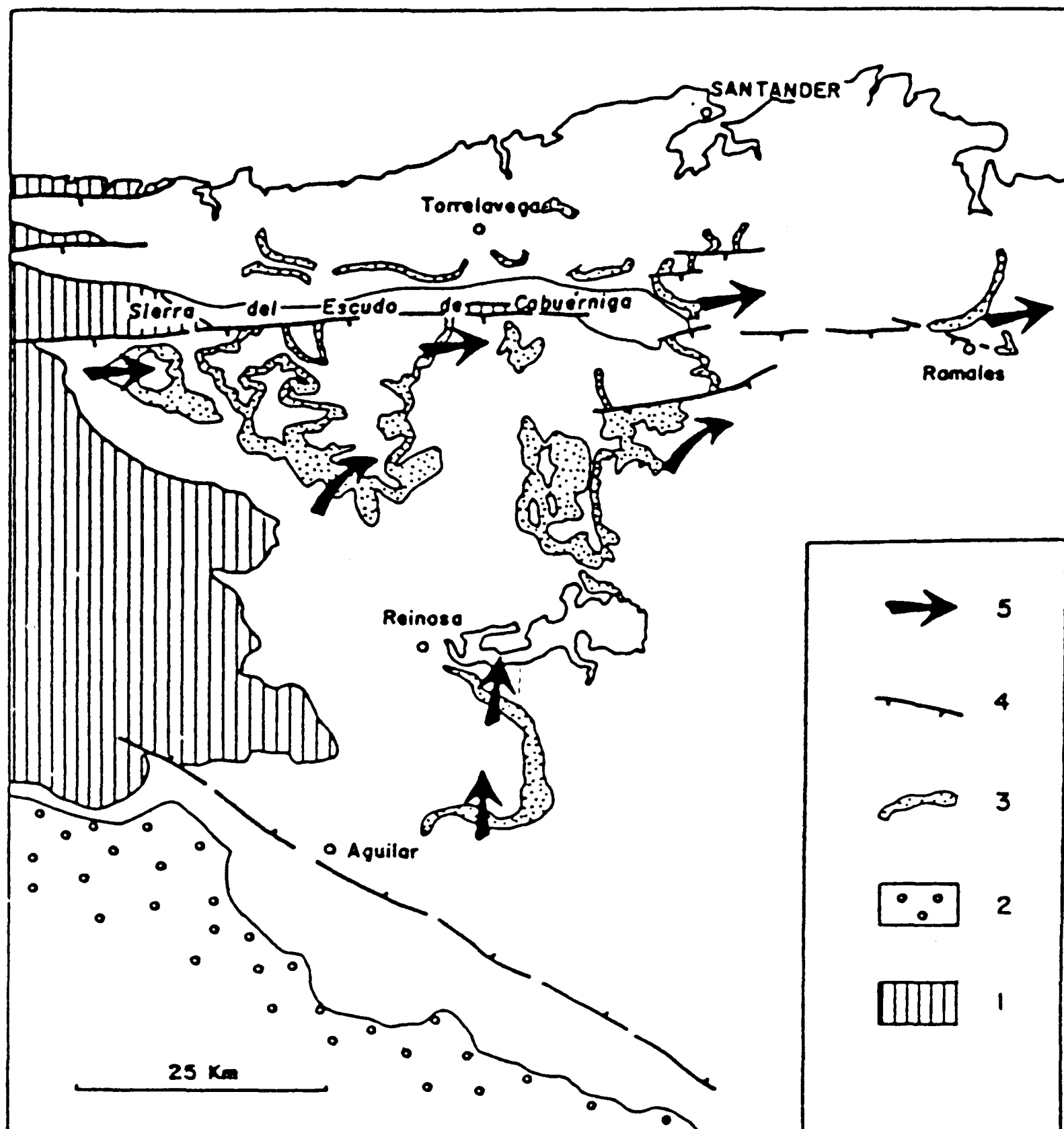


FIGURE 4-9.

Palaeocurrent directions in the Barcena Major Fm. of the Pas Group. Note the source from the S/SW of the Santander basin but also the turn to the east further north due to the syndepositional activity of the Escudo de Cabuerniga fault. The Barcena Major Fm. only extends into the southern area of NW Santander because of the overall southward tilting of the NW Santander block. Key : 1 : Asturian massif, 2 : Tertiary of the Duero basin (limit of outcrop), 3 : Outcrops of the Barcena Major Fm., 4 : Faults active during the deposition of the Barcena Major Fm., 5 : Palaeocurrents in this formation. After Garcia Mondejar & Pujalte, 1981.

FIGURE 4-10.

Ribbon fluvial channel of the Vega de Pas Fm. (red beds member) on the Cuchia section (57319828 and Section 15, 35-41m). This meandering river channel has a sharp, erosional base and trough cross-bedding near its base (seen under hammer in bottom left of picture). Higher in the channel fill parallel lamination cross lamination occurs in the sandstones. The mottled, red overbank mudstones are seen in the top of the picture with thin (crevasse splay ?) sandstones and pedogenic mottling. Relatively typical example of this facies association. Correct orientation and hammer is 30cm long.

FIGURE 4-11.

Lacustrine limestone in the Vega de Pas Fm. of the Cuchia section (57319828 and Section 15, 46m). The photograph shows well-developed oncoliths, locally encrusting charophyte stems. Rare black pebbles occur at the top of the photograph. Considerable reworking of the oncoliths during and after deposition. Taken from the upper part of this lacustrine limestone. Lens cap is 5cm wide and the photograph is in correct orientation.

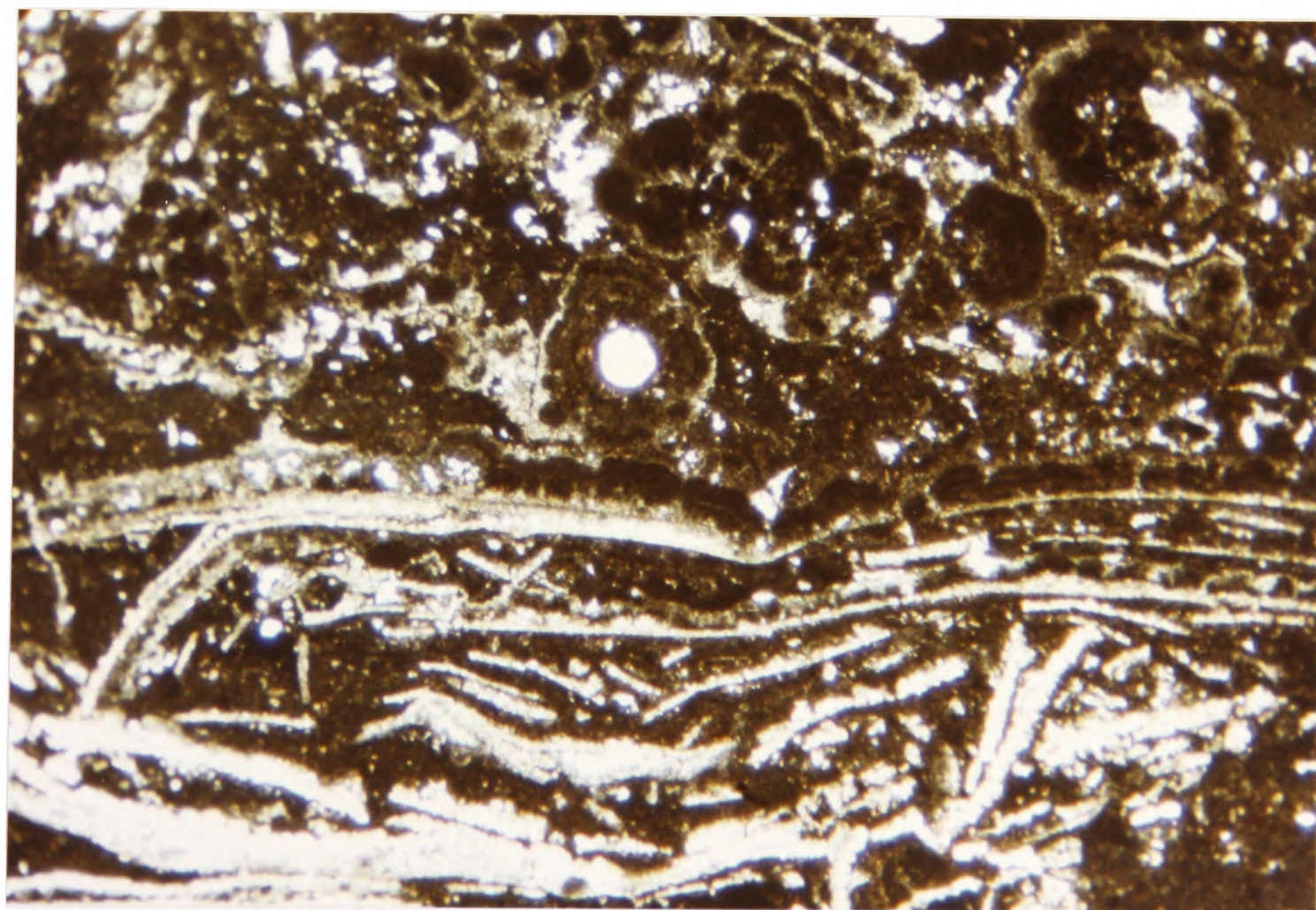
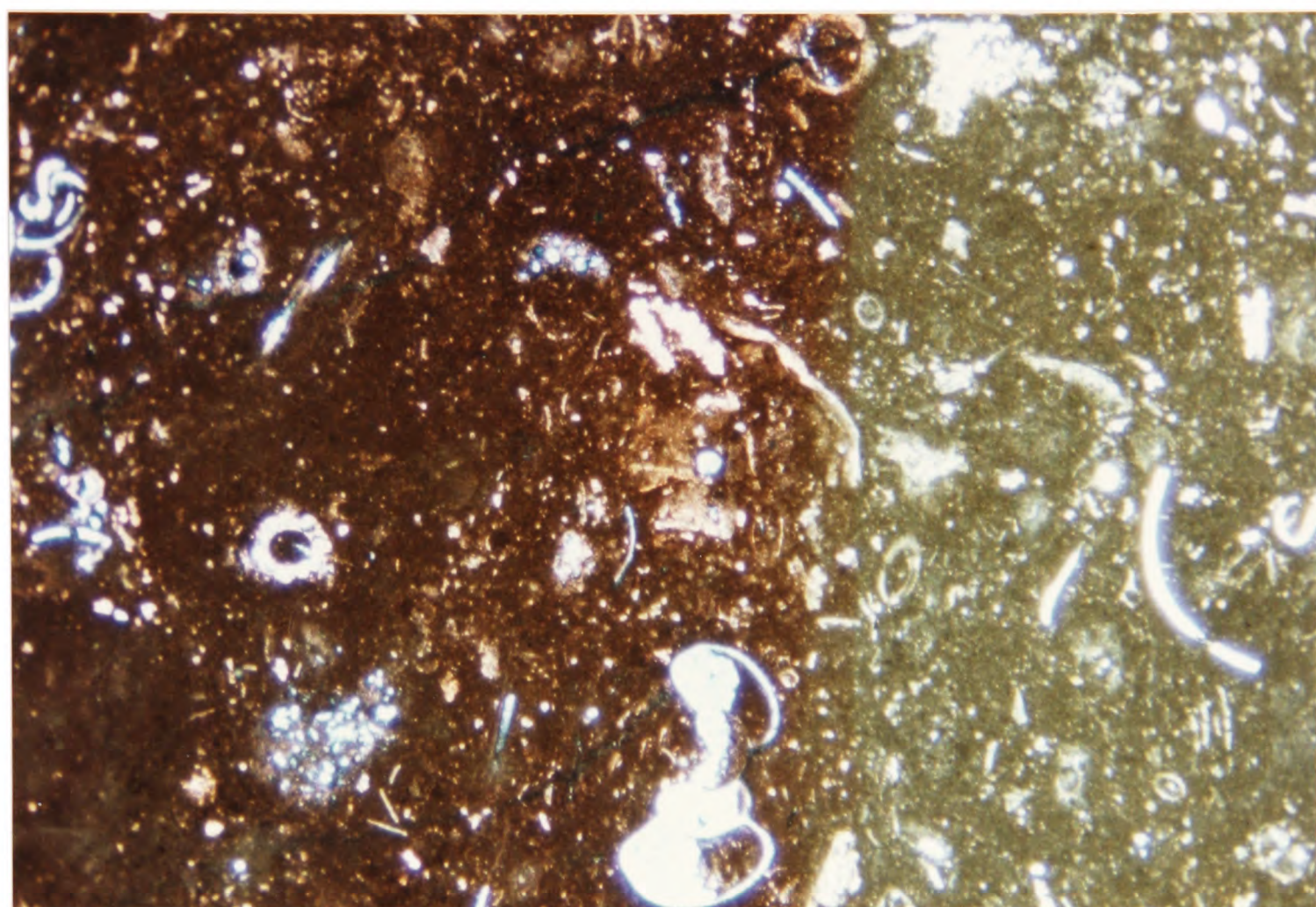


FIGURE 4-12.

This is an example of the open lacustrine limestone from the Cuchia section of the Vega de Pas Fm. The left hand of the photograph has been stained with potassium ferricyanide/Alizurin Red S solution and shows that the spar is ferroan, whereas the micritic matrix is non-ferroan. This lacustrine assemblage includes charophyte oogonia and stems, gastropods, ostracod shells and is totally bioturbated. It was taken in plane-polarized light of an area 6mm by 9mm wide.

FIGURE 4-13.

This is an example of the lacustrine cyanophyta limestone from the Vega de Pas Fm. on the Cuchia section. It shows the extensive growth of the cyanophyta on leaves and charophyte (?) stems as well as in oncoidal growths. There is a late, ferroan spar. It was taken in plane-polarized light of an area 6mm by 9mm wide.



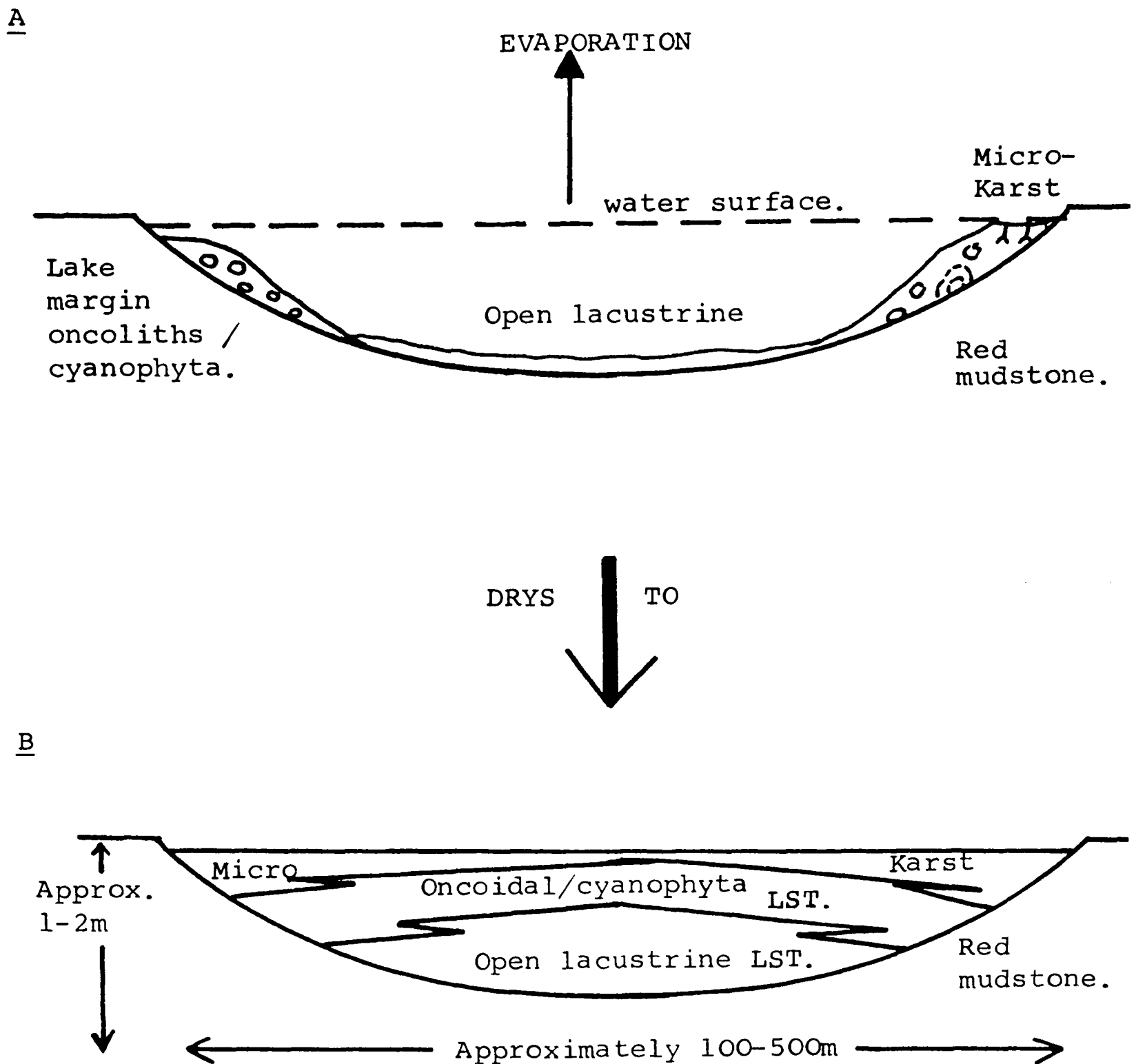


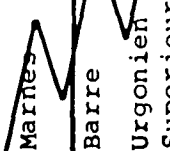
FIGURE 4-14

General model for the pure lacustrine limestones in the Wealden Vega de Pas Fm. of NW Santander. Upper diagram (A) shows the initial development of the open-lacustrine lake with marginal areas rich in cyanophyta/oncoliths and capped at the very edges by subaerial micro-karsts. This lake directly overlies the red mudstone. The lower diagram shows the evolution of the lake through time as progressive evaporation and final complete dessication of the lake occurs (Fig. B). LST = Limestone.



FIGURE 4-15.

General view of the Wealden Vega de Pas Fm. (Hauterivian-Barremian) on the Cuchia section at 57319828 and on Section 15, 46-98m. This shows the typical lithologies of the Wealden and is the best exposure of the Wealden in NW Santander. Section shown is 50m thick. At the base two lacustrine limestone metre thick beds occur and are exposed on the beach (bottom right). The upper one forms a semi-continuous outcrop. Above these thin meandering river channels can be seen encased in red mudstone that is mainly grass covered. The top channel complex (below posts) consists of three incised channels. The youngest is the upper left one. In the top right-hand corner the well-bedded rocks are the base of the Umbrera Fm. of the Urganian Torrelavega Group.

AGE	MENGAUD (1913b, c and 1920).	RAT, (1959) and Ciry et al. , (1967).	MONSEUR, (1967).	Collignon et al., (1979) & Vadala, (1981).	IGME maps a,b,g & i.	Garcia Mondejar et al., (1982).	Garcia Mondejar & Pujalte, 1981.	Hines, (1985a) and this work.	GROUP
LOWER ALBIAN.	Gres steriles.	Bancs gresieux du Supra-Urgonian.	?		C ¹ ₁₆	Las Penosas Formation.	A ₃ Garcia Mondejar 1979a,b,c. U ₃ ¹	Las Penosas Formation.	SANTANDER GROUP.
	Marnes 								
	Barre Urgonien Superieur	Barre (Masse) Urgonienne principal / superieure.	Barre Urgonienne Superieur	Barre Urgonienne Superieure		Reocin Formation.	C ₂ U ₂ ²	Comi- llas Mb. Sierra Member	
	Calcaires marneux a Ammonites.	Serie detritique intermediaire.	Calcaire marneux a Exogyra Latissima		C ²³ C ₁₅		Reocin Formation.	U ₂ ¹ U ₂ ^{sup.}	Novales Member Barrio Member.
GARGASIAN / CLANSAYESIAN.	Gres et argiles steriles.			Formation terrigena superieure		Cuchia Formation.	A ₂	Rodezas Formation	
	Barre Urgonienne Inferieur.	Masse / Barre Urgonienne Inferieure.	Barre Urgonienne Inferieur.					Calderon Member. Arroyo Member.	
				Barre Urgonienne Inferieur	C ¹ ₁₅₃	Caliza de San Esteban Formation.	C ₁	San Esteban Formation.	
	Banc gresieux O ₂ a Orbitolines a aptiennes.	Transition entre la serie argilo-gresuse et les facies calcaires.		Formation terrigena inferieure				Patrocinio Formation.	
BEDOULIAN	Marnes de la Playa de Patrocinio.				C ¹ ₁₅₂	Caranceja Formation.	A ₁		
	O ₁ Calcaires gresieux de la Punta de la Umbra			Formation calcareo- gresuse.	C ¹ ₁₅₁			Canales Member.	
BARREMIAN	Wealdien.	Wealdien			C ³⁻⁰ C _{W12} -14			Umbreira Formation.	
								Vega de Pas Fm.	

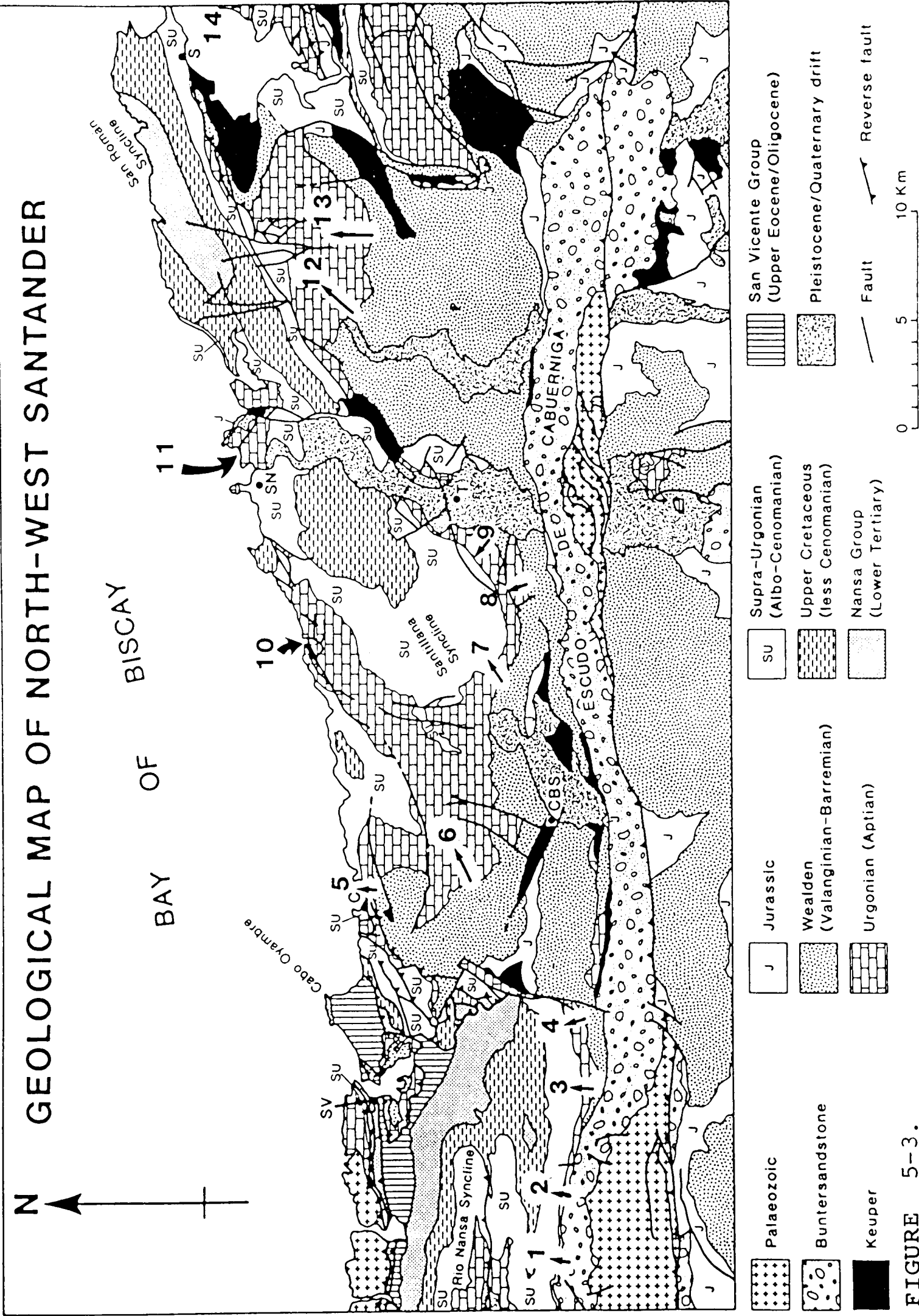


FIGURE 5-3. Location diagram for the sections shown in Fig. 5-2 through the Lower Aptian sequence.

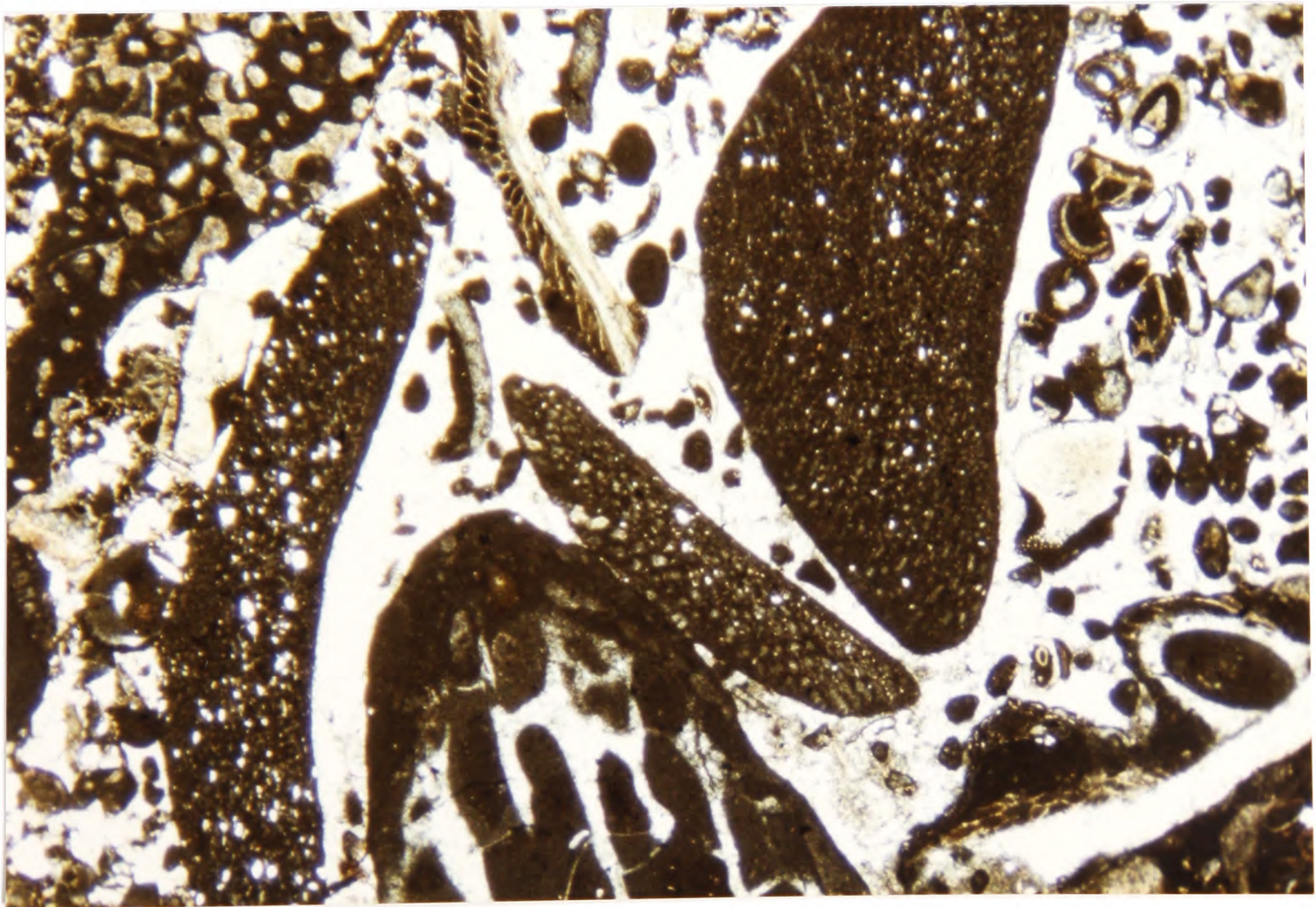
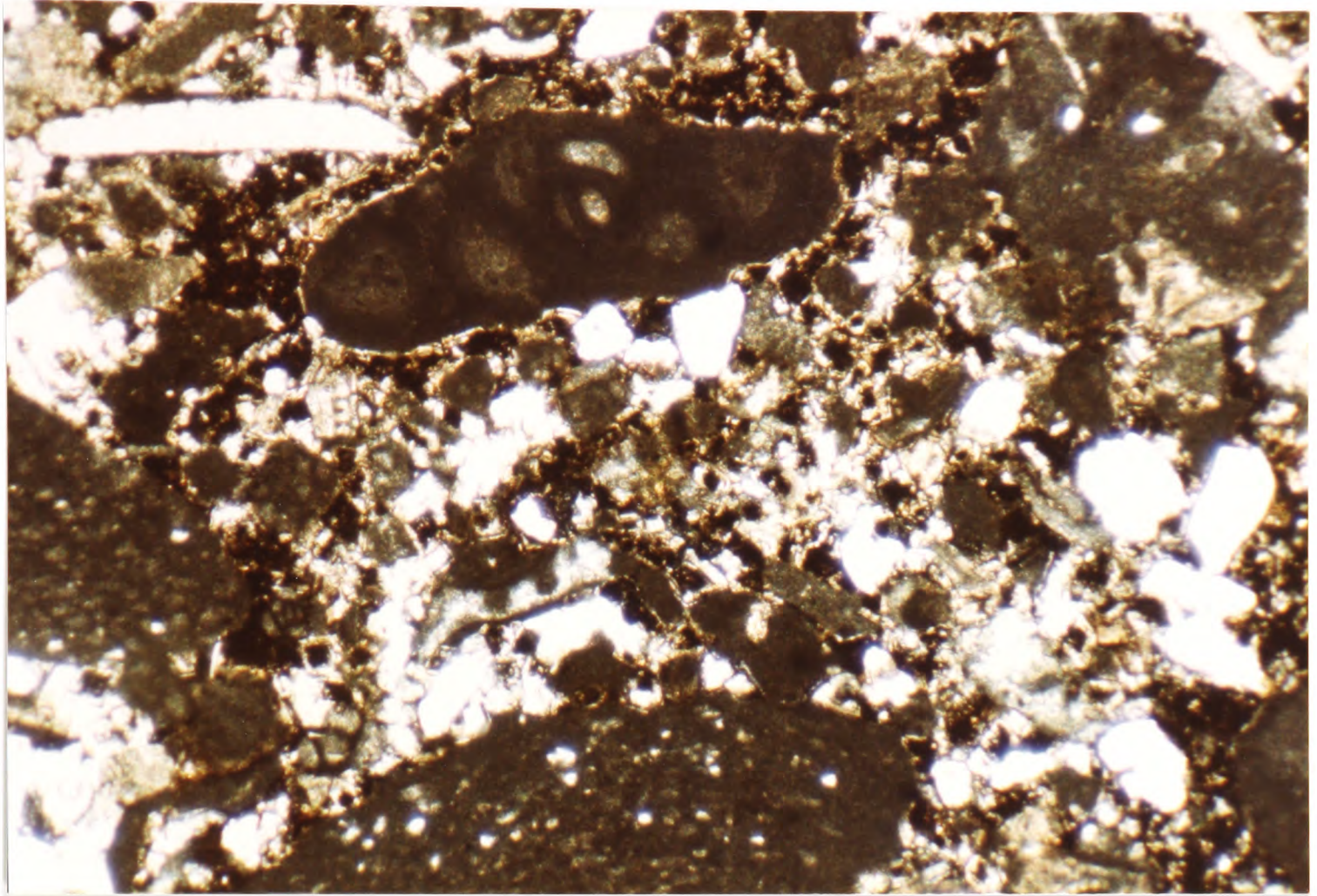


FIGURE 5-4.

This shows a typical photomicrograph of the Umbrera Fm. from the Cuchia section. The skeleta includes orbitolinids, bivalve cortoids, miliolids and other marine skeleta (see Chapter 5.2.1). The white areas on the photograph are quartz sand grains or ferroan, equant calcite spar. There is then a late diagenetic, idiomorphic ferroan dolomite with euhedral crystals. This was taken in plane-polarized light of an area 2.4 by 3.6mm wide.

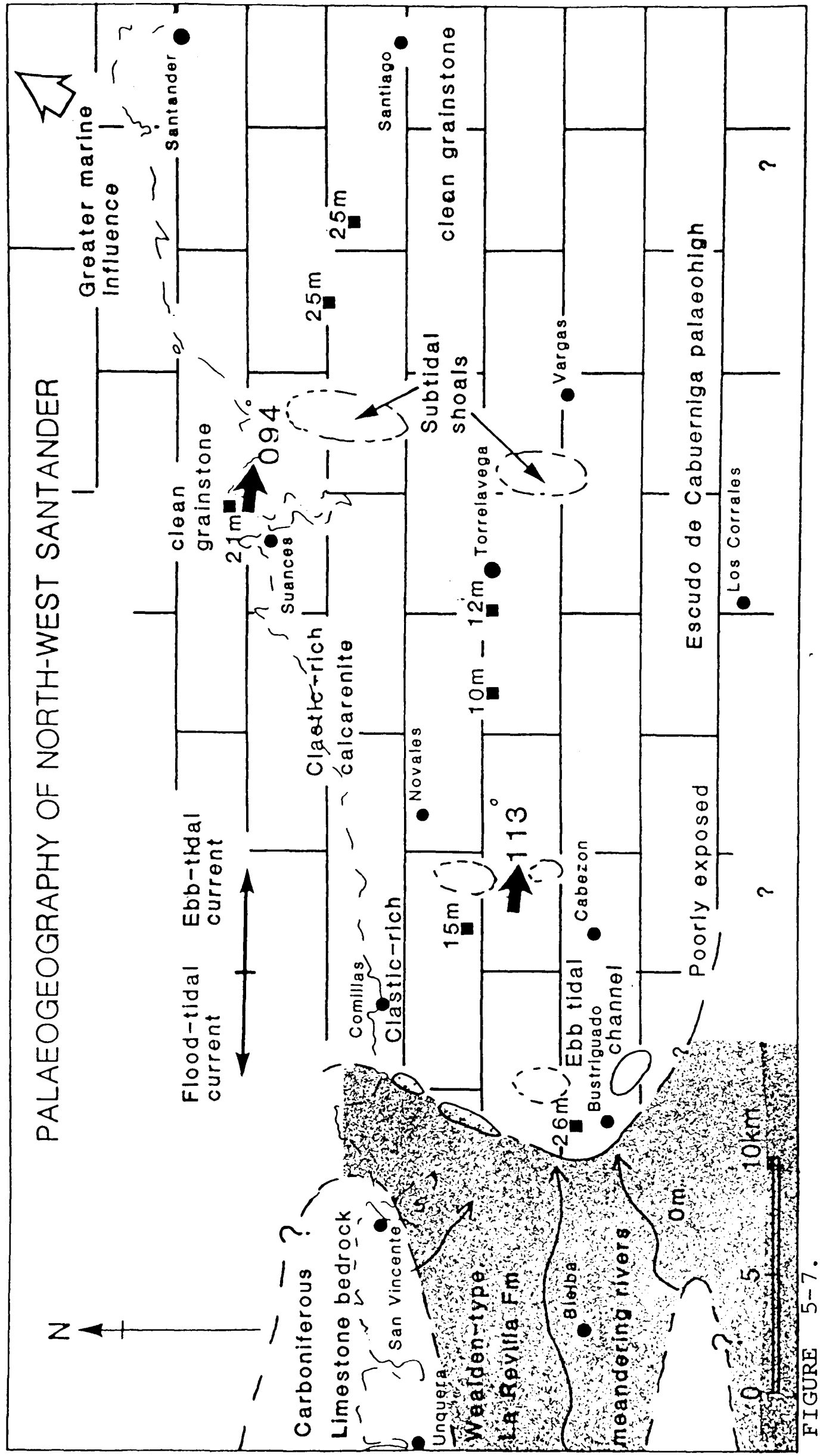
FIGURE 5-5.

This is a typical example of the high-energy, grainstones from the Umbrera Fm. and was taken from the Cuchia section. It contains abundant orbitolinids along with corals, intraclasts, rhodophyta, dasycladaceae, gastropods, ooids, serpulids, arenaceous foraminifera, echinoderms, bivalve cortoids and other neritic skeleta. It has a ferroan, sparry matrix with equant crystals and late diagenetic dolomite crystals (Fig. 5-4). This was taken in plane-polarized light of an area 6mm by 9mm.



FIGURE 5-6.

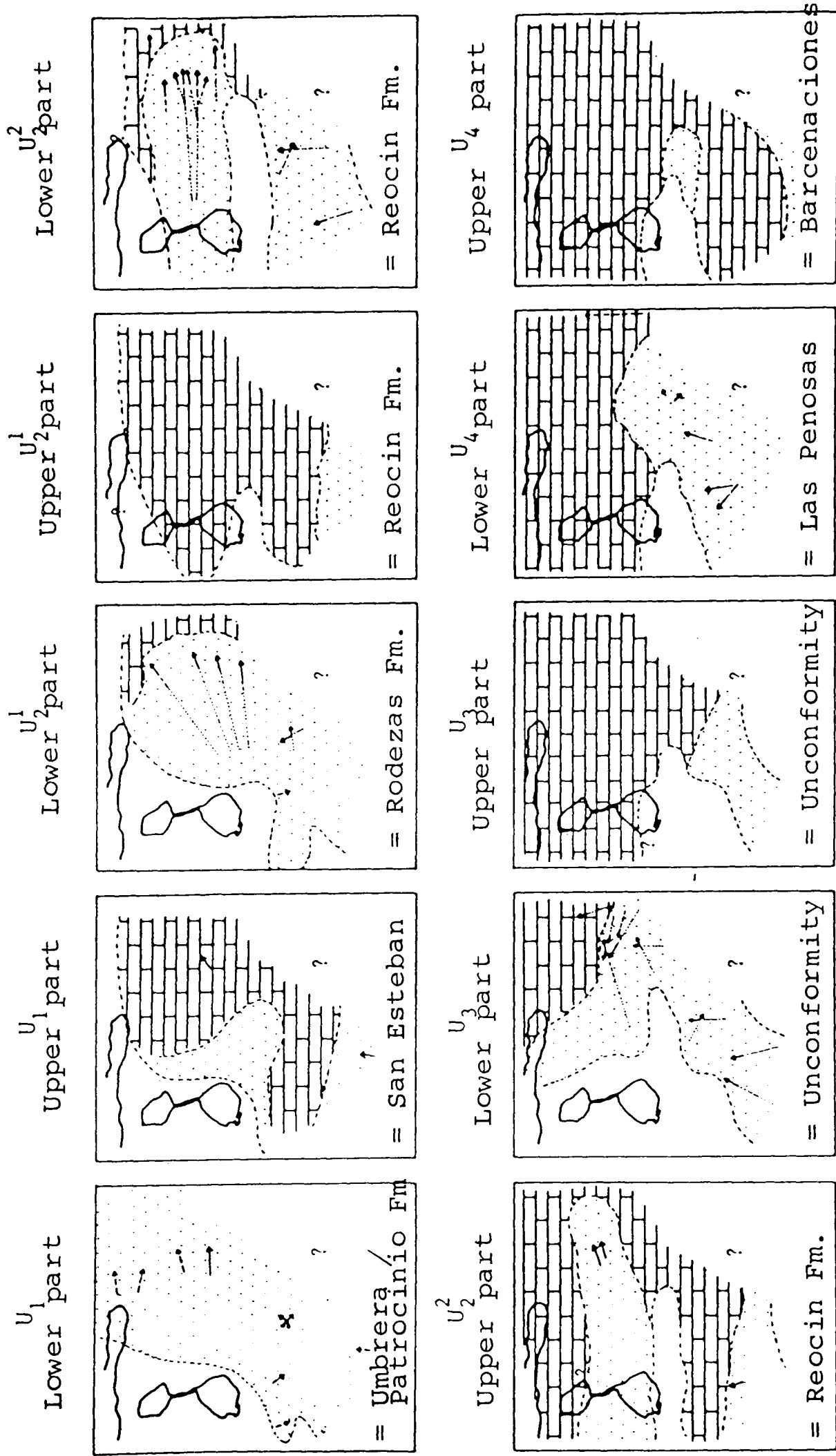
Uppermost part of the Umbrera Fm. (Torrelavega Group) / basal part of the Patrocínio Fm. on the type section at Cuchia (57319826, Playa de Patrocínio). The lower half of the photograph shows the well-bedded pack/grainstones of the Umbrera Fm.. Note the tongue of hemipelagic marl that rapidly thins out from the bottom right to the middle left on the photograph. It is an interdigitation of the Patrocínio Fm. with the Umbrera Fm.. The Canales Mb. of the Patrocínio Fm. is the recessive weathering marl in the upper half of the photograph. Note its colour banding.



Palaeogeography for the basal Bedoulian (= Lowermost Aptian) during the deposition of the Umbrera Fm.. Key: - ■ : Thickness of the Umbrera Fm. in metres;  : Mean palaeocurrent direction from cross-bedding in the Umbrera Fm.;  : Area of deposition of Umbrera Fm. lithology;  : Area of deposition of the fluvial La Revilla Fm.;  : Subtidal calcarenite shoals; ● : Town. Bedrock exposed at this time shown in west.

FIGURE 5-8.

Palaeogeographic evolution for the SW Basco-Cantabrian basin during the Apto-Albian. The U_1 to U_4 stratigraphy is taken from Garcia Mondejar, 1979b. The area shown in the eight boxes is for the area south of the Escudo de Cabuerniga and is the area outlined in Fig. 5-9. At the bottom of individual boxes is the formation with which it correlates in NW Santander. For correlations see Fig. 5-1.



Adapted from Garcia Mondejar, 1979b.

-  Continental sedimentation predominantly.
-  Marine sedimentation predominantly.
-  Erosion / non-deposition.
-  Mean palaeocurrent directions.

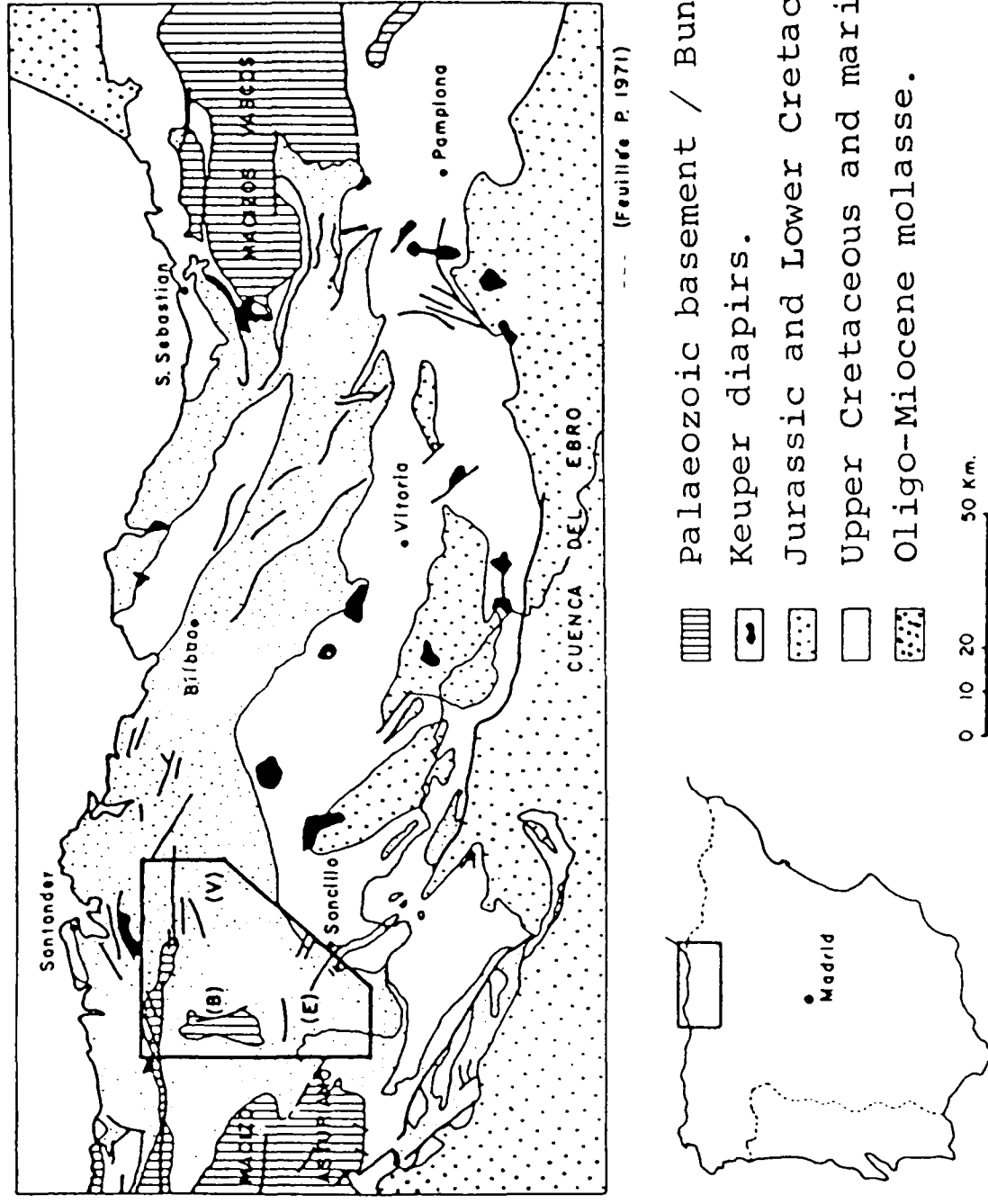


FIGURE 5-9.

Location of the SW Basco-Cantabrian basin area for which palaeogeographies are produced in Fig. 5-8. All the eight palaeogeographies of Fig. 5-8 show the lense-shaped Escudo de Cabuerniga at their tops and the two Buntersandstone outcrops of Besaya in the top left. Key:- V:Valnera; B:Besaya; E:Ebro. These three localities are used by Garcia Mondejar as distinct subareas for the Urgonian s.l. deposition and give rise to local subdivisions of the Urgonian e.g. V₁ to V₄ for the Valnera area, B₁ to B₄ for the Besaya area. Diagram adapted from Garcia Mondejar, 1979b.

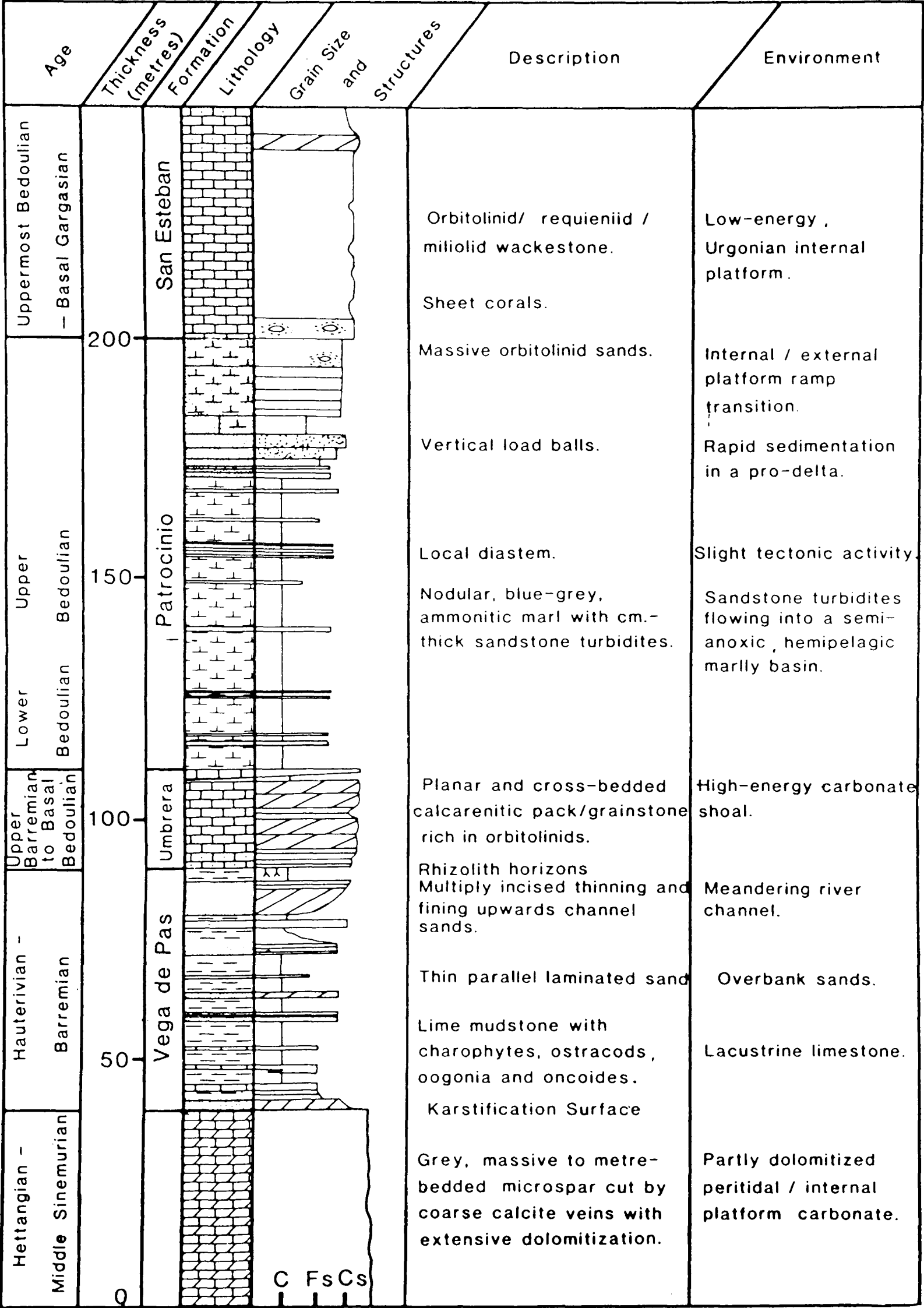


FIGURE 5-10.

General vertical sequence log of the Playa de Patrocinio section, Cuchia (57299825; Section 15/1, 0 to 197.4m, Section 15A/1, 0 to 63m). See chapters 4 and 5 for further description

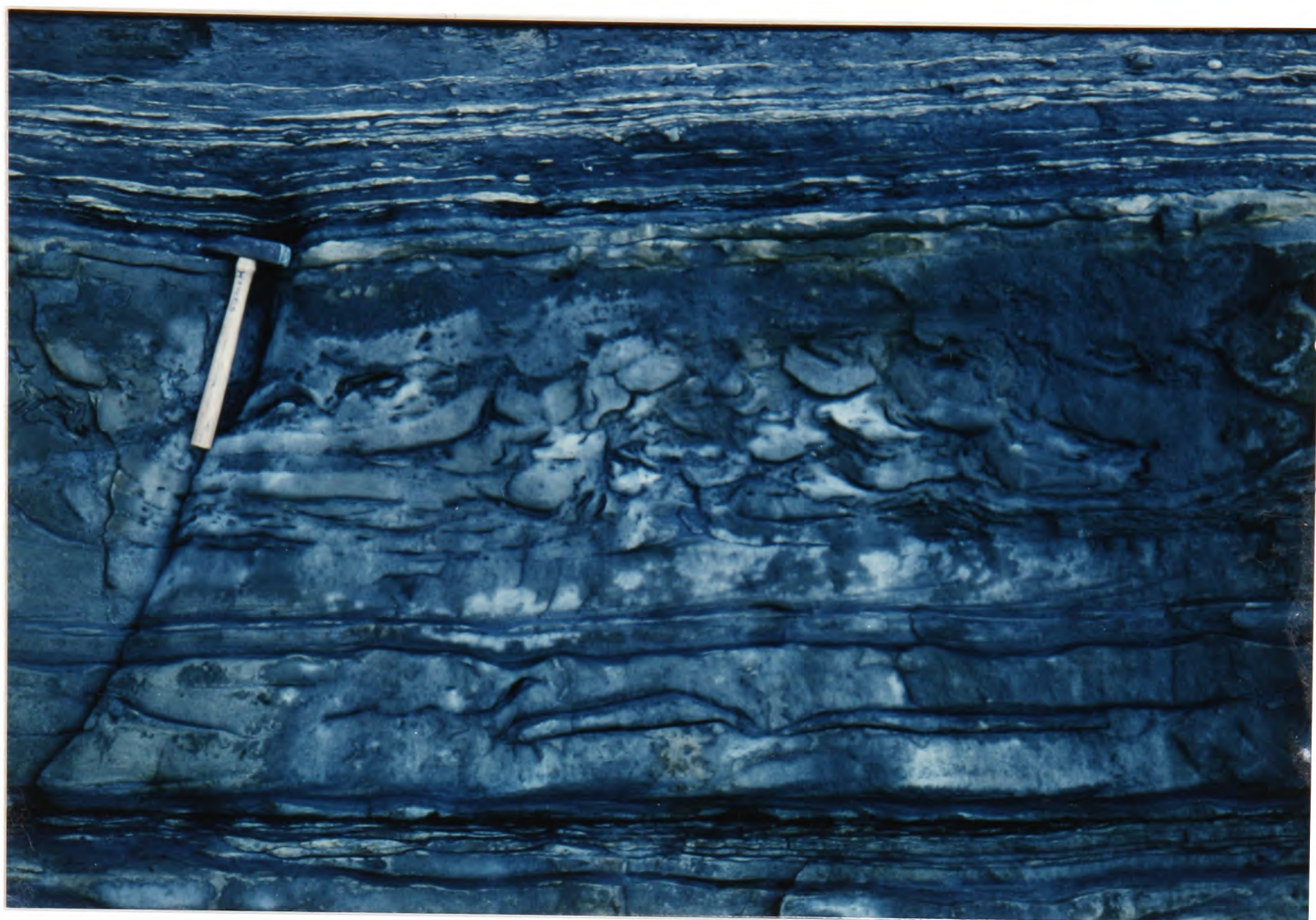


FIGURE 5-11.

The upper Lanchas Member of the Patrocinio Formation on the type section at the Playa de Patrocinio, Cuchia (57289822; Section 15A/1, 4-6m). Thin-bedded turbidites/tempestites are present in the upper third of the photograph. The central bed shows extensive soft sediment deformation - sand balls, flame structures, etc.. Wave ripples can be seen in the basal thin-bedded "event" sandstones. The hammer is 20cm long.

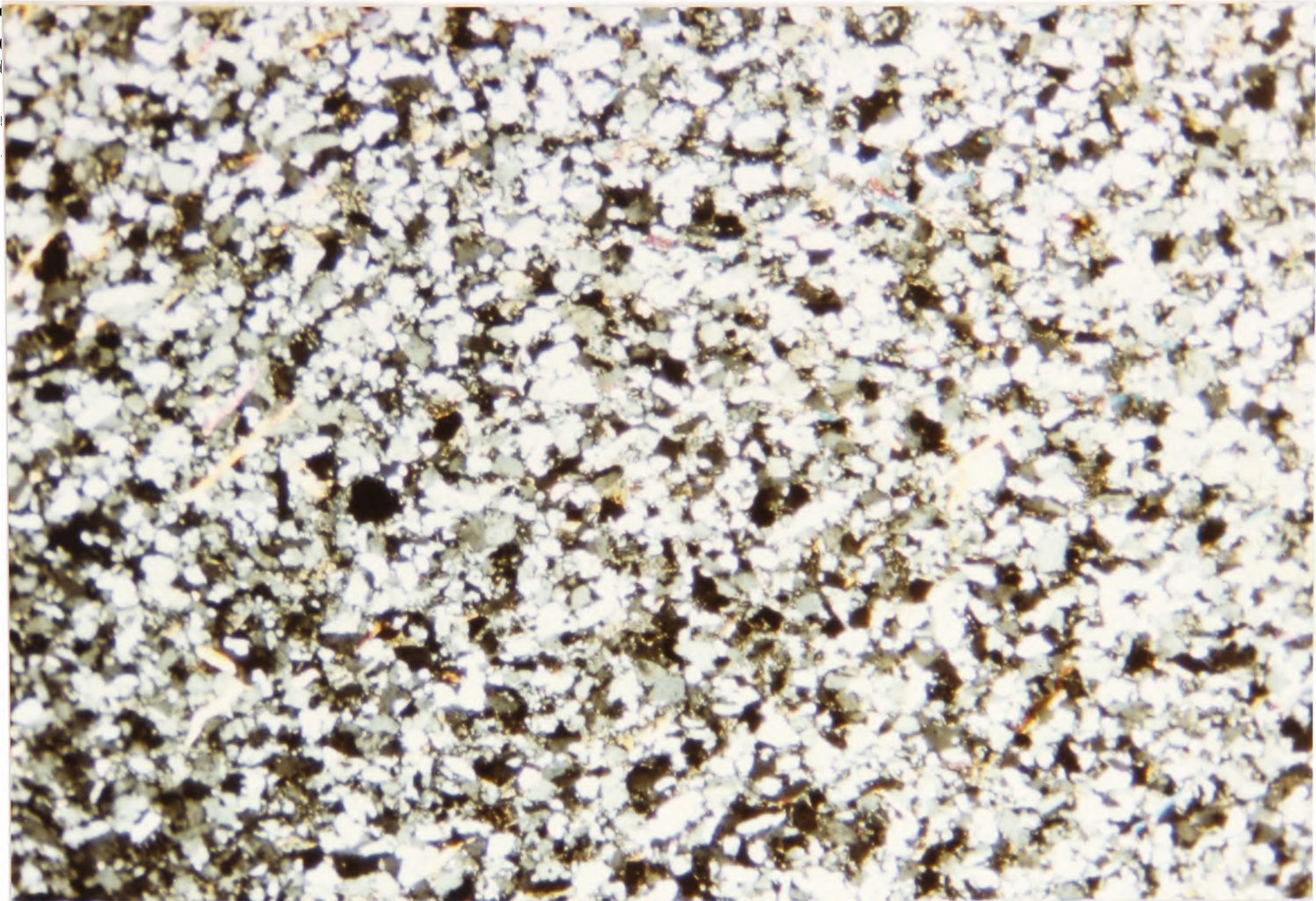
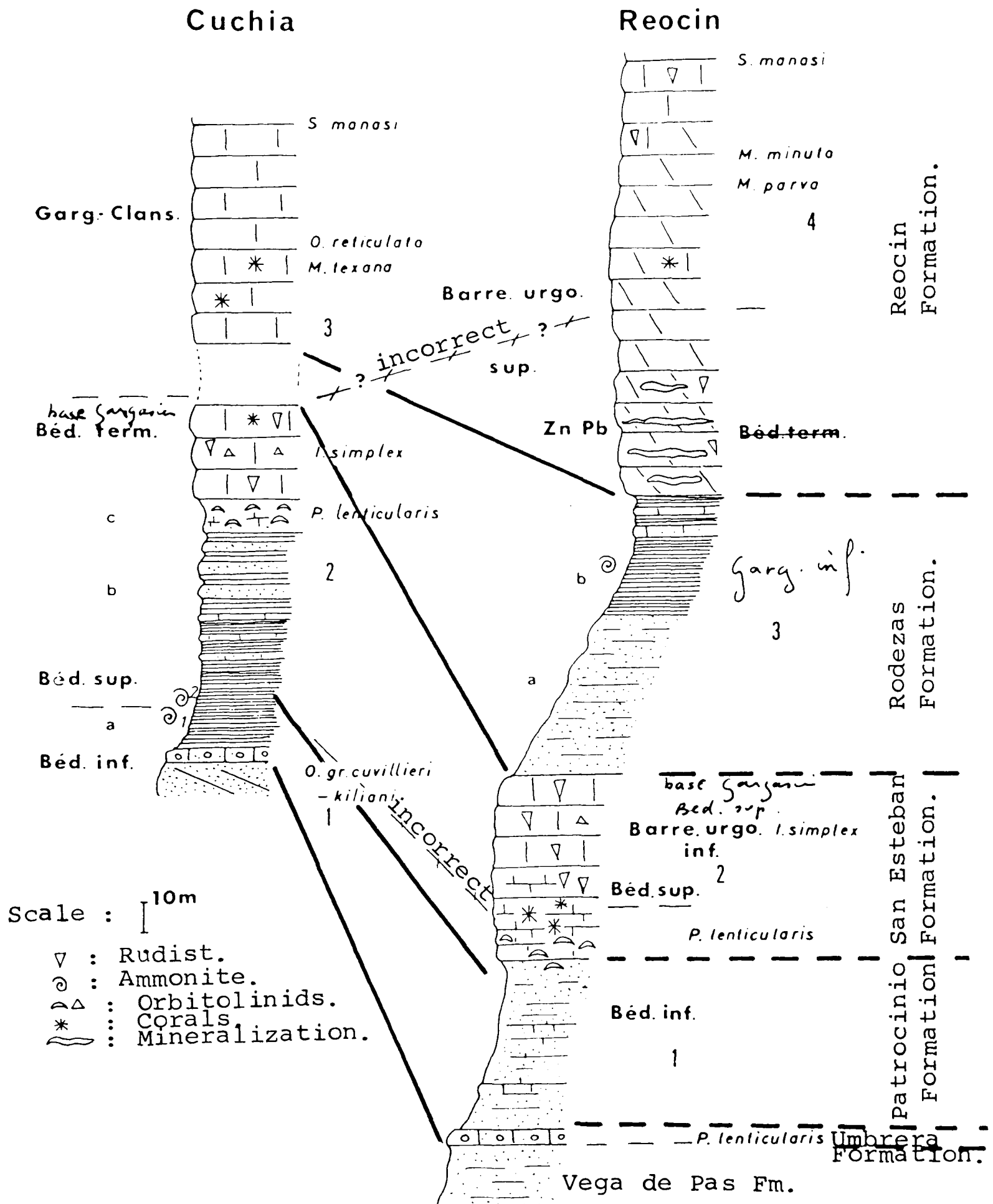


FIGURE 5-12.

This is a typical microfacies of the Patrocinio Formation from the Cuchia section and shows one of the thin-bedded sandstones. It is dominated by medium to fine grained, well sorted quartz sand with only a minor feldspar content. It also has numerous mica flakes of muscovite. This was taken in cross-polarized light of an area 6mm by 9mm wide.

FIGURE 5-13.

A stratigraphic comparison between the Cuchia (Section 11 on Fig. 5-2) section and the Reocin section (Section 9 on Fig. 5-2) from Collignon et al., 1979. These authors proposed biostratigraphic correlation of the lithologies (incorrect dashed lines below) that were revised by Pascal pers. comm. (bold lines below). The revised dating for the Reocin section is written in hand-script



on that section (Pascal, pers. comm.). A correlation with lithostratigraphy (sensu Hines, 1985a) is shown in the right-hand column. The key conclusion of the revised stratigraphy is that the lithostratigraphic formations are more synchronous than originally thought by Collignon et al., 1979. Diagram adapted from Collignon et al., 1979.

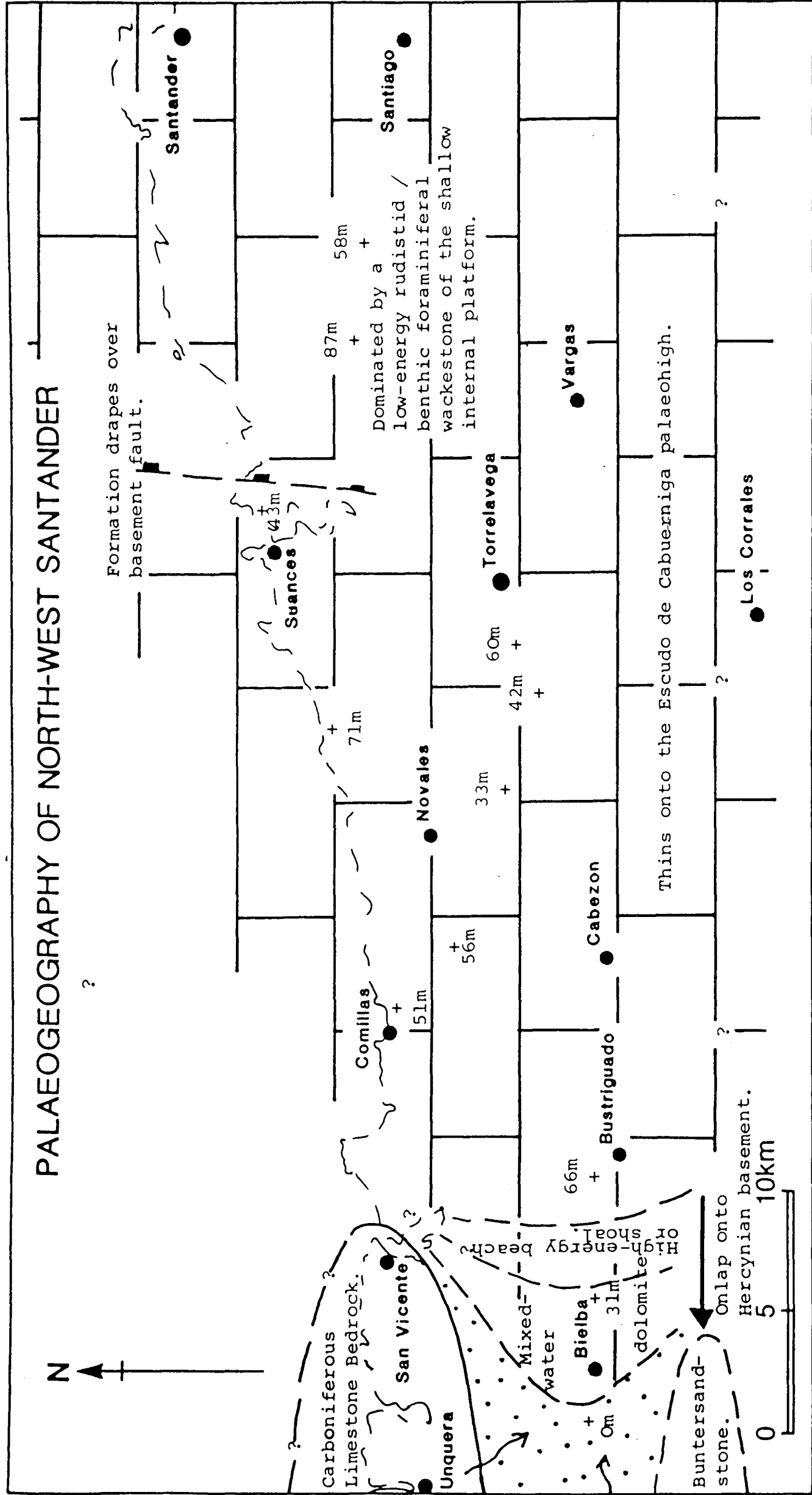


FIGURE 5-14.

Palaeogeography of the uppermost Bedoulian/basal Gargasian during the deposition of the San Esteban Fm.. Key:- + : Thickness of the San Esteban Fm. in metres; / : Fault with gentle differential movement; ::::: Zone of Wealden-type fluvial La Revilla Fm. sedimentation; ● : Towns; — : Area of deposition of the San Esteban Fm. lithology. Note the shoaling towards the west.

FIGURE 5-15A.

General view of the Lower Aptian sequence around Canales (55299714) looking NNW towards the sea. The central karstified limestone shown on the photograph (positioned between the two red-rooved houses on the left of the photograph) is the 56m thick San Esteban Fm.. Above and below it are the poorly-exposed, marly Rodezas and Patrocinio Fms. respectively. In the top right-hand part of the photograph is the basal part of the Reocin Fm.. The photograph illustrates the typical style of outcrop in the area.

FIGURE 5-15B.

Metre-bedded outcrop of the San Esteban Fm. at Canales (55299714). This is typical for this formation. The person is 1.8m tall.



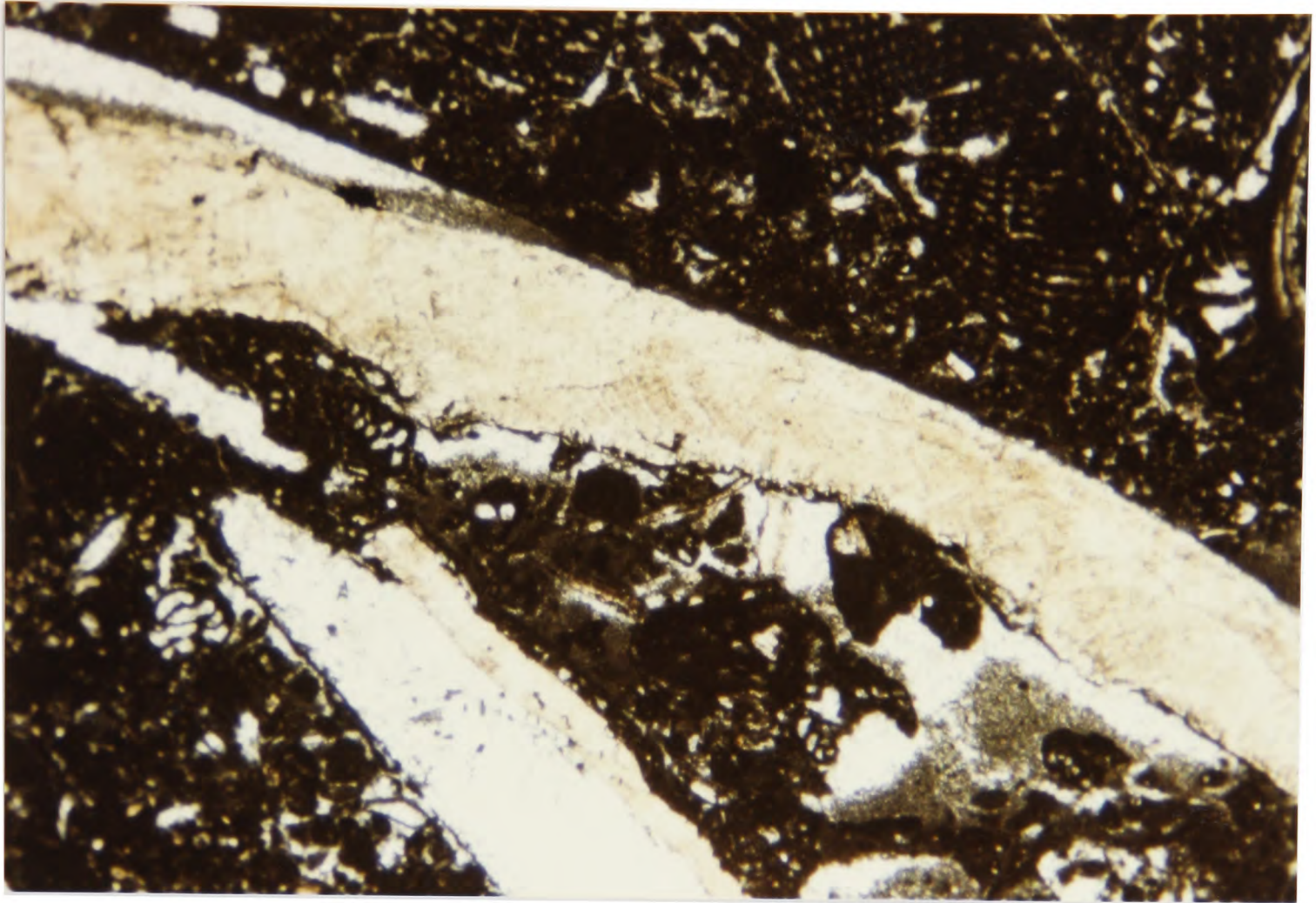


FIGURE 5-16.

A typical microfacies of the San Esteban Fm. from the Cuchia section showing the abundant orbitolinids, miliolids and requienid rudist shells along with other benthic foraminifera. Across the centre of the figure is an unrecrystallized rudist shell, showing the original prismatic structure of the rudist. The clotted, micritic matrix is rich in benthic foraminifera and has local zones of neomorphic and space-filling spar. This was taken in plane-polarized light of an area 6mm by 9mm wide.

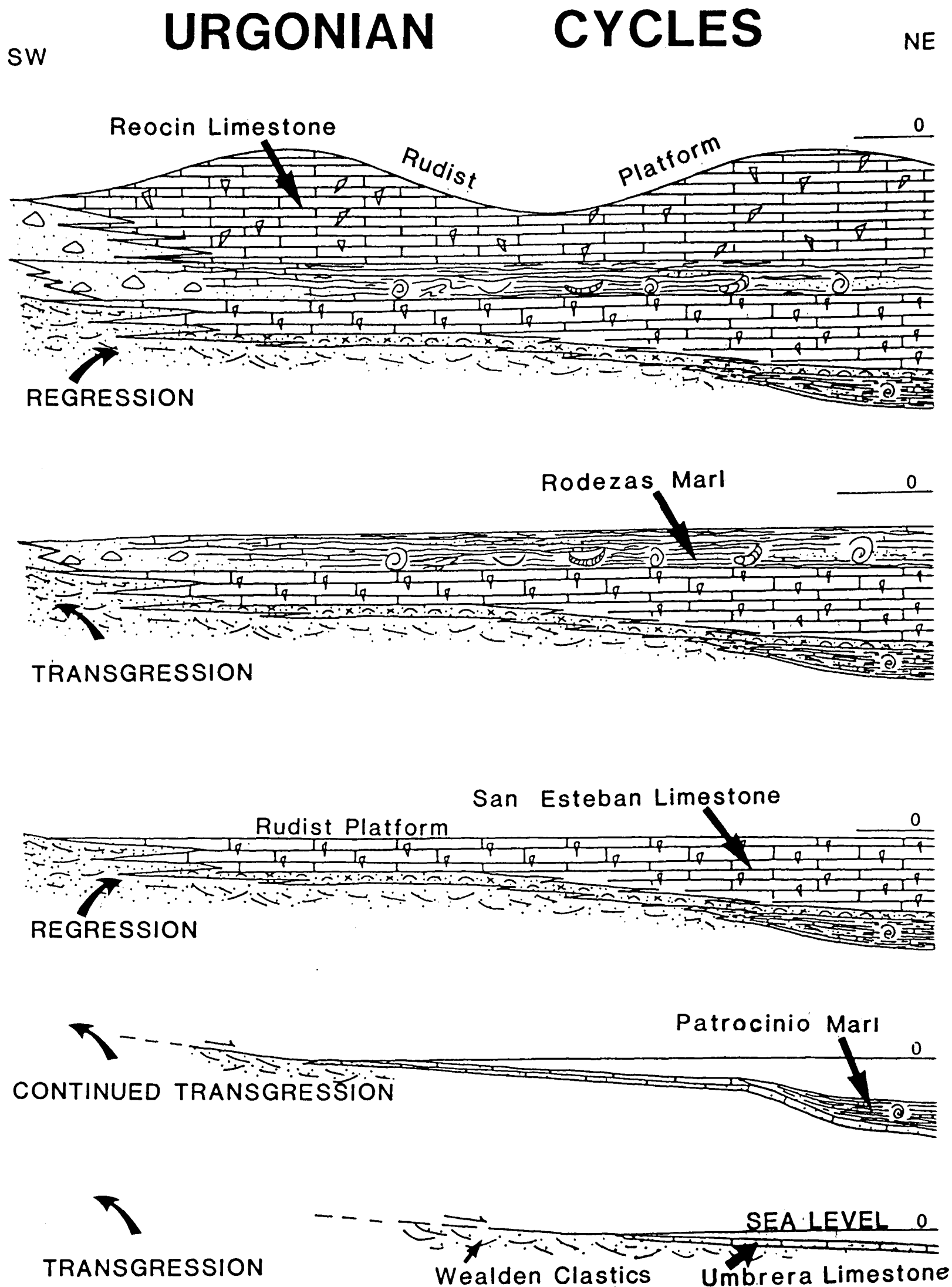


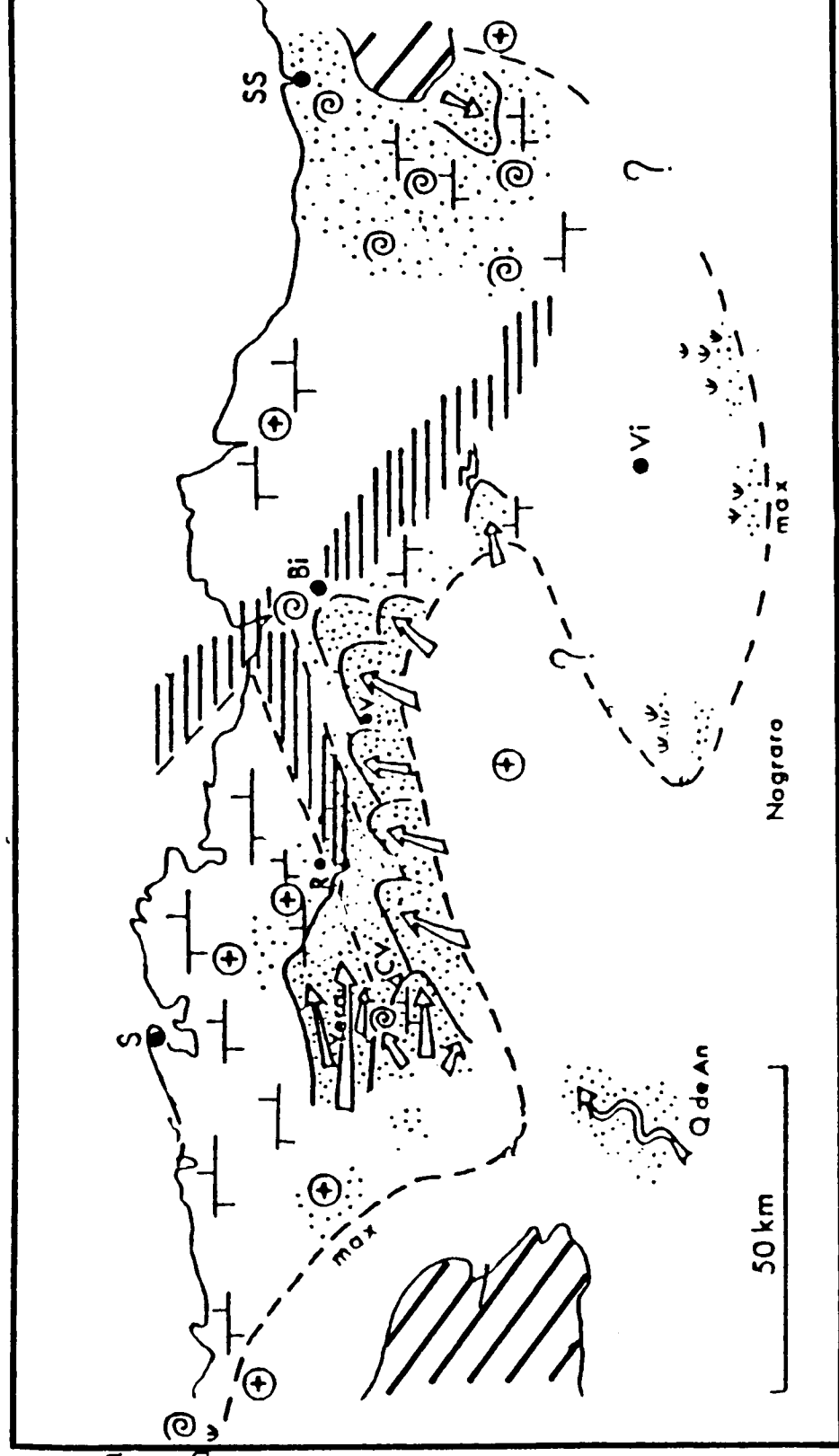
FIGURE 5-17.

Sequential evolution of the Torrelavega Group (Aptian) from the southwestern marginal areas to the more open marine northeastern areas of NW Santander. The oldest Umbrera Fm. is at the base and the youngest Reocin Fm. at the top (Fig. 2-1). Sea level is indicated by the "0" at the right of each diagram.

The undulatory top of the Reocin Fm. is meant to indicate lateral thickness and facies changes due to active diapirism.

TOWNS :

Bi : Bilbao.
 CV : Castro Valnera
 Q de V : Quintan-
 illa de An
 R : Rmales.
 S : Santander.
 SS : San Sebastian
 Vi : Vitoria.



KEY :
 — : Rudistid carbonate platforms.
 — : Marls and black mudstones.
 . : Sandstones and siltstones from a deltaic s.l. facies
 ⊕ : Positive areas.
 v : Brackish environments.
 ~ : Slumps.
 → : Generalized of directions of clastic input.
 -max- : Maximum extension of marine influence
 ⊙ : Ammonites.
 — : Palaeozoic basement.

FIGURE 5-18.

Palaeogeography for the Basco-Cantabrian basin during uppermost Bedoulian / basal Gargasian time, the period of deposition of the San Esteban Fm. in NW Santander. Note the major "deltaic" development around San Sebastian, the NW-SE trending marls around Bilbao and the major clastic trough around Castro Valnera and Rmales. Extensive internal carbonate platforms developed in NW Santander and beyond in positive areas. Isolated outcrops of brackish marine/non-marine clastics occur in the very southerly part of the basin. Adapted from Pascal, 1985.

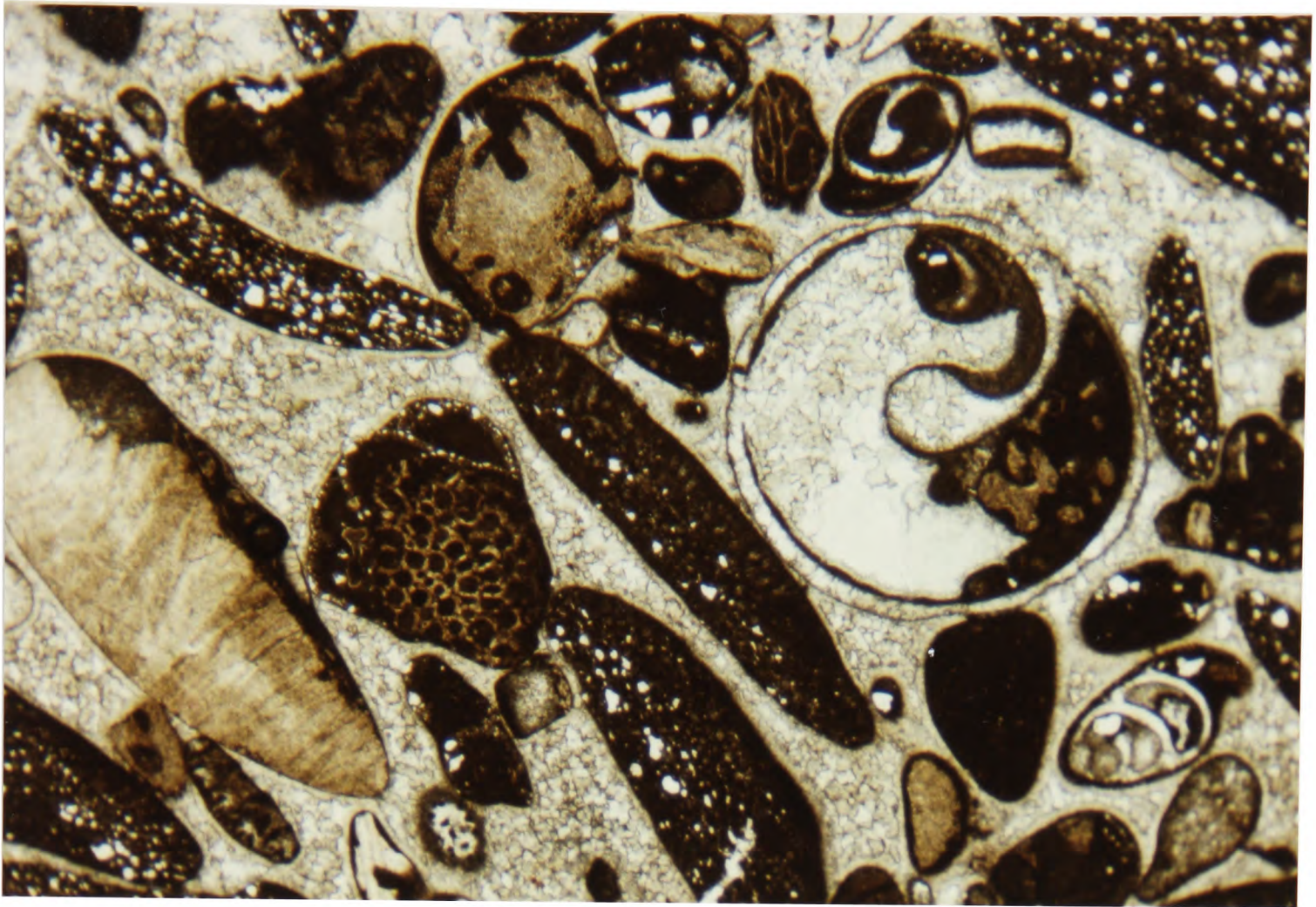


FIGURE 5-19.

This is an example of the rare, high-energy facies of the San Esteban Fm. from its western around Bustablado. It is a clean, well-sorted, coastal grainstone with orbitolinids, gastropods, bryozoa, rudist fragments, intraclasts, ooids, bivalve cortoids, and dasycladaceae. There is an early, isopachous (marine phreatic ?) cement followed by a later equant spar. This was taken in plane-polarized light of an area 6mm by 9mm wide.

(NOT TO SCALE)

WEST

EAST

Basal Aptian relative sea-level rise moves barrier system towards the hinterland to the W/SW.

Well-washed, clean barrier sands.
(Quartz sand ?).

Spillover lobe of cross-bedded calcarenite into the deeper-water marls

COASTAL PLAIN

LAGOON

BARRIER

BEACH

OFFSHORE CALCARENITIC SHOAL

MARLS

Wealden fluvial sands/muds.

High Tide

Foreshore

Low Tide

Erosional contact of the shoreface retreat as it erodes through the barrier and lagoonal deposits to deposit the offshore calcarenite shoal of the Umrera Fm. directly onto the Wealden fluvials as at Cuchia.

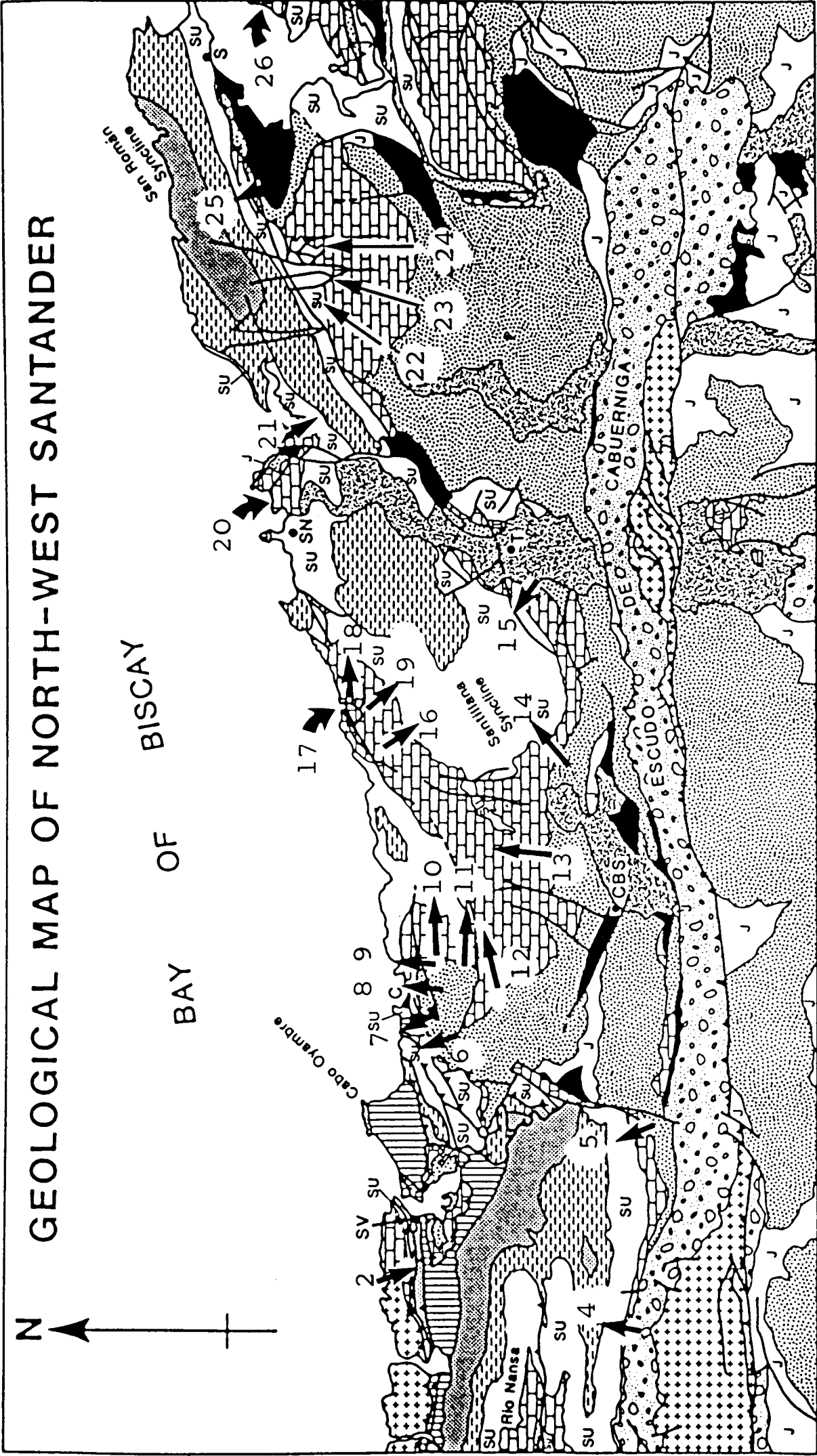
Offshore, subtidal calcarenite of the Umrera Fm.

Muds/muddy sands of the lagoon with a generally brackish fauna. Washovers from the barrier itself or the offshore calcarenite are rare and the lagoon is dominated by crevasse splay siliciclastics from the fluvial Wealden.

Patrocinio Fm. marls

FIGURE 5-20.

A model for the barrier destruction during transgression of the Umrera Fm. over the fluvial Wealden (Vega de Pas Fm.) by shoreface retreat.



Section 1
at Puron 20Km
further west.

Section 3
at Rio Deva
1Km further
west.

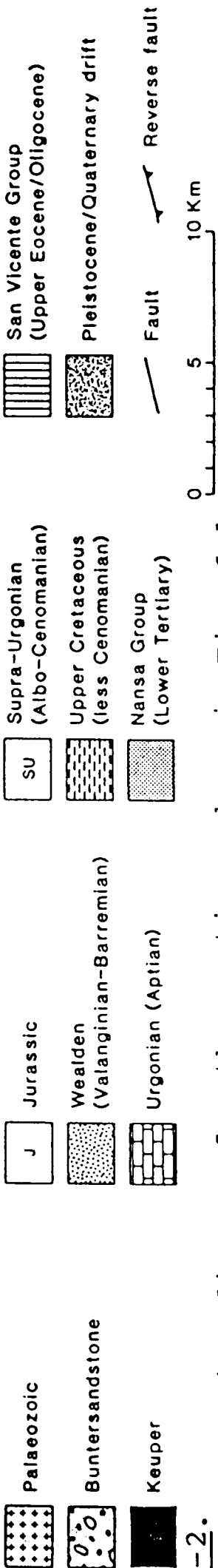


FIGURE 6-2. Location diagram for the sections shown in Fig. 6-1 through the Reocin Fm.. Arrows show the direction of logging.



FIGURE 6-3.

General view of the Reocin Formation, Sierra Member at a cement quarry just SE of San Esteban (56239705). It shows the generally massive to metre-bedded nature of this formation, it's white karstification, it's grey/white colour and well-developed joint pattern. The earth mover is about 5m high.



FIGURE 6-4.

Aetostreon latissima wackestone from the Sierra Member, Reocin Formation at the cement quarry just SE of San Esteban (56239705). The matrix is a benthic foraminiferal, wackestone. This is a typical example of Facies 1 of Chapter 6.4. It is a plan view and the lens cap is 5cm wide.

FIGURE 6-5.

A typical lime mudstone/wackestone microfacies from the Reocin Fm. taken from the Comillas road section. It is dominated by clotted, totally bioturbated micritic matrix. It contains benthic foraminifera, rare, broken rudist shells, cortoid bivalves, broken ostracods, echinoderms and brachiopods (see Chapter 6.4, Facies 1 and 2). This was taken in plane-polarized light of an area 6mm by 9mm wide.

FIGURE 6-6.

A typical benthic foraminiferal/rudistid packstone from the Reocin Fm. (Comillas section). This section shows a rudist shell of prismatic calcite in the centre and right of the figure. It has a micritic matrix with orbitolinids, miliolids, uni- and biserial benthic foraminifera. There is some neomorphic spar infill of foraminiferal chambers. This was taken in plane-polarized light of an area 6mm by 9mm wide.

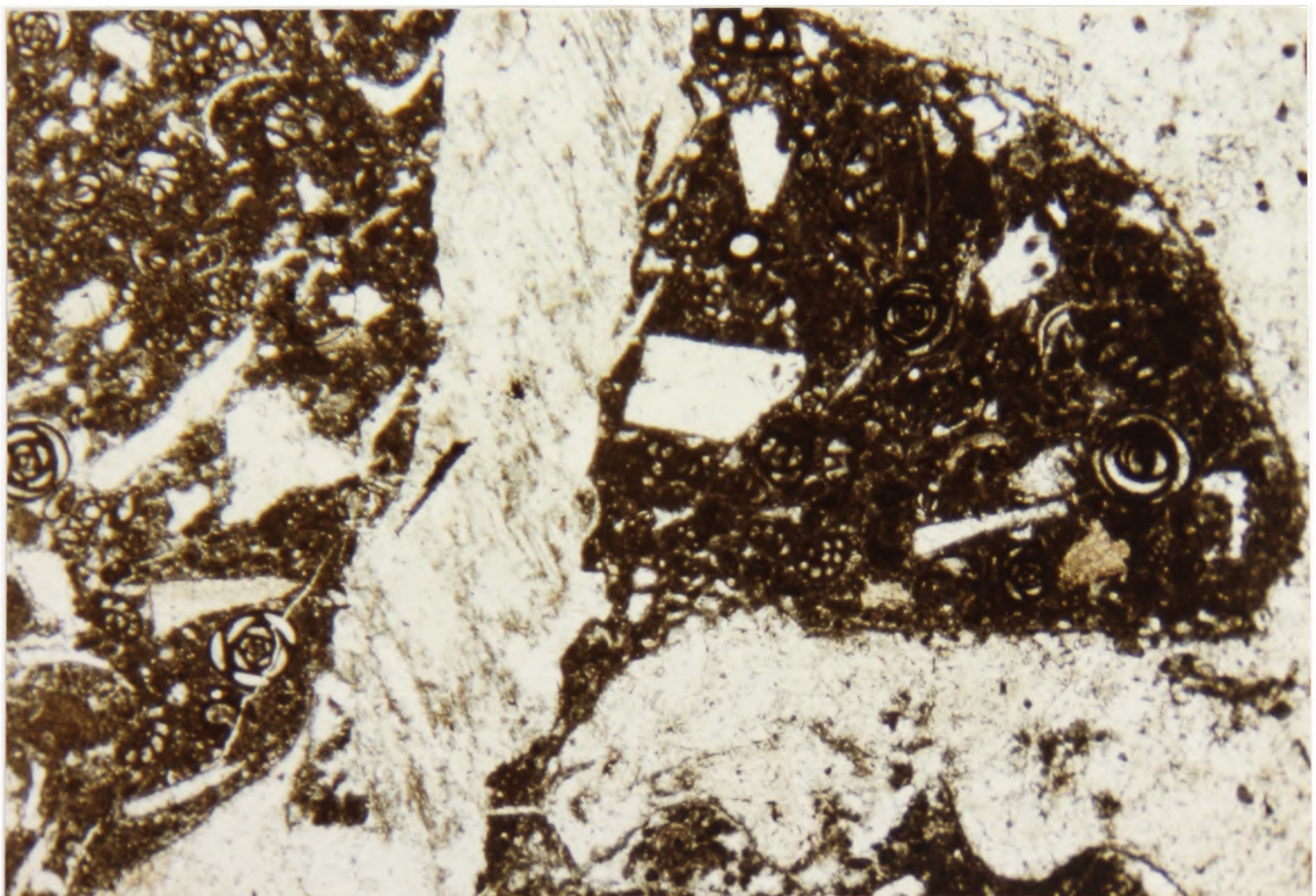
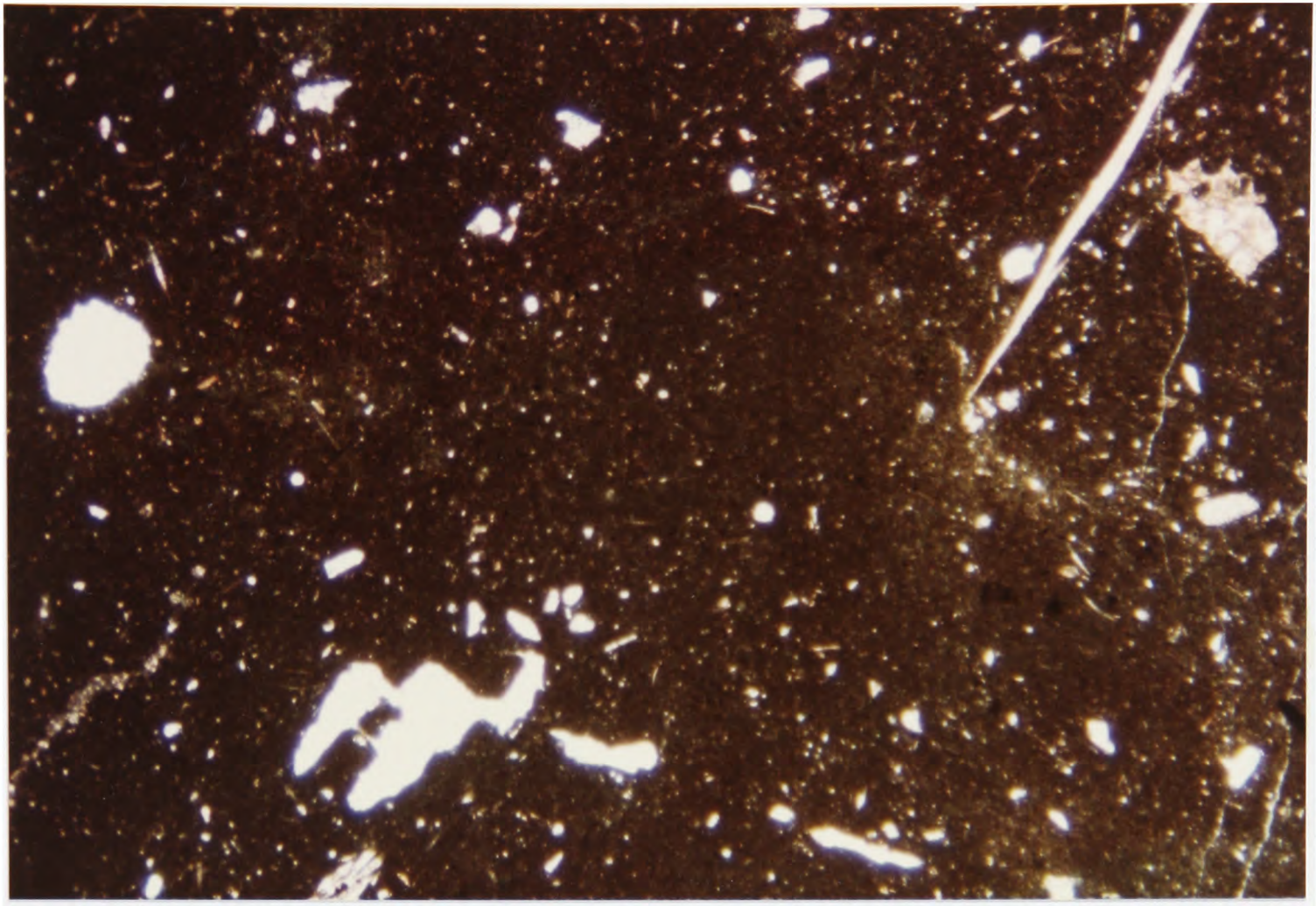


FIGURE 6-7A.

General view of the requienid wacke/packstone (Facies 5 of Chapter 6.4) from the Sierra Member, Reocin Formation at the cement quarry just SE of San Esteban (56239705). This photograph shows well developed, whole Pseudotoucasia santanderensis not in life position. They were probably reworked into local banks by storm action in the internal carbonate platform. The lens cap is 5cm wide.



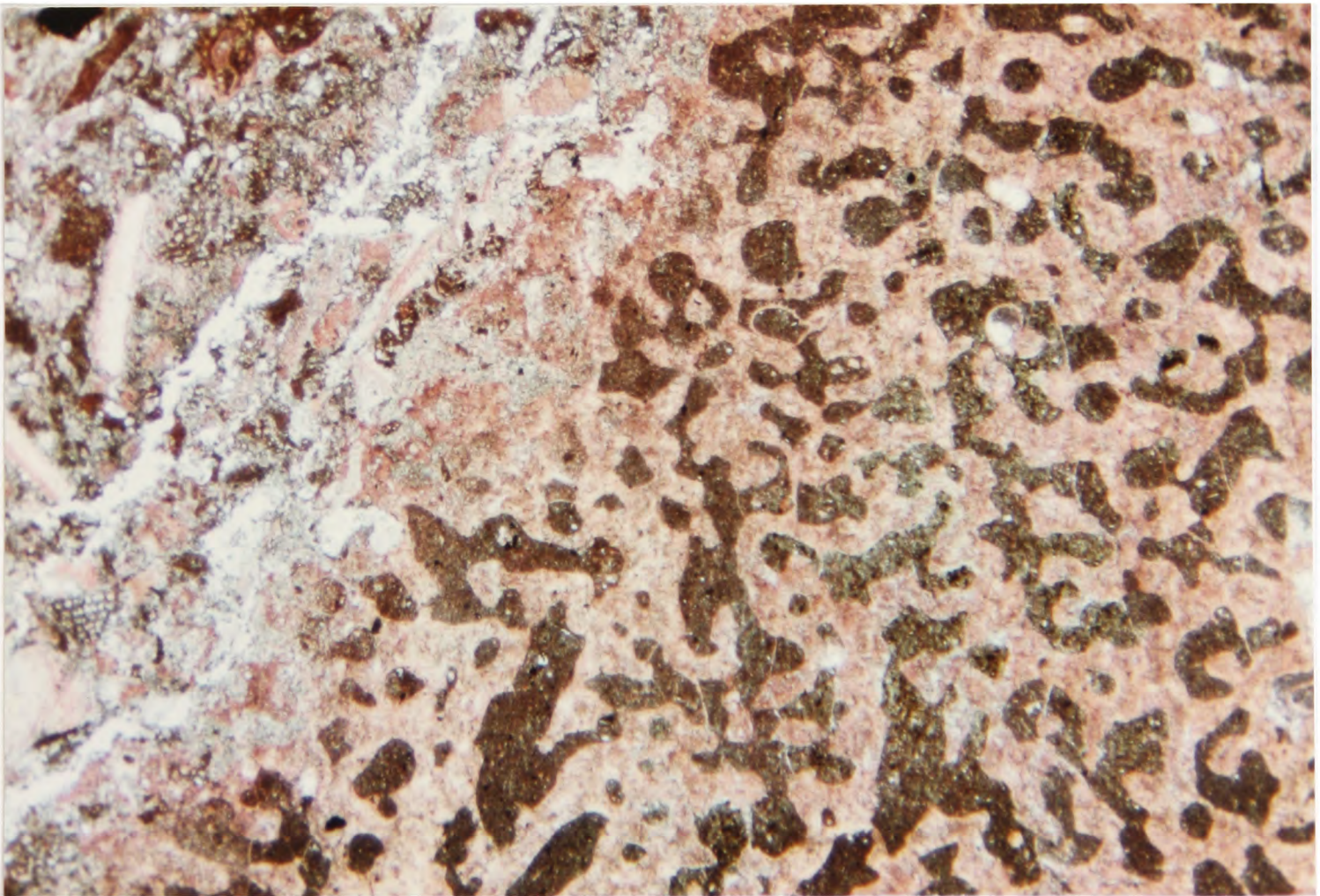
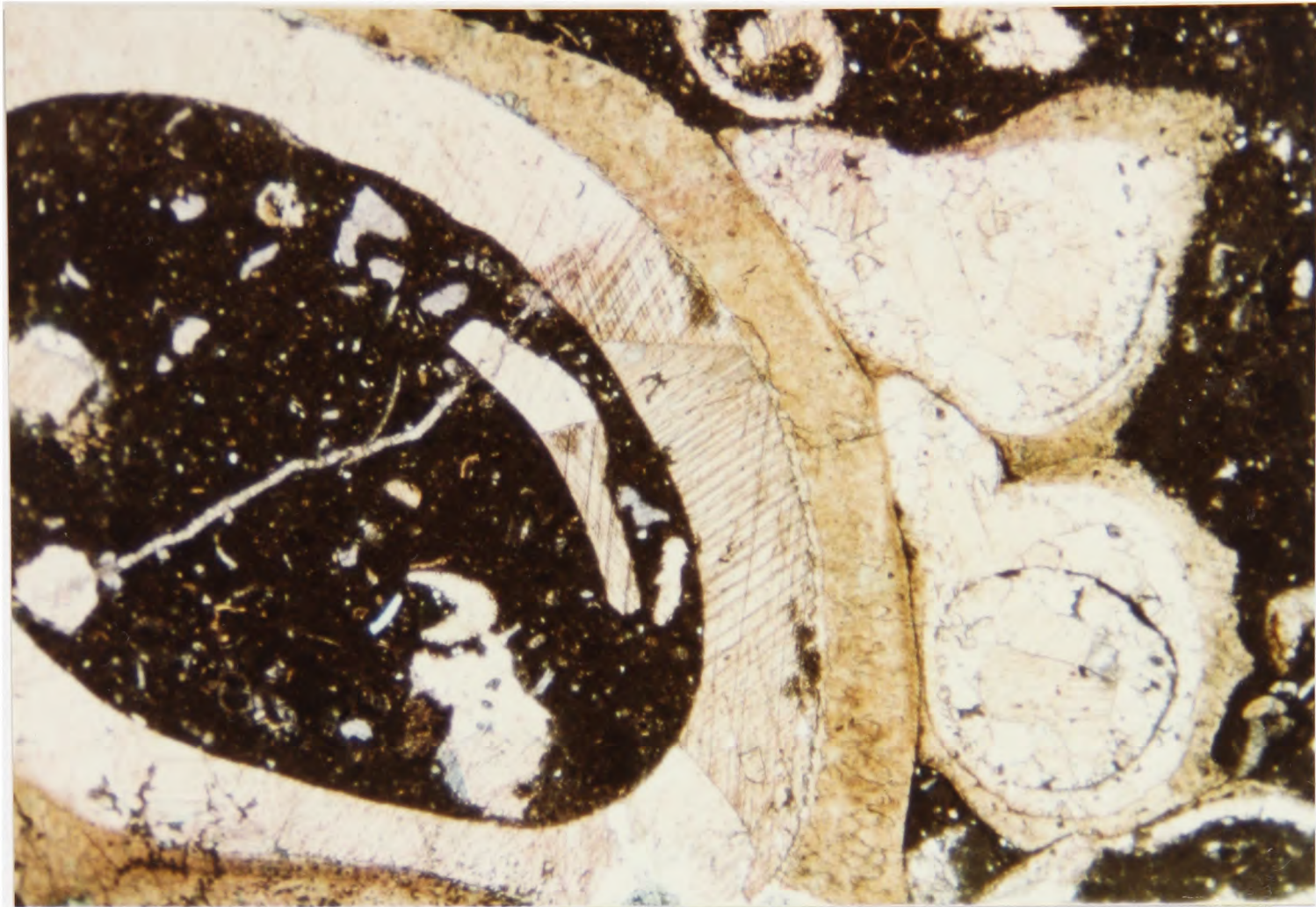
FIGURE 6-7B.

This is a requienid packstone from the Reocin Fm. that was taken in plane-polarized light of a thin-section stained with potassium ferricyanide/Alizurin Red S solution. It shows the two-layer sytucture of the rudist with an outer, prismatic, original calcite layer and an inner, sparry layer of blocky, neomorphic calcite. It has the usual micritic matrix. This was taken of an area 6mm by 9mm wide.

See Facies 5 of Chapter 6.4.

FIGURE 6-8.

This is a typical example of the sponge bioherm from the Reocin Fm. (Facies 8 of Chapter 6.4). It was taken under plane-polarized light of a thin-section stained with potassium ferricynide/Alizurin Red S. In the top left hand corner is some typical packstone of the Reocin Fm.. This was taken of an area 6mm by 9mm wide.



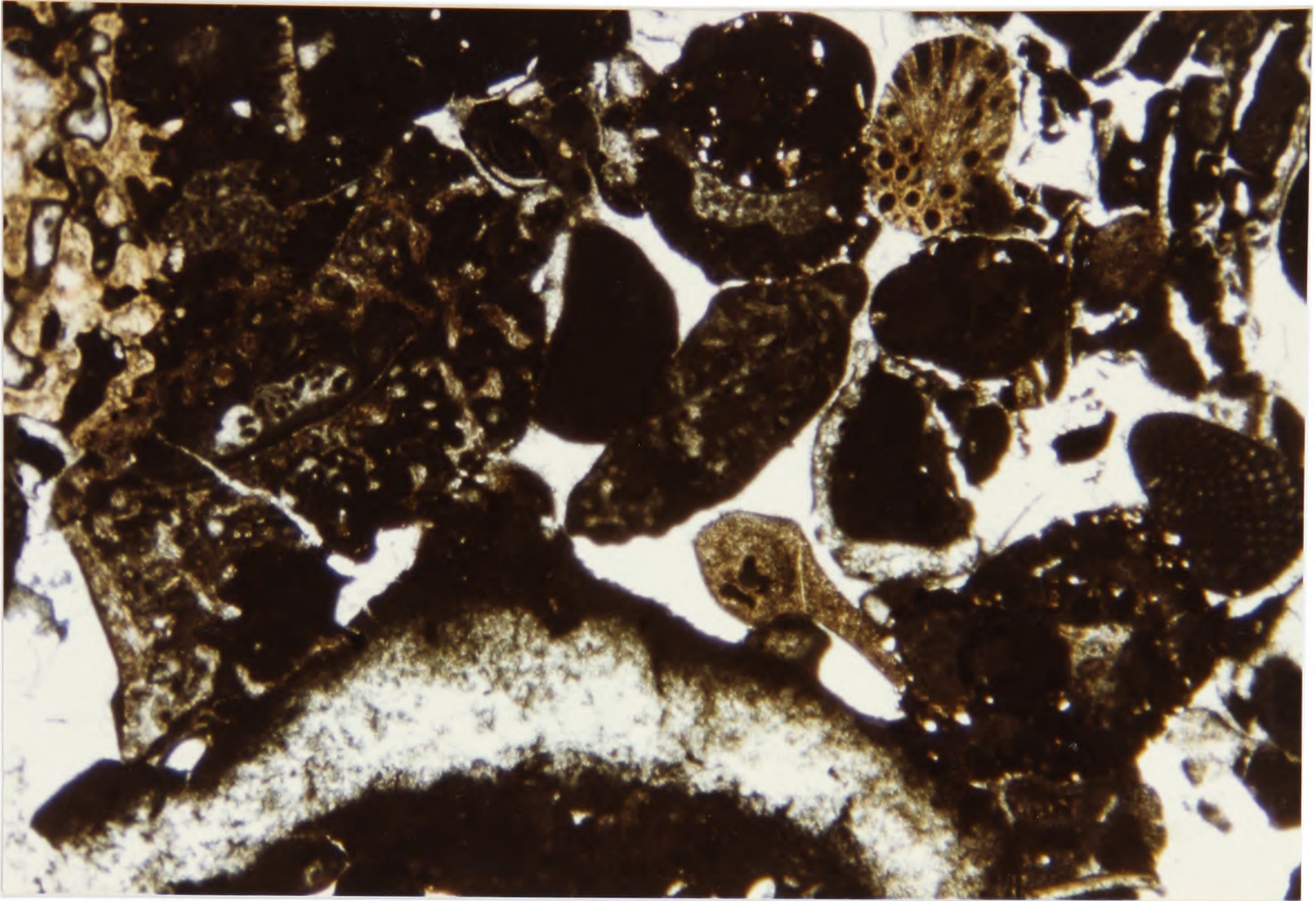


FIGURE 6-9.

This is a typical example of the grainstone facies of the Reocin Fm. (Facies 9 of Chapter 6.4). These have bivalve cortoids with micritic envelopes, orbitolinids, intraclasts, peloids, bryozoa, dasycladaceae, miliolids, echinoderms, calcareous sponges, gastropods, ostracods and serpulids. It has an equant to drusy spar matrix. This was taken in plane-polarized light of an area 6mm by 9mm wide.



FIGURE 6-10.

Typical view of the Comillas Member, Reocin Formation from the type section at SW Miradorio (55269764). This section is illustrated in Section 5/26, 482 to 484m. The hammer is 25cm long and the younger beds are to the left. Just beneath the hammer is a typical exposure of Bioturbated marl (Facies 10 of Chapter 6.4). The hammer is resting on a bed of Sandy, bioturbated, marly wackestone (Facies 11 of Chapter 6.4). Note the gradational contact at the of this bed. The bed below the marl bed mentioned above is a high-energy Sandy, skeletal pack/grainstone (Facies 12 of Chapter 6.4).



FIGURE 6-11.

General view of the Reocin Formation at the SW corner of Miradorio east of Comillas (55269764). Here the Reocin Formation is overturned and dips at about 70° to the south. This structural inversion is due to piercement faults associated with the Comillas diapir. The cliff exposes the benthic foraminiferal wackestone (Facies 3 of Chapter 6.4) overlain by the nodular biomicrite (Facies 2 of Chapter 6.4). At the base of the cliff is the rhythmic wackestone/marl alternation of the younger Comillas Member of the Reocin Formation. Note the generally poor inland exposure. The cliff is about 25m high. The photograph was taken looking WSW.



FIGURE 6-12.

Typical view of the Sandy, skeletal pack/grainstone (Facies 12 of Chapter 6.4) of the Comillas Member, Reocin Formation from SW Miradorio just east of Comillas (55269764). Note the well-developed ripple bedforms. This bed is shown in Section 5/27, 485.5m. The ripples were generated by wave/ripple action. The block to the right of the grass is nearly perpendicular to the block to the left of the grass. The beds are younger towards the top of the photograph. The lens cap is 5cm wide.



FIGURE 6-13.

Plan view of a requienid/nerineid/sponge/coral bioherm from the Comillas Member, Reocin Formation from SW Miradorio just east of Comillas (55269764). This is a typical example of Facies 13 of Chapter 6.4. This bed is shown on the type section log of Section 5/27, 489.2m. It shows the large domal corals, nerineid gastropods and requienid rudists (top left). This small bioherm was destroyed by an influx of clay-rich marl just above this bed. The boulders (bottom left) are Recent beach ones and the hammer is 25cm long.

COMILLAS SECTION.

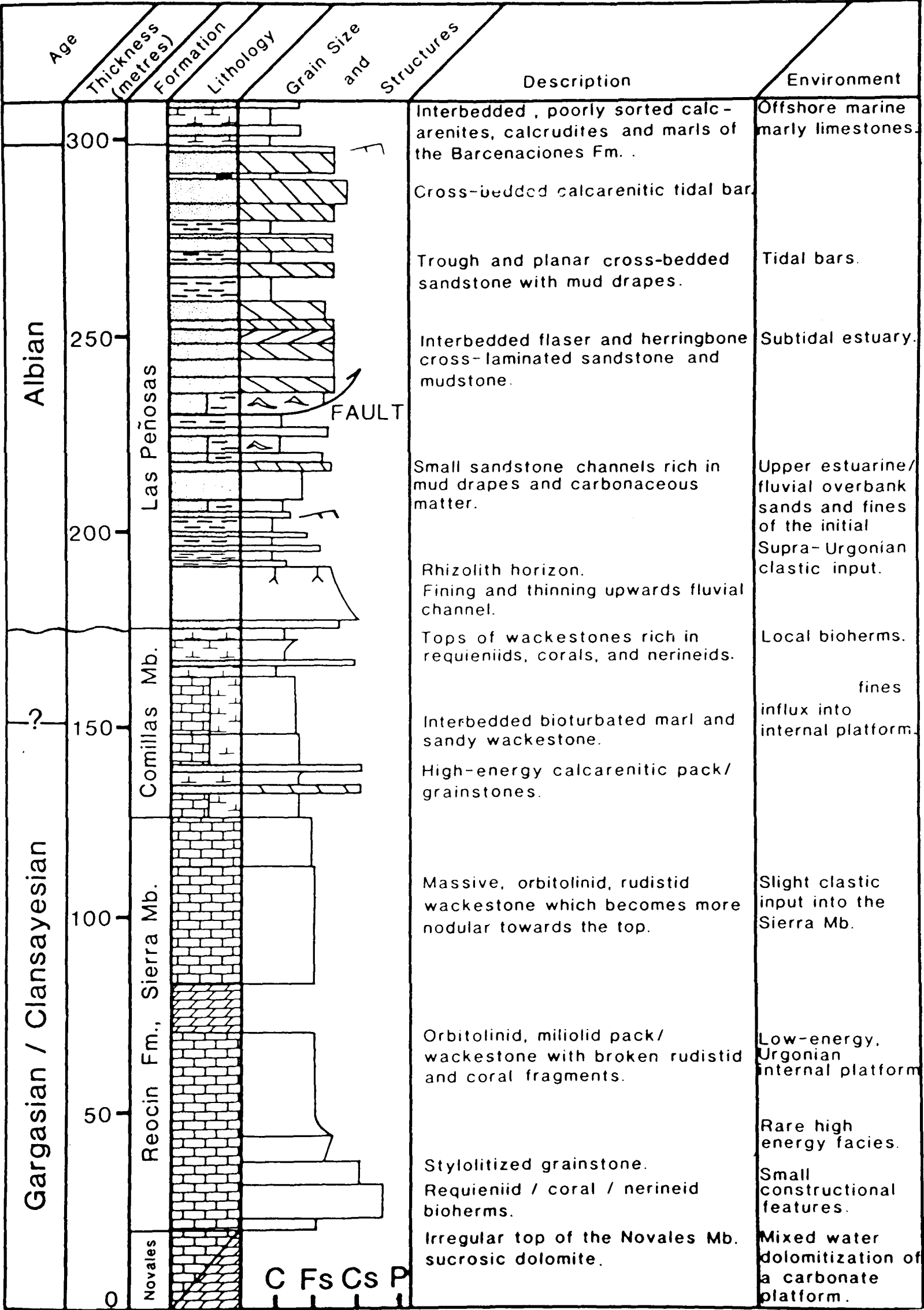


FIGURE 6-14.

Summary log of the top of the Reocin Fm., the Las Penosas Fm. and basal Barcenaciones Fm. from the section west of Miradorio just east of Comillas (55269764). This section is shown in detail in Sections 5 and 6.

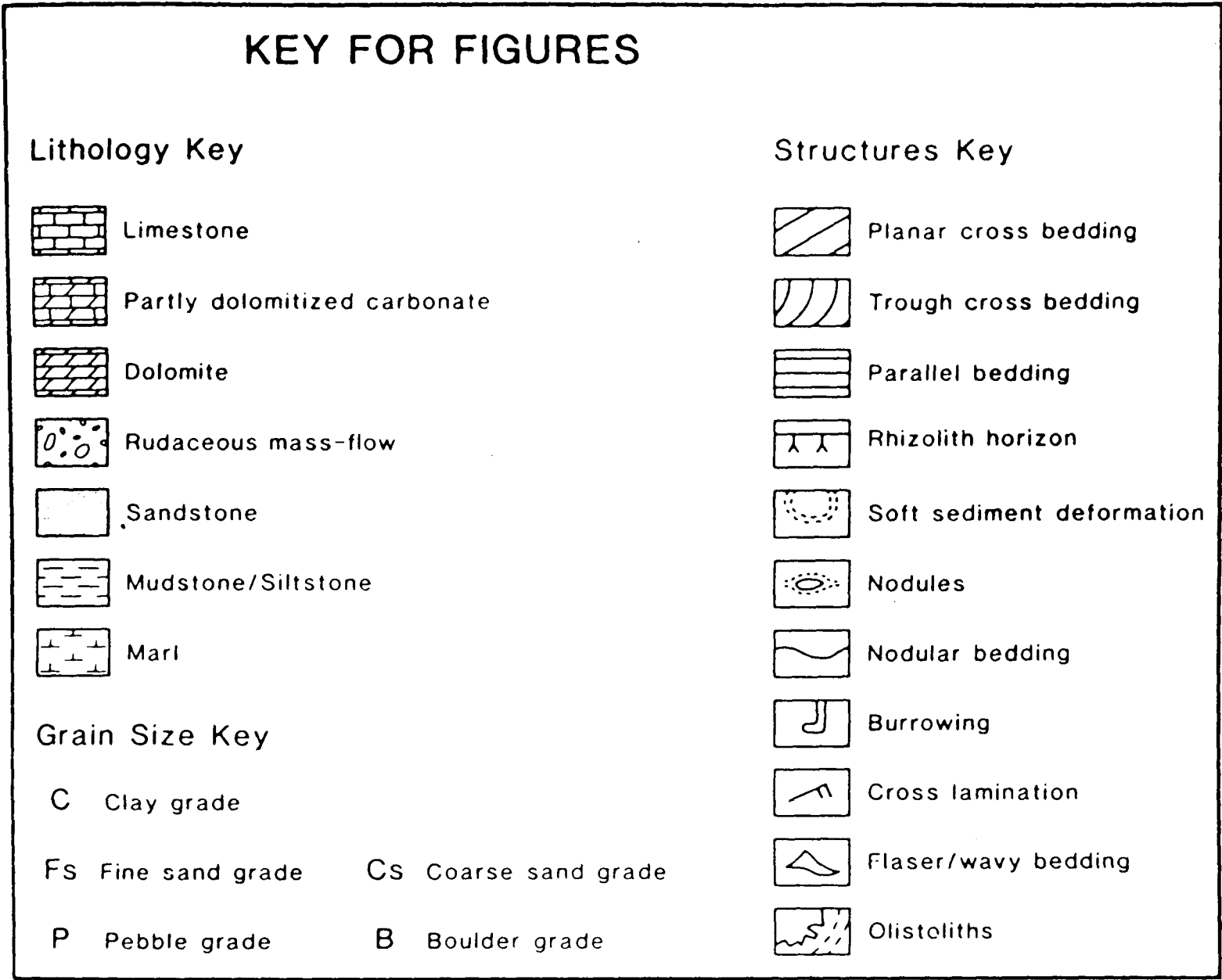
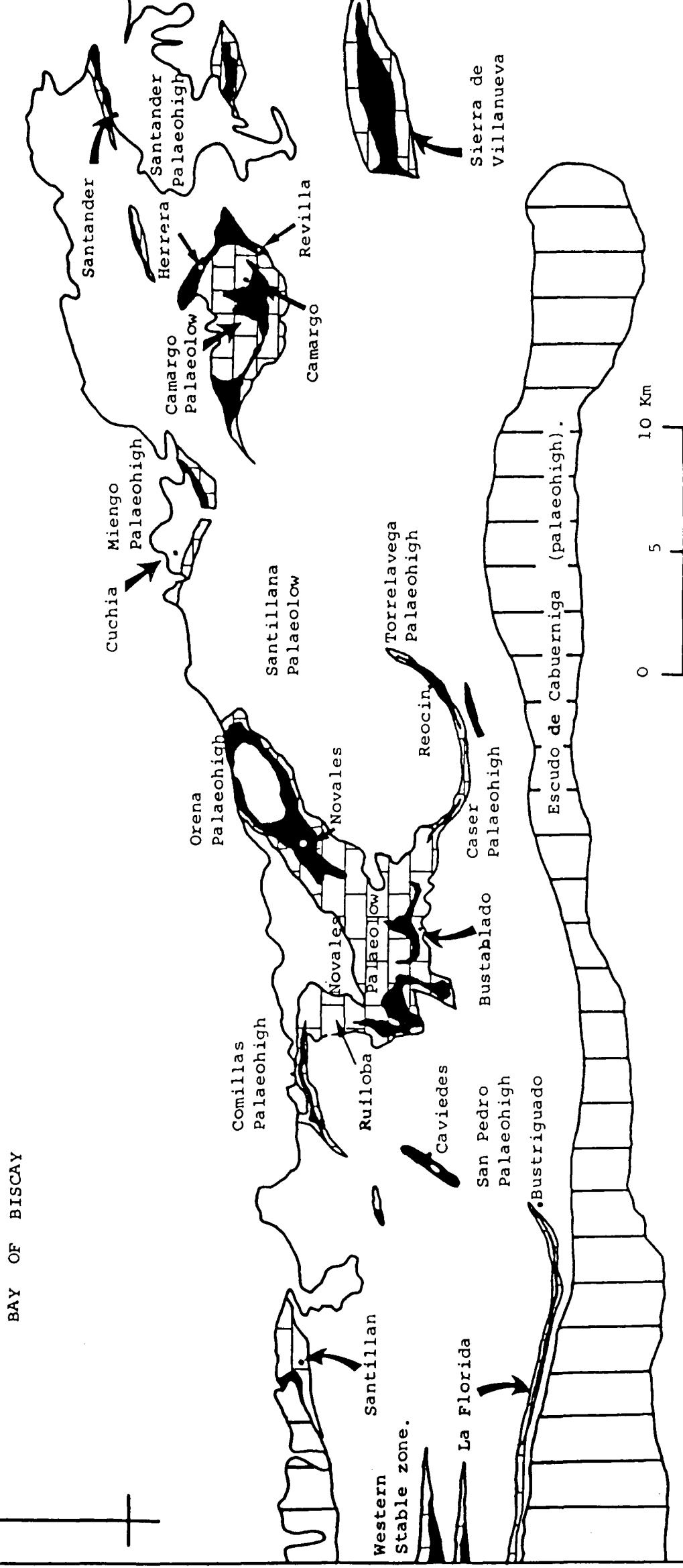


FIGURE 6-15.

Key to the summary logs. This is the key to
Fig. 6-14.

BAY OF BISCAY



Palaeozoic / Buntersandstone basement.

Map of the Upper Aptian Reocin Formation in NW Santander showing the distribution of the Novales Mb. dolomite (Key opposite). The Upper Aptian palaeohighs and palaeolows are also indicated and sections through them are shown in Fig. 6-1. The locations of more detailed maps of this Novales Mb. dolomite are shown in Fig. 6-33. The background geology to this outcrop map is shown on Figs. 2-3, 2-4 and 2-5.

Palaeozoic / Buntersandstone basement.

Mesozoic / Tertiary cover excluding the Upper Aptian Reocin Fm..

Reocin Formation dolomite
(Novales Mb.)

Reocin Formation limestone
(Barrio and Sierra Mbs.)

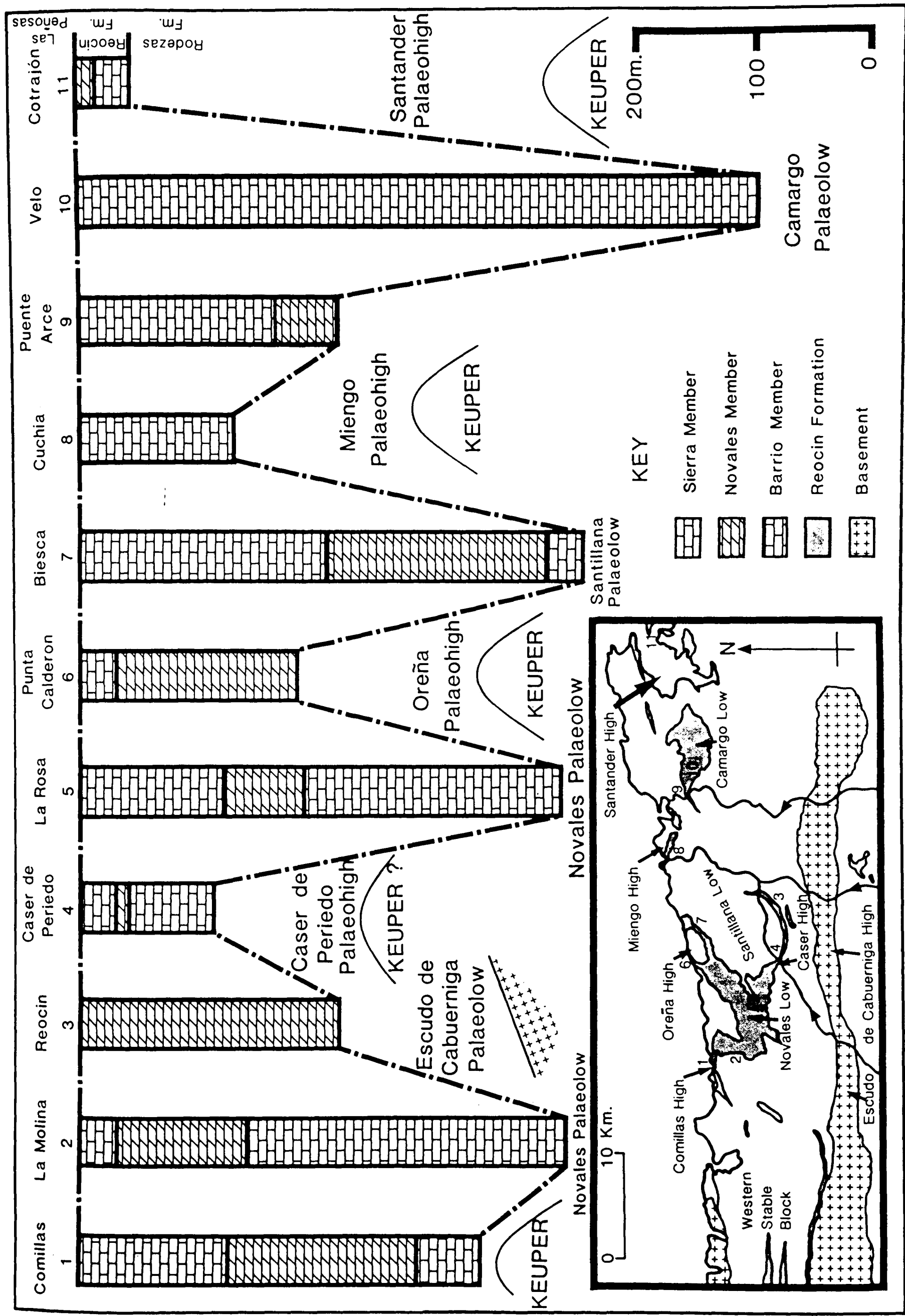


FIGURE 6-17. : Sections through the Reocin Formation. Insert map shows palaeohighs and palaeolows.

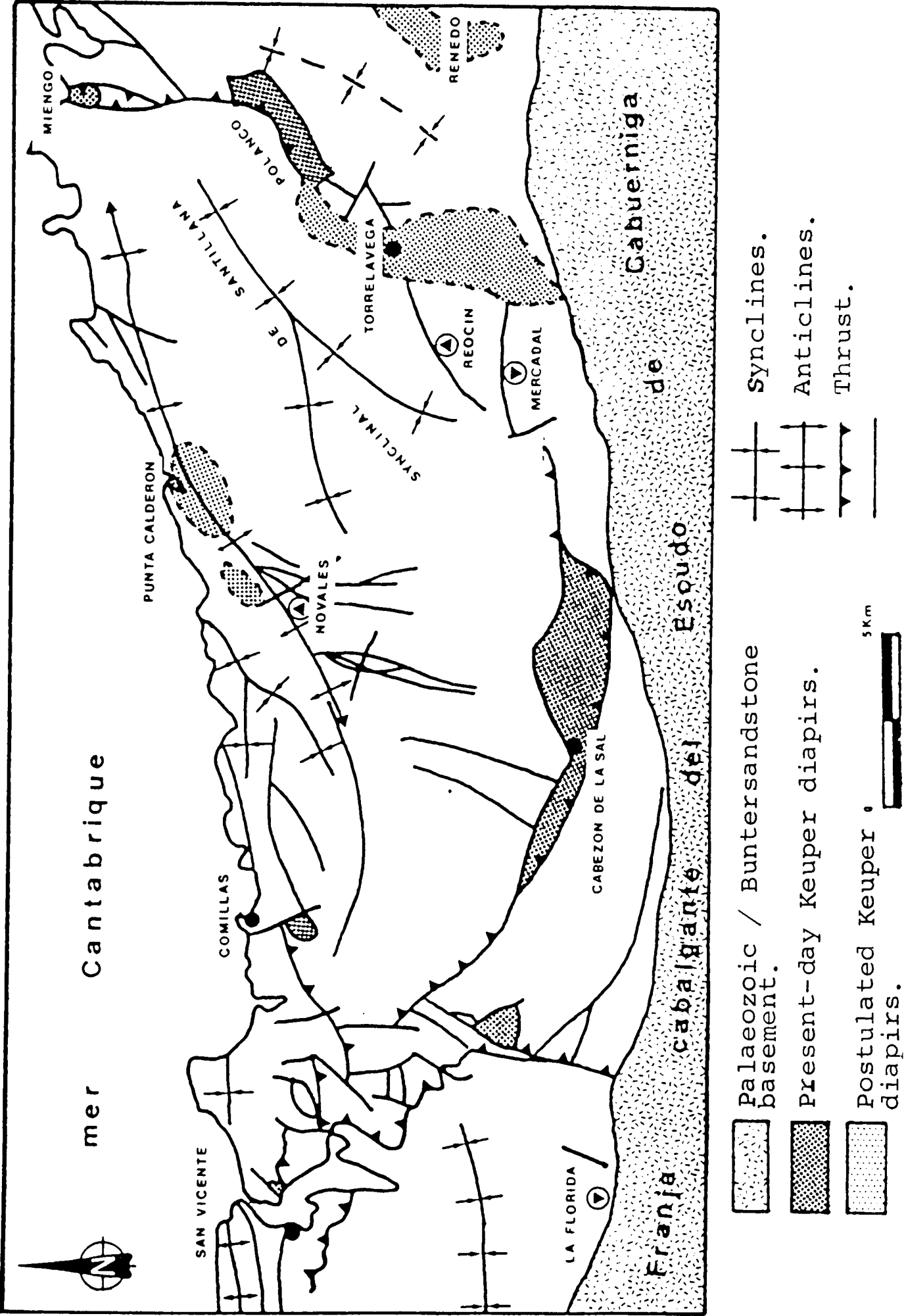


FIGURE 6-18.

Map of the known and postulated Keuper diapirs of NW Santander. Note the relationship with the dolomitization of the Reocin Fm. of Fig. 6-16. From Vadala, 1981.

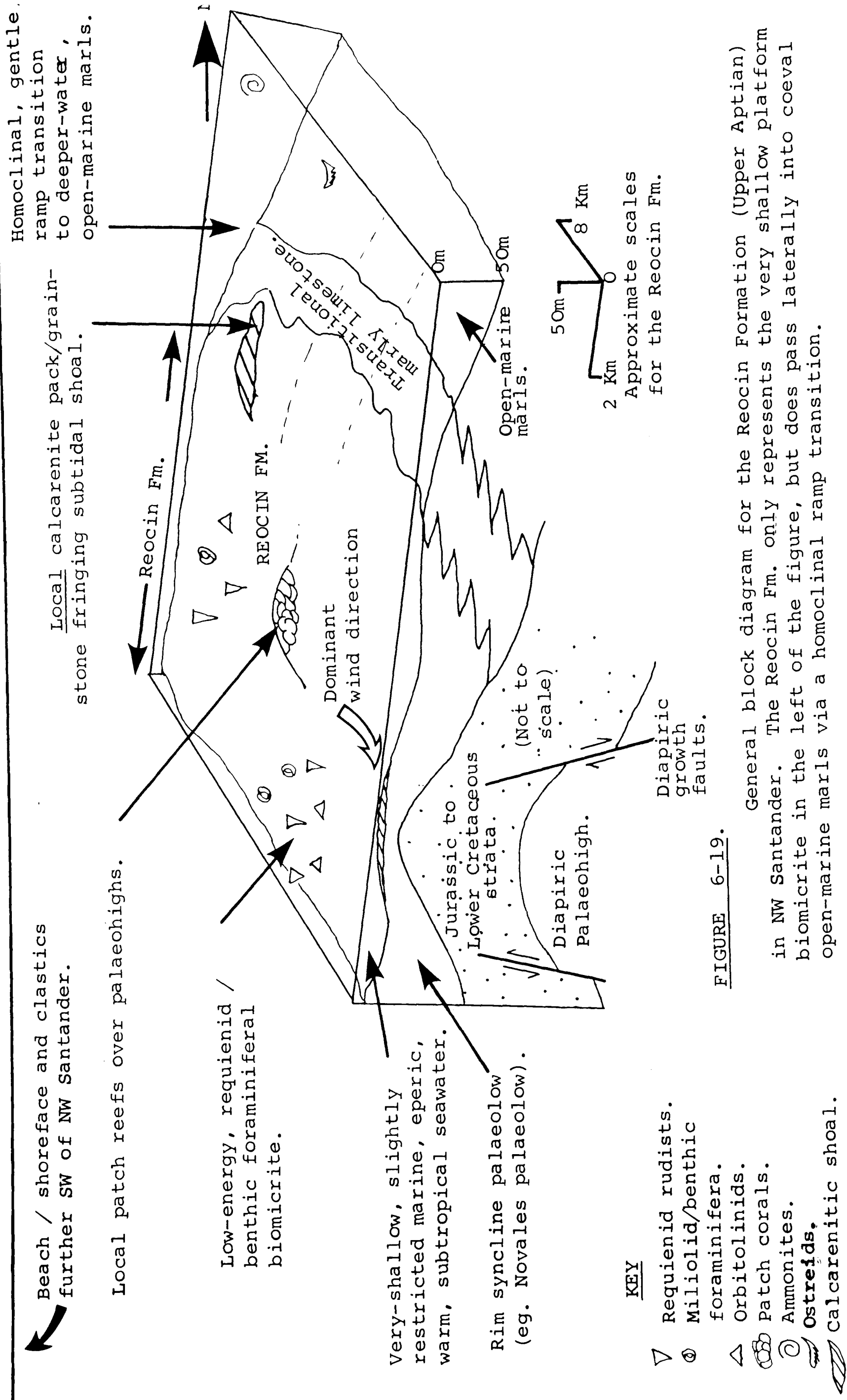


FIGURE 6-19.

General block diagram for the Reocin Formation (Upper Aptian) in NW Santander. The Reocin Fm. only represents the very shallow platform biomicrite in the left of the figure, but does pass laterally into coeval open-marine marls via a homoclinal ramp transition.

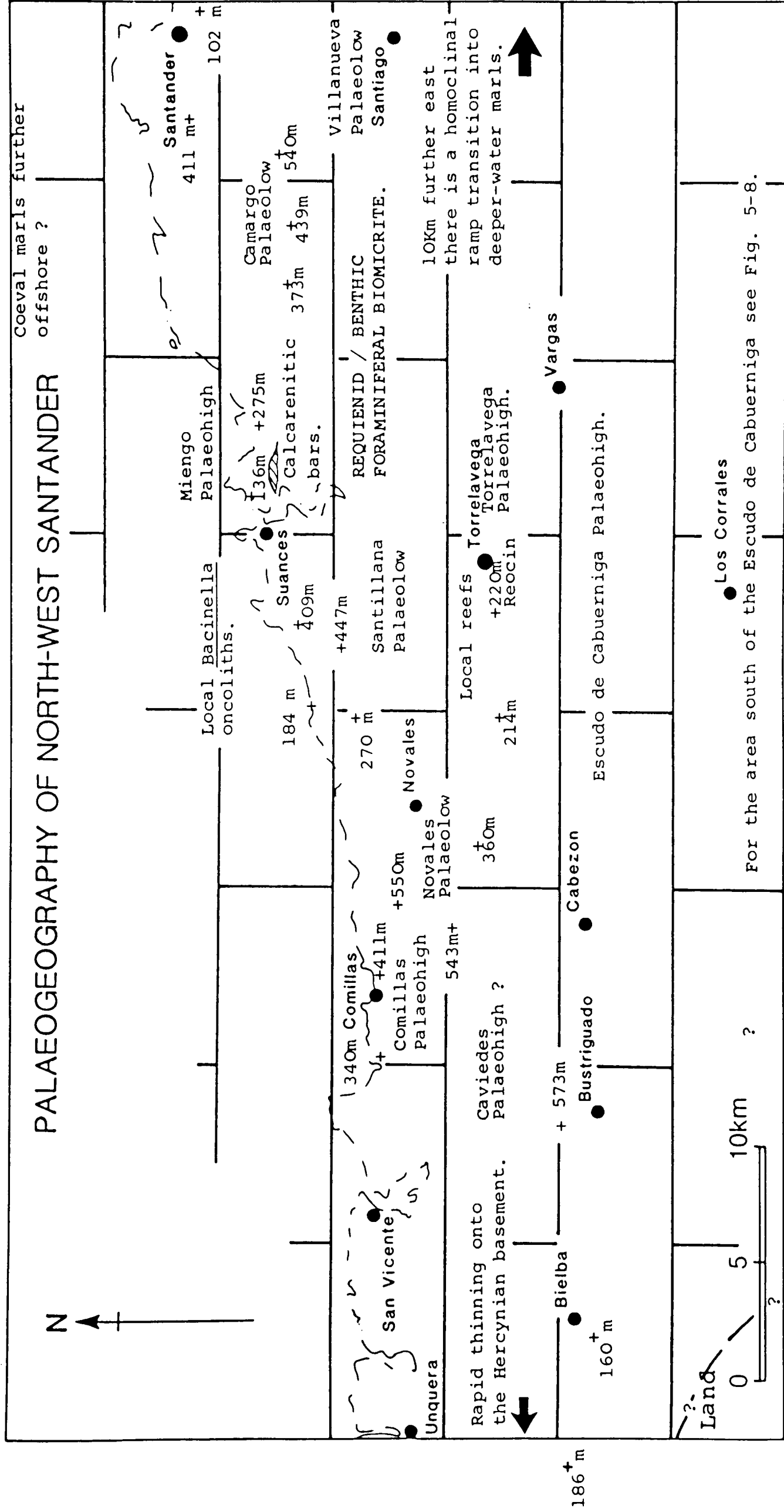
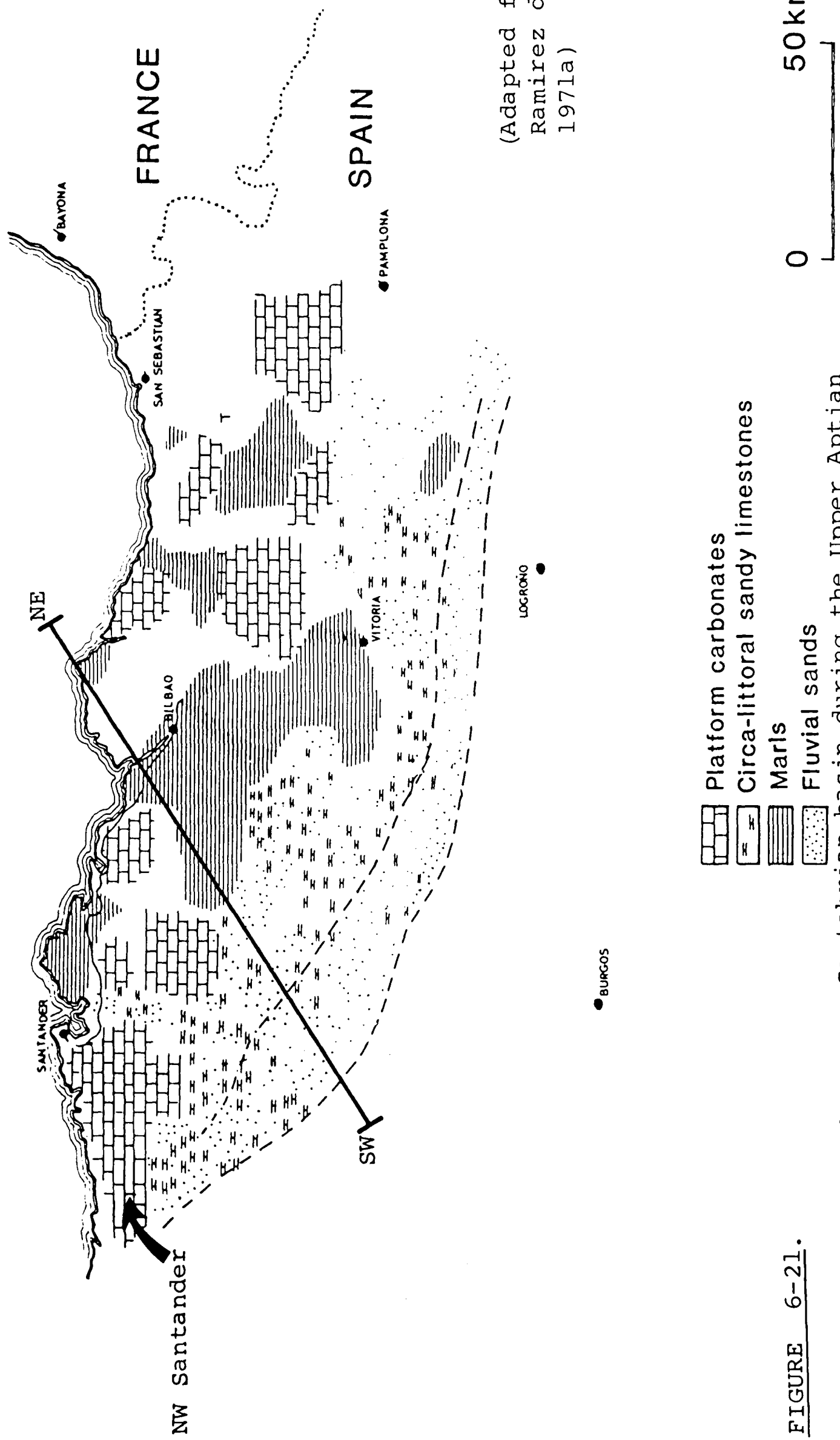


FIGURE 6-20.

Palaeogeography of the Reocin Formation (Sierra Member) in the Upper Aptian of NW Santander. A very uniform requienid/benthic foraminiferal biomicritic platform limestone was developed right across NW Santander but this passed into coeval marls to the N and E of NW Santander. In the very west of the area the formation thins onto the Hercynian basement. Over the rest of the area diapiric palaeohighs and lows were developed during the pillow stage of diapir

URGONIAN PALAEOGEOGRAPHY



(Adapted from
Ramirez del Pozo,
1971a)

FIGURE 6-21.

Palaeogeography of the Basco-Cantabrian basin during the Upper Aptian when the Reocin Fm. was deposited in NW Santander. The time/facies NE-SW section of Fig. 6-22 is shown.

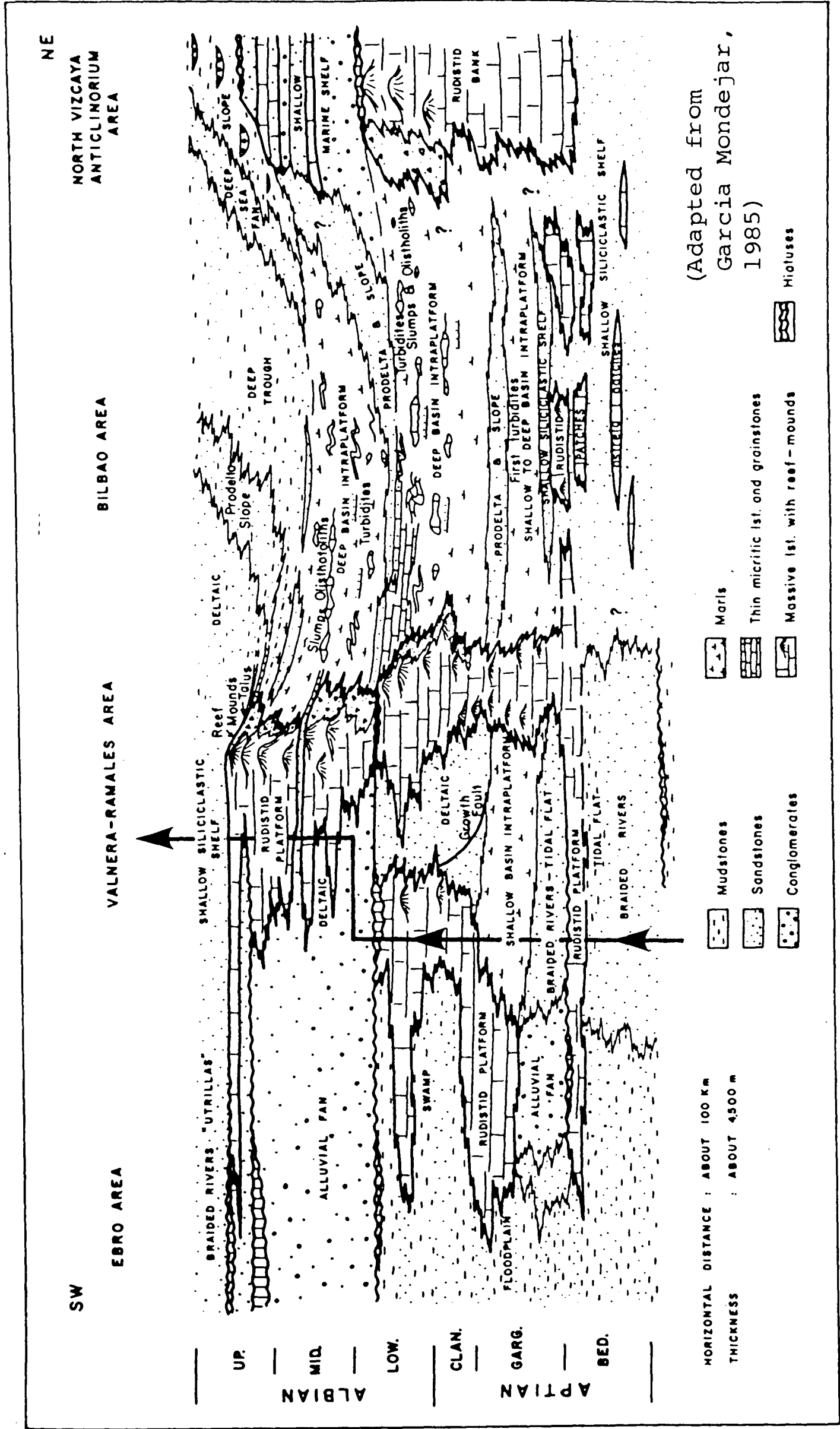


FIGURE 6-22.

General facies/time cross-section of the Basco-Cantabrian basin during the Apto-Albian. The section runs from the generally non-marine SW part of the basin via the rudistid platforms of the Valnera-Ramales-NW Santander area to the deeper-water facies of the Bilbao area. Rudistid platforms are again developed NE of the Bilbao area around North Vizcaya. Facies section located in Fig. 6-21. Vertical, arrowed line gives the NW Santander facies evolution path.

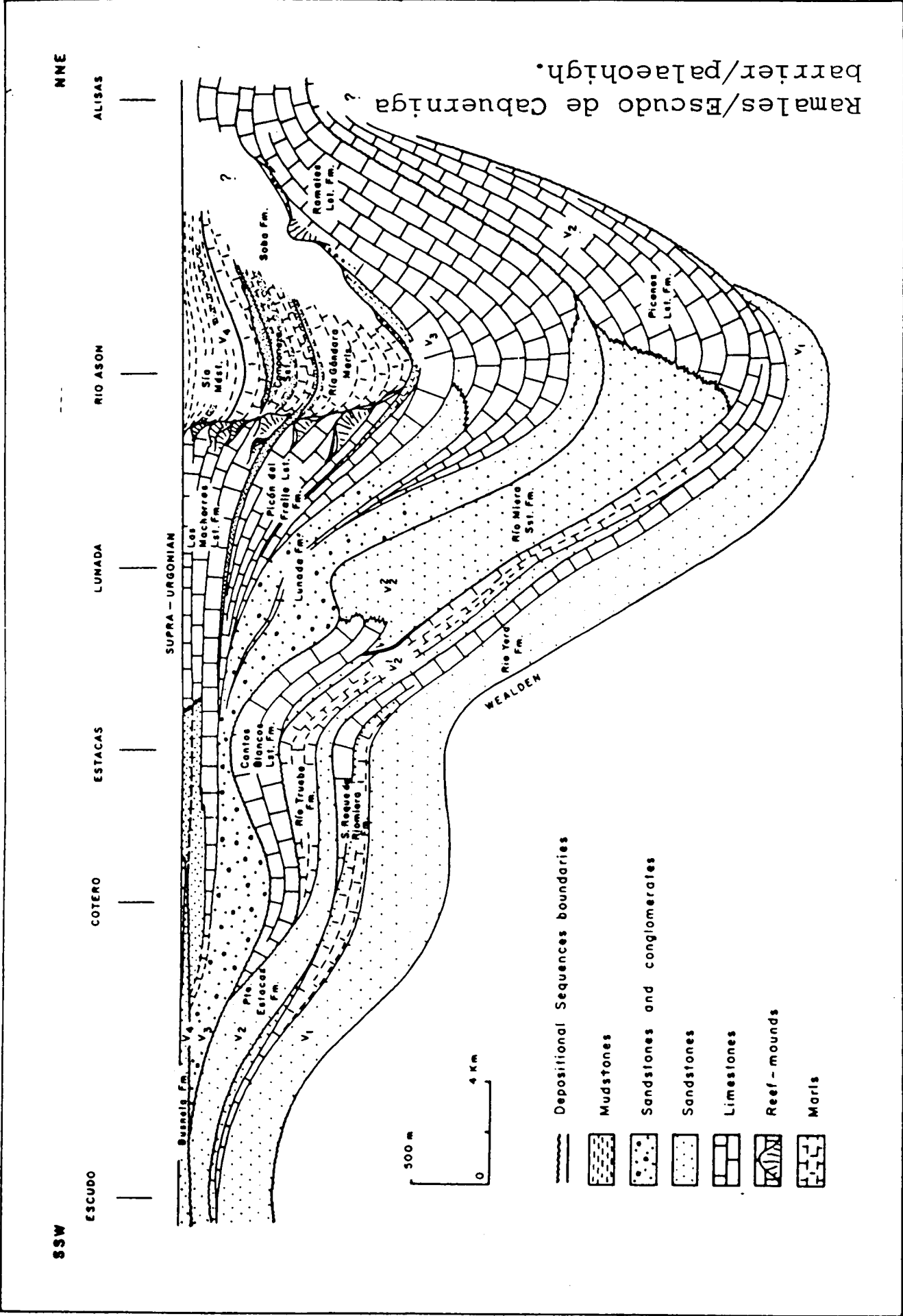


FIGURE 6-23 A .

N/S facies/thickness cross-section through the Apto-Albian (Urgonian) of the Valnera area, restored to the base of the Cenomanian (from Garcia Mondejar, 1985). The section is through sector III (location on Fig. 6-24) which preserves a greatly thickened and more complex sequence relative to the 700m thick sequence for the corresponding Albo-Aptian sequence in NW Santander (Chapters 5,6&7). The "V₁ etc." nomenclature corresponds directly with the U₁ etc. set used by Garcia Mondejar in Figs. 5-1 & 5-8. These figures show correlations with the NW Santander stratigraphy. The ages of the formations in this figure are shown in Fig. 6-23B. The Ramales/Escudo de Cabuerniga barrier (Alisas section above) ponds clastics to it's south. This protection allows major carbonate platforms to develop in the NW Santander-Laredo-Castro Urdiales area to the north of the barrier.

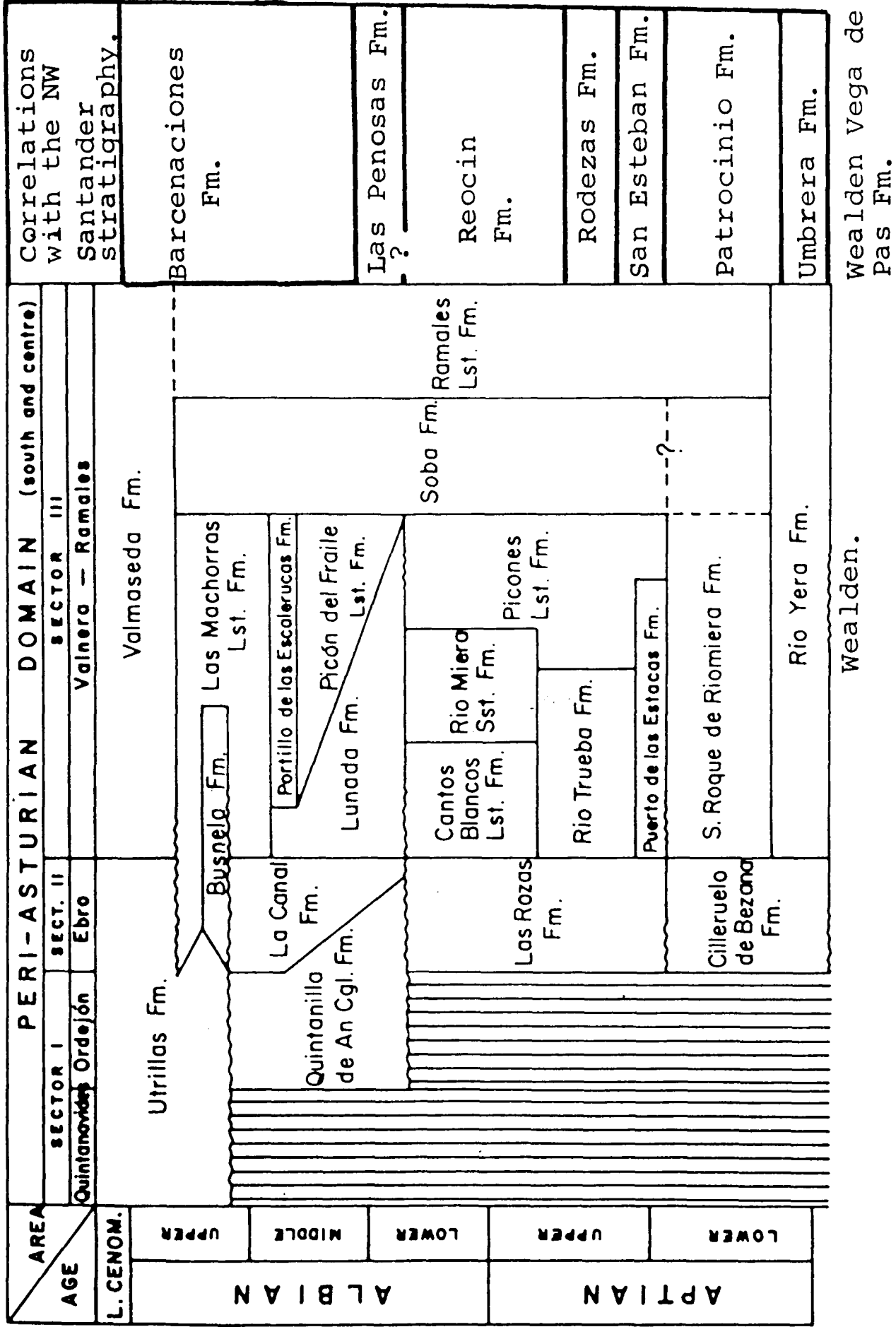


FIGURE 6-23B.

A stratigraphic correlation diagram for the Apto-Albian of the Valnera area to the south of the Escudo de Cabuerniga (location in Fig. 6-24). The formations mentioned in the figure above are shown in Fig. 6-23A. A broad correlation with the formations of NW Santander is shown to the right of the figure. From Garcia Mondejar, 1985.

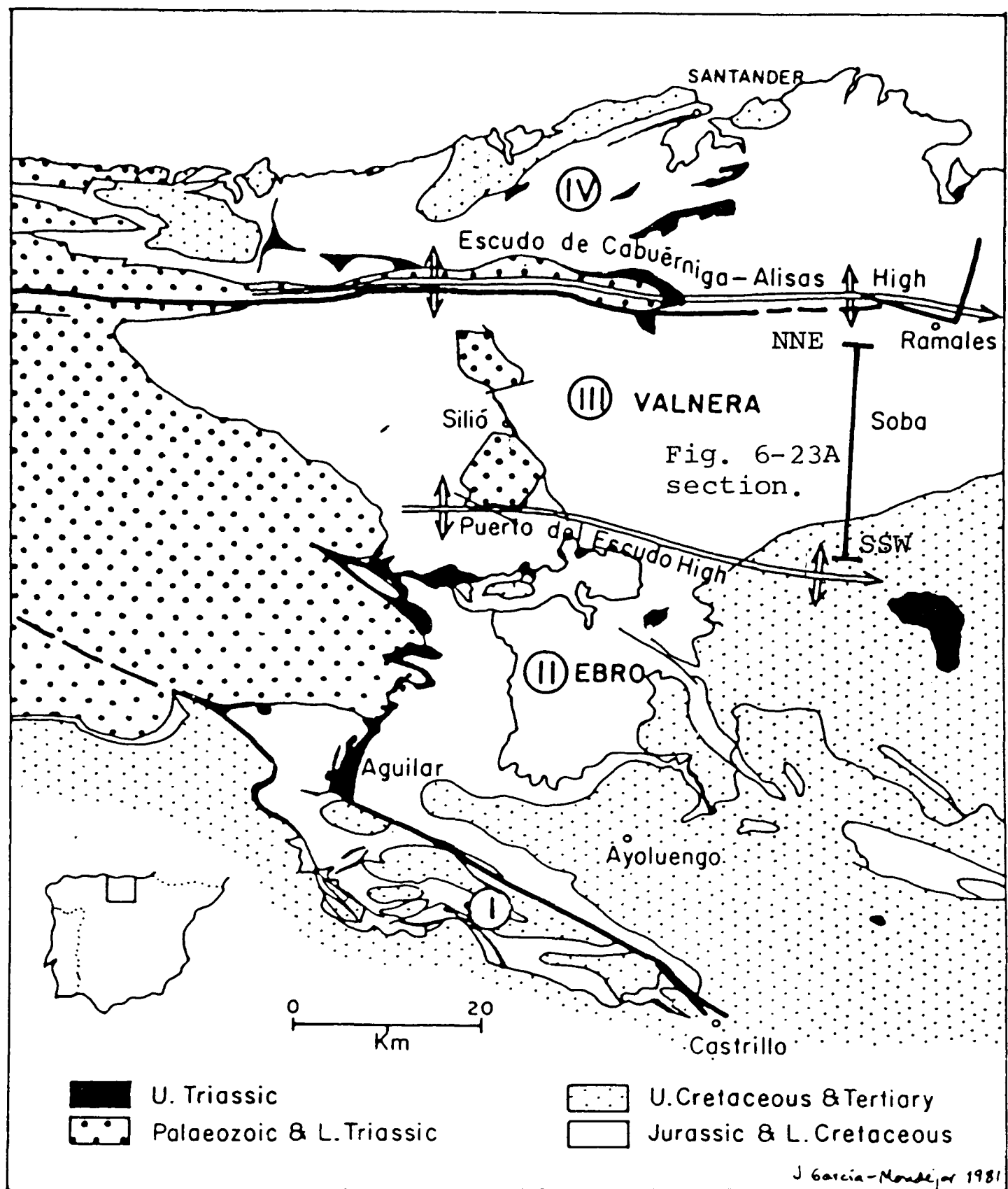


FIGURE 6-24.

Main tectonostratigraphic sectors in the Peri-Asturian domain during the Apto-Albian. The sectors are identical to those used for the Wealden (Fig. 4-1) reflecting the continuation of the broad tectonic control from the Wealden to the Urgonian. This tectonic control is mainly reactivation of Hercynian lineaments. The facies cross-section of Fig. 6-23A is shown in the Valnera sector III. From Garcia Mondejar, 1985.

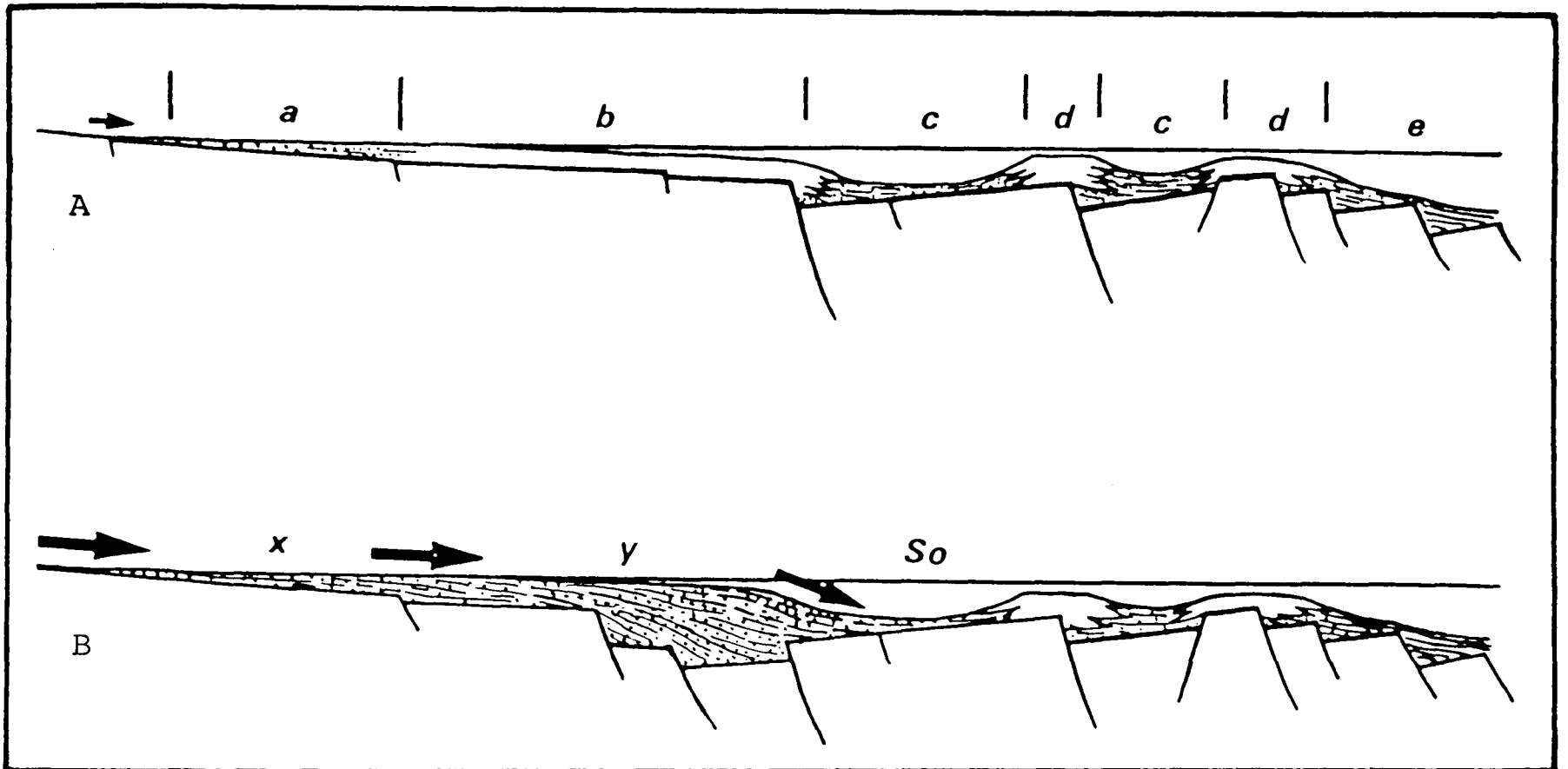


FIGURE 6-25.

General models of the Basco-Cantabrian Urgonian (Apto-Albian). Model A : A continental shelf that receives relatively little terrigenous input (such as NW Santander); Key : a: Areas of terrigenous/marly limestone at the very edge of the carbonate basin; b: Uniform rudistid platform carbonate; c: Rapidly subsiding intra-platform basins with marls, marly limestones and sandstones that are being supplied laterally; d: Isolated Urgonian platforms; e: Marine slope deposition. The NW Santander area would fall into a type d situation with the siliciclastics being ponded to the south in the Soba valley area (Figs. 6-23A, 6-23B and 6-24).

In model B (lower diagram) there was major terrigenous input from the hinterland (eg. Valnera area). Key : x: Delta plain; y: Delta front and pro-delta. Adapted from Rat and Pascal, 1979.

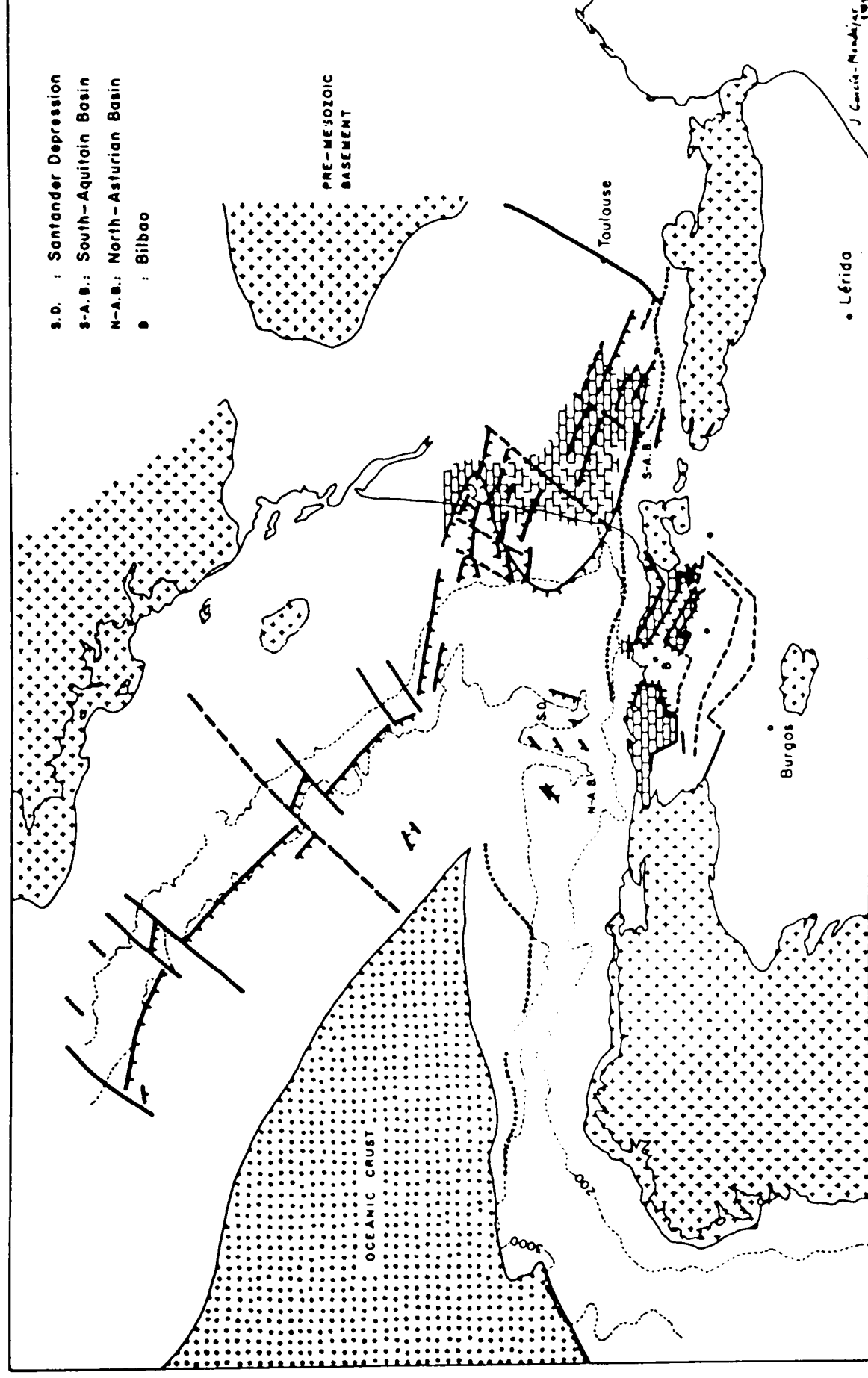


FIGURE 6-26.

Palaeogeographic map of central western Europe during the Aptian showing the WNW-ESE orientation of the major structural lineaments in both the Basco-Cantabrian and Aquitaine basins. These structural lineaments were the primary control on the distribution of the carbonate platforms in that they controlled the locations of platform margins (cf. Bahama Bank). Offshore data from Deregnacourt and Boillot, 1982; Aquitaine basin data from Masse and Philip, 1981. Adapted from Garcia Mondejar, 1985.

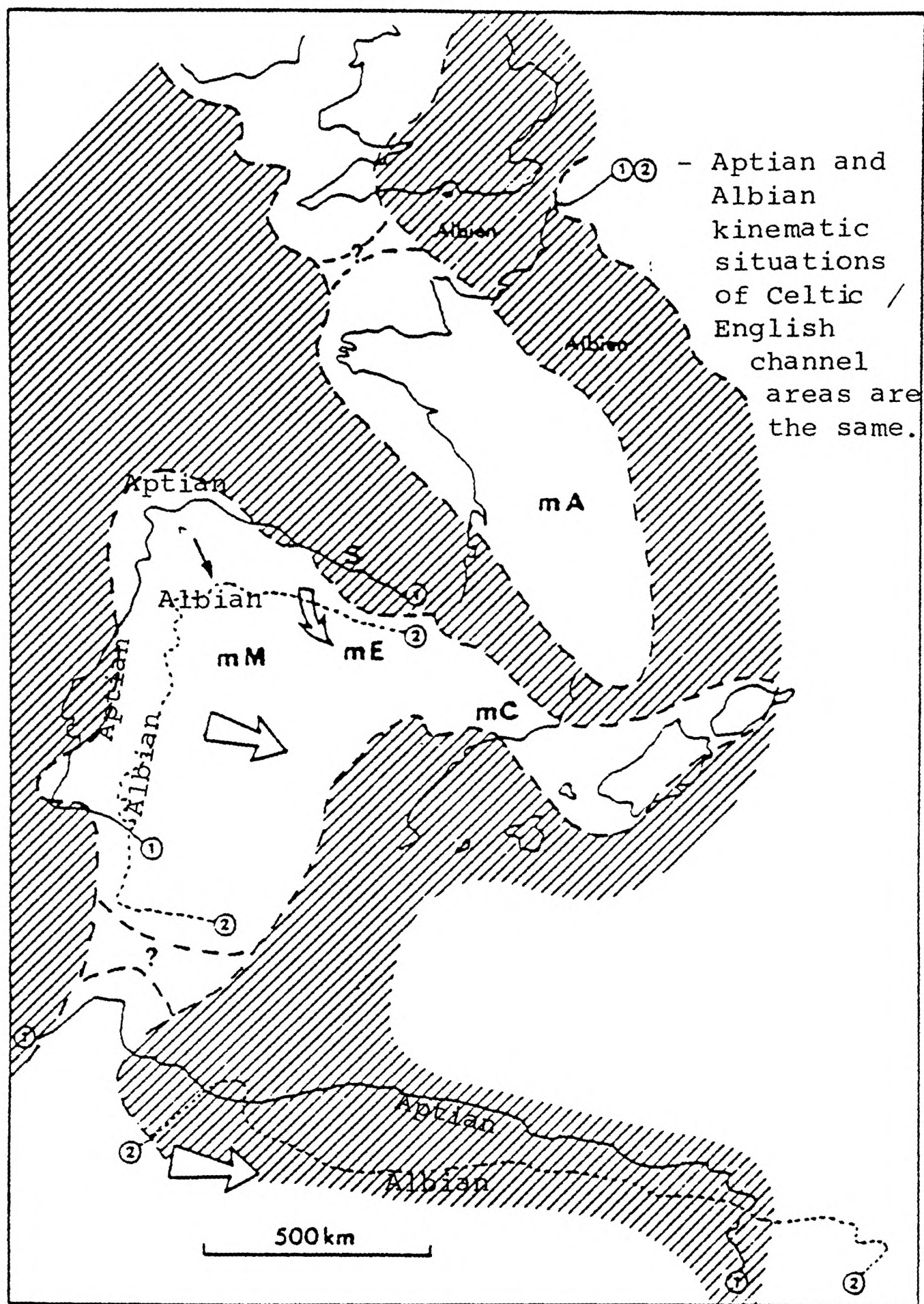


FIGURE 6-27.

Palaeogeographic / kinematic situation of the Basco-Cantabrian basin during the Apto-Albian within western Europe. The oblique lined area is that of the Aptian seaway. Position ① is the situation in the Aptian and ② that in the Albian. The kinematic movements of Iberia relative to (presumed stable) Europe are shown by the arrows. Key : S: Santander; mM: Meseta block; mE: Ebro block; mC: Catalan and Corso-Sardinian block; mA: Armorican and Celtic block. From Pascal, 1985.

DIAGENETIC PRODUCTS AND PROCESSES	ESTIMATE OF DEPTH/AGE OF EACH EVENT.
1) Micritization of allochems under marine, phreatic conditions	Sea floor during Reocin Fm. times.
2) Marine phreatic cementation.	Sea floor incipient hard-grounds.
3) Marine phreatic cementation with early, fringing cement.	Top few metres to tens(?) of metres of Reocin Fm. times.
4) Compaction.	Top few 10's of metres during Reocin Fm. times.
5) Preferential leaching of unstable aragonite/high-Mg calcite under meteoric, probably phreatic, conditions.	This occurred under 1) local shoal emergence during Reocin Fm. times & 2) Major emergence and meteoric diagenesis from the end Reocin Fm. disconformity.
6) Precipitation of limpid, equant spar under meteoric, phreatic conditions.	Similar timing to 5).
7) Sucrosic dolomitization from meteoric/groundwater lenses over palaeohighs.	Similar timing to 5) & 6) under mixing of seawater with meteoric/groundwater conditions.
8) Ferroan, equant, drusy spar.	Late-stage, hypersaline (?) -related connate water precipitation under a few 100's to 1000's of metres.
9) Stylolitization.	Chemical solution under a few 100's to 1000's of metres.
10) Ferroan dolomitization linked to the mixing of hot, hypersaline brines with surface-related waters.	As early as basal Cenomanian (main mineralization phase), but latter fracture-related spar that was pre-Upper Eocene also occurred. Some syn-orogenic fracture-related spar.
11) Recent surface-related weathering, iron (oxy)hydroxide weathering of the ferroan dolomites and caliche growth.	Post-Miocene/Pliocene, syn-karstification alteration.

FIGURE 6-28.

General diagenetic sequence for the Reocin Fm. carbonates from initial deposition (1) to Recent exposure (11).

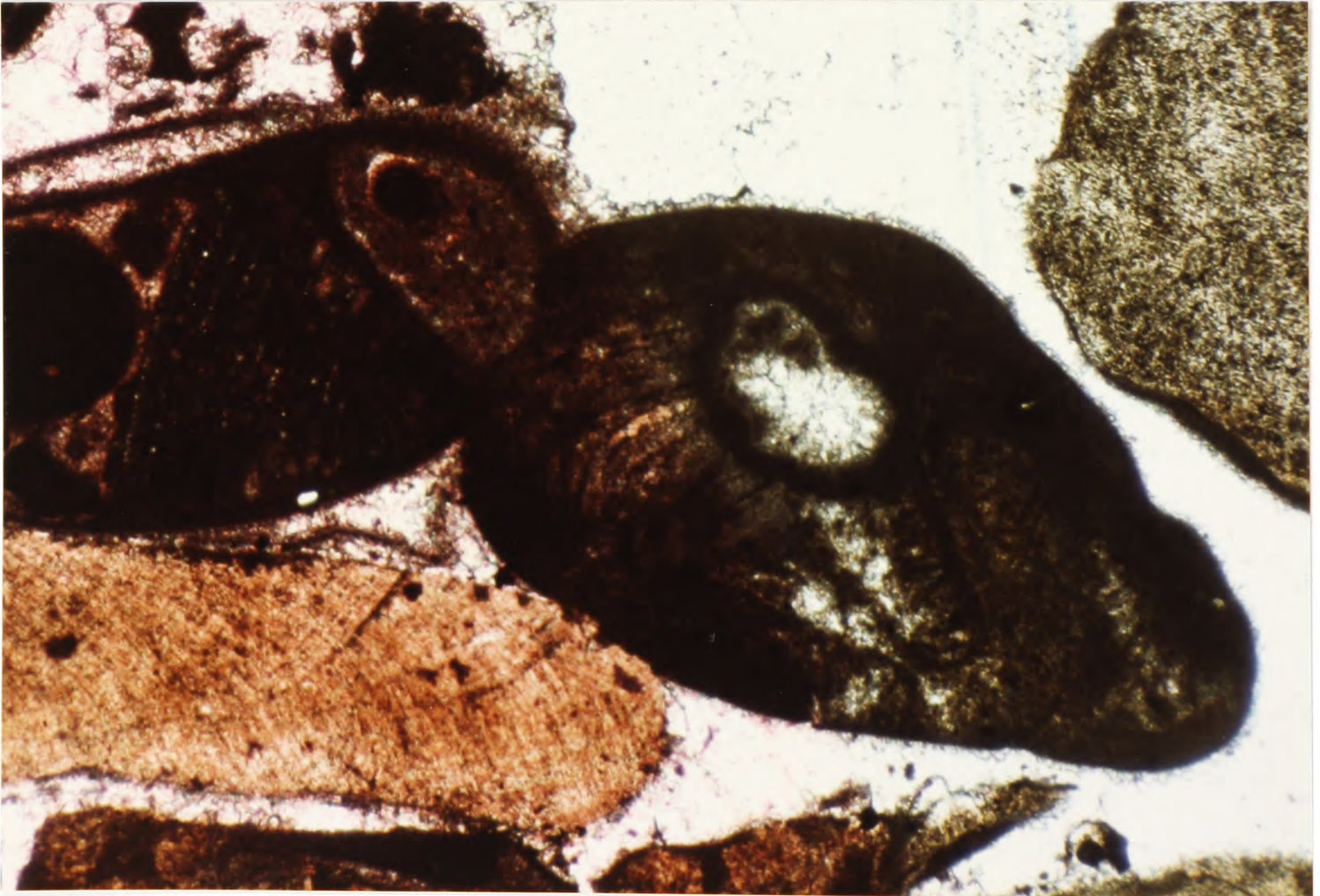
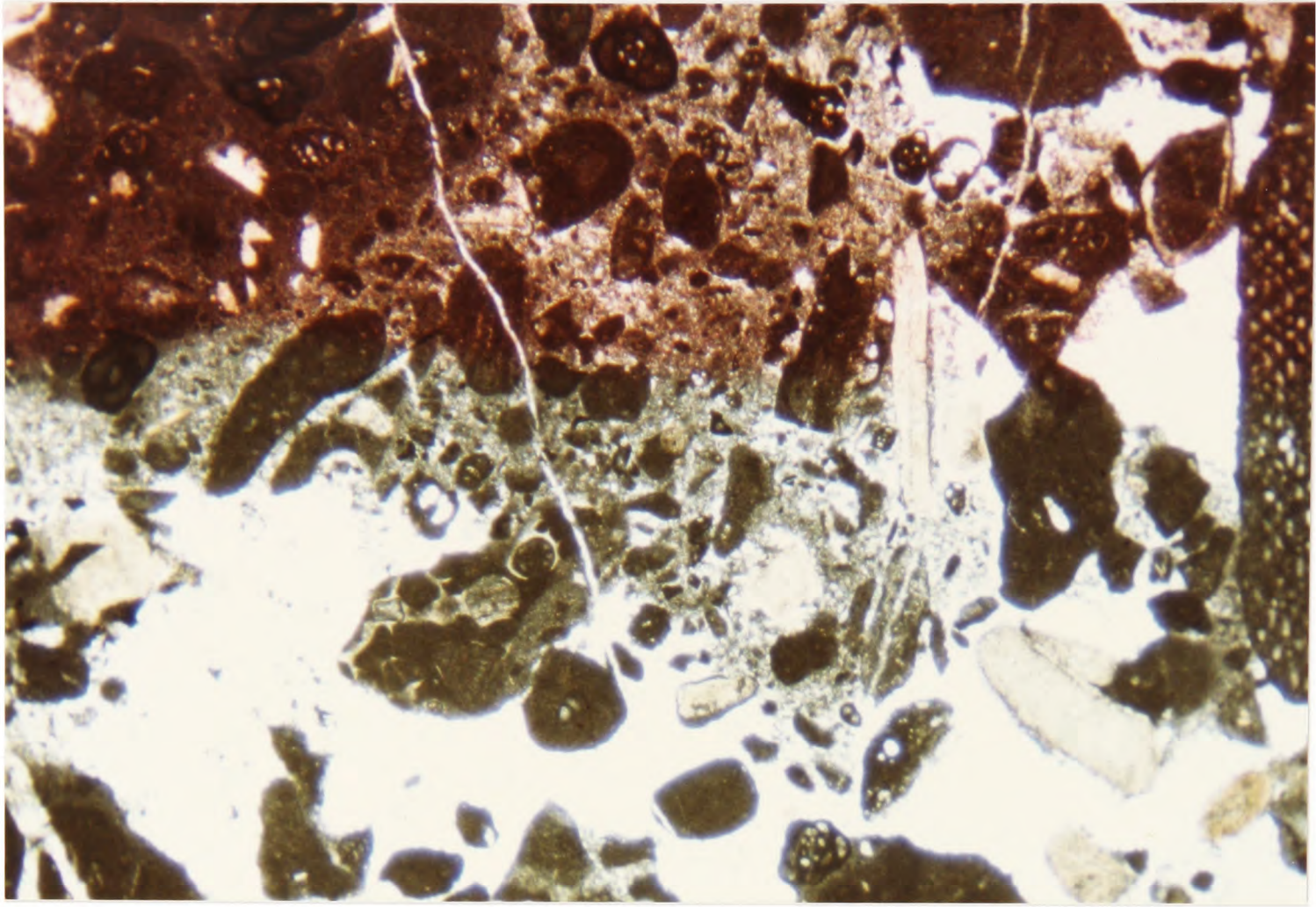


FIGURE 6-29.

This shows the early fringing cement of a grainstone from the Reocin Fm. It is encrusting bivalve peloids and rudists and intraclasts. It is generally isopachous and does not show meniscus or drip-stone forms. It is hence interpreted as an early, marine phreatic fringing cement. The left hand side of the micrograph has been stained with potassium ferricyanide/Alizurin Red S solution. It was taken under plane-polarized light of an area 2.4mm by 3.6mm wide.

FIGURE 6-30.

This shows the vadose silt of the Reocin Fm. from the Cuchia section. This silt is linked to major meteoric invasion at end Reocin Fm. times. There is then a later generation of equant spar. This was taken in plane-polarized light of an area 6mm by 9mm wide.

	Sr	Na	Mn	Mg	Zn
Rudistid/miliolid LST.	(110 à 450) moyenne : 348	m : 156,8	(25 à 220) m : 38,3	m : 3790	m : 10,2
Iraquia/orbitolinid LST.	(150 à 450) m : 272	m : 147,5	m : 63,2	m : 3175	
Orbitolinid LST. Stromatolitic LST. Mud-mound facies.	m : 211 (150 à 320) m : 223 m : 220	m : 131,5 m : 121 m : 125	m : 52 m : 99,1 m : 75	m : 3250 m : 3470 m : 3300	
Orbitolinid facies. Orbitolinid marble.	(100 à 1600) m : 516 m : 675	m : 157,4 m : 157,5	(20 à 1200) m : 184,6 m : 294	m : 5597 m : 5687	m : 8,6
Orbitolinid/coral LST.	(200 à 950) m : 481	m : 164,5	m : 115,5	m : 4428	
Crinoidal limestone.	m : 407	m : 157,5	m : 230	m : 5269	.
Rhodaphyta calcarenite.	m : 1400	m : 125	m : 104	m : 4511	
Charophytic LST. Facies under emersion surfaces.	122 à 219 131 à 210	102 à 159,3 44 à 122	1198,9 à 1235 26 à 130	1719 à 3137 = 2000 à 3000	3,9 à 33 5 à 15
Blue-grey marls.	(300 à 1800) m : 796	m : 1808	m : 216	m : 4060	m : 19,5
Black bassinal marls. Albian marls with red nodules.	(550 à 1900) m : 1185 1194	m : 278,3 1407	(80 à 1000) m : 308 536	m : 4928 4356	(0 à 115) m : 34,8 jusqu'à 214
High-energy LST.	(460 à 1300) m : 1084	(73,7 à 179,4) m : 126,5	(64 à 81,6) m : 72,8	m : 3691	
Mean values.	350 à 600	130 à 250	80 à 300	3500 à 5000 ?	1 à 20 ?

FIGURE 6-31.

Trace element values in ppm of the principal facies in the Urgonian of the Basco-Cantabrian basin. "m" stands for mean values. From Pascal, 1979.

REOCIN FM. BARCENACIONES FM. BIELBA FM.

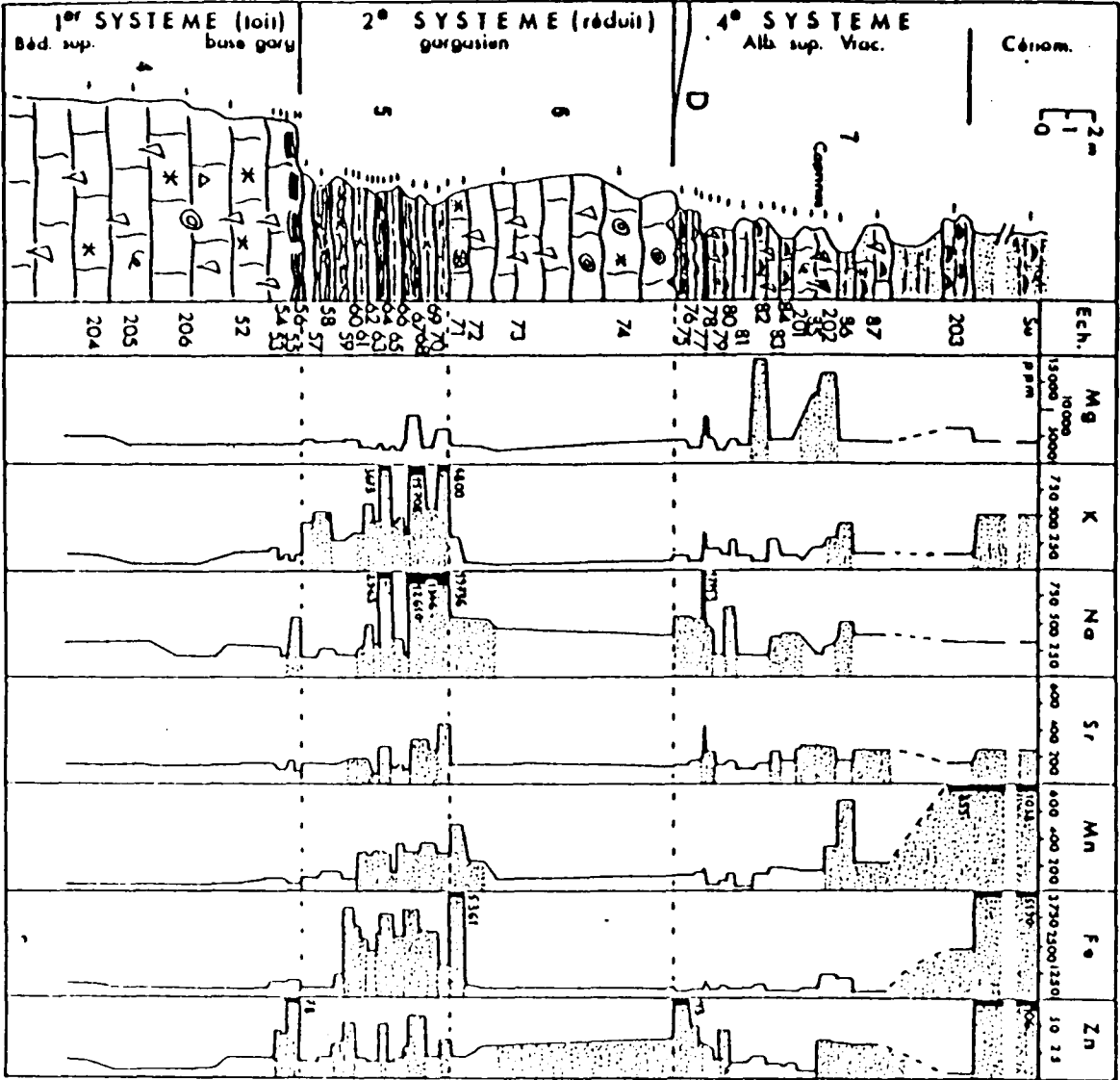
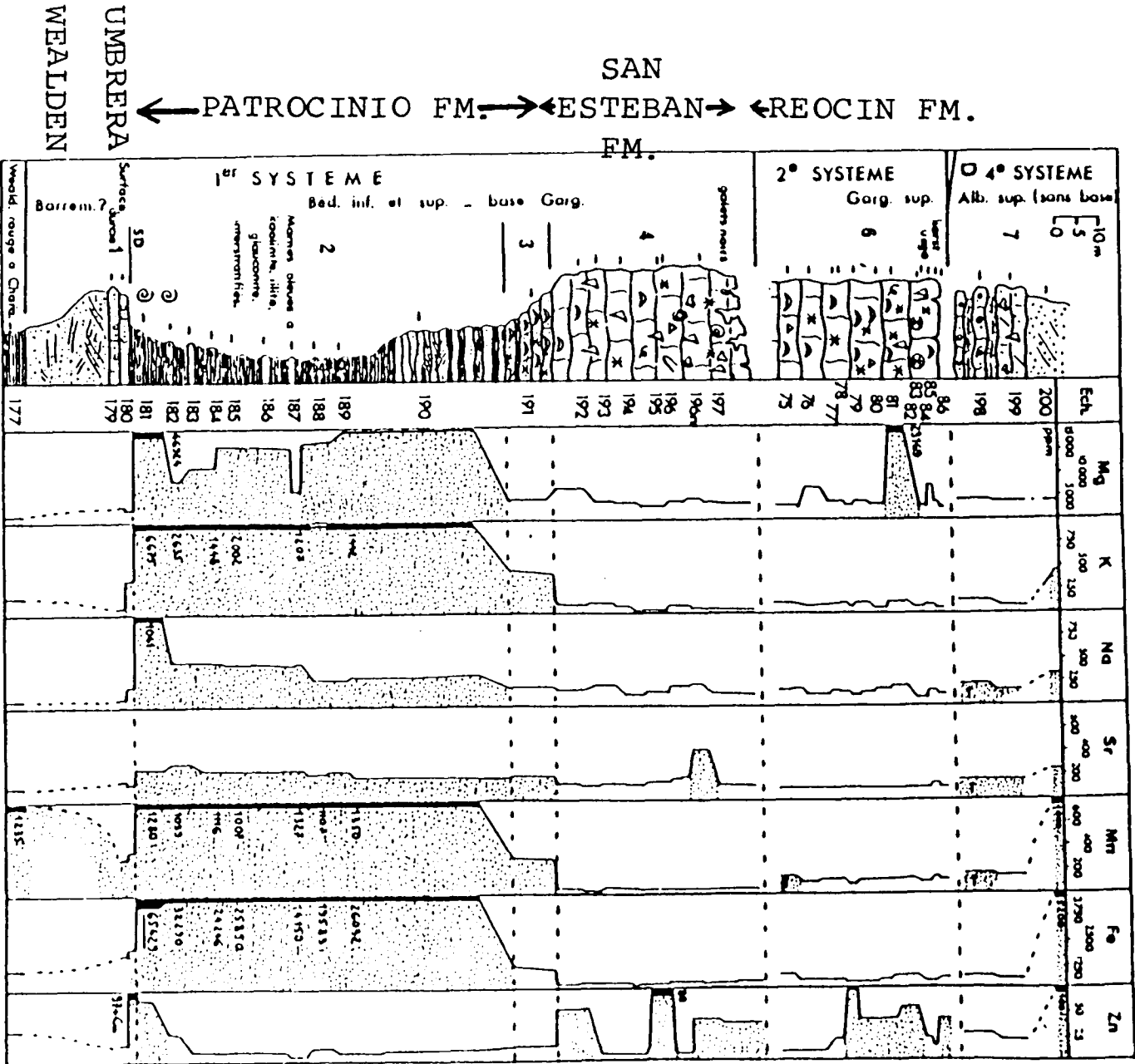
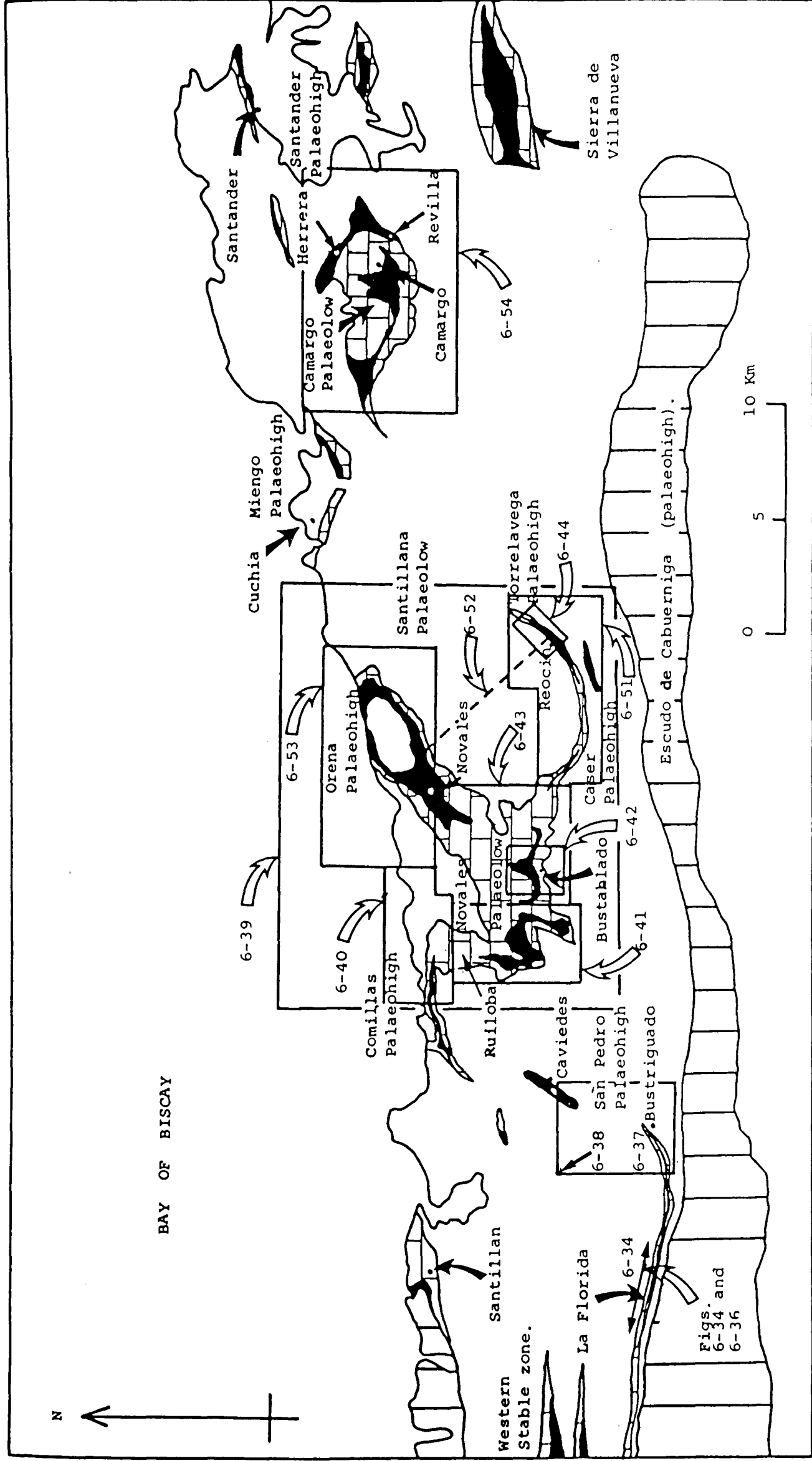


FIGURE 6-32.

Trace element data from the Torrelavega Group at A) Punta del Dichoso, north of Suances and at B) Cuchia (Section 15A). Results are in ppm. Note the low whole-rock values for Na, Sr, K, Mn and Fe in the San Esteban and Reocin Fms. platform limestones. Data from Pascal, 1985.





Palaeozoic / Buntersandstone basement.

Mesozoic / Tertiary cover excluding the Upper Aptian Reocin Fm.

Reocin Formation dolomite (Novales Member).

Reocin Formation limestone (Barrio and Sierra Mbs.)

FIGURE 6-33.

Location map for the detailed maps and sections of the Novales Mb. dolomite in the Reocin Formation. The "6-nn" numbers refer to figure numbers of these detailed sections and maps in this chapter. The dotted line of Fig. 6-52 between Reocin and Novales refers to a cross-section based on boreholes.

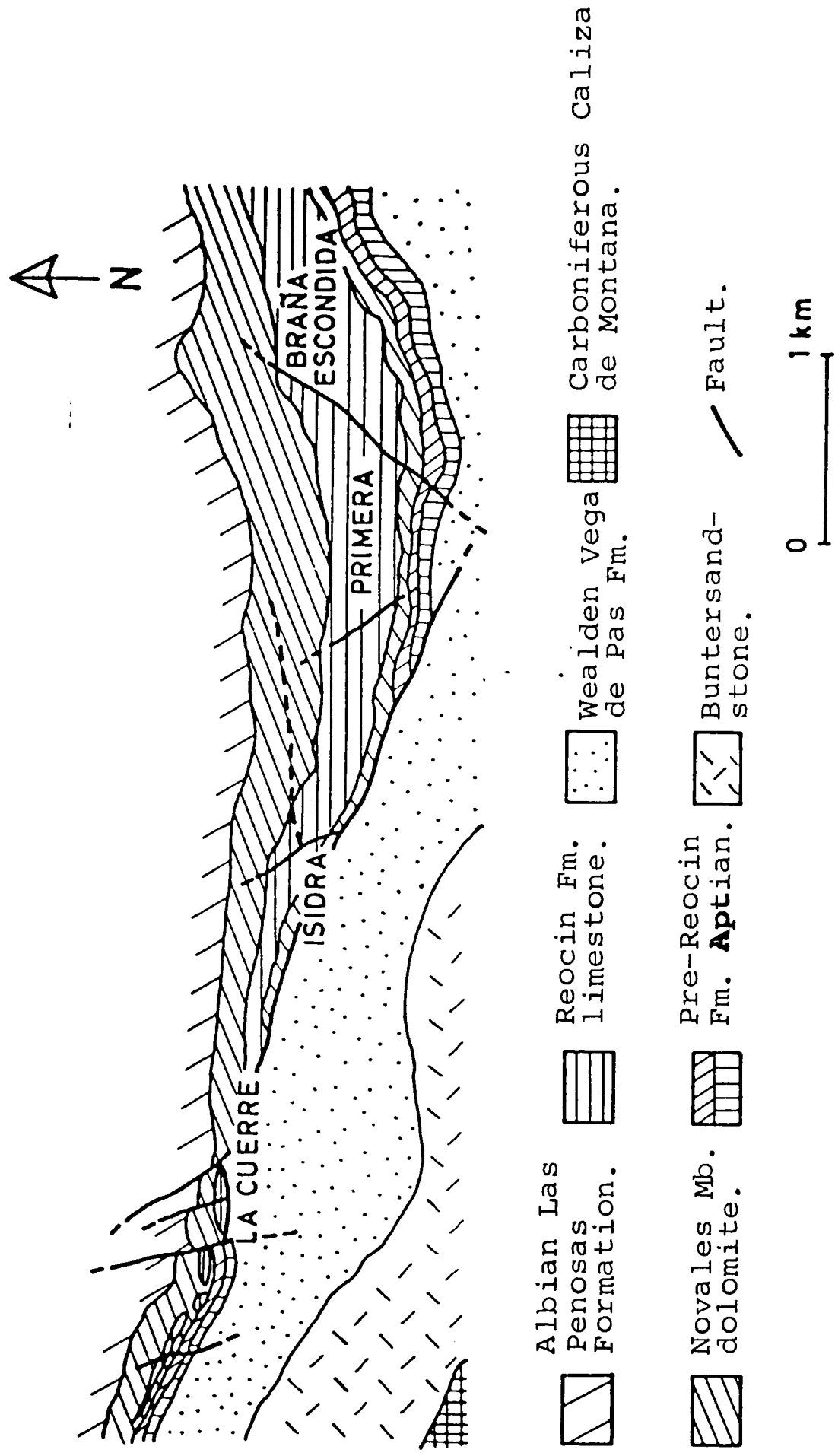


FIGURE 6-34.

Simplified geological map of the La Florida area, west of Bustriguado. For location see Fig. 6-33. Note the tongue of Novales Mb. dolomite that thins westward and the cross-cutting faults around La Cuerre (= La Florida). Adapted from Adelhardt, 1968.

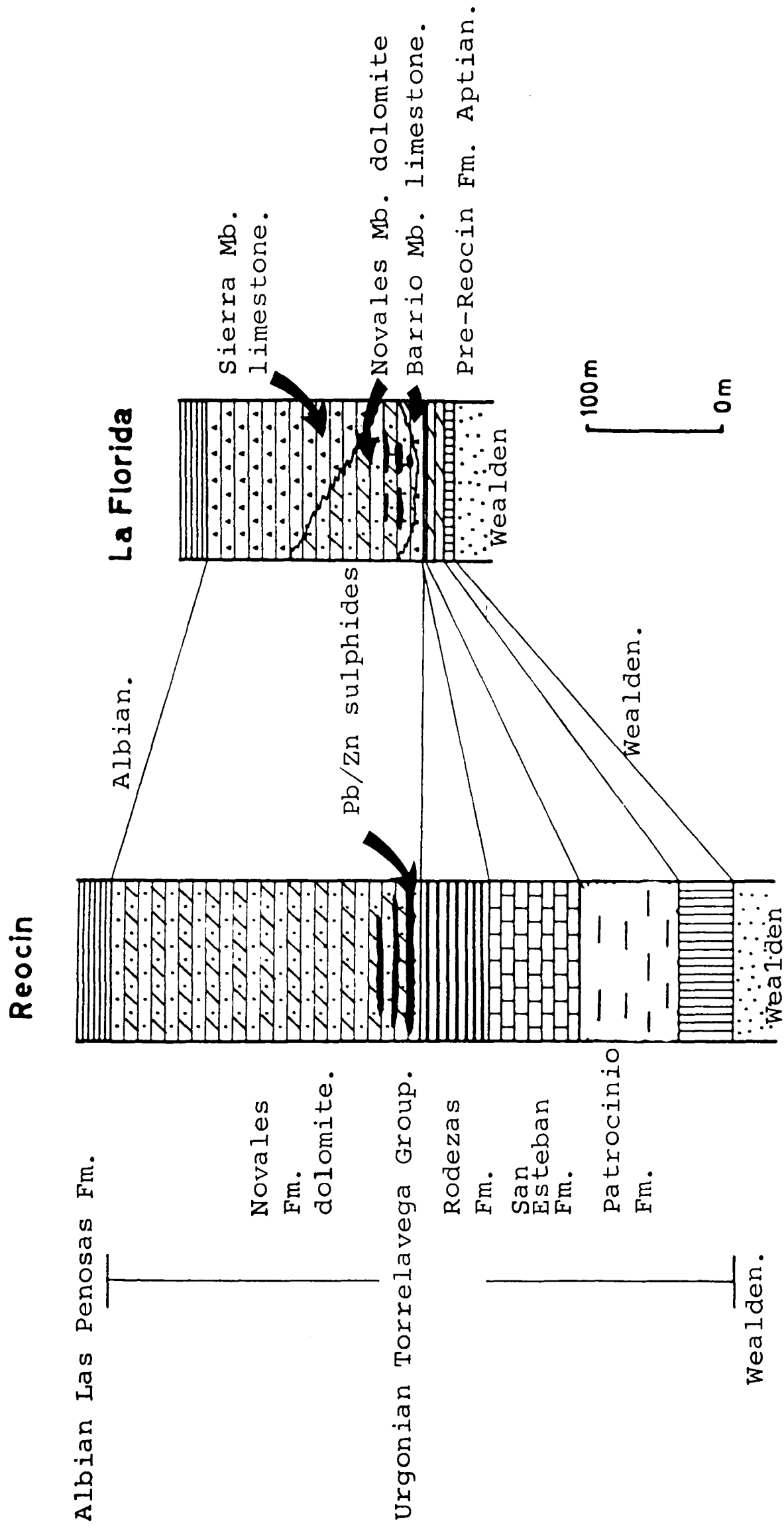


FIGURE 6-35.

A correlation of the Urganian Torrelavega Groups at Reocin (Section 15 in Fig. 6-1) and La Florida (Section 4 in Fig. 6-1). Note the thinning of the sequence at La Florida. The lateral facies and thickness changes are discussed in Chapters 5 and 6. Adapted from Adelhardt, 1968.

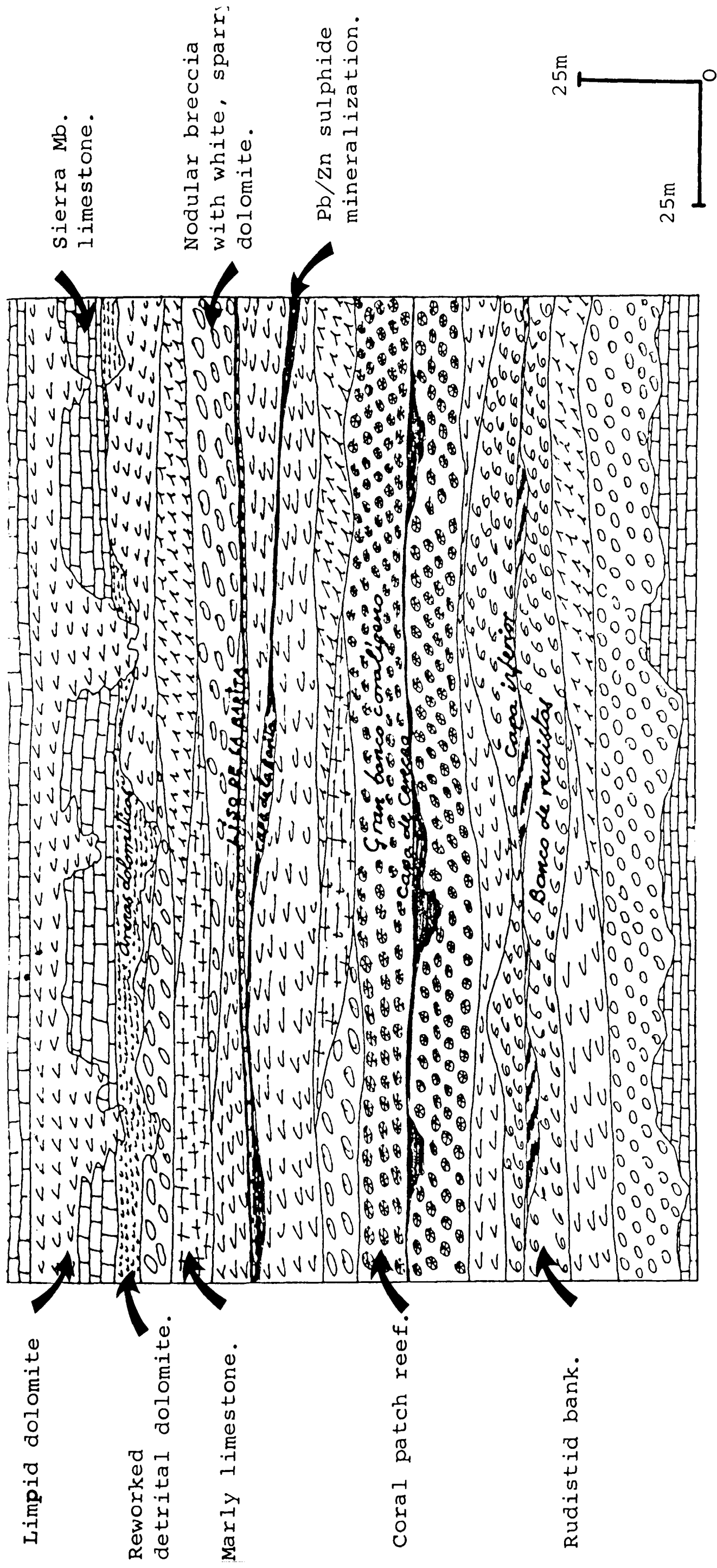


FIGURE 6-36.

A section through the mineralized zone at the base of the Novales Member (Reocin Formation) in the mine at La Florida (54079664; location on Fig. 6-33). Note the intimate association of the Pb/Zn sulphide mineralization with the high permeability coral and rudistid horizons. The three "capas" (= beds) shown are the key mineralization horizons. They are subparallel to bedding. Adapted from Sanchez, 1976.

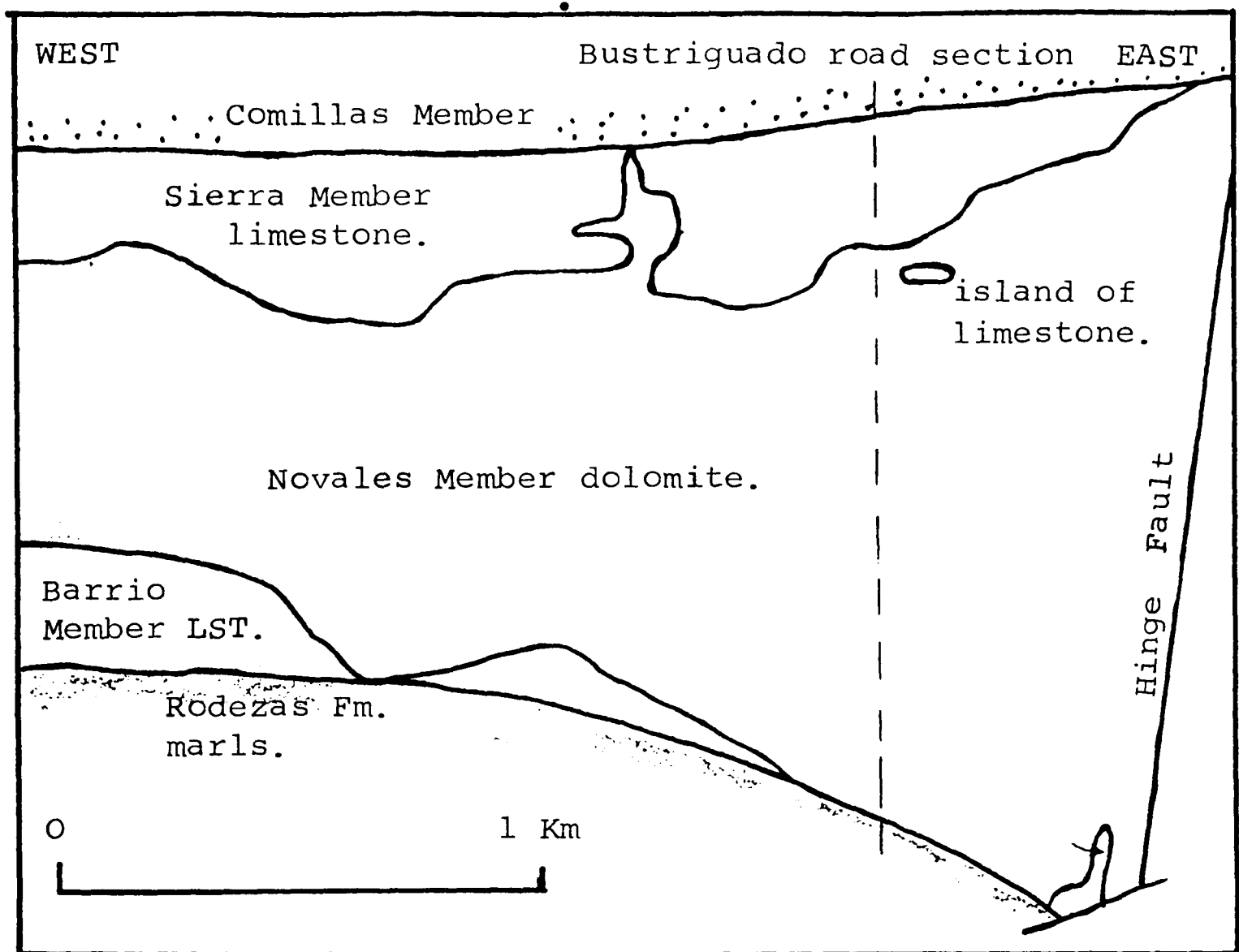


FIGURE 6-37.

Sketch section of the extent of dolomitization in the Reocin Formation (Upper Aptian) immediately north of Bustriguado (54669667; location on Fig. 6-33). Note the lateral complexity on a 100's of metres scale in the Novales Member dolomite and the isolated island of limestone in the dolomite (possibly connected to the body of the Sierra Mb. limestone in three dimensions). The location of the Bustriguado road section is marked.

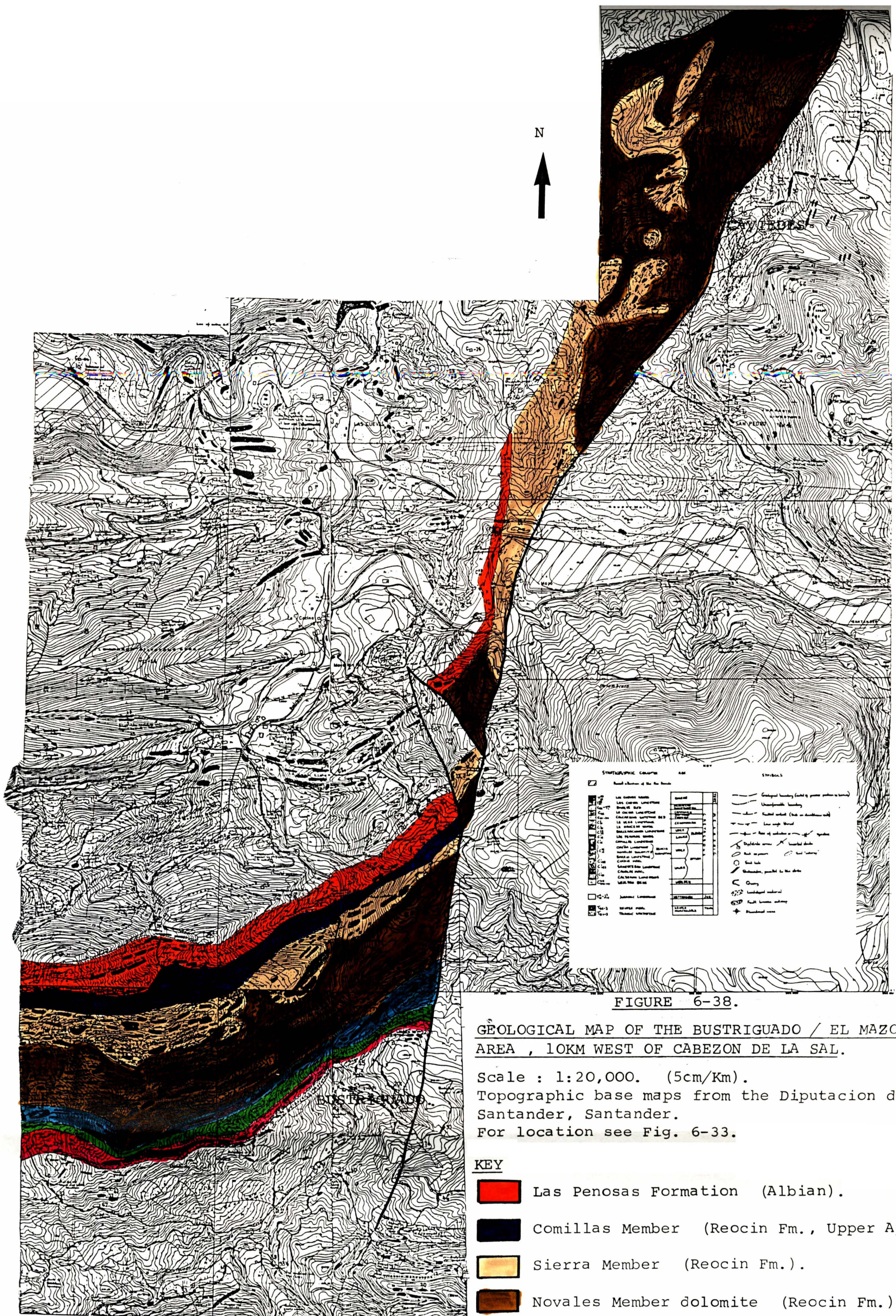


FIGURE 6-38.

GEOLOGICAL MAP OF THE BUSTRIGUADO / EL MAZO AREA , 10KM WEST OF CABEZON DE LA SAL.

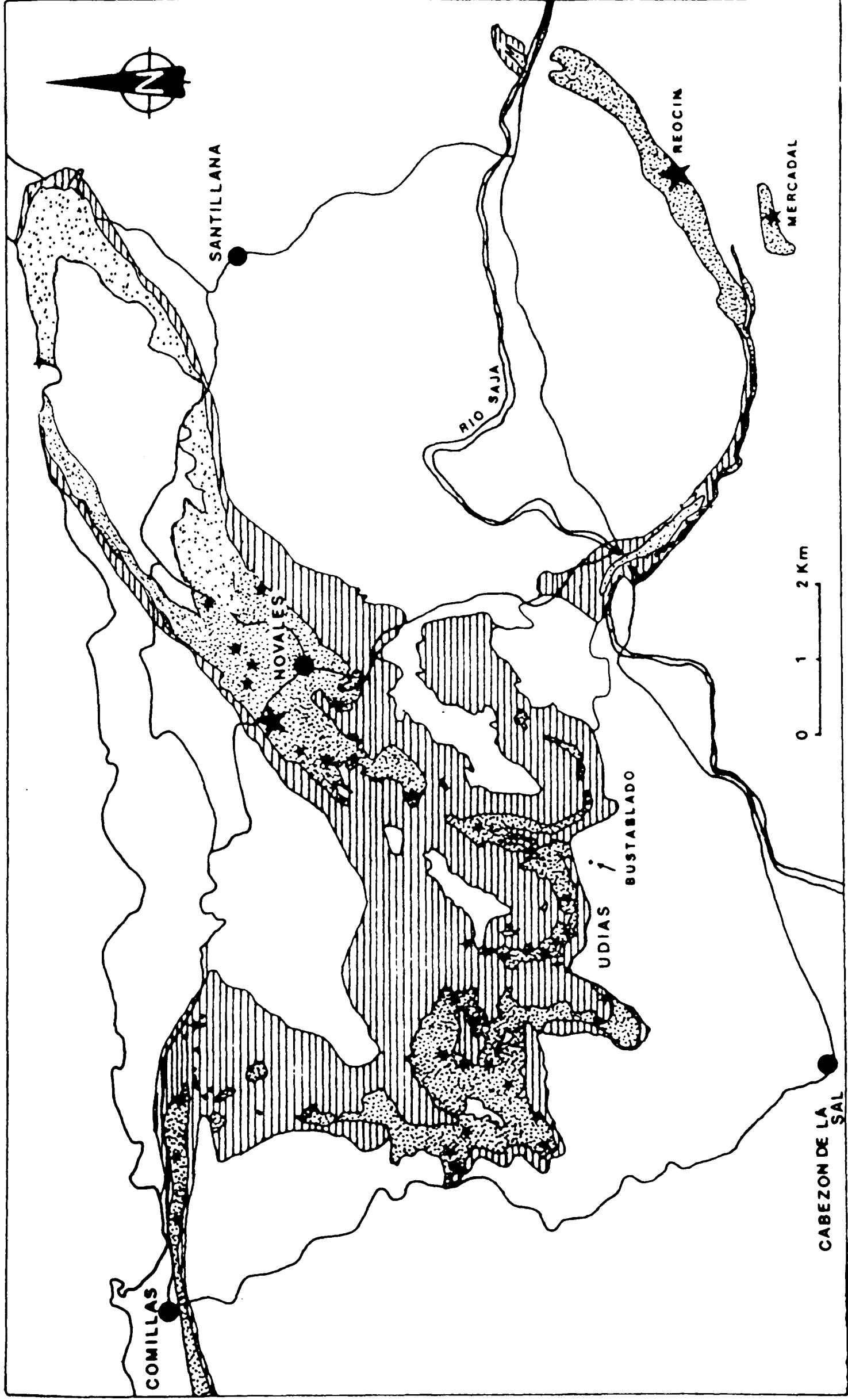
Scale : 1:20,000. (5cm/Km).

Topographic base maps from the Diputacion de Santander, Santander.

For location see Fig. 6-33.

KEY

- Las Penosas Formation (Albian).
- Comillas Member (Reocin Fm., Upper Aptian).
- Sierra Member (Reocin Fm.).
- Novales Member dolomite (Reocin Fm.).
- Barrio Member limestone (Reocin Fm.).
- Rodezas Formation.
- San Esteban Formation.



 Reocin Fm. limestones.
  Novales Mb. dolomite.
 ★ Major Pb/Zn sulphide mines.

FIGURE 6-39. Geological map of the Reocin Fm. in the central region of Comillas/Reocin showing the distribution of the Novales Mb. dolomite within the formation. For location see Fig. 6-33. Adapted from Vadala, 1981.

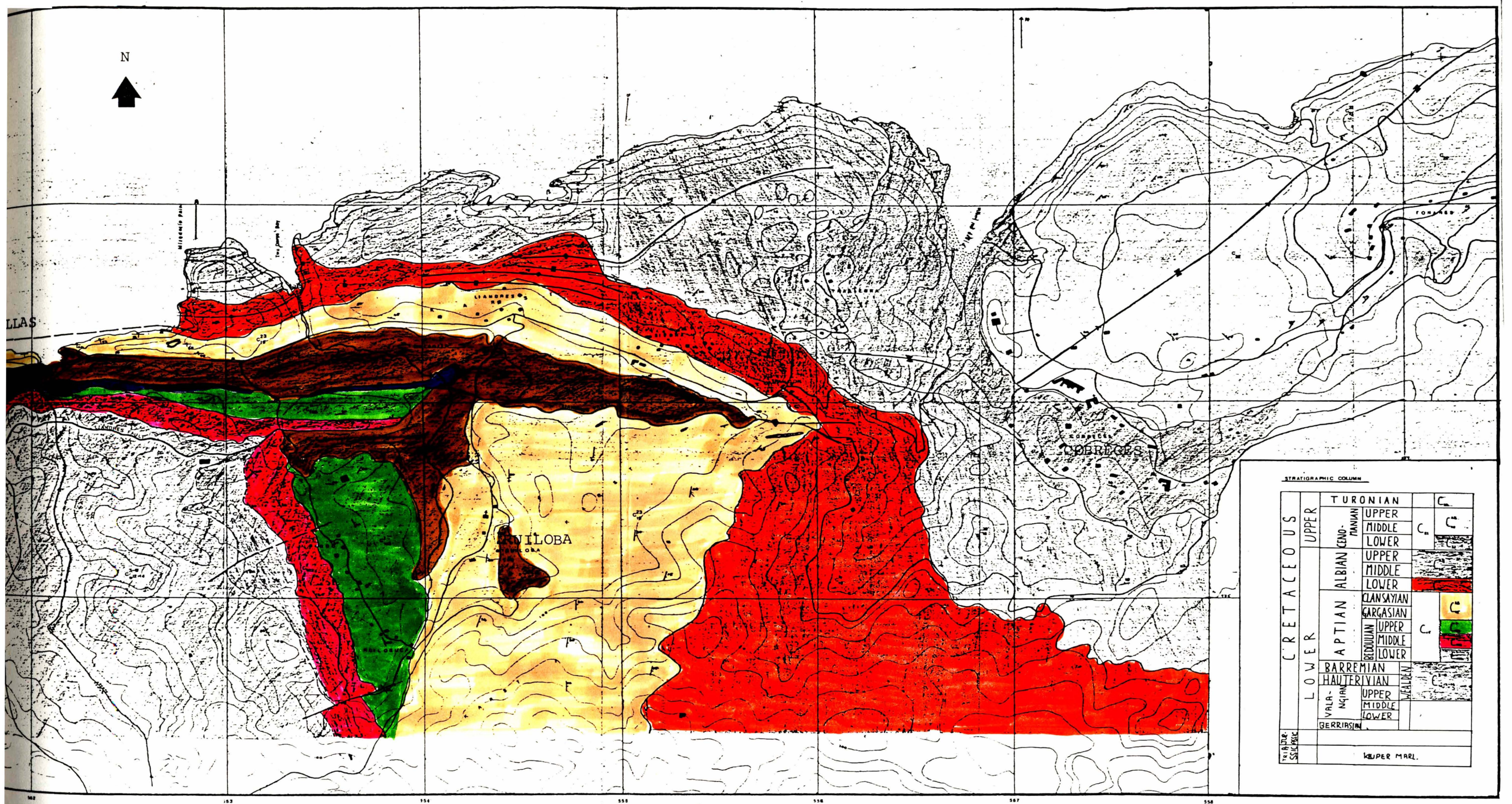


FIGURE 6-40.

Geological map of the Comillas/Ruiloba/Cobreces area at a scale of 1:20,000 (5cm/Km). A kilometre square grid is shown and the map is located on Fig. 6-33. Key :-

- | | | | |
|---|---|---|---------------------------------|
|  | Las Penosas Formation. (Albian) |  | Barrio Member of the Reocin Fm. |
|  | Sierra and Comillas Members of the Reocin Fm. (Upper Aptian/basal Albian limestones). |  | Rodezas Formation. |
|  | Novales Member dolomite of the Reocin Fm. |  | San Esteban Formation. |

N



Scale:

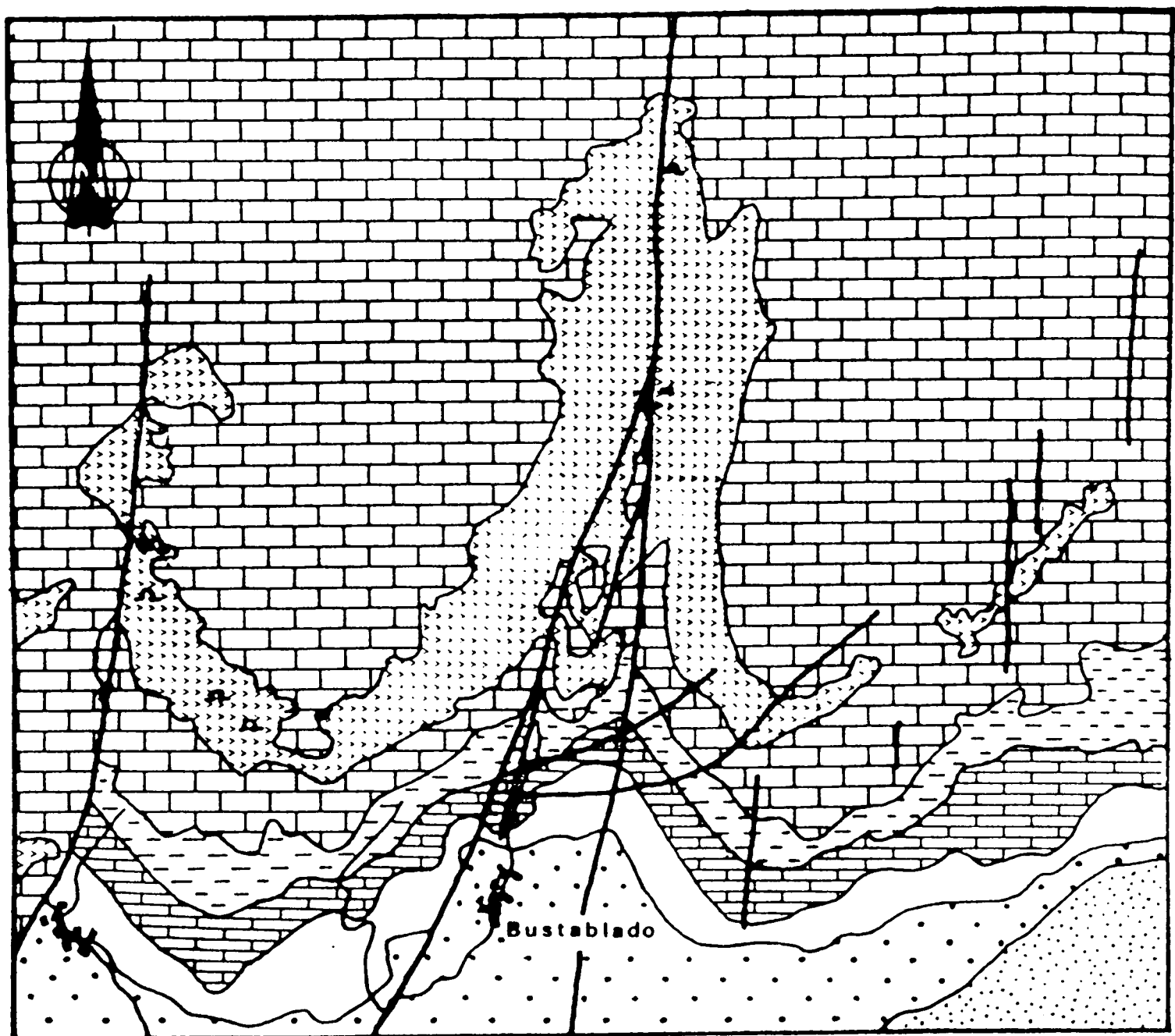


FIGURE 6-41.

Geological map of the Canales/Udias area, 5Km north of Cabezon de la Sal. The map is at a scale of 1:20,000 (5cm/Km) and has a 500m² grid system. It is located within the area as a whole on Fig. 6-33. Key:-

-  Las Penosas Fm. (Albian).
-  Sierra and Comillas Mbs. of the Reocin Fm. (Upper Aptian).
-  Novales Member dolomite (Reocin Fm.)
-  Barrio Member limestone.
-  Rodezas Formation.
-  San Esteban Fm.





0 1 Km

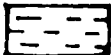
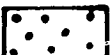
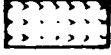
- | | | | |
|---|-----------------------------|---|-----------------------|
|  | Rodezas Formation. | | |
|  | Wealden Vega de Pas Fm. |  | Reocin Fm. limestone. |
|  | Umbrera and Patrocinio Fms. |  | Novales Mb. dolomite. |
|  | San Esteban Formation. |  | Quaternary drift. |

FIGURE 6-42.

A geological map of the Bustablado area showing the Novales Mb. dolomite development. Note the major development of the Novales Mb. around the N/S faults through Bustablado. Adapted from Vadala, 1981.

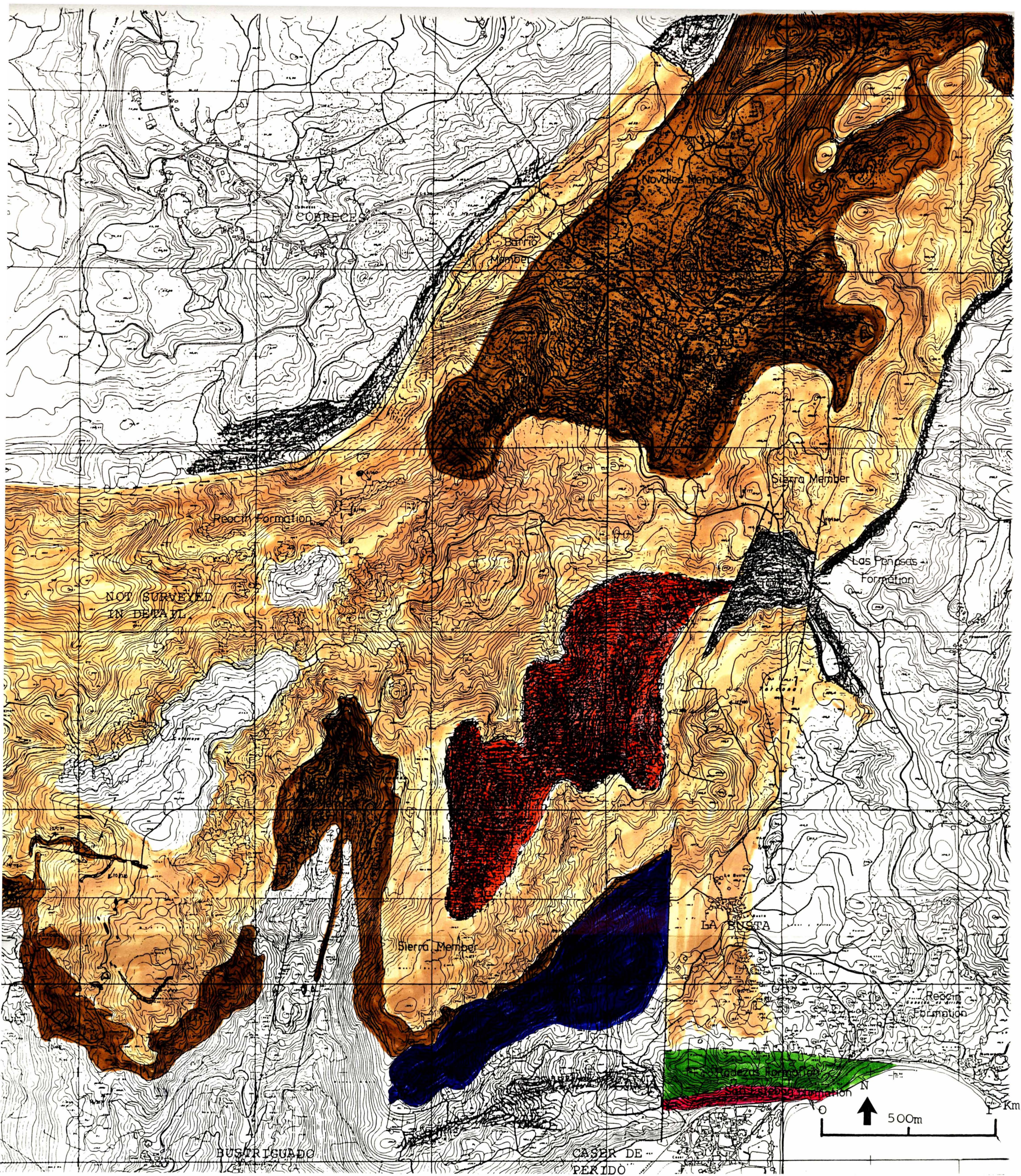


FIGURE 6-43. : Geological map of the Bustriguado/Novales area at a scale of 1:20,000 (5cm/Km). The map has a 1km grid and is located on Fig. 6-33. KEY:-

- | | |
|---|--|
| Las Penosas Fm. | Barrio Mb. (Reocin Fm.) |
| Comillas and Sierra Mbs. of the Reocin Fm. | Rodezas Formation. |
| Novales Mb. dolomite. | San Esteban Formation. |

FIGURE 6-44. (caption)

A geological map of the Reocin area showing the well developed dolomitization of the Reocin Fm.. This map is located on Fig. 6-33. Note the north orientation. Key:-

- 1 : Mine working tips.
- 2 : Quaternary drift.
- 3 : Middle/Upper Cenomanian Altamira Formation.
- 4 : Lower Cenomanian Bielba Formation.
- 5 : Upper Albian Barcenaciones Formation,
- 6 : Albian Las Penosas Formation.
- 7 : Novales Member of the Reocin Formation.
- 8 : Barrio Member of the Reocin Formation.
- 9 : Basal marly Barrio Member of the Reocin Formation.
- 10 : Rodezas Formation.
- 11 : San Esteban Formation.
- 12 : Umbrera/Patrocinio Formations.
- 13 : Wealden Vega de Pas Formation.
- 14 : Fault.
- 15 : Probable fault.
- 16 : Stratigraphic contact.
- 17 : Probable stratigraphic contact.

Adapted from Cendrero Uceda et al., 1974.

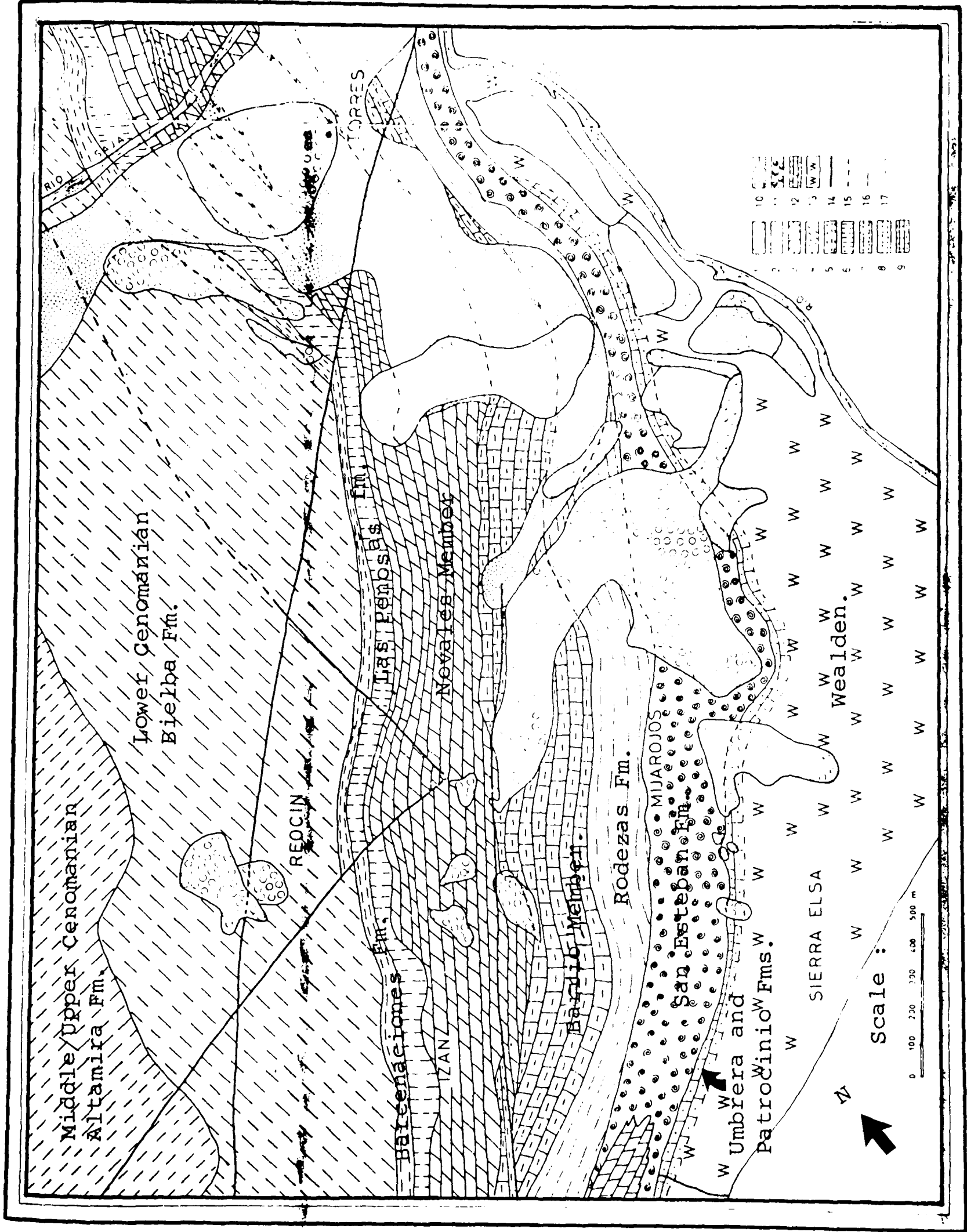


FIGURE 6-44. : Geological map of the Reocin area, caption opposite.

WEST

EAST

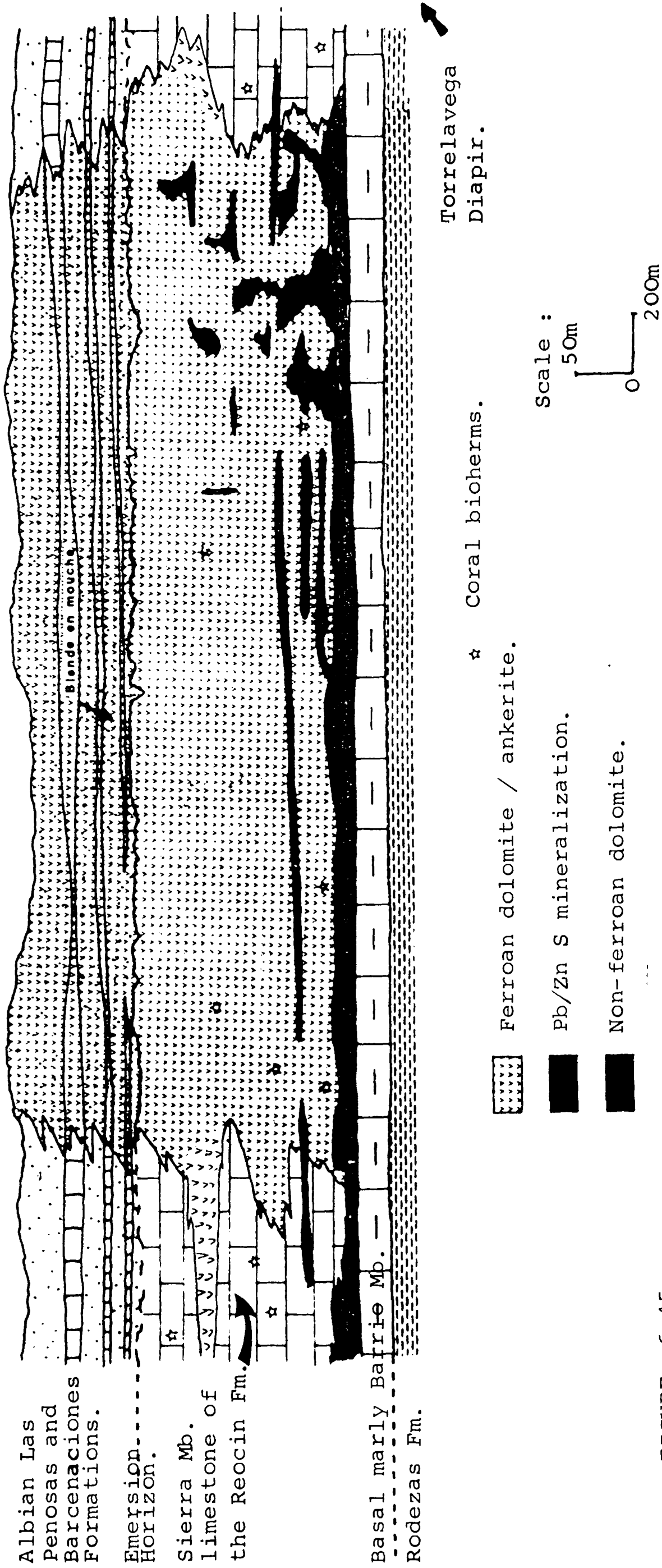


FIGURE 6-45.

General cross-section of the Upper Aptian/Albian in the Reocin mine area showing the bedding parallel nature of the major Pb/Zn S ore bodies which are named on Figs. 6-47 & 6-48. Note the emersion horizon at the top of the Reocin Fm.. Adapted from Vadala, 1981.

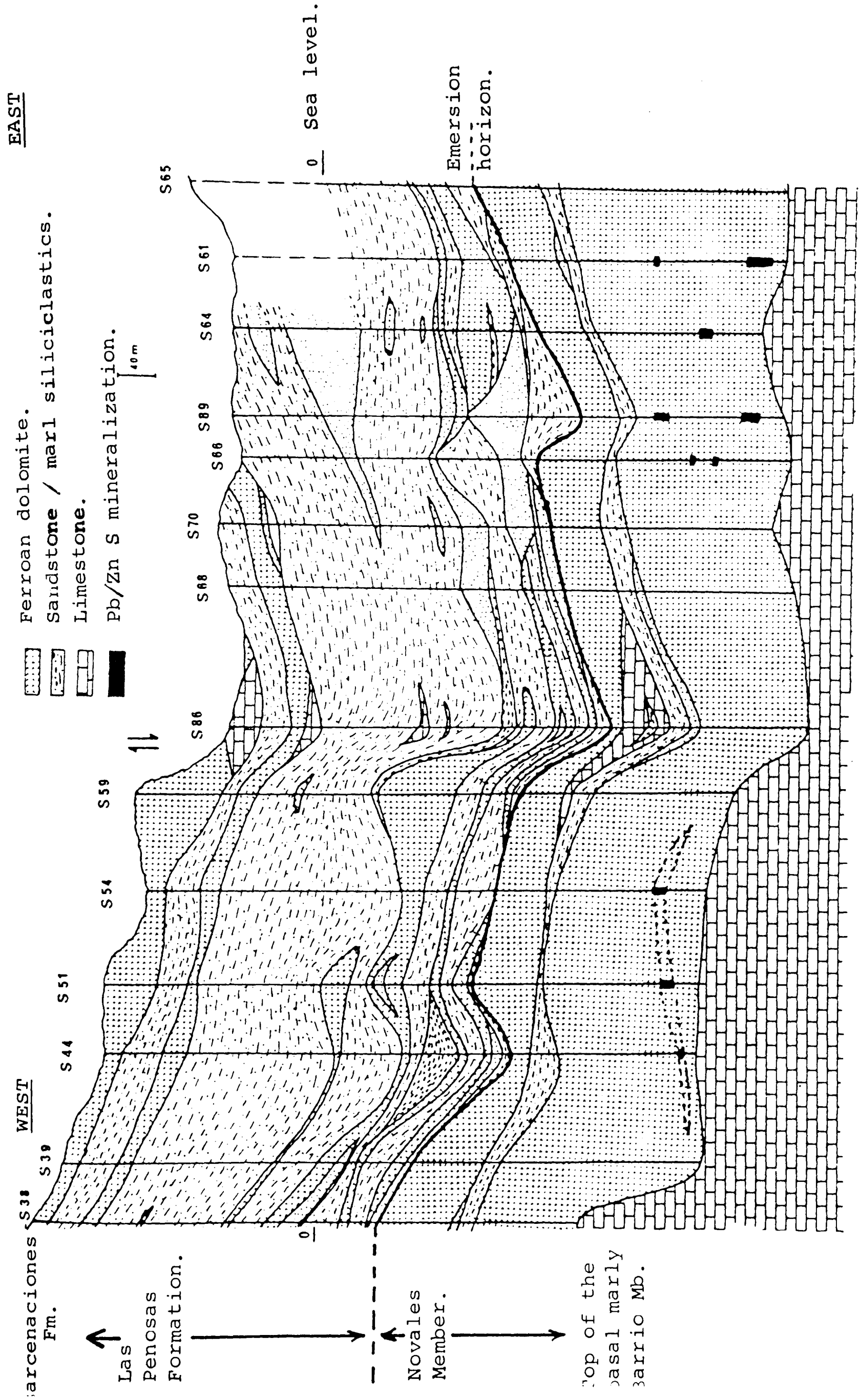


FIGURE 6-46.

A bore-hole correlation section through the mineralized zone at Reocin. Note the extensive ferroan dolomitization of the Albian Las Penosas and Barcenaciones Fms..

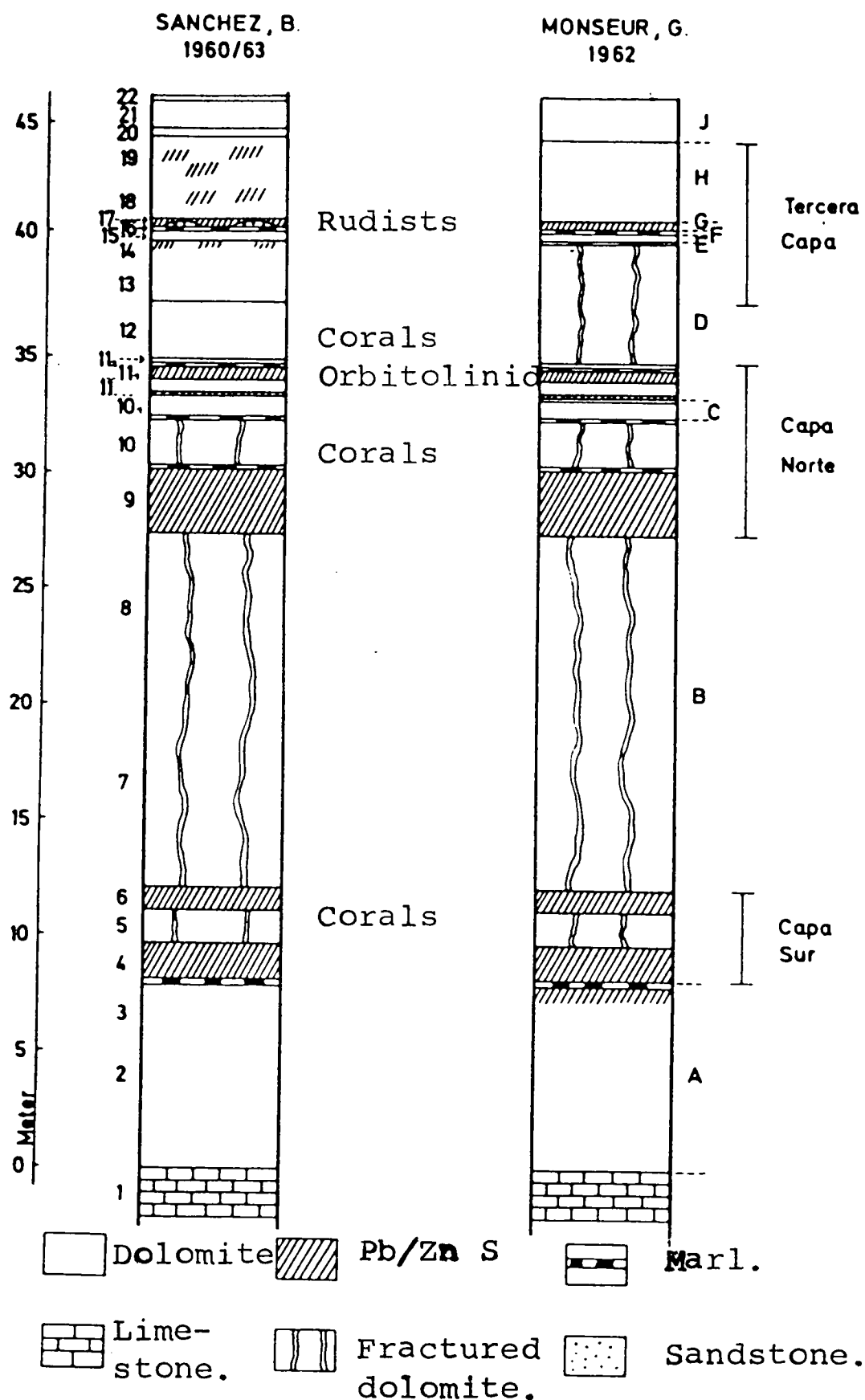


FIGURE 6-47.

Detailed logs of the basal 45m of the Novales Member at Reocin showing the three key mineralized horizons. The log on the left is after Sanchez, 1960, 1963 & 1971. The log on the right is from Monseur, 1962. Both authors show a remarkable degree of similarity in their descriptions of the mineralized horizons. The scale on the far left is in metres. Adapted from Adelhardt, 1968.

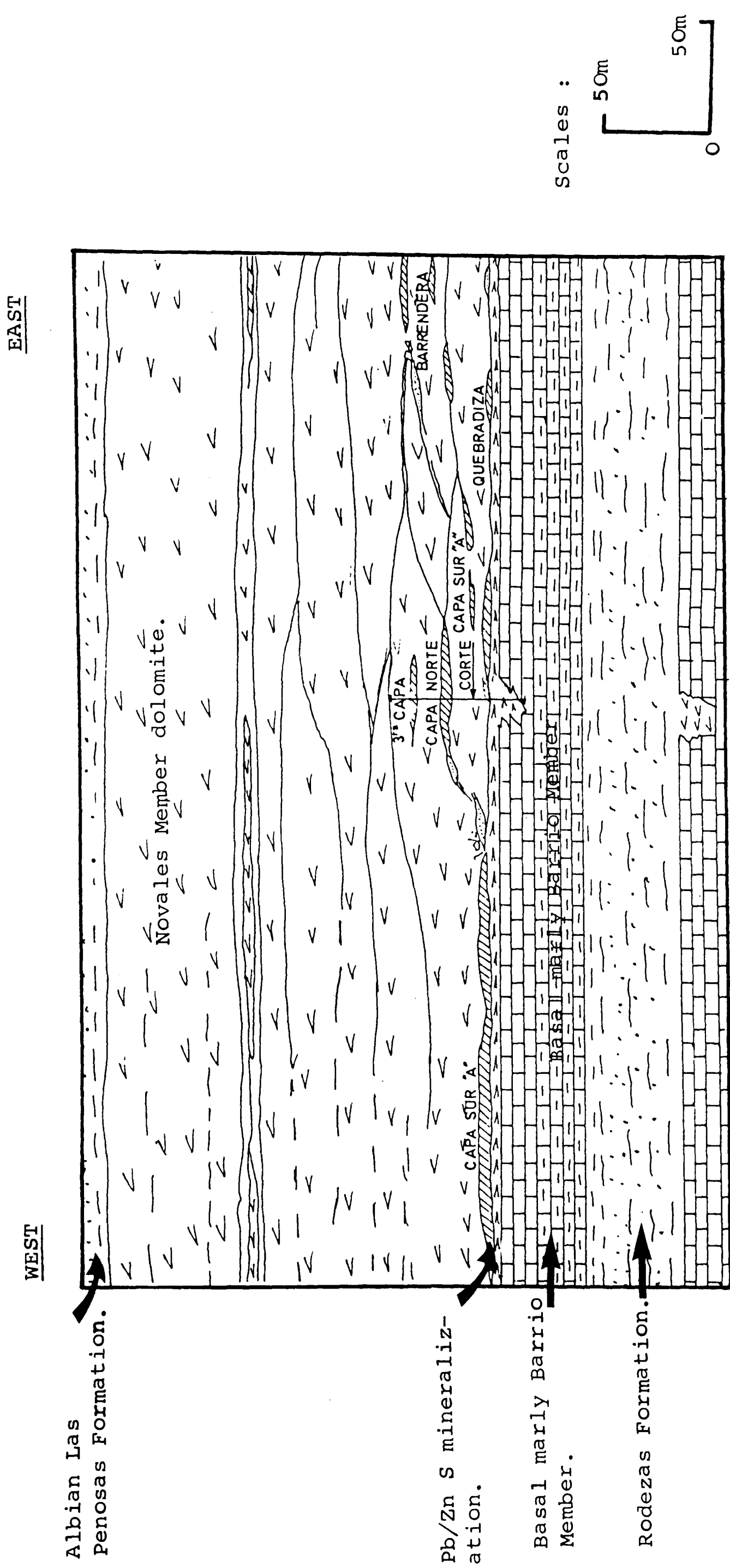


FIGURE 6-48. Section through the mineralized part of the Reocin mine with the main Pb/Zn S horizons marked. The vertical section marked through the Capa Norte is shown in Fig. 6-47. Adapted from Sanchez, 1971.



FIGURE 6-49.

A photograph of the banded to massive sphalerite/galena of the Capa Sur ore body (Figs. 6-45, 6-47 & 6-48), Reocin mine. Note the intimate association of the sulphides with the white, sparry, space-filling dolomite. The hammer is 20cm long.

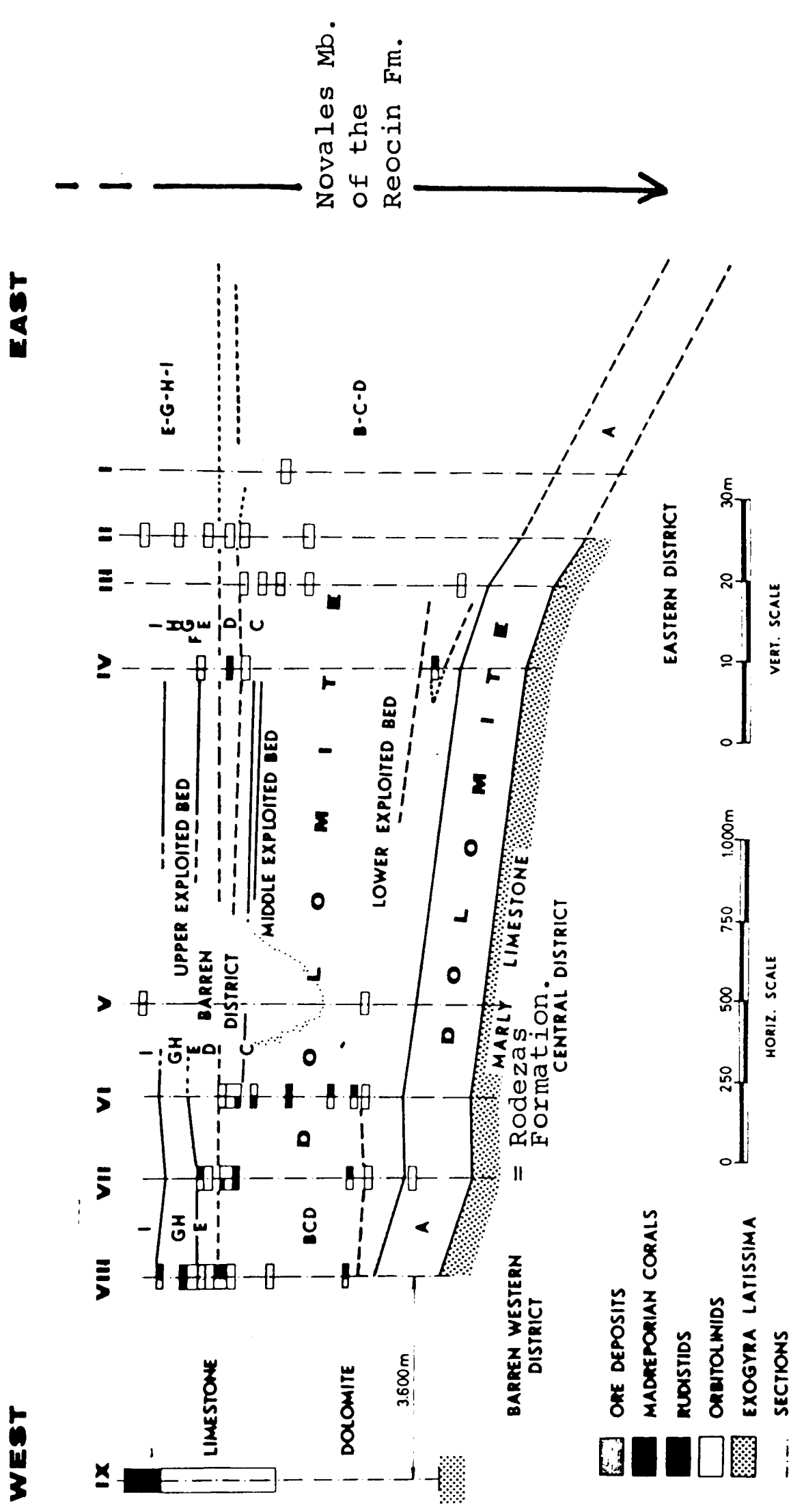


FIGURE 6-50.

Cross-section through the basal, mineralised 50m of the Novales Mb. at Reocin. The borehole sections with roman numerals are located on Fig. 6-51 and the capital letters refer to Monseur's classification of the mineralised lithologies shown in Fig. 6-47. Adapted from Monseur and Pel, 1973.

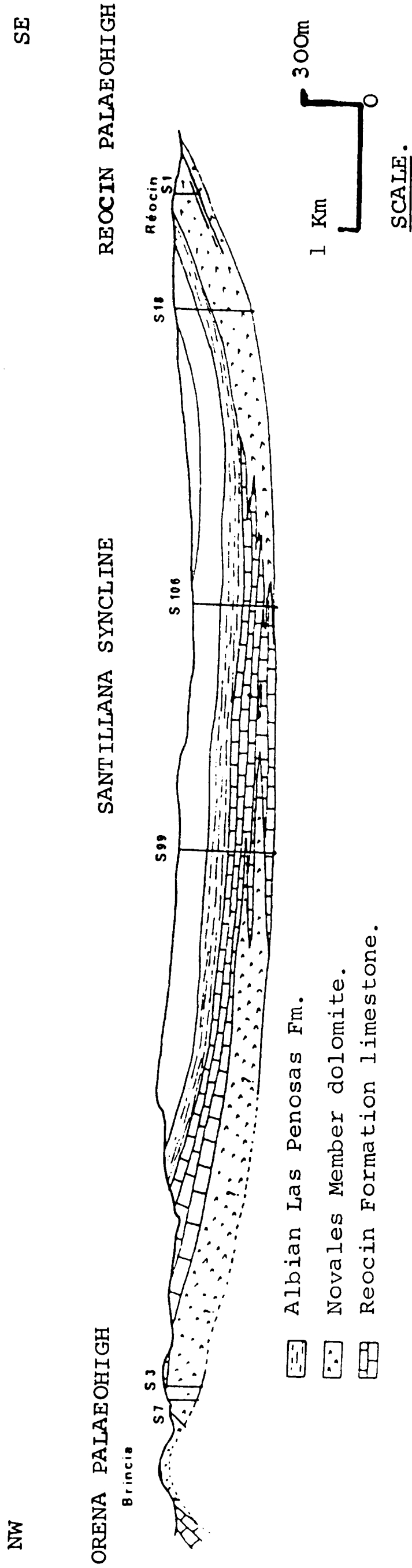
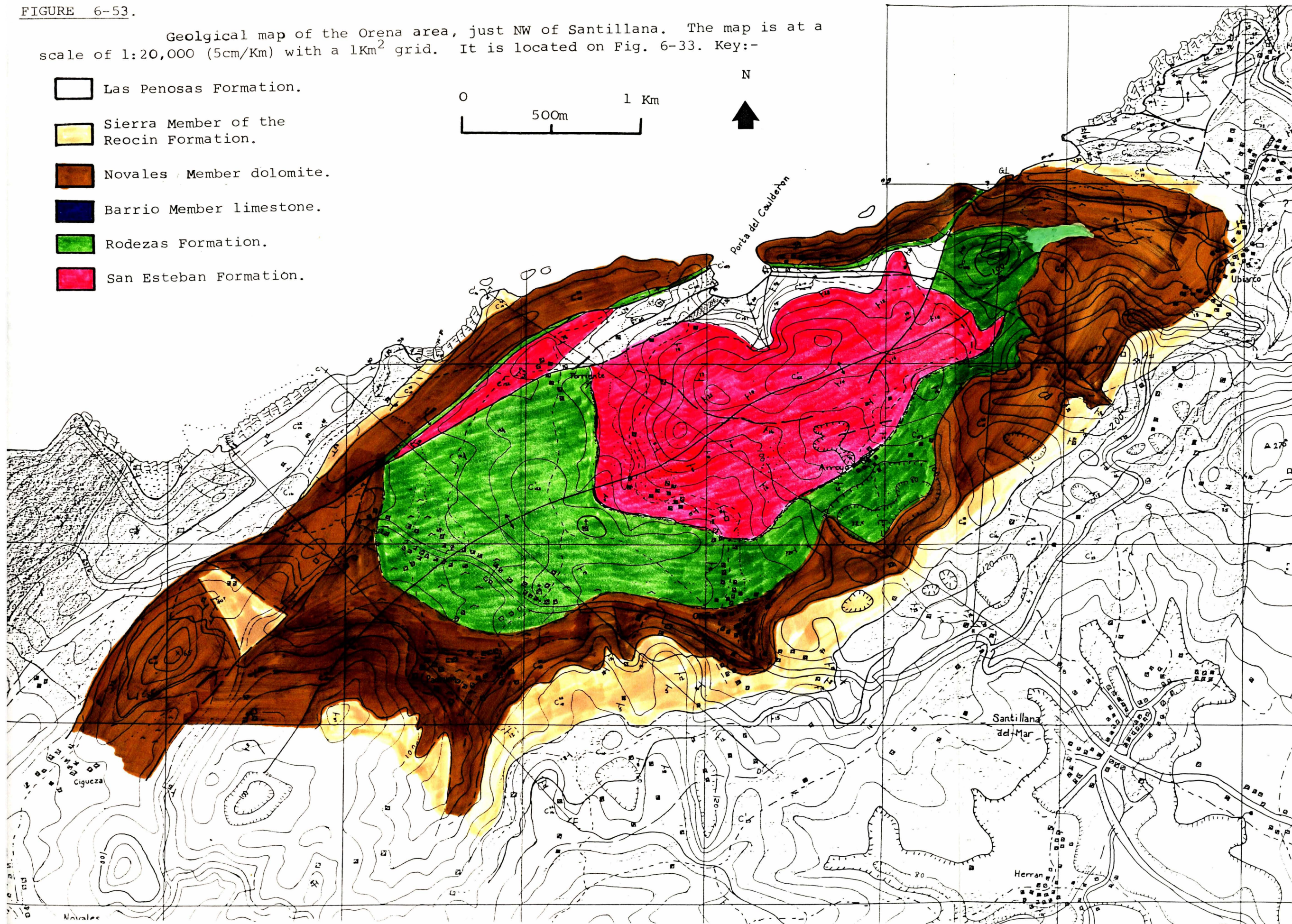
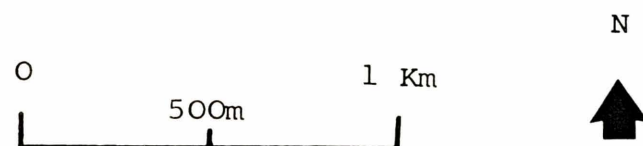


FIGURE 6-53.

Geological map of the Orena area, just NW of Santillana. The map is at a scale of 1:20,000 (5cm/Km) with a 1Km² grid. It is located on Fig. 6-33. Key:-

- Las Penosas Formation.
- Sierra Member of the Reocin Formation.
- Novales Member dolomite.
- Barrio Member limestone.
- Rodezas Formation.
- San Esteban Formation.



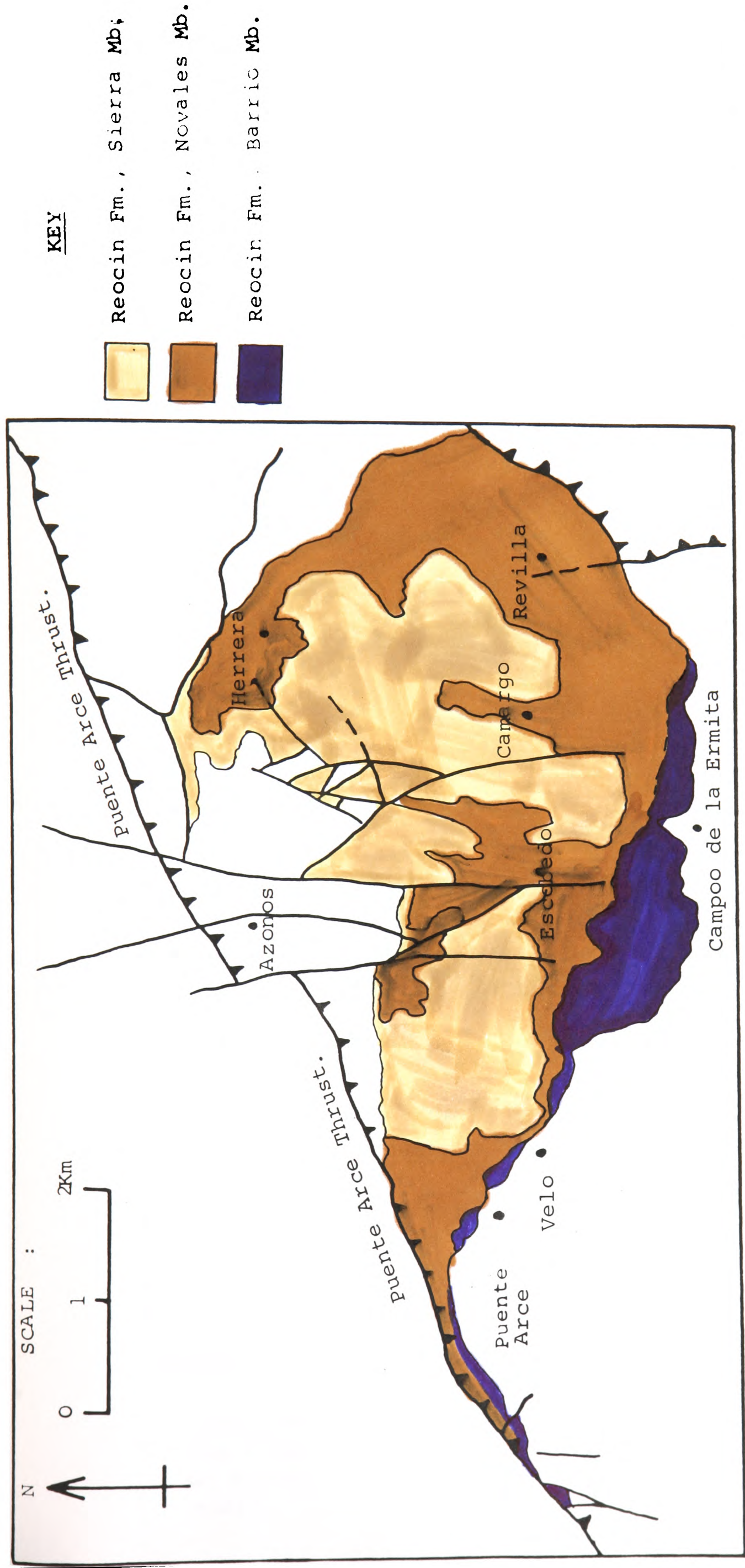
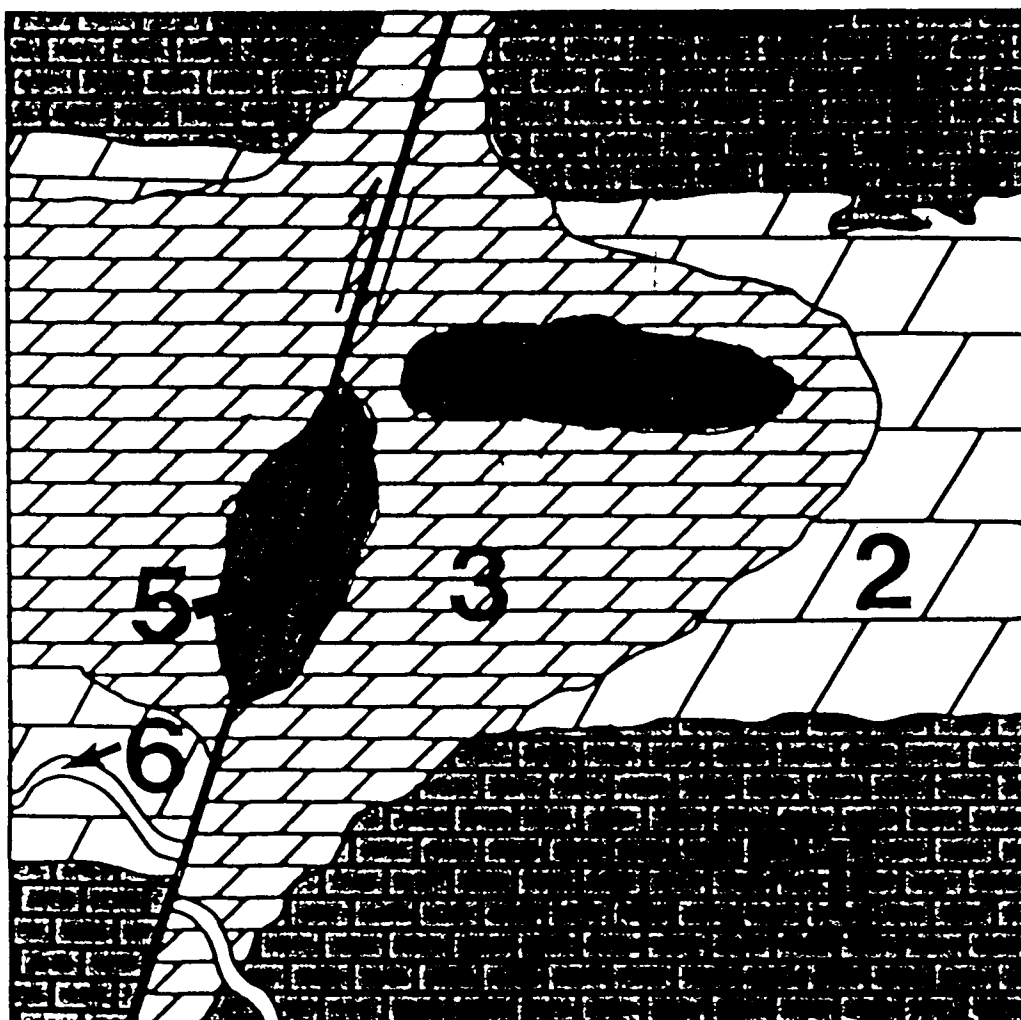


FIGURE 6-54.

A geological sketch map of the Reocin Formation (Upper Aptian) in the Camargo palaeolow, just SW of Santander. The map is located on Fig. 6-33. Note the extensive dolomitization of the Reocin Fm. here and it's partial fault control. This map is partly based on IGMec, the Torrelavega sheet - Map 3.

Diagenetic model of dolomite relations commonly seen in the Reocin Formation



- 1) Barrio/Sierra Members Limestone
- 2) Non-ferroan sucrosic dolomite
- 3) Ferroan sucrosic dolomite
- 4) Sparry/baroque ferroan dolomite
- 5) Pb/Zn S mineralization
- 6) Late stage calcite veins (and dolomite too).

FIGURE 6-55.

A generalized summary of the relative diagenetic relations seen in the Reocin Fm. dolomites. The order 1 to 6 gives an idea of the relative timing of events, though the diagram is not meant to be to scale.

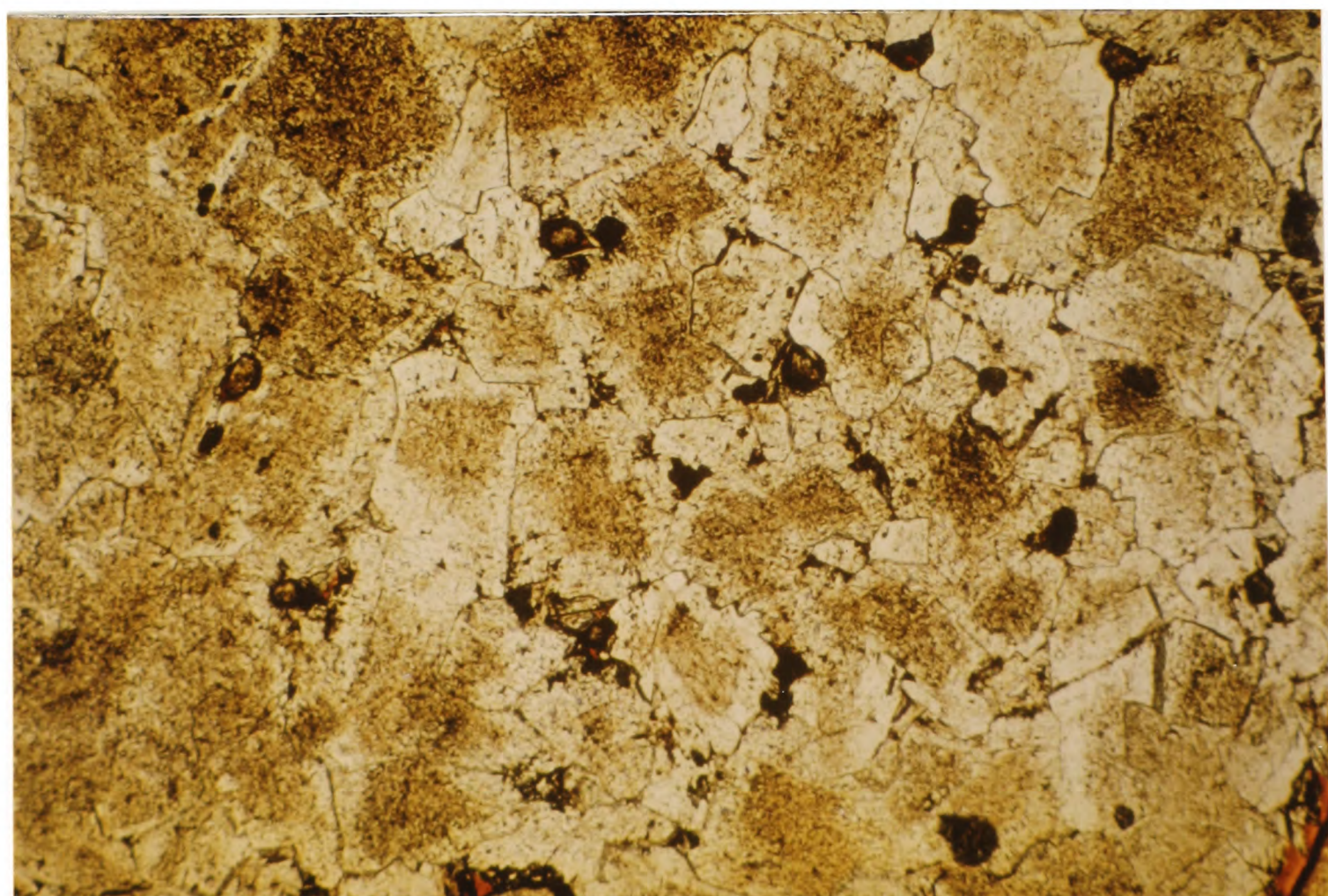
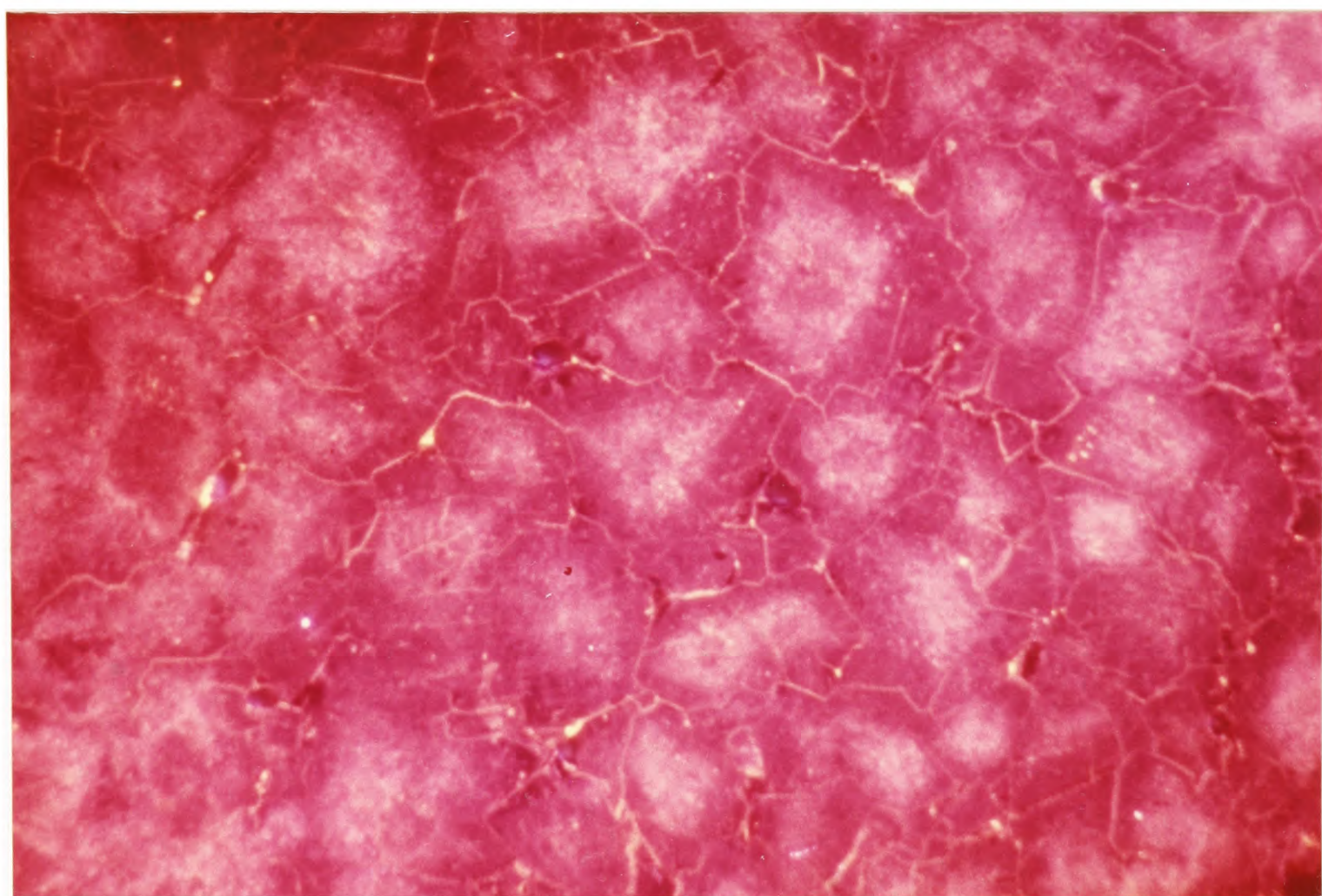


FIGURE 6-56.

This is a typical view of the hypidiotopic low-Fe, sucrosic dolomite of the Novales Mb. that was formed in a mixed water zone. Note the inclusion-rich cores and the more limpid rims. This dolomite generation is described in Chapter 6.9.2, section 1. The dolomite is medium- to coarse-grained and the field of view is approximately 9mm wide.

FIGURE 6-57.

This is a cathodoluminesce photograph of the picture above and shows the high Mn/Fe, brighter-luminescing cores to this low-Fe, sucrosic dolomite. A very late stage, moderate luminescing dolomite has followed in the cracks of the intercrystalline boundaries. This dolomite shows a rather uniform luminescence with little strong zoning, indicating that it was formed from a rather homogeneous water body that gently progressed towards lower Mn/Fe ratios towards the edges of crystals. See Chapter 6.9.2..



FIGURE 6-58.

This shows the interdigitation of the white-weathering Sierra Mb. (Reocin Fm.) limestone with the light brown-weathering Novales Mb. dolomite. The limestone is present as two bands in the top of the cliff exposure. This photograph was taken in the "Productos Dolomia" mine/quarry at Revilla (58559782). The cliff is about 20m high and shows the interdigitatory contact between the Novales and Sierra Mbs..

FIGURE 6-59.

Tabulation of the stable results of carbon and oxygen for the carbonates from the Reocin Formation, Santander, Spain.

	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{18}\text{O}_{\text{PDB}}$
A) Limestone values		
H2/1L	+3.39	-3.43
H3/1L	+3.40	-3.43
H14/1L	+2.70	-3.74
H15/1L	+2.85	-3.55
H16/1L	<u>+2.44</u>	<u>-4.20</u>
mean $\pm$ (2.error in mean)	+2.96 $\pm$ 0.38	-3.67 $\pm$ 0.29
B) i) Non-ferroan sucrosic dolomites		
H6/1D	+3.27	-6.95
H7/1D	+3.27	-6.98
H8/1D	+3.26	-6.94
H9/1D	+2.92	-6.40
H9/2D	+2.92	-6.34
H10/1D	+3.18	-7.12
H17/1D	<u>+3.24</u>	<u>-6.95</u>
mean $\pm$ (2.error in mean)	+3.15 $\pm$ 0.12	-6.81 $\pm$ 0.23
ii) Ferroan, sucrosic dolomite		
H4/1D	-0.44	-6.76
H5/1D	<u>-0.27</u>	<u>-6.77</u>
mean $\pm$ (2.error in mean)	-0.35 $\pm$ 0.17	-6.76 $\pm$ 0.01
iii) Sparry, limpid, ferroan dolomite		
H1/1D	-1.13	-7.15
H11/1D	-0.94	-7.64
H12/1D	-0.72	-6.77
H13/1D	<u>-0.80</u>	<u>-6.69</u>
mean $\pm$ (2.error in mean)	-0.90 $\pm$ 0.18	-7.06 $\pm$ 0.43
iv) Baroque, sparry ferroan dolomite		
H18/1D	+1.52	-7.75
H19/1D	+1.52	-7.67
H19/2D	+1.44	-7.61
H20/1D	<u>+0.52</u>	<u>-8.08</u>
mean $\pm$ (2.error in mean)	+1.25 $\pm$ 0.49	-7.78 $\pm$ 0.21
<u>Control Values</u>		
TDS-1/1	+1.87	-10.79
TDS-1/2	+1.83	-10.87
(Preferred values for TDS-1	+1.835	-10.787)

$\delta^{13}\text{C}_{\text{PDB}}$ against $\delta^{18}\text{O}_{\text{PDB}}$ for Upper Aptian carbonates, Santander.

FIGURE 6-60.

Del ^{13}C versus del ^{18}O
 for the different
 generations of dolomite
 in the Reocin Fm..
 See Chapter 6.9 for
 explanation.

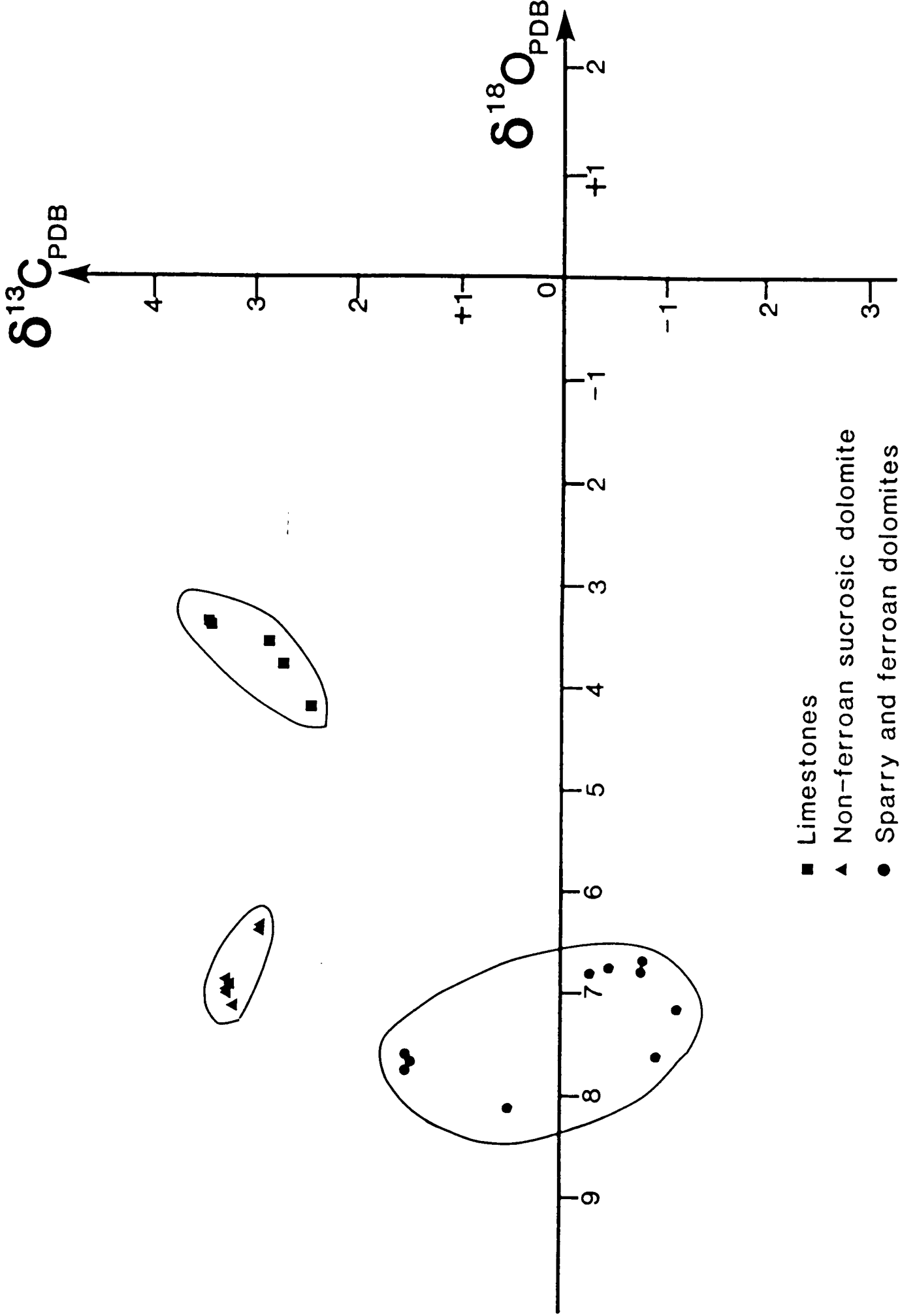


FIGURE 6-61A. : Mean major and minor element microprobe analyses for the Reocin Fm. carbonates in mole %. NM = Not Measured and a horizontal line through a reading indicates that it was beyond detection limits for the probe. Na and Sr were both beyond detection limits.

A) LIMESTONES.													
Sample	Number of analyses.	Ca	Error in Ca	Mg	Error in Mg	Mn	Error in Mn	Fe	Error in Fe	Si	Error in Si	Description.	Line
H2,H3	13	97.83	0.16	1.92	0.12	0.016	0.008-	0.068	0.049	0.076	0.07	Lime mudstone micrite.	1
"	10	98.46	0.33	1.44	0.31	0.024	0.025	0.008-	0.008-	0.030	0.03	Meteoric phreatic equant cement	2
"	8	98.59	0.22	1.31	0.20	0.016	0.014	0.074	0.140	NM, = not		Miliolids of a wackestone.	3
Z1315a	3	98.91	0.30	1.06	0.32	0.022	0.025	0.001-	0.001-	NM	measured	Echinoderms of a wackestone.	4
"	5	97.89	1.31	0.81	0.17	0.030	0.020	0.060	0.040	NM		Coarse equant LMC spar.	5
Weighted Mean	39	98.23		1.46		0.020		0.048		0.06			6
B) DOLOMITES.													
1) LOW-FE SUCROSIC DOLOMITES.													
H6,H7,H8	20	50.31	0.13	49.21	0.13	0.014	NM	0.24	0.11	0.12	0.04	Sucrosic,hypidiotopic dolomite.	7
"	24	50.04	0.25	49.55	NM	0.011	0.004-	0.21	0.08	0.103	NM	"	8
Z1383	7	52.80	0.53	45.88	0.70	0.061	0.018	1.10	0.21	NM		Inclusion-rich, hypidiotopic	9
"	15	53.30	1.01	45.48	1.03	0.080	0.025	1.13	0.27	NM		" dolomite	10
Z1352	7	51.07	0.69	46.66	1.68	0.028	0.014	1.10	0.36	NM		"	11
"	6	51.30	2.23	45.59	2.09	0.037	0.031	1.71	0.94	NM		"	12
"	8	51.64	0.87	43.96	1.38	0.064	0.029	3.84	1.59	NM		"	13
Weighted Mean.	87	51.20		47.46		0.036		0.96		0.11			14
2) HIGH-FE XENOTOPIC DOLOMITES.													
H4,H5	21	49.56	0.16	47.74	0.19	0.080	0.010	2.38	0.19			Sucrosic, mainly xenotopic, medium-grained	15
"	14	49.58	0.14	47.96	0.20	0.080	0.010	2.19	0.09	"		dolomite.	16
"	10	49.67	0.26	47.66	0.31	0.100	0.010	2.56	0.25	"			17
Z1381	7	51.80	1.03	43.38	1.52	0.142	0.033	3.57	1.06			Non-sucrosic, limpid, xenotopic,medium-grained	18
"	7	51.67	0.42	41.91	2.42	0.170	0.042	4.27	1.10			"	19
Weighted Mean	59	50.10		46.60		0.100		2.73					20
3) BAROQUE / WHITE SPARRY DOLOMITE.													
H1,H11, H12,H13.	13	51.84	0.46	42.33	0.60	0.264	0.047	5.57	0.24			Coarse sparry, non-void-fill white spar dolomite	21
"	19	50.29	0.10	44.89	0.34	0.246	0.015	4.56	0.29			"	22
"	10	51.98	0.37	40.10	1.15	0.320	0.041	7.61	0.94			Pore/void-filling, coarse baroque dolomite	23
"	7	51.77	1.10	39.79	1.60	0.360	0.040	8.08	0.94			"	24
Capa Norte	5	52.32	1.01	36.38	1.50	0.430	0.060	10.72	0.63			ZnS-associated,baroque ankerite, Reocin.	25
"	11	51.36	0.66	37.01	0.87	0.420	0.030	10.36	0.41			"	26
"	10	51.89	0.62	37.49	1.14	0.410	0.030	9.90	0.61			"	27
"	7	51.77	0.63	38.41	0.83	0.376	0.035	8.92	0.30			"	28
"	6	51.27	0.67	38.52	2.42	0.360	0.070	8.00	3.97			"	29
"	9	52.59	0.98	36.15	1.72	0.430	0.050	10.69	1.09			"	30
Weighted Mean	97	51.34		40.48		0.330		7.56					31

FIGURE 6-61B. : Continues directly from Fig. 6-61A.

4) <u>FRACTURE-RELATED SPARRY DOLOMITE.</u>										LINE.
SAMPLE	NUMBER OF ANALYSES.	Ca	Error in Ca	Mg	Error in Mg	Mn	Error in Mn	Fe	Error in Fe	
H18,H19,H20	15	49.97	0.14	44.10	0.37	0.235	0.02	5.48	0.21	32 33 34 35
Z1315a	8	56.04	1.09	43.72	1.10	0.059	0.018	0.18	0.08	
"	3	59.09	3.33	40.41	3.33	0.040	0.020	0.47	0.05	
"	1	54.77		40.19		0.020		0.47		
Weighted Mean	27	53.00		43.43		0.150		3.17		36

C) <u>SPHALERITE AND GALENA FROM THE CAPA NORTE AT REOCIN.</u>										
Electron microprobe analyses of the ore in mole % at 100μ spacing (15μ wide beam, 20kv beam).										
SAMPLE	Zn	Fe	S	SAMPLE	Zn	Fe	S			
Massive colloform ZnS from the Capa Norte, Reocin.	48.3	2.3	49.4	Zebra ore of cm bands of ZnS and ankerite.	49.4	1.9	48.7			
	49.5	1.6	48.8		50.6	1.2	48.3			
	49.7	1.7	48.5		50.0	1.3	48.7			
	50.4	1.4	48.2		50.3	1.1	48.6			
	48.6	2.9	48.7		50.4	1.2	48.3			
	49.9	1.3	48.8		48.7	2.4	48.9			
	49.9	1.8	48.2		50.7	0.4	48.7			
	48.6	2.5	48.6							
	49.1	2.4	48.4		Isolated ZnS	50.2	1.5	48.2		
	48.7	2.9	48.4		crystals in	49.9	1.9	48.2		
	50.1	1.4	48.5		ankerite from	48.7	3.3	48.0		
	49.1	2.3	48.5		the Capa Norte	48.8	3.1	47.8		
49.6	1.6	48.7	at Reocin.	48.1	4.1	47.7				
50.8	1.2	48.0		49.4	2.6	47.9				
50.2	1.3	48.5		48.3	3.2	48.5				
50.2	1.2	48.5		49.0	2.3	48.6				
50.5	1.2	48.3		50.1	1.9	48.0				
50.6	0.9	48.4		50.9	1.4	47.7				
50.3	1.2	48.4		49.5	2.6	47.9				
				50.3	2.0	47.7				
	50.4	1.0	48.6		50.8	1.2	47.9			
Zoned colloform	49.0	1.7	49.3		50.1	1.6	48.2			
ZnS as above.	50.7	1.4	47.9	.	50.1	1.8	48.0			
	49.5	1.9	48.6		50.1	2.3	47.6			
Zebra ore	50.5	0.9	48.6	Zoned colloform	48.4	3.3	48.3			
of cm bands	49.6	1.7	48.7	ZnS from Reocin.	46.2	5.4	48.4			
of ZnS and	49.4	1.7	48.8		49.8	2.2	48.0			
ankerite.	49.5	2.0	48.4		49.6	2.1	48.3			
	48.5	2.7	48.7		44.7	7.3	48.1			
	49.4	1.9	48.6							
				Mean :	49.5	2.0	48.4			

FIGURE 6-61C.

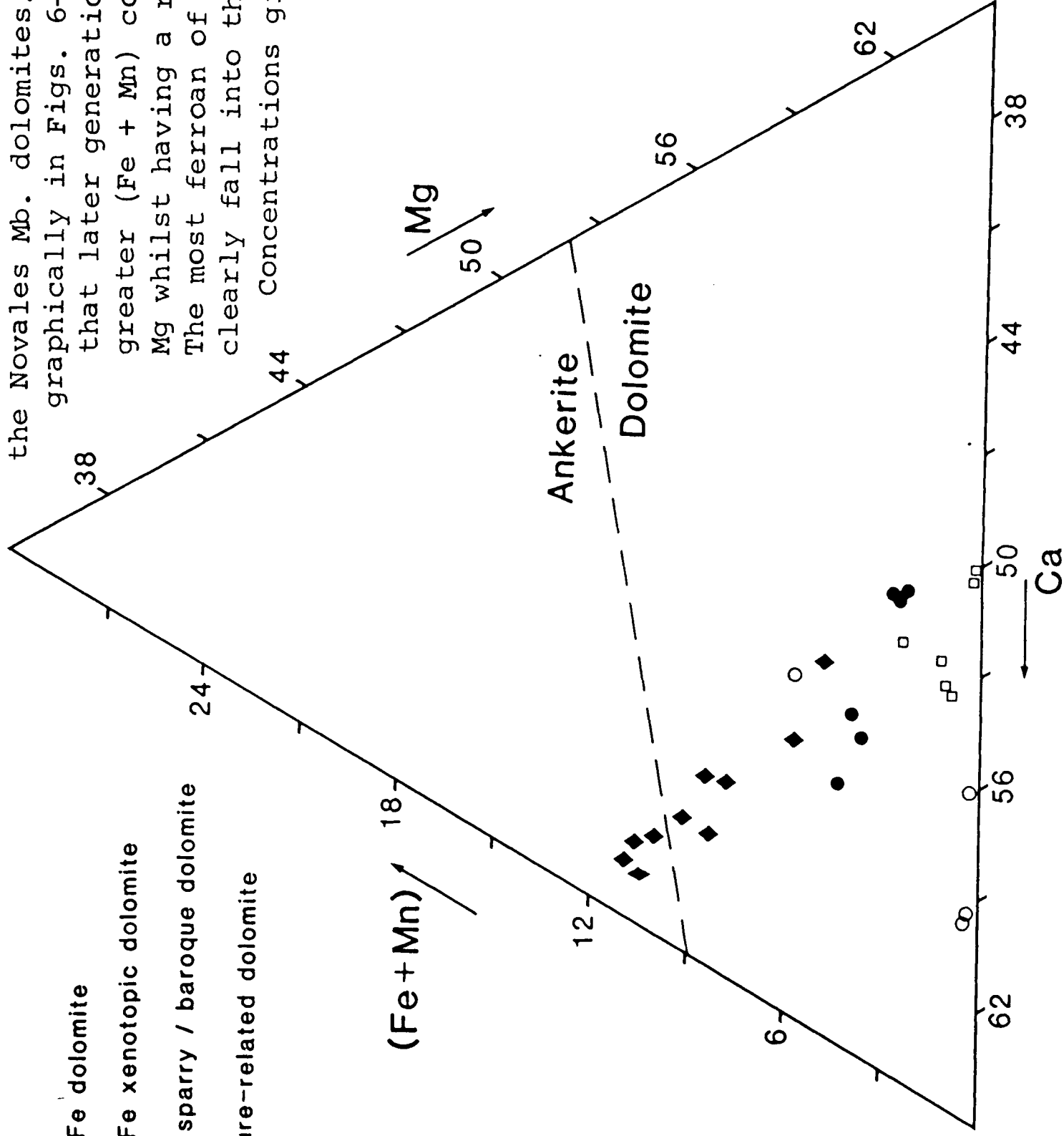
Galena analyses of the Capa Norte ore body
at Reocin in mole % from electron microprobe.

SAMPLE	Pb	Zn	Fe	S
Cubic crystals of	53.4	NM	0.03	46.2
PbS from the zebra	53.5	NM	0.02	46.2
ore of cm bands	52.8	0	0.2	46.9
of ZnS and	53.7	0.23	0.09	45.9
ankerite.	52.8	0	0.2	46.9
	53.7	0.23	0.09	45.9
	53.4	0	0.11	46.5
	53.6	0.3	0.16	45.8
Means:	53.4	0.12	0.09	46.3

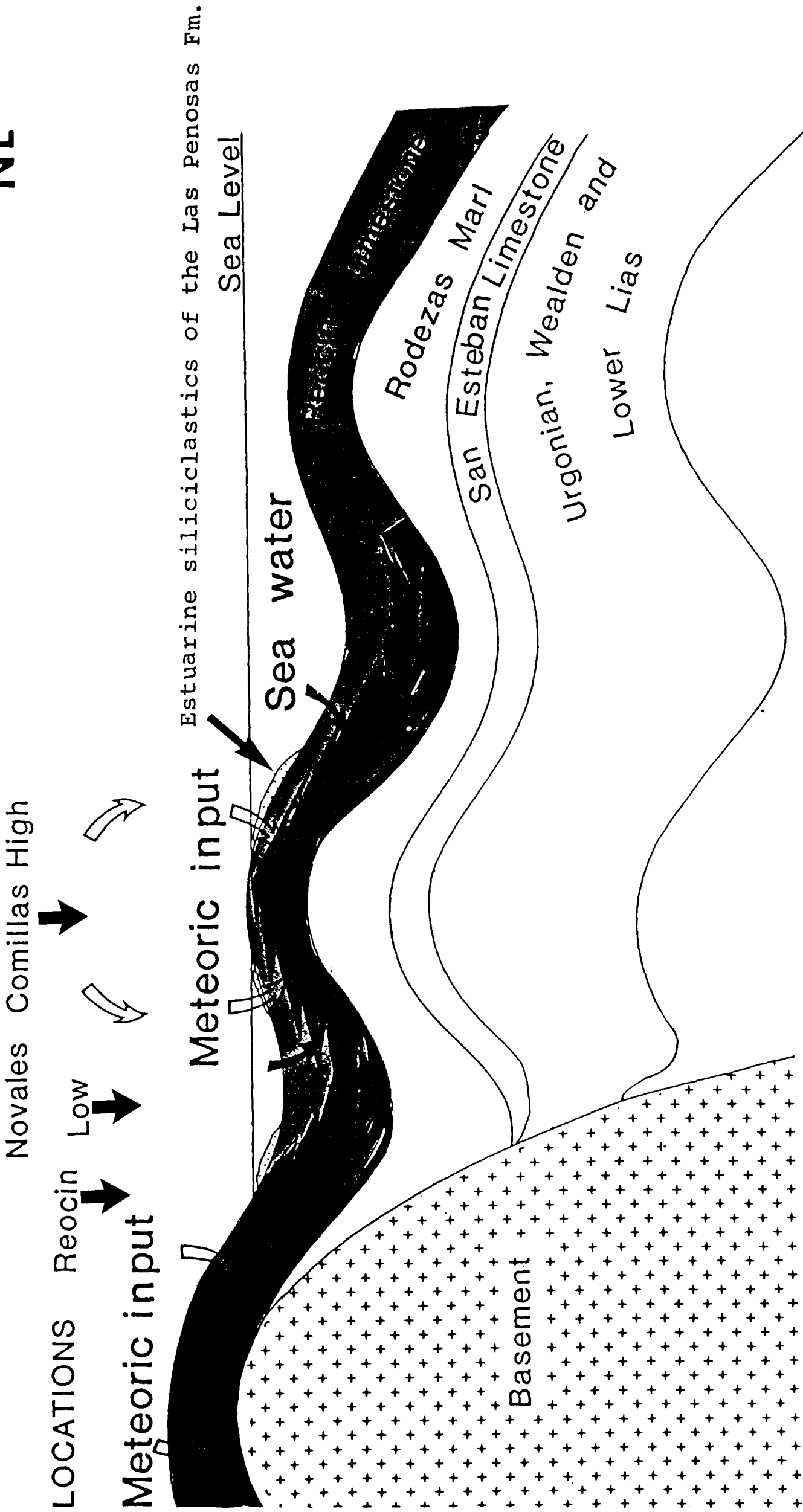
FIGURE 6-61D.

A triangle plot of the Ca, Mg and (Fe + Mn) in the Novales Mb. dolomites. The data is given graphically in Figs. 6-61A & 6-61B. Note that later generations show a progressively greater (Fe + Mn) content at the expense of Mg whilst having a reasonably constant Ca. The most ferroan of the baroque dolomites clearly fall into the ankerite field.

- Low-Fe dolomite
- High-Fe xenotopic dolomite
- ◆ White sparry / baroque dolomite
- Fracture-related dolomite



SW DOLOMITIZATION MODEL (in Lower Albian) NE



KEUPER

(Not to scale)

FIGURE 6-62.

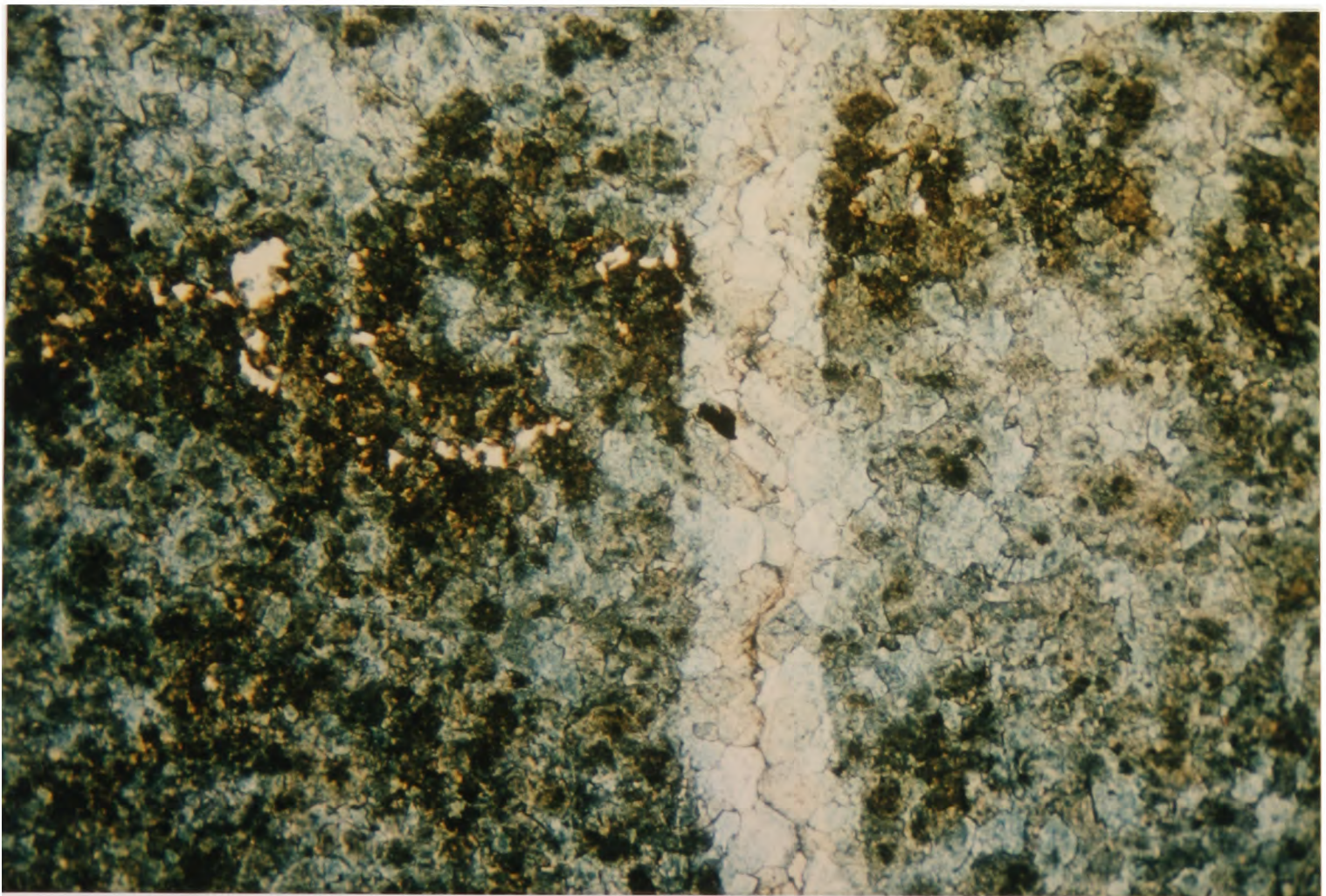
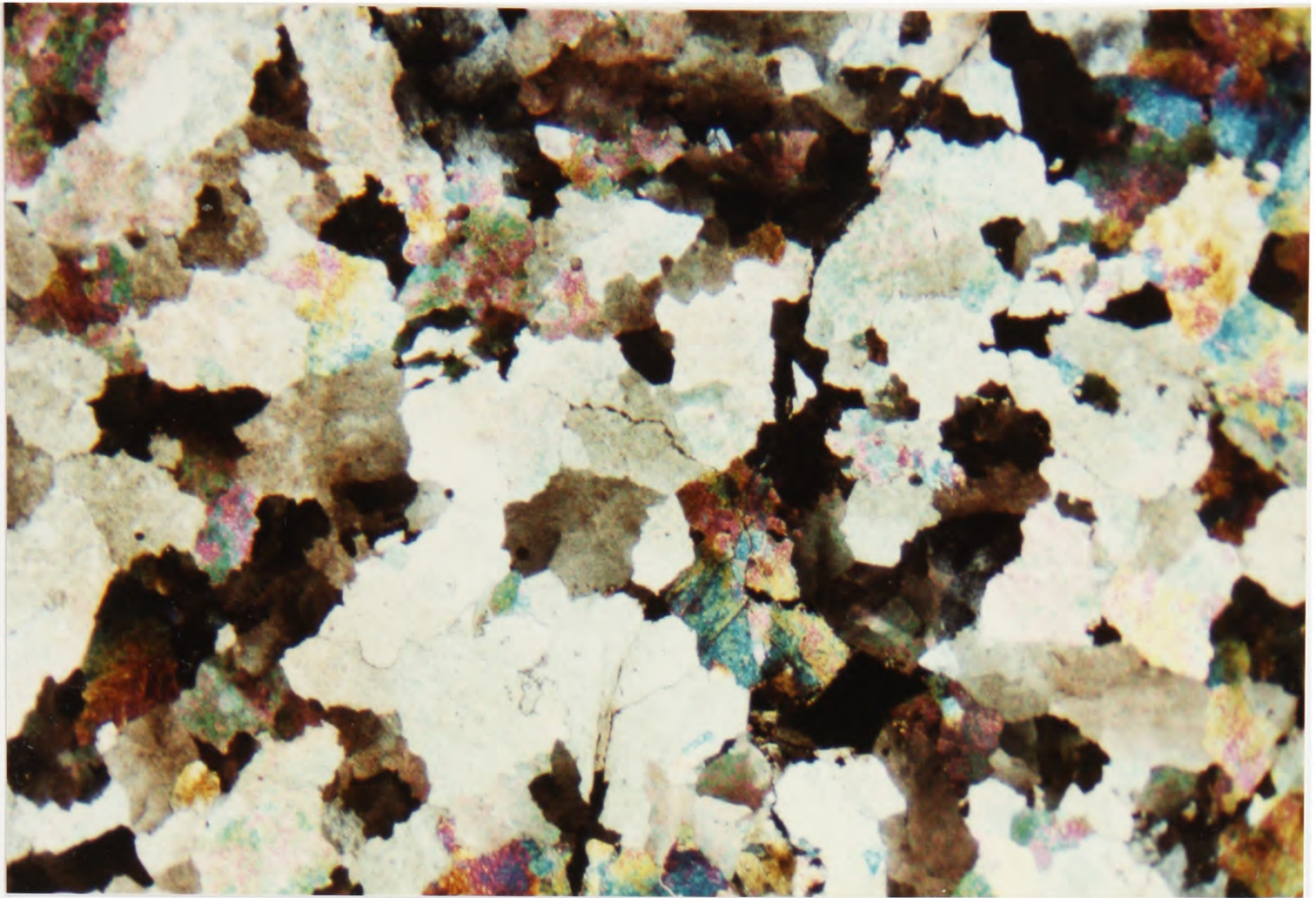
A general model for the generation of the low-Fe dolomite by mixing of seawater and meteoric from the Lower Albian Las Penosas Fm.

FIGURE 6-63A.

This is a typical example of the xenotopic dolomite from the Novales Mb. and shows the sutured crystal boundaries. This was taken in **cross**-polarized light of an area 6mm by 9mm wide. See Chapter 6.9.2.

FIGURE 6-63B.

This is potassium ferricyanide/Alizurin Red S stained thin section of the high-Fe, hypidiotopic to xenotopic dolomite that has been cut by a late-stage, fracture-related, sparry dolomite that is low in Fe and so takes only a light stain with the solution. Note the sucrosic texture of this transitional type of dolomite (cf. Chapter 6.9.2, section 2). The field shown is about 9mm wide.



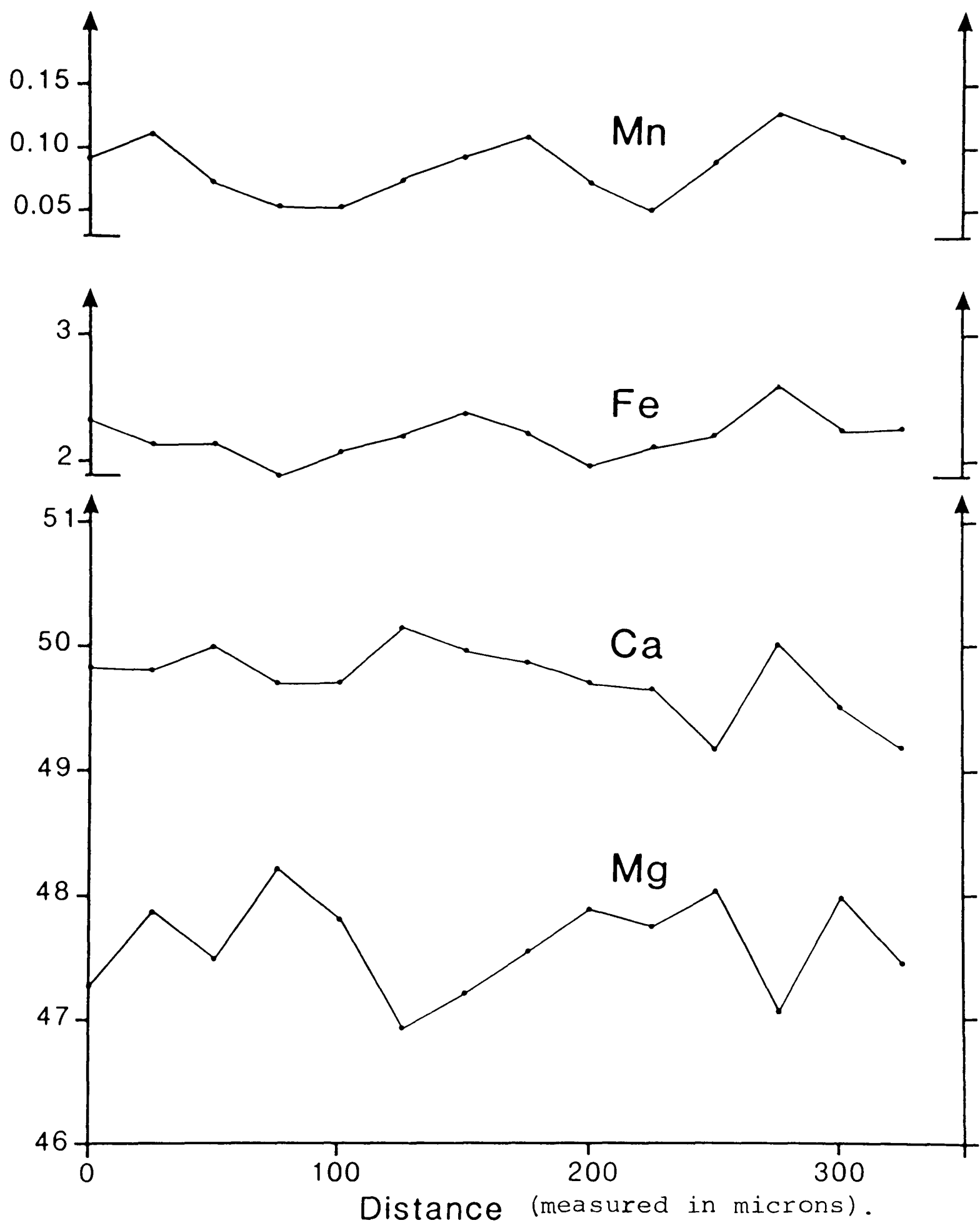


FIGURE 6-64.

An electron microprobe traverse across a sucrosic, ferroan dolomite with concentrations measured in mole %. Note the mild zonig with Fe/Mn-rich, Mg-poor rims to the dolomite. Note the changes of scale for Mn or Fe or (Ca + Mg).

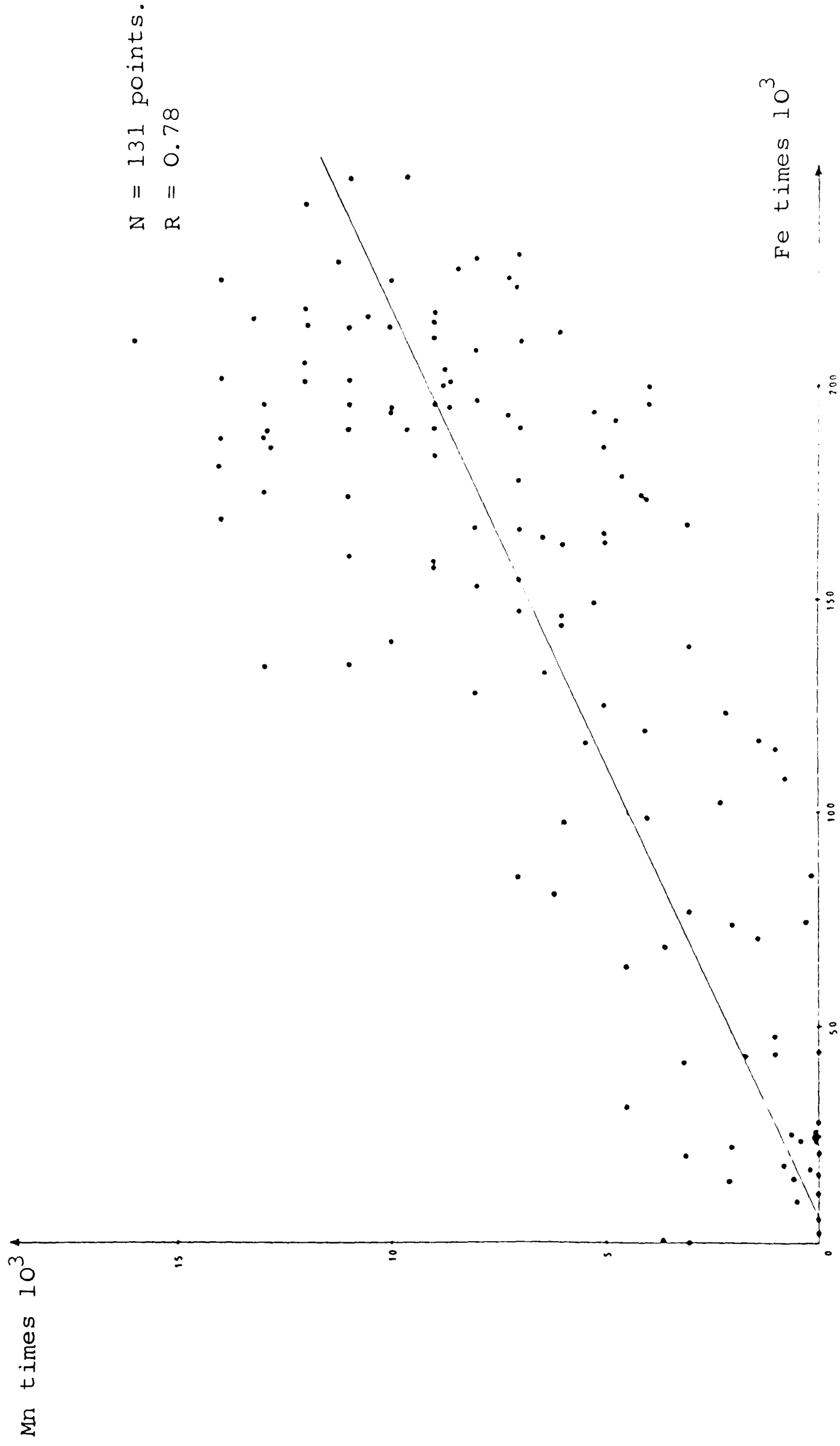


FIGURE 6-65. : A graph of the Mn against the Fe concentrations for all the dolomites of the Novales Mb...
Note the well-developed proportional relationship between these elements ($R = 0.78$)
suggesting that they have a common origin (the estuarine muds of the Santander Group).
From Vadala, 1981.

FIGURE 6-66.

Black, sucrosic, hypidiotopic to xenotopic ferroan dolomite cut by a few fracture-related, white, sparry dolomites. Petrography shows the the black colour is due to the inclusion of fine-grained humic organic matter, similar to that seen in the estuarine muds of the Las Penosas or Bielba Fms.. Sample from the "Productos Dolomia" quarry at Revilla (58559783). The lens cap is 5cm wide.

FIGURE 6-67.

This shows the tan grey weathering, ferroan, sucrosic dolomite with a vuggy porosity that has been coated in white sparry / baroque dolomite. Note the well-developed euhedral crystals of baroque dolomite that line the inside of the vuggy porosity seen just below the lens cap. The sample comes from the same locality as Fig. 6-66 and the lens cap is 5cm wide.





FIGURE 6-68.

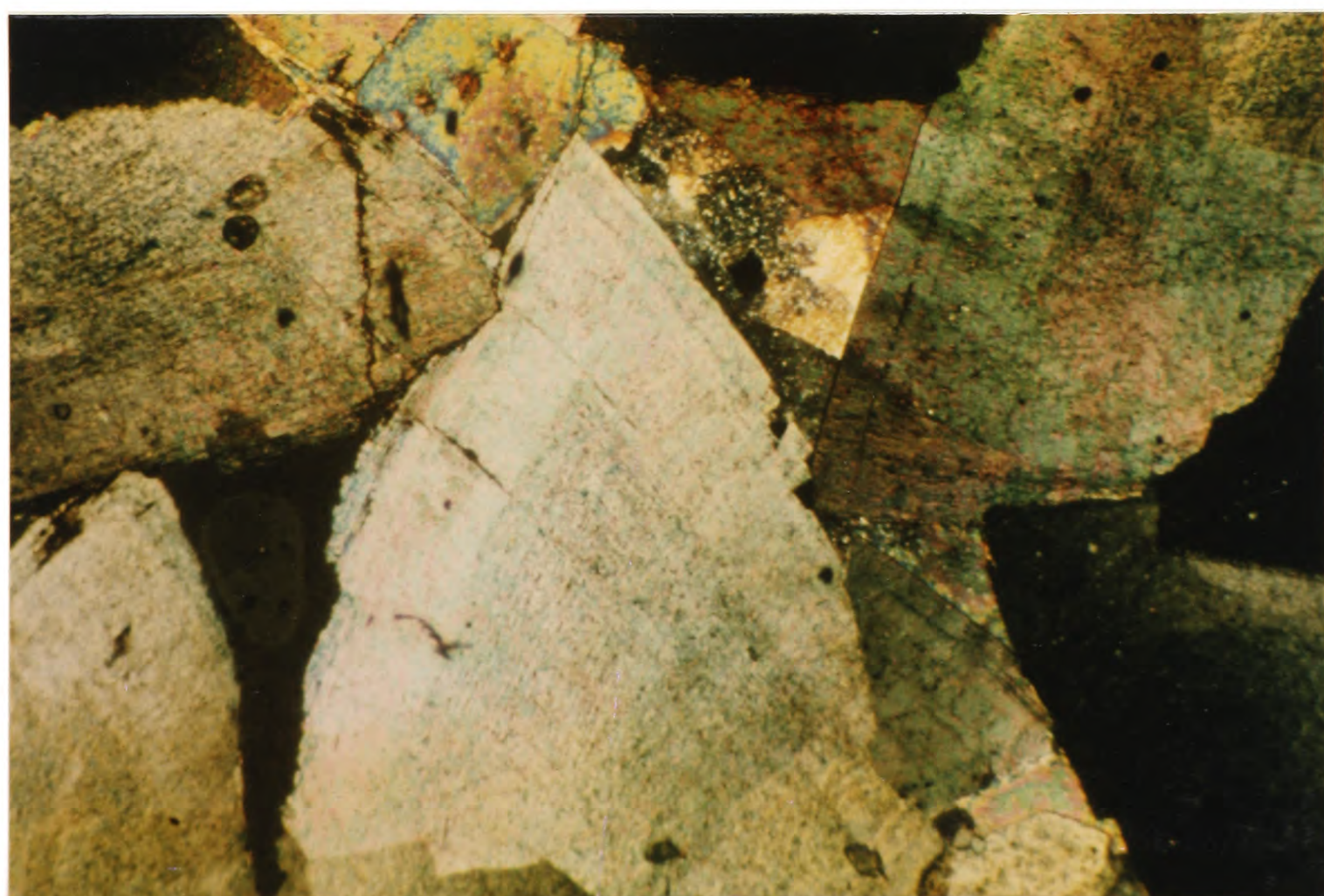
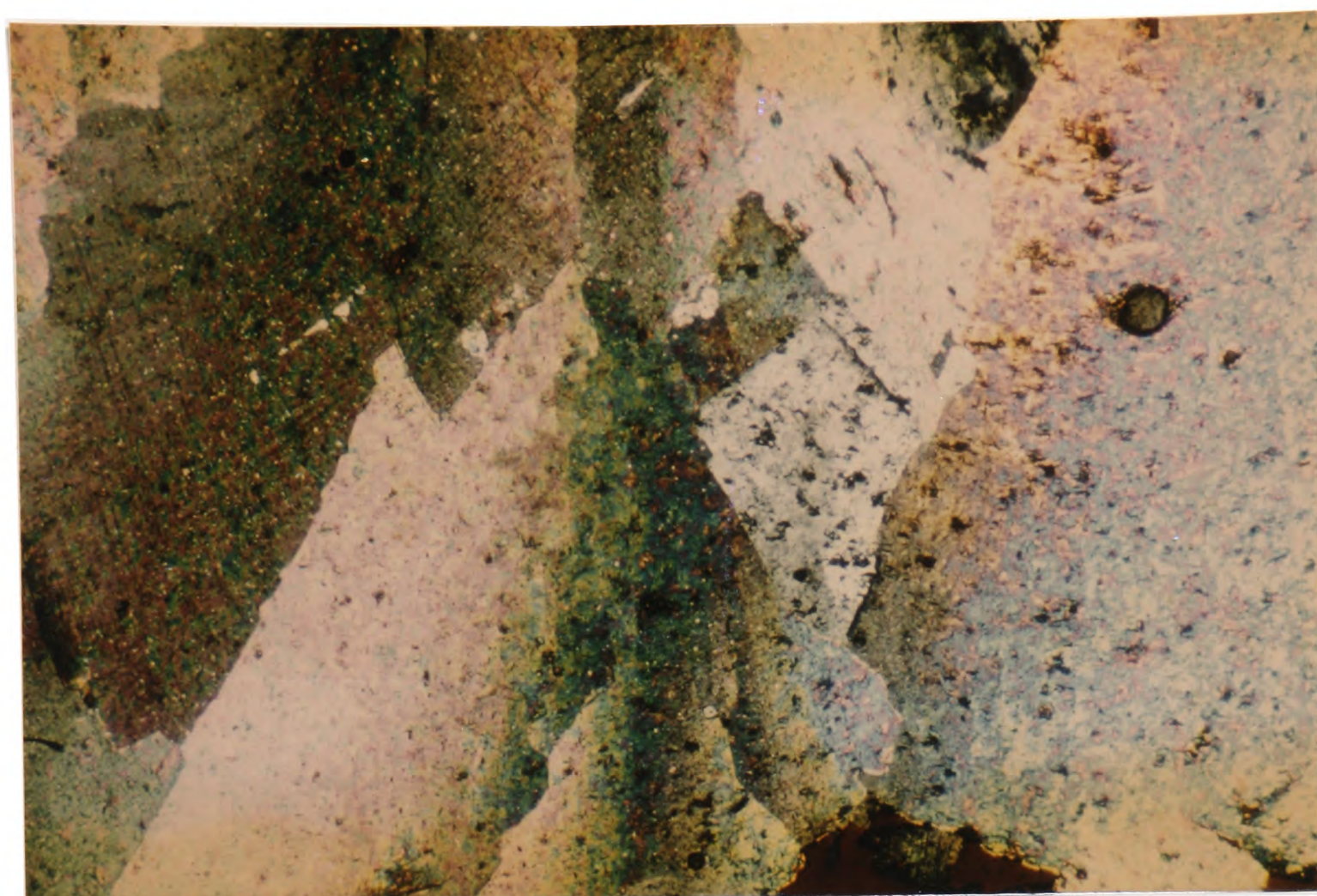
A general view of the tan grey-weathering sucrosic dolomite that has been cut by abundant, fracture-related, coarse sparry dolomite. Taken from the same locality as Fig. 6-66 and the hammer is 25cm long.

FIGURE 6-69.

A typical view of the massive white sparry high-Fe dolomite that forms an interlocking mosaic. The microfacies was taken in crossed polars and shows the sweeping extinction characteristic of this dolomite generation in the dark zones across crystals (such as the centre bottom one). The area shown is 3mm across.

FIGURE 6-70.

This shows a well-developed baroque high-Fe dolomite/ankerite with angular, scimitarlike crystal terminations, strongly undulose extinction (as above). A clear inclusion-rich to inclusion-poor zoning can be seen in the centre bottom crystal. The right hand side of this crystal also shows the slightly curved crystal faces that are commonly seen in baroque dolomites. The field of view is 3mm wide and the photograph was taken in cross-polarized light.



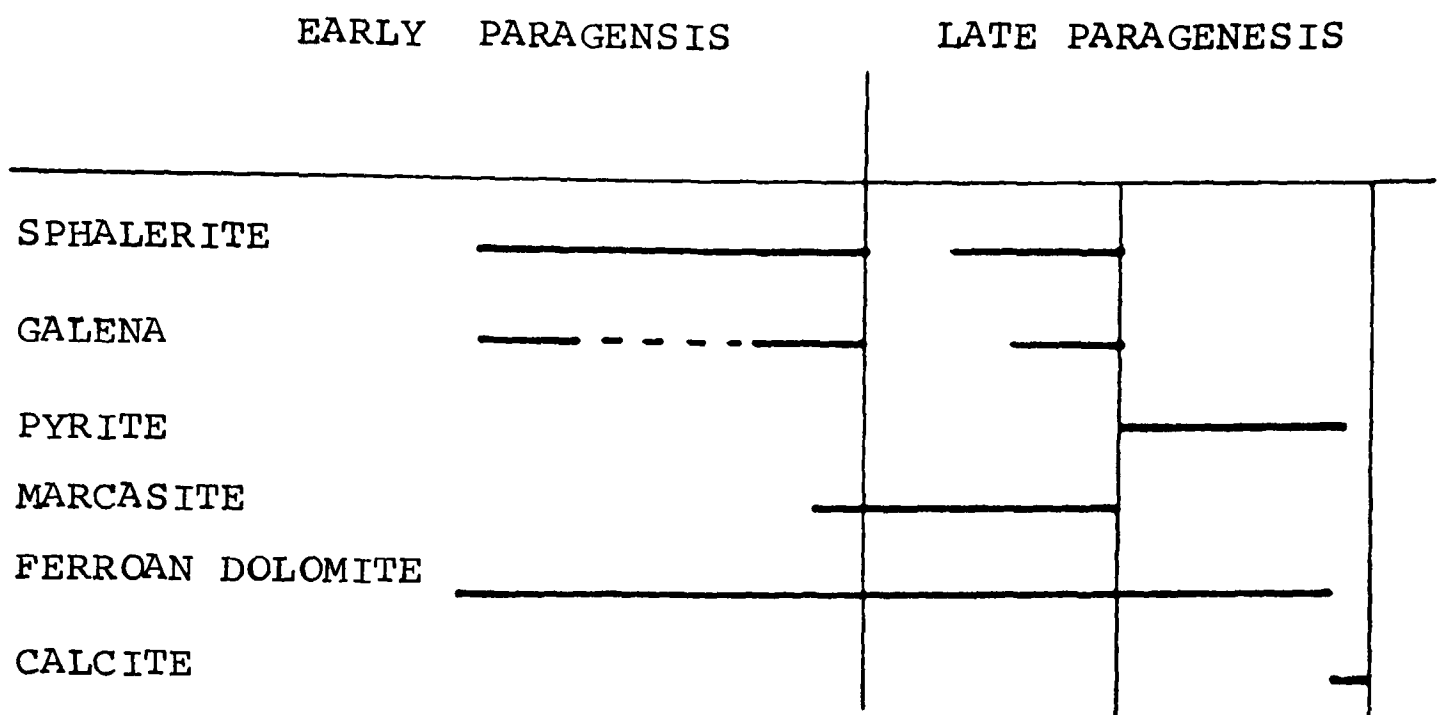


FIGURE 6-71.

General paragenesis sequence seen in the Novales Mb., especially around Reocin. The pyrite is minor volumetrically as is the calcite. Adapted from Vadala, 1981.

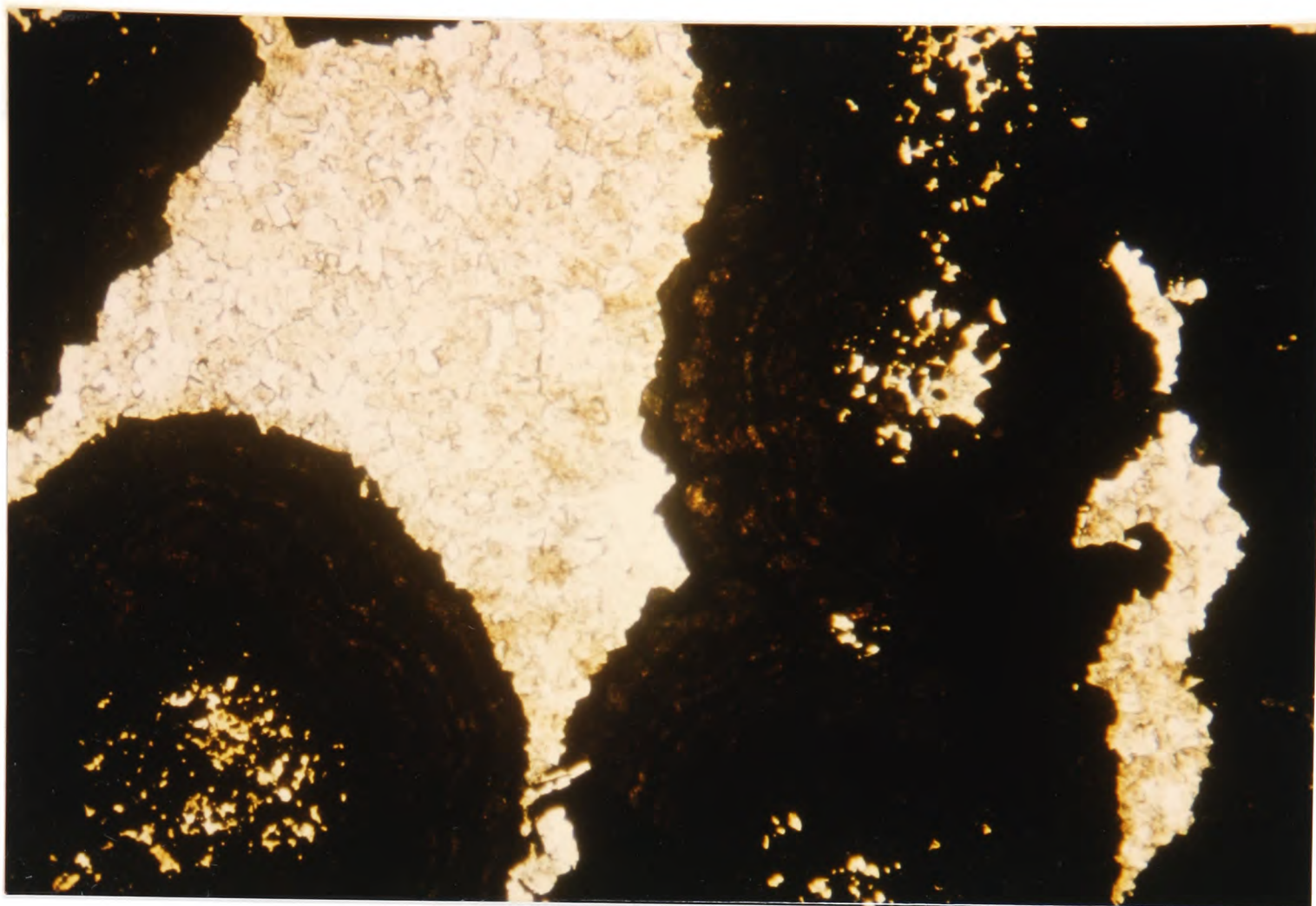


FIGURE 6-72.

A typical view of the colloform sphalerite from the key ore horizons at Reocin. The colloform texture can be clearly seen and zoning within the colloform growth, though this does not photograph well. The isolated crystals of ZnS can be seen within the cores of some of the colloform patterns. The matrix to the ZnS is xenotopic high-Fe dolomite which was photographed in plane polarised light. The field of view is 9mm wide.

FIGURE 6-73.

The PbS/ZnS geochemical data is given in Fig. 6-61B and Fig. 6-61C.

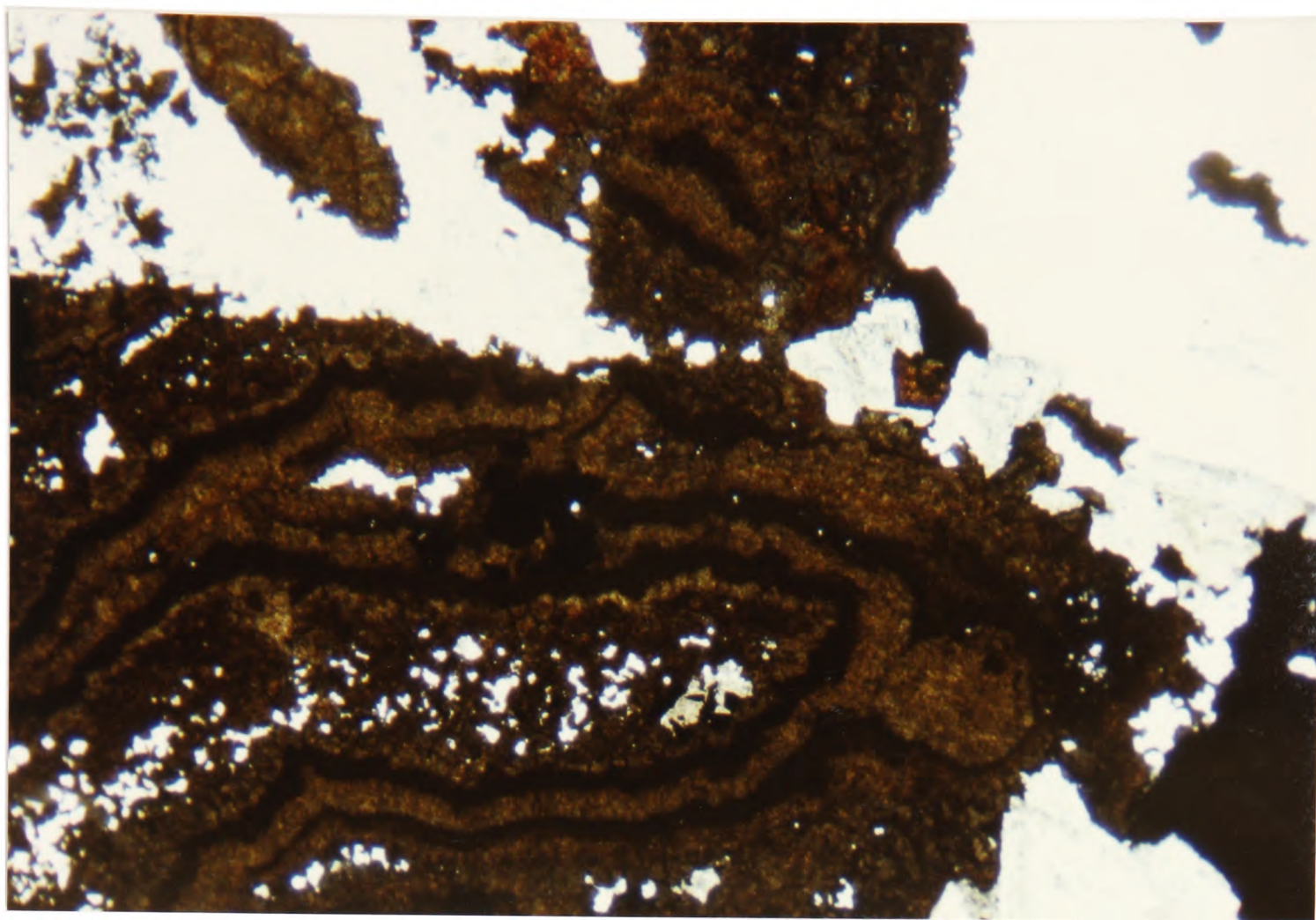


FIGURE 6-74.

This shows the colloform sphalerite associated with single-crystals of euhedral sphalerite in the matrix of the dolomite (bottom left). This occurrence of euhedral sphalerite is common in aureoles around the colloform sphalerite. This was taken in plane-polarized light of an area 6mm by 9mm wide:

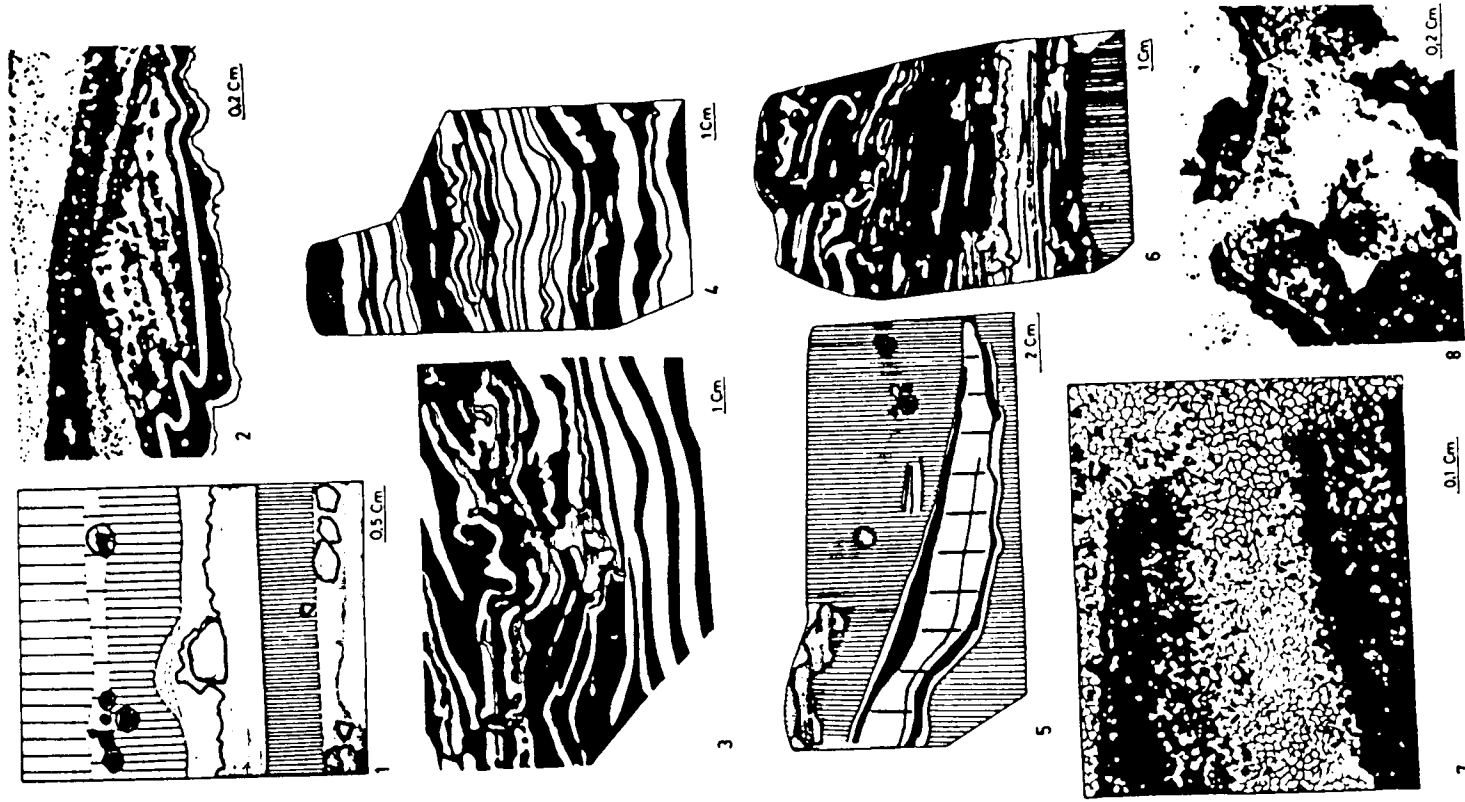


FIGURE 6-75. :

Diagrams of the typical habit of the ore body at Reocin showing the soft-sediment deformation structures (slumping and bed contortion etc.) that is common in these karstic cavern infills Taken from Monseur, 1967.

Fig. 1. Détail d'une minéralisation finement litée. Le dépôt de marcassite a été localement sensible à des déformations minimes et la disposition, en traînées ou en sphérules soulignant les limites entre zones, suggère l'intervention d'un processus sédimentaire. (Coupe IV, horizon B—secteur central—L.M.). (Marcassite massive, hachures horizontales; en sphérules, structure rayonnante; en traînée, traits interrompus; pyrite; hachures obliques; dolomies; hachures verticales; dolomite; en blanc).

Fig. 2. Minuscule dépression dont le fond, constitué par une mince couche plissotée de blende zonaire, a été comblée partiellement et progressivement par des grains de blende disposés suivant des lignes de courant; la partie supérieure de la zone comblée est rigoureusement plane tandis que la partie inférieure présente un talus. Les dépôts sous-jacents sont discordants, par rapport au sommet de la zone envisagée. Cette microstructure suggère un phénomène sédimentaire et non une imprégnation hydrothermale (Horizon A—secteur occidental—L.M.). (Blende foncée; masse noire; dolomite; mince bande blanche; grains de blende; petites taches noires; dolomite; masse blanche).

Fig. 3. Marcassite, en minces rubans, partiellement descendue, sous forme de pseudo nodule, dans la blende claire zonaire sous-jacente; blende et marcassite, légèrement plissées, soulignent la stratification (coupe VIII, couche inférieure exploitée—secteur occidental—Ech.). (Marcassite; hachures horizontales; blende zonaire; alternance de bandes noires et blanches).

Fig. 4. Structure finement zonaire de la marne minéralisée coiffant l'horizon A (Secteur central—Ech.). (Blende; en blanc; marne; en noir; dolomite; quadrillage oblique).

Fig. 5. Structure en cuvette de la blende au sommet de l'horizon D (coupe IV, secteur central—Ech.). (Blende claire; minces bandes blanches; blende foncée; en noir; galène; hachures obliques; marcassite massive; hachures horizontales; en sphérules, structure rayonnante; dolomies; hachures verticales).

Fig. 6. Blende zonaire dont la structure interne, soulignée par de fines bandes de blende claire, témoigne de remaniements et de déformations au cours même de la minéralisation (coupe IV, couche inférieure exploitée—secteur central—Ech.). (Blende foncée; masse noire; blende claire; fines bandes blanches; marcassite; hachures horizontales; dolomite associée à la marcassite; en blanc; dolomite; hachures verticales).

Fig. 7. Blende zonaire en lits constituée par une alternance de laves minéralisées et stériles; toutefois si la partie supérieure des laves minéralisées se compose de grains de blende jointifs, ils s'individualisent vers la base. De même, dans le sens latéral, ces laves peuvent s'arrêter brusquement ou s'éffiloche en traînées sans que pour autant on observe une variation de la texture de la dolomite; la blende s'est donc déposée dans une roche non encore entièrement consolidée. (Horizon A—secteur occidental—L.M.). (Blende massive; masse noire; grains de blende; taches noires; dolomite; structure granulaire).

Fig. 8. Mince bande de blende déformée et fracturée durant la sédimentation; des grains individualisés de blende se rattachent encore à cette structure (Coupe IV, horizon C—secteur central—L.M.). (Blende; masse ou taches noires; dolomite; en blanc). (Ech = échantillon macroscopique; L.M. = lame mince, lumière naturelle; la partie supérieure des croquis indique le sens stratigraphique ascendant).

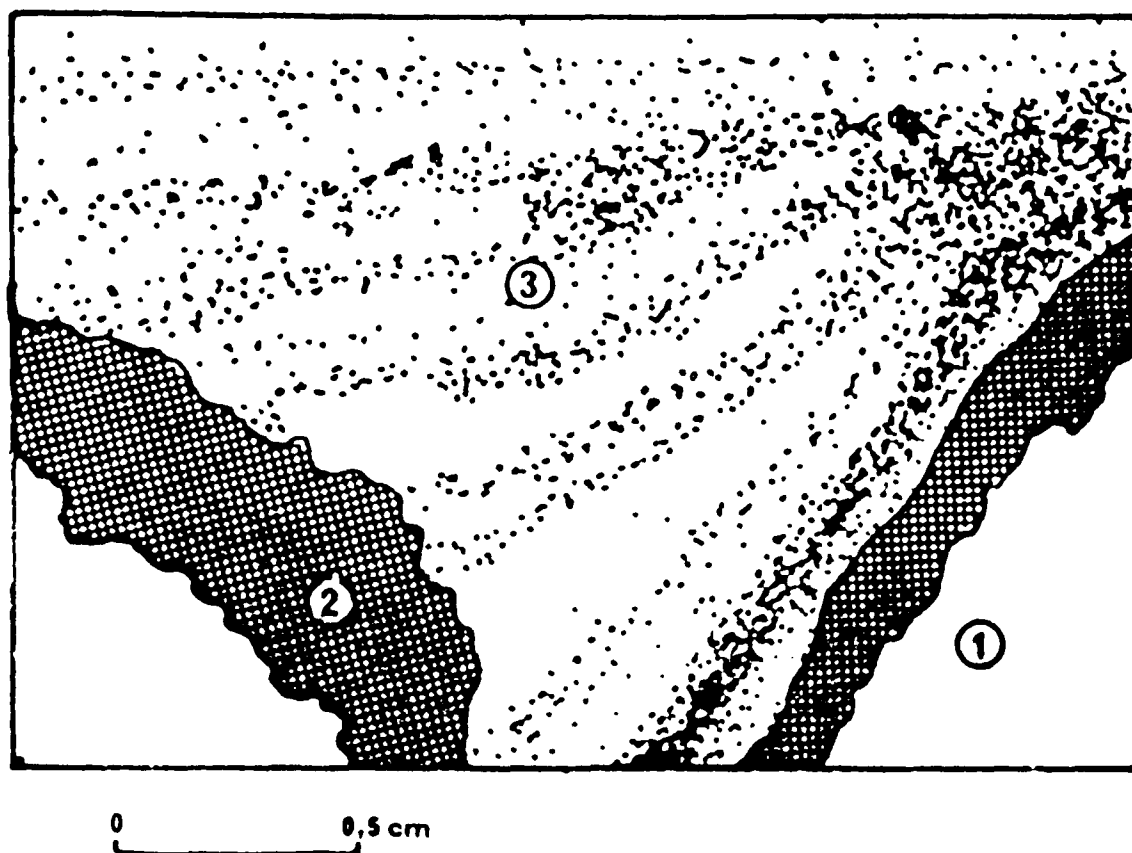
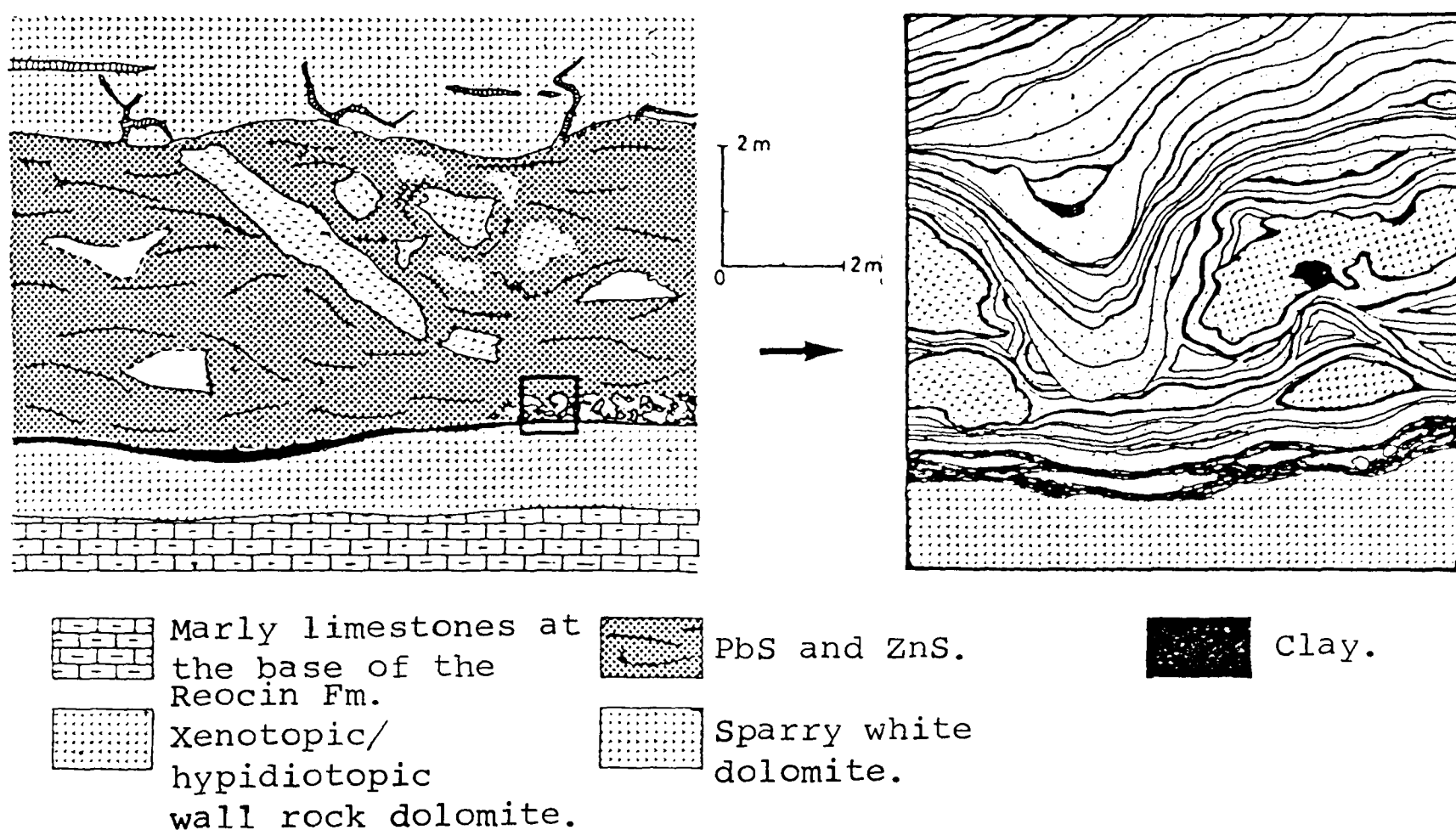


FIGURE 6-76.

Mechanical infill of a small, cm-sized depression at the base of the Capa Sur ore body at Reocin illustrating the varve-like infill of the high-Fe dolomite/sphalerite (3) of this depression. 1 = Enclosing sparry dolomite, 2 = Colloform sphalerite and 3 = Geopetal infill of the depression by alternations of sphalerite and a buff tan xenotopic detrital internal sediment dolomite. Such soft sediment features are quite common in the Reocin ore horizons. Adapted from Vadala, 1981.

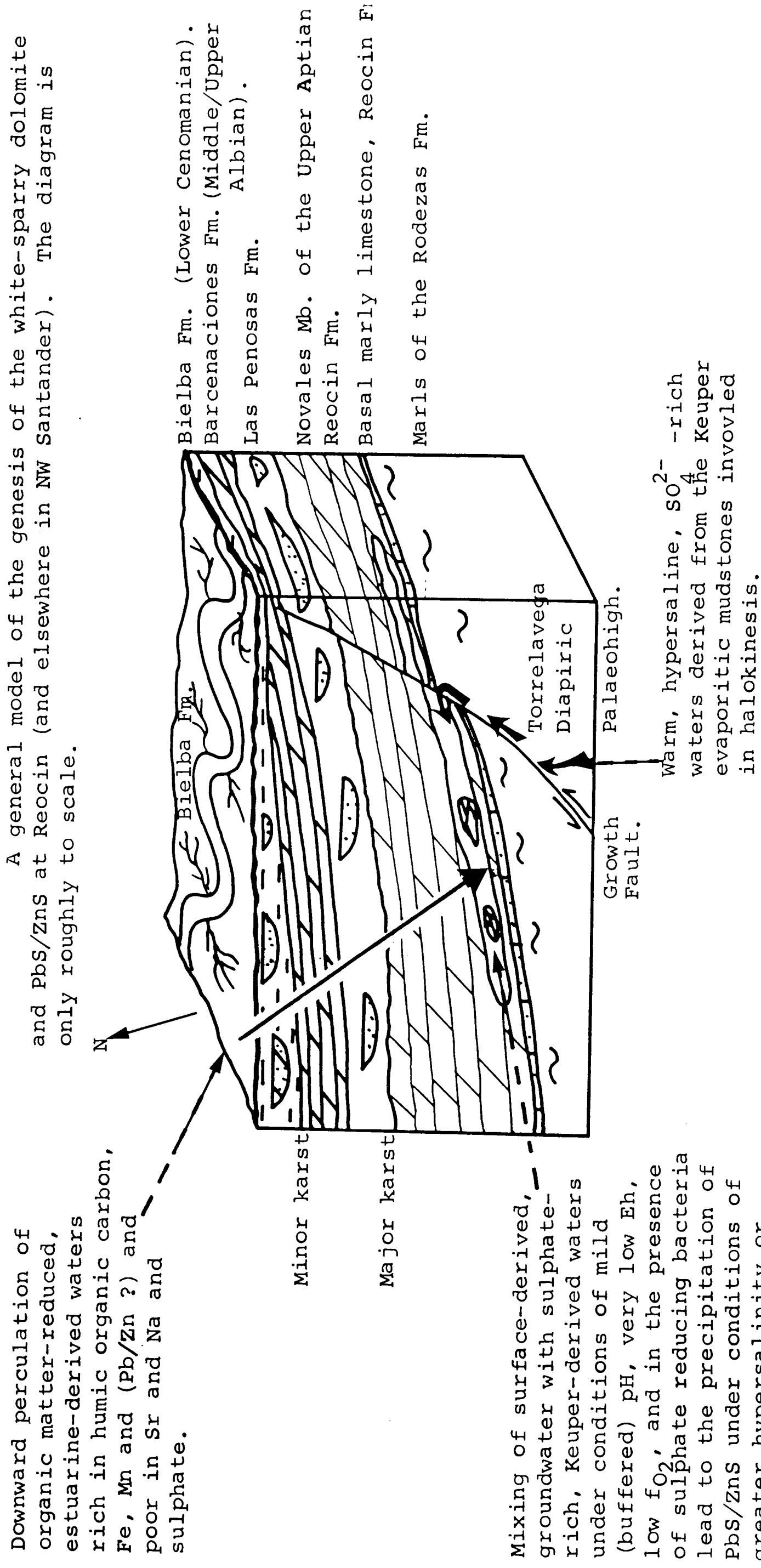


Scale refers to the left hand figure.

FIGURE 6-77.

An illustration of the collapse breccia in the Capa Sur ore body at Reocin. The mineralisation contains blocks of pre-lithified hypidiotopic/xenotopic dolomite within the ore horizon (left hand diagram). This is clearly at the very base of the Novales Mb. at Reocin, only just above the less permeable marly limestones/marls of the Rodezas Fm. Note the basal black mud at the base of the karstic cavern which is very similar to those seen in the estuarine muds of the Las Penosas and Bielba Fms.. The more detailed right hand side diagram shows the geopetal infilling of depressions by detrital tan grey dolomite, thin muds and sphalerite. Adapted from Vadala et al., 1981.

FIGURE 6-78.



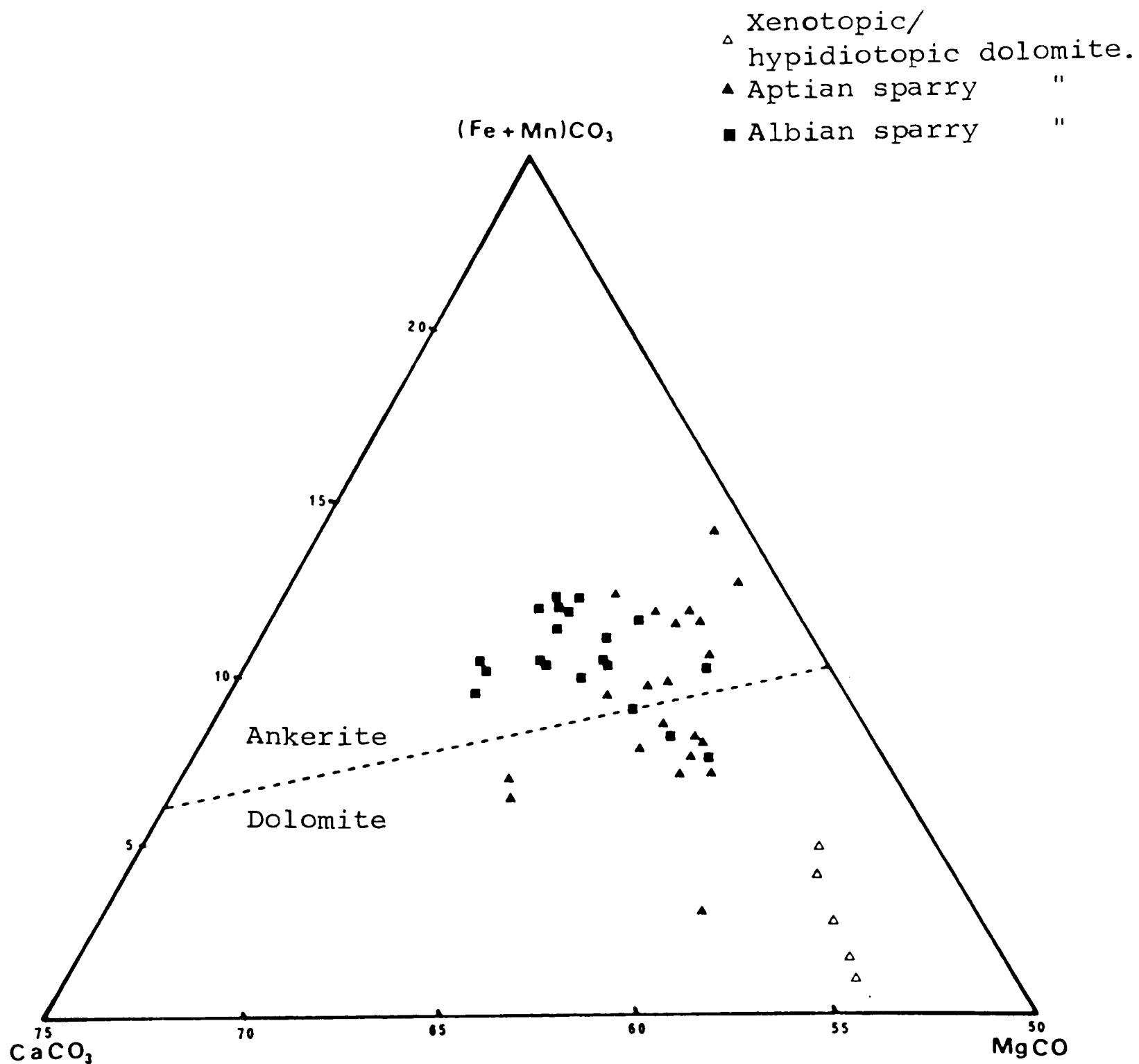


FIGURE 6-79.

A triangular plot in mole % of the Mg, Ca and (Fe + Mn) of the Upper Aptian and Albian white sparry / baroque dolomites from the Reocin area. Note the exceptional overlap between the data from the Albian and that from the Aptian strata, indicating that these dolomites were derived from the same source. Hence, the high-Fe sparry dolomitization was post the Albian carbonate deposition. Adapted from Vadala, 1981.

Stable sulphur isotopes of the Reocin Fm. Pb/Zn Sulphides.

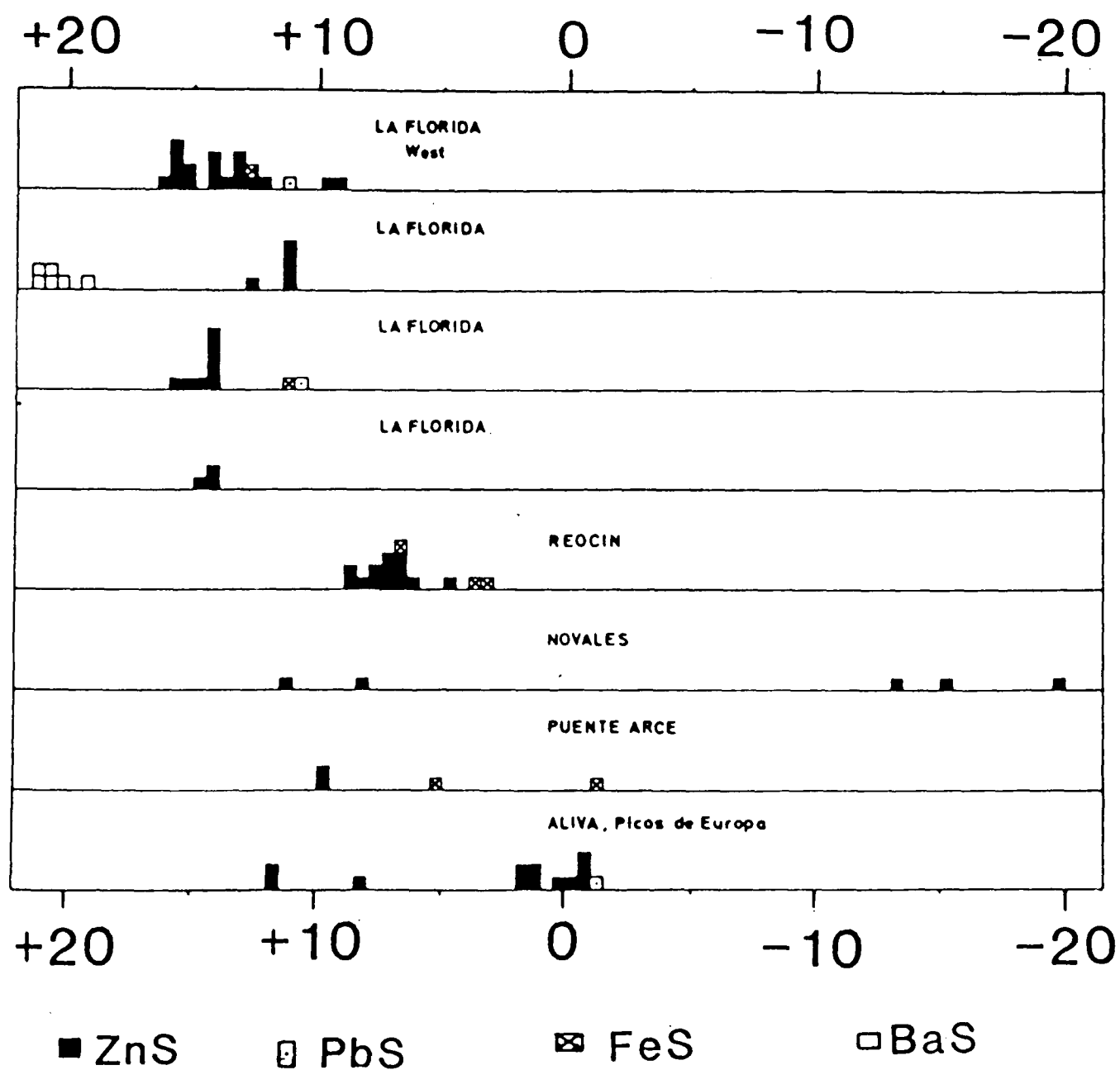


FIGURE 6-80.

The stable sulphur isotopes of the Reocin Fm. ZnS, PbS, FeS and BaS from Adalhardt, 1968. One reading is indicated by a small square such as that at -20%. Note the progressive increase in $\delta^{34}\text{S}$ towards the western end of NW Santander. For discussion see Chapter 6.9.2, section 3.

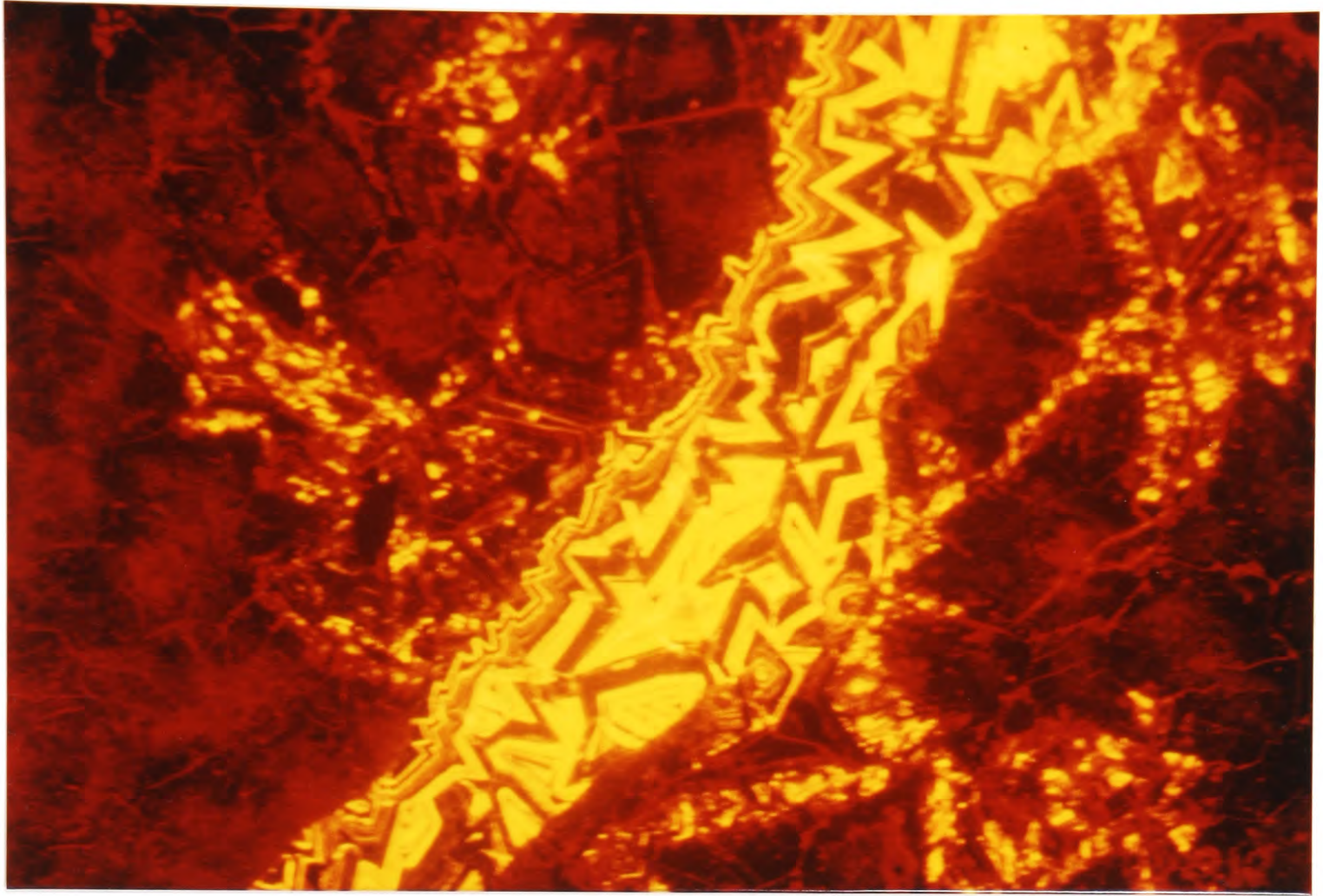
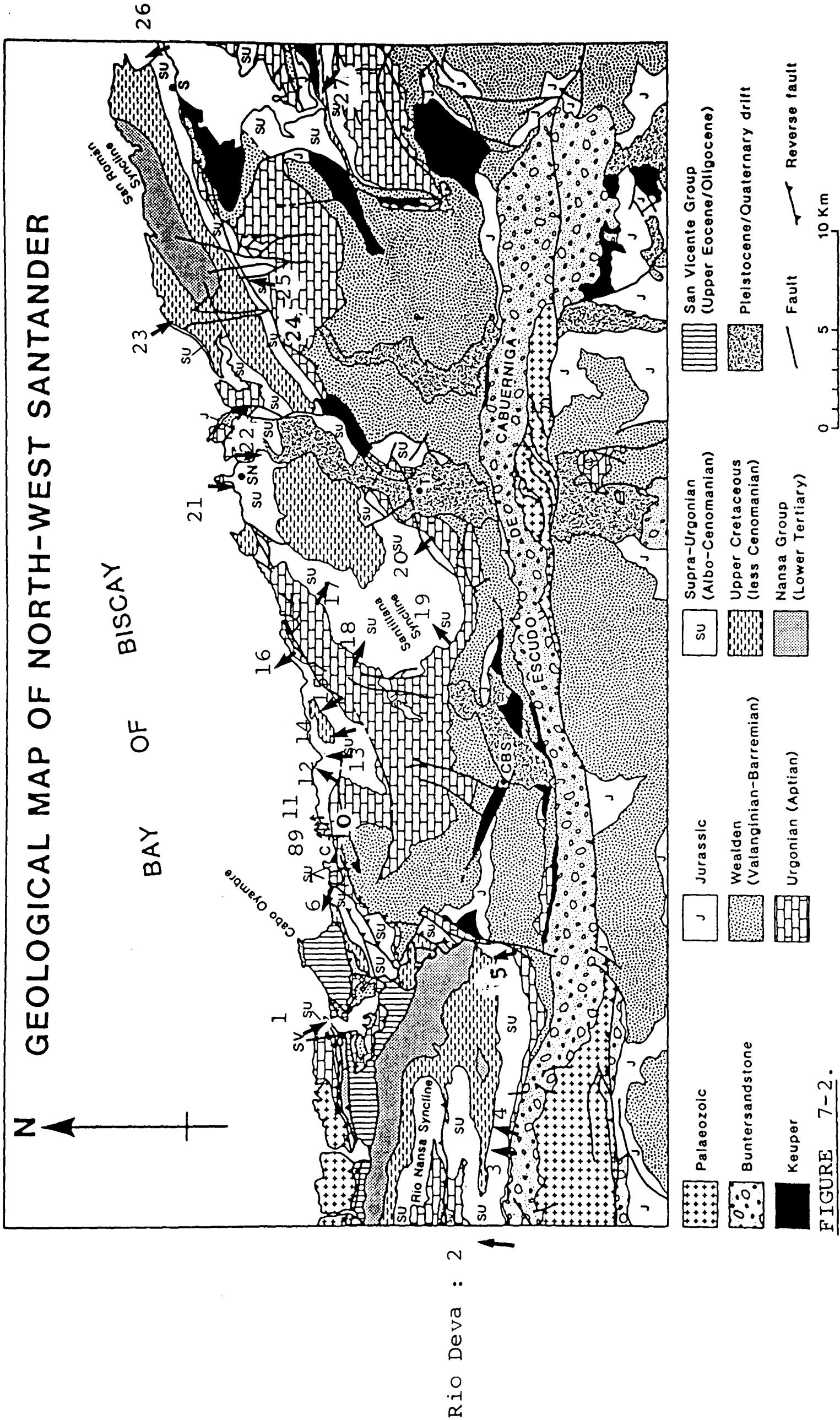


FIGURE 6-81.

This is a cathodoluminescence photograph of the fracture-related dolomite showing the well-developed zoning characteristic of this final dolomite generation. The zoning is due to variation in the Mn/Fe ratio and the presence of such luminescence indicates that this is a low-Fe dolomite with less than about 1.5 weight % FeCO_3 . Such luminescence is typical of the later generations of fracture-related dolomite.

The field of view shown is 9mm wide.



Location map of the sections in the Albian used in Fig. 7-1 by numbers. Arrows show direction of logging.

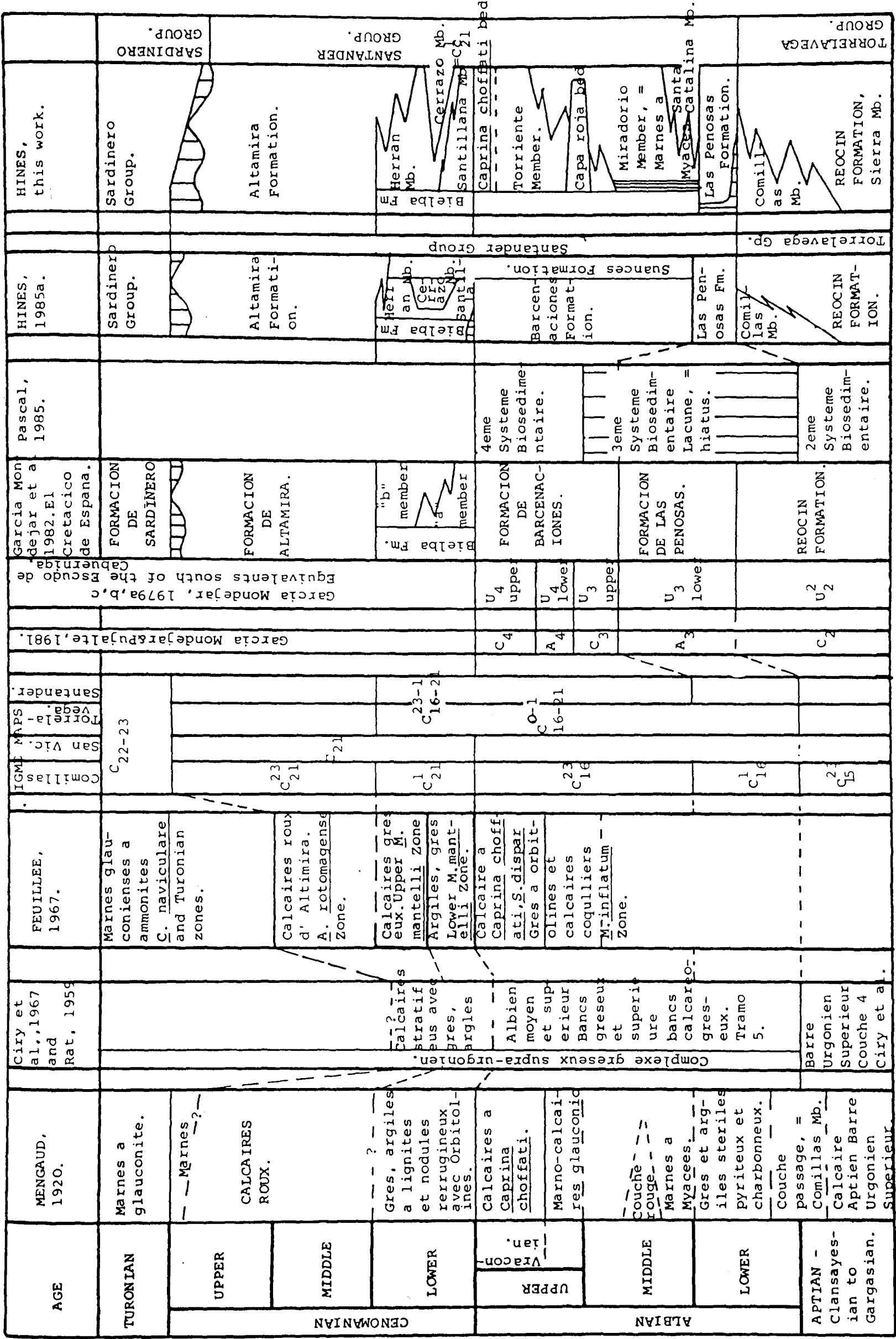


FIGURE 7-3. : Correlation of the various stratigraphies used for the Albo-Cenomanian of NW Santander. Vertical lines imply a hiatus.

SANTANDER ALBIAN SEQUENCE

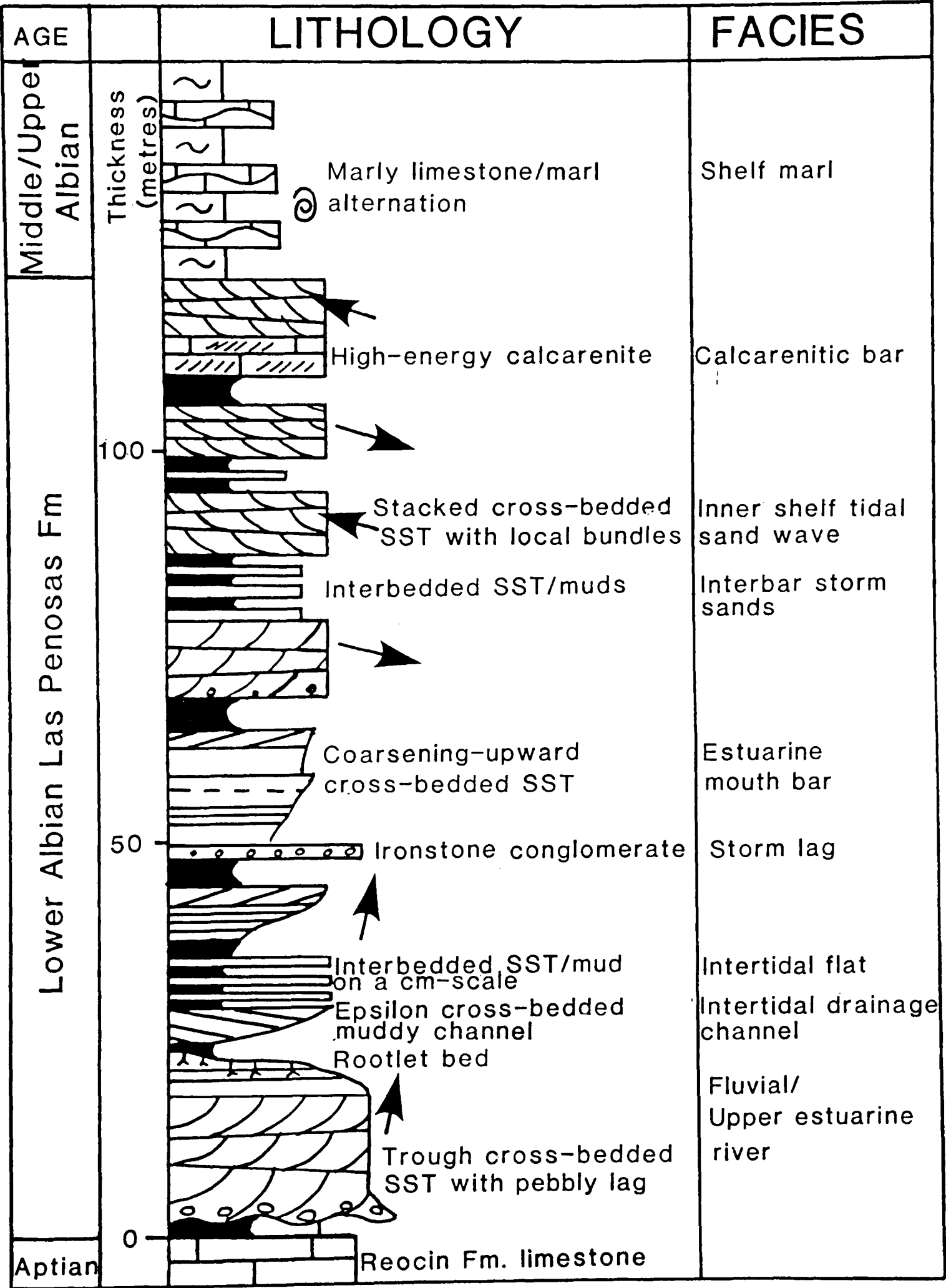


FIGURE 7-4.

A general summary of the lower part of the Albian sequence in NW Santander taken from the Comillas area. The arrows to the right of the graphic log are general palaeocurrent directions.

FIGURE 7-5.

General view of the base of the Lower Albian Las Penosas Fm. from the Seminario Pontificio section (Section 7 on Fig. 7-1). This shows the sandy channels of the basal sheet fluvial sandstone of this formation in the Comillas area. In the bottom right is a faulted contact with the grey marls/wackestones of the Comillas Mb.. Above this is a sand-dominated fluvial channel (cf. base of Section 7 of Fig. 7-1) that is 6m thick. Details of this channel are given in Figs. 7-6 & 7-8. Above this basal channel is a similar sandy fluvial channel. Together they form the basal fluvial sheet of the Las Penosas Fm. in this area.

The pebbles/cobbles in the bottom left hand corner are Recent beach ones and the overall section exposed in the photograph is 12m thick. This section is shown in detail in Section 10/1, 0 to 12m.

FIGURE 7-6.

Detail of the planar and trough cross bedding in the basal channel shown in Fig. 7-5. This shows the stacked cross-bedded sands of a South Saskatchewan-type braided river that make up this basal sheet sand. The palaeocurrent pattern shows a unimodal NNE/NE pattern, showing that these rivers were coming from the hinterland to the S/SW. The section above the sea level is approximately 7m thick.



FIGURE 7-7.

A view of the trough cross-bedding in the fluvial sandstones of the basal fluvial sheet sandstones in the lowermost part of the Las Penosas Fm. on the Southwest Miradorio section (Section 8 of Fig. 7-1). This section is illustrated in Section 5/31, 502m. Note the general lack of tidal features (herringbone cross-bedding etc.) but this photograph does show the faint mud-draping of some sets. The top of sequence is to the left in this photograph and the hammer is 25cm long. The white-weathering colour is due to the slightly coarser-grained nature of this sandstone (medium to coarse sandstone) and it's higher than average feldspar content (more proximal fluvial deposits are less mature).

FIGURE 7-8.

A detail of the trough cross-bedded sandstones of the basal fluvial sheet sand of the Las Penosas Fm. from the Seminario Pontificio section (Section 7 of Fig. 7-1). Note the rarity of mud drapes in these cross-beds which relate to minor tidal incursions up these rivers. This section is shown in Section 10/2, 9m. The lens cap is 5cm wide and the photograph is the right way up.



FIGURE 7-9.

Rootlet bed at the top of the sheet fluvial sandstones of the Southwest Miradorio section (Section 8 of Fig. 7-1). These rootlets overlies parallel bedded sandstones that themselves overlies trough cross-bedded sandstones towards the base of the channel. This section is illustrated on Section 5/32, 506 to 512m, with the rootlets at the top of this channel section. It is possible that some of the vertical structures are Skolithos burrows, but the presence of organic matter in many of the burrows suggests that they are, in the main, rootlets. The photograph is the right way up and the hammer is 25cm long.

FIGURE 7-10.

This illustrates some of the lenticular crevasse splay deposits of the lower part of the muddy estuary of the Las Penosas Fm.. Rare palaeo-current directions are often oblique or perpendicular to the main estuarine channel direction, suggesting that they are crevasses from the channel. The deformation at the right hand side of the photograph is tectonic and linked to the overturning of the lower part of the Las Penosas Fm. on the Southwest Miradorio section (Section 8 on Fig. 7-1). Note also the structural deformation in the muds beneath the hammer. These crevasse splay sands built out into peritidal muds/lagoons and are graphically illustrated in Section 5/36, 527 to 529m. The hammer is 25cm long and the photograph is the right way up. The pebbles in the top left hand corner are Recent. This is a typical example of Facies 2 of Chapter 7.



FIGURE 7-11.

Slightly muddy, flaser bedded sandstone of the lower part of the estuarine system that was deposited as a crevasse splay deposit from the estuarine channel. This lithology is typical of the storm-related crevasse splay sands and is far too muddy to be a back-barrier washover sandstone. It is relatively sheet-like and represents a splay that was developed by a number of storm events into the peritidal mud/lagoonal area. It shows slight bioturbation, as is typical in this part of the estuary. Peritidal muds can be seen at the base of the photograph. The lens cap is 5cm wide and the photograph is the right way up.

FIGURE 7-12.

This is the basal plan view of a totally bioturbated crevasse splay sheet sandstone that developed in the lower part of the estuary. This sheet sandstone is in Section 5/35, 521.5m to 522.6m. This sandstone is slightly muddy and seems to have a high abundance, low diversity ichnofauna, characteristic of a brackish environment (amongst others). This too would fall into Facies 2 of Chapter 7. The lens cap is 5cm wide and the photograph was taken looking vertically upwards.



FIGURE 7-13.

A convoluted crevasse splay sandstone (centre) that shows abundant soft-sediment deformation. This example is taken from the Punta Calderon/Punta de Carrastrada section (Section 16 of Fig. 7-1) and is shown in detail in Section 11/11, 53-55m. It is a typical example of Facies 3 of Chapter 7. The top of the photograph shows an intertidal black mudstone overlain by the slightly erosive base of the distributary estuarine channel of this section. The hammer is 25cm long and the photograph is the right way up.

FIGURE 7-14.

This shows a typical example of a dendritic, intertidal drainage channel which has been infilled by soft-sediment collapse of its banks. This small channel occurs to the left of the hammer. Below this are crevasse splay sandstones in peritidal mudstone. This is an example of Facies 6 of Chapter 7. The pebbles at the top of the photograph are Recent beach ones. This channel occurs on Section 5/35, 524.5m. The hammer is 25cm long and the photograph is the right way up.



FIGURE 7-15.

A typical estuarine distributary channel from the Punta Calderon / Punta de Carrastrada section (Section 16 of Fig. 7-1). The base of the channel (base of photograph) is slightly erosional and cuts into black mudstones beneath it. The lower part of the channel is dominated by trough cross-bedded sandstones with a basal lag of ironstone conglomerates and carbonaceous wood fragments. The upper part of the channel is heterolithic (Figs. 7-16 & 7-17) and consists of a fining- and thinning upwards sequence that becomes more bioturbated towards its top. The top of the clastic channel is by the base of the calcarenitic channel of the Santa Catalina Mb., Barcenaciones Fm.. This channel is illustrated on Section 11/12, 56 to 66m as well as on Section 16 of Fig. 7-1. The photograph is of a section about 15m thick and is the right way up. A 25cm hammer is shown in the bottom left.

FIGURE 7-16.

This is a detail of the heterolithic upper part of the estuarine distributary channel shown in Fig. 7-15. It represents the very low-angle, upper subtidal to lower supratidal epsilon cross-bedding that infilled the non-active part of this major estuarine channel. Parallel lamination, wave- and unidirectional ripple cross-lamination are the main sedimentary structures in the sands of this facies. It is described in more detail in Facies 7 of Chapter 7. The note book is 15cm long and the photograph is the right way up.

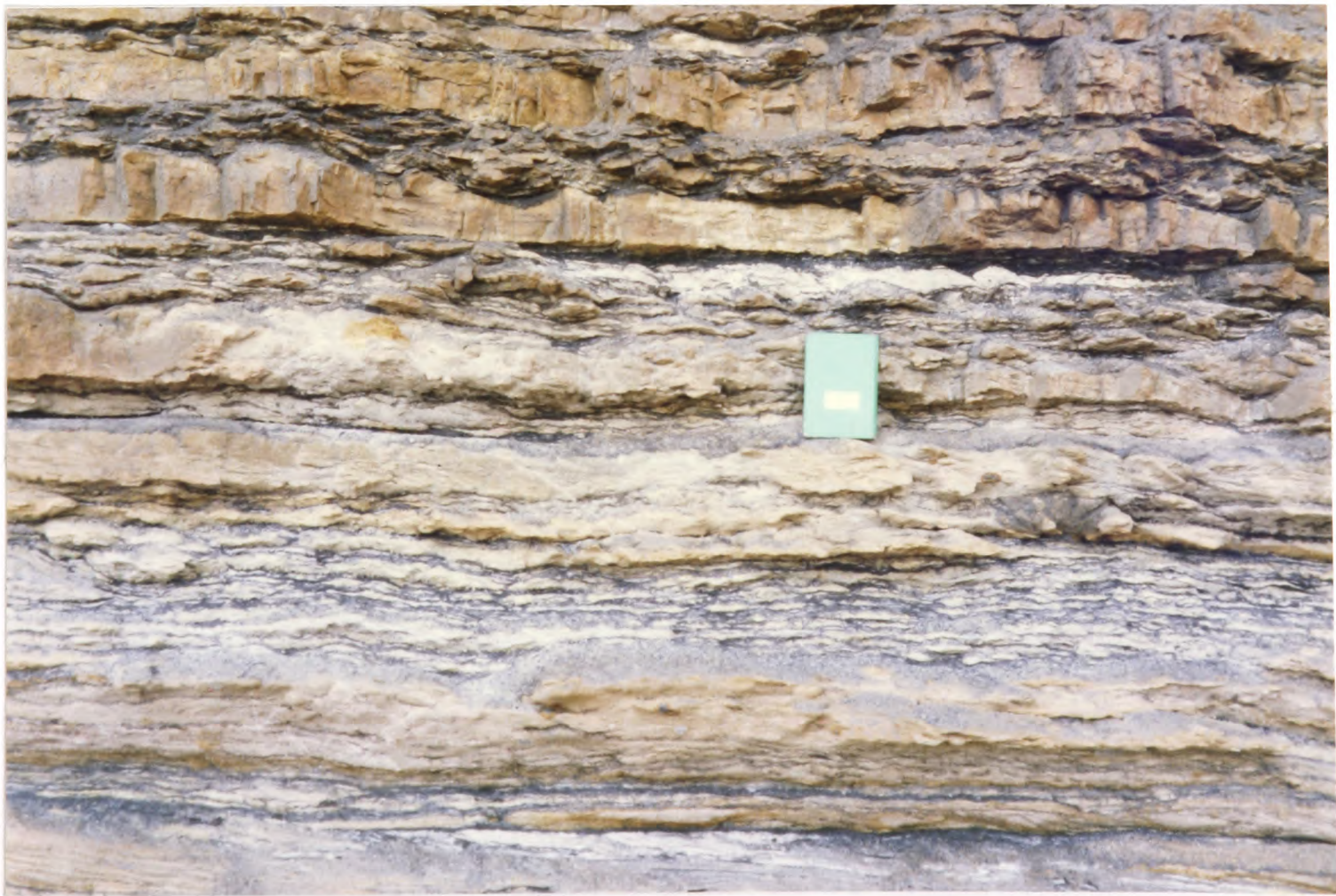


FIGURE 7-17.

This is a detail of the uppermost part of the upper heterolithic section of the estuarine distributary channel shown in Figs. 7-15 & 7-16. It represents the finest-grained, thinnest bedded and most bioturbated part of this channel. Location of this channel is given in the captions to Figs. 7-15 & 7-16.

FIGURE 7-18.

Epsilon cross-bedded tidal creek channel of Facies 8 of Chapter 7. The base of the channel is near the Recent beach pebbles in the bottom right of the photograph. Note the centimetre-scale couplets of muddy sandstone and sandy mudstone that infill the channel. These couplets have an epsilon geometry that dips off to right (E). This was taken from the west side of Casasolo Bay (Section 9 of Fig. 7-1) in the upper part of the estuarine sequence. The photograph is the right way up and the hammer is 25cm long.



FIGURE 7-19.

This is a thin, cross-bedded channel sandstone in peritidal mudstones. It was taken from the west side of Casasolo Bay (Section 9 of Fig. 7-1). It occurs towards the top of the estuarine sequence. The pebbles at the base of the photograph are Recent. The photograph is the right way up and the hammer is 25cm long.

FIGURE 7-20.

This is a longitudinal view of the lower part of a major sandy estuarine channel. Just beneath the base of the photograph is a basal lag to this channel. Note the herringbone cross-bedding in the sets to the left of the hammer. This is a typical example of Facies 9 of Chapter 7. The photograph is the right way up and the hammer is 25cm long. This channel was taken from the east side of Casasolo Bay (Section 10 of Fig. 7-1) and is described there as "Estuarine channel".



FIGURE 7-21.

Top of the estuarine channel shown in Fig. 7-20. This is the top of the fining- and thinning-upwards sequence of this channel and consists of thin (storm ?) sands interbedded with black mudstone. Current and wave ripples have been found in the sandstone laminae. Above this photograph is a thick (4m) sequence of black mudstones. The orange cobbles in the top left are Recent beach ones. This was taken from the "Estuarine channel" of Section 10 of Fig. 7-1 on the east side of Casasolo Bay, east of Comillas. The photograph is the right way up and the hammer is 25cm long.

FIGURE 7-22.

This is a typical example of the intertidal mixed flats developed within the estuarine sequence of the west side of Casasolo Bay (Section 9 of Fig. 7-1). It is a typical example of Facies 10 of Chapter 7. It consists of interbedded clean to flaser bedded sandstones in a lenticular-bedded mudstone. Wave and current ripples have been found in the sand laminae which probably represent storm sands onto the peritidal flat. A small fault is seen to the right of the lens cap. The photograph is the right way up and the lens cap is 5cm wide.



FIGURE 7-23.

An intertidal flat / dendritic drainage channel deposit from the upper estuarine sequence of Southwest Miradorio (Section 8 of Fig. 7-1). This shows the abundant mud-draping of the flaser bedded sandstone, local bundling of the mud drapes, local double mud drapes and down coset decrease in angle of repose. All these features are indicative of tidal action in the intertidal flat of this estuary. This unit comes from Section 5/38, 539.5m. The photograph is the right way up and the hammer is 25cm long.

FIGURE 7-24.

This is an ironstone conglomerate developed from the upper part of the outer estuarine sequence on the western side of Casasolo Bay (Section 9 of Fig. 7-1). This is an example of Facies 11 of Chapter 7. It was deposited by either a high-energy storm event into the intertidal flat or is the basal lag of a transgressive beach deposit which has been reworked by the transgression itself. The photograph is the right way up and the lens is 5cm wide.



FIGURE 7-25.

An overall view of the coarsening- and thickening-upwards estuarine mouth bar sequence of the outer part of the estuary. The photograph shows the northern limb of a small anticline on Southwest Miradorio (Section 8 of Fig. 7-1) and shows a thickening-upwards sequence from the base (above Recent beach deposits) to the thick beds in the grassed area. The oblique structures in the thick-bedded sandstone just below the base of the grass are accommodation structures to the tectonic folding. This section is graphically illustrated in Section 6/1, 0 to 10m. and is a typical example of Facies 12 of Chapter 7. The section shown is the right way up and exposes about 10m. of rock.

FIGURE 7-26.

This is a detail of the lower part of the coarsening- and thickening upwards sequence of the estuarine mouth bar shown in Fig. 7-25. It was taken from about 1.5m below the position of the hammer in Fig. 7-25. It shows the decimetre interbedding of a flaser and ripple bedded sandstone with a wavy bedded sand/mud which is illustrated in more detail in Fig. 7-27. This is in the basal part of Facies 12 of Chapter 7. It is illustrated in Section 6/1, 0.4 to 0.8m. Locations are given in the caption to Fig. 7-25. The photograph is the right way up and the lens cap is 5cm wide.



FIGURE 7-27.

A detail of the wavy bedded part of the decimetre interbedded flaser bedded sandstone and wavy bedded sand/mud of the lower part of an estuarine mouth bar of the outer part of the Las Penosas Fm. estuary. The mm to cm thick laminae show local bundled upbuilding, irregular lower set boundaries, form discordant ripples and swollen lens-like sets that indicate wave reworking of these sandstone laminae. This is shown in Section 6/1, 0.7m. The photograph is the right way up and the lens cap is 5cm wide.

FIGURE 7-28.

This is a plan view of the wave ripples at the top of the estuarine mouth bar of Figs. 7-25, 7-26 & 7-27. Note the sharp ripple crests and minor burrowing in these ripples. The reworking of the top of the estuarine mouth bar in a transgressive sequence means that if an beach/spit was present this is likely to have been reworked by these very waves and not preserved into the ancient. This is discussed in Facies 12 of Chapter 7. The wave ripple orientation is generally WNW-ESE, ie. parallel to the palaeoshoreline. This top to the estuarine mouth bar is shown in Section 6/2, 10m. The lens cap is 5cm wide.



FIGURE 7-29.

One of the major logs from the estuarine mouth bar area of the Southwest Miradorio sequence (Section 8 on Fig. 7-1). It is developed within Section 6/3, 15 to 16m. It is associated with local reduction and the development of pyrite, sulphur and complex yellow clays. The presence of such large logs is typical of subtropical, humid estuaries (Tucker, 1973). A minor degree of tectonic deformation has occurred in the right hand side of the photograph. The photograph is the right way up and the hammer is 25cm long.

FIGURE 7-30.

This is a typical example of the inshore tidal bar facies from the Southwest Miradorio sequence (Section 8 of Fig. 7-1). It is Facies 13 of Chapter 7. The dominant structures are cross-laminated and cross-bedded sandstones with rare lenticular bedded mudstone, bedded on a centimetre to decimetre scale. A gravel bed is shown in the dark brown beds in the left of the photograph. This section is illustrated in Section 6/8, 36 to 40m.. The pebbles in the bottom right and centre top are Recent ones. The section is younger to the left and the hammer is 25cm long.



FIGURE 7-31.

A detail of the herringbone cross-lamination in the inshore tidal bar facies of Fig. 7-30. The directions of the cross-lamination are parallel-to-shore WNW-ESE tidal ones as are the dominant palaeocurrent directions in the inner shelf, marine part of the Las Penosas Fm. (Fig. 7-35). Note the interbedded wavy and flaser bedded sandstones beneath the lens cap. This comes from Facies 13 of Chapter 7 and is shown in Section 6/8, 37.3m. It was taken from the Southwest Miradorio section (Section 8 on Fig. 7-1). The photograph is the right way up and the lens cap is 5cm wide. This picture was taken from about 40cm stratigraphically higher than the hammer in Fig. 7-30.

FIGURE 7-32.

A well developed sand wave from the inner shelf of the Las Penosas Fm. This is an example of Facies 15 of Chapter 7 and was taken from the Southwest Miradorio sequence (Section 6/15, 70 to 74.5m). Note the medium-scale trough cross-bedded sandstones that are stacked on top of each other to form this tidal sand wave. It shows a dominant unimodal palaeocurrent direction to the WNW, a shore-parallel, ebb tidal direction. At the top of the sand wave is a recessive-weathering grey marl that is the base of the middle shelf Barcenaciones Fm.. The photograph is the right way up and the sand wave is 4.5m thick. The boulders at the bottom left are Recent.





FIGURE 7-33.

This complex tidal sand wave occurs in the inner shelf sequence of the Southwest Miradorio section (Section 8 of Fig. 7-1). The lower part of this sand wave consists of bioturbated sandstone and is overlain by a quartz-sand-rich calcarenite that is rather muddy. The uppermost part of this sand wave seen in the photograph is also rather bioturbated. This is an intermediate lithology between the sand waves of the top of the Las Penosas Fm. and the pure calcarenites of the Santa Catalina Mb.. It is shown in Section 6/12, 58m to 67m. At the very base of the sand wave are the inner shelf interbar mud facies (Facies 14 of Chapter 7). The blue folder (left) is 30cm long and the section shown is about 9m thick. It is also the right way up.

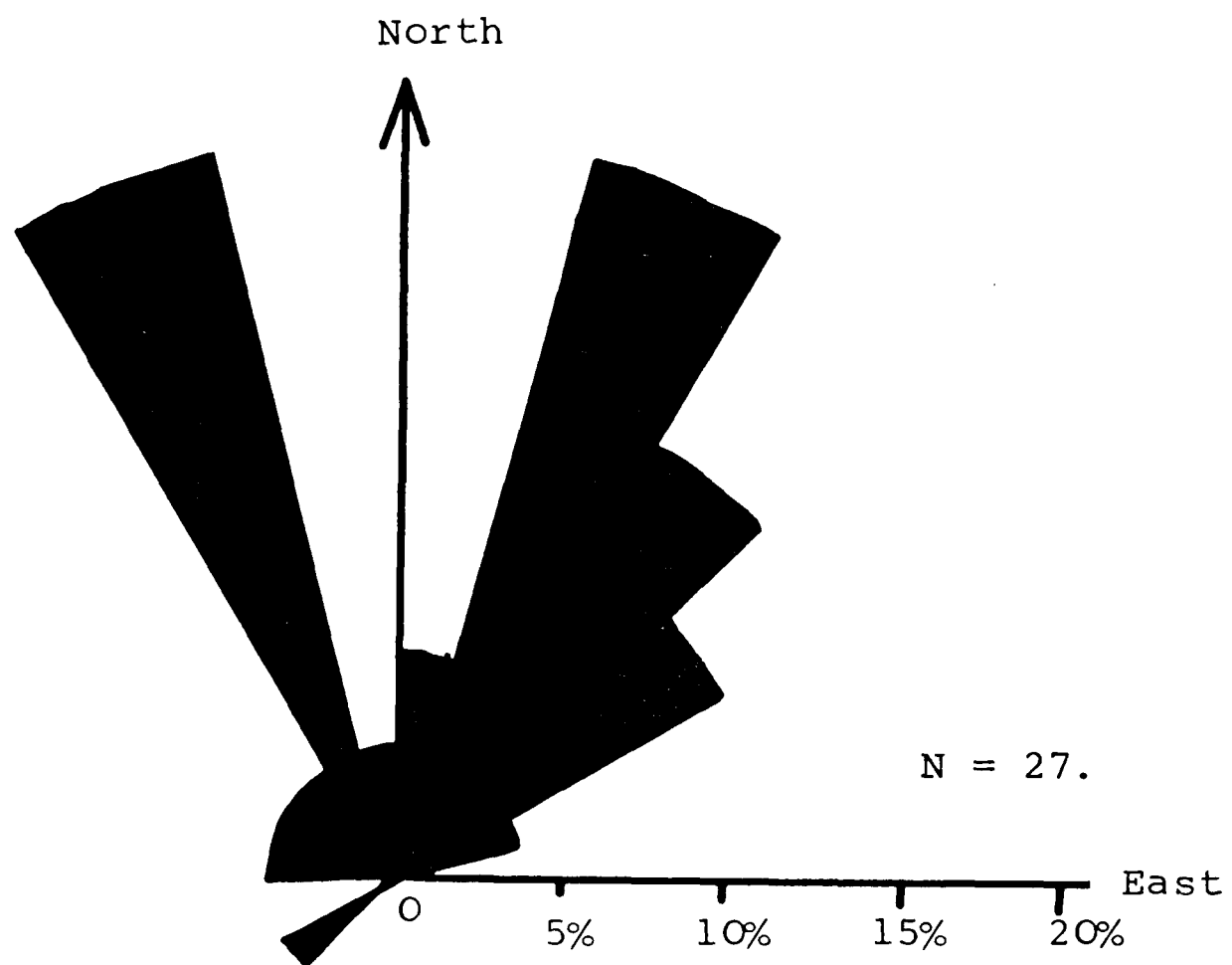


FIGURE 7-34A.

A rose digram for the palaeocurrents from the basal fluvial channel sandstones of the Las Penosas Fm. in the Comillas area. Note the general N/NNE direction of flow of these channels with sand being derived from non-marine "Utrillas" to the S/SW of the NW Santander area. These channels are shown in Fig. 7-36.

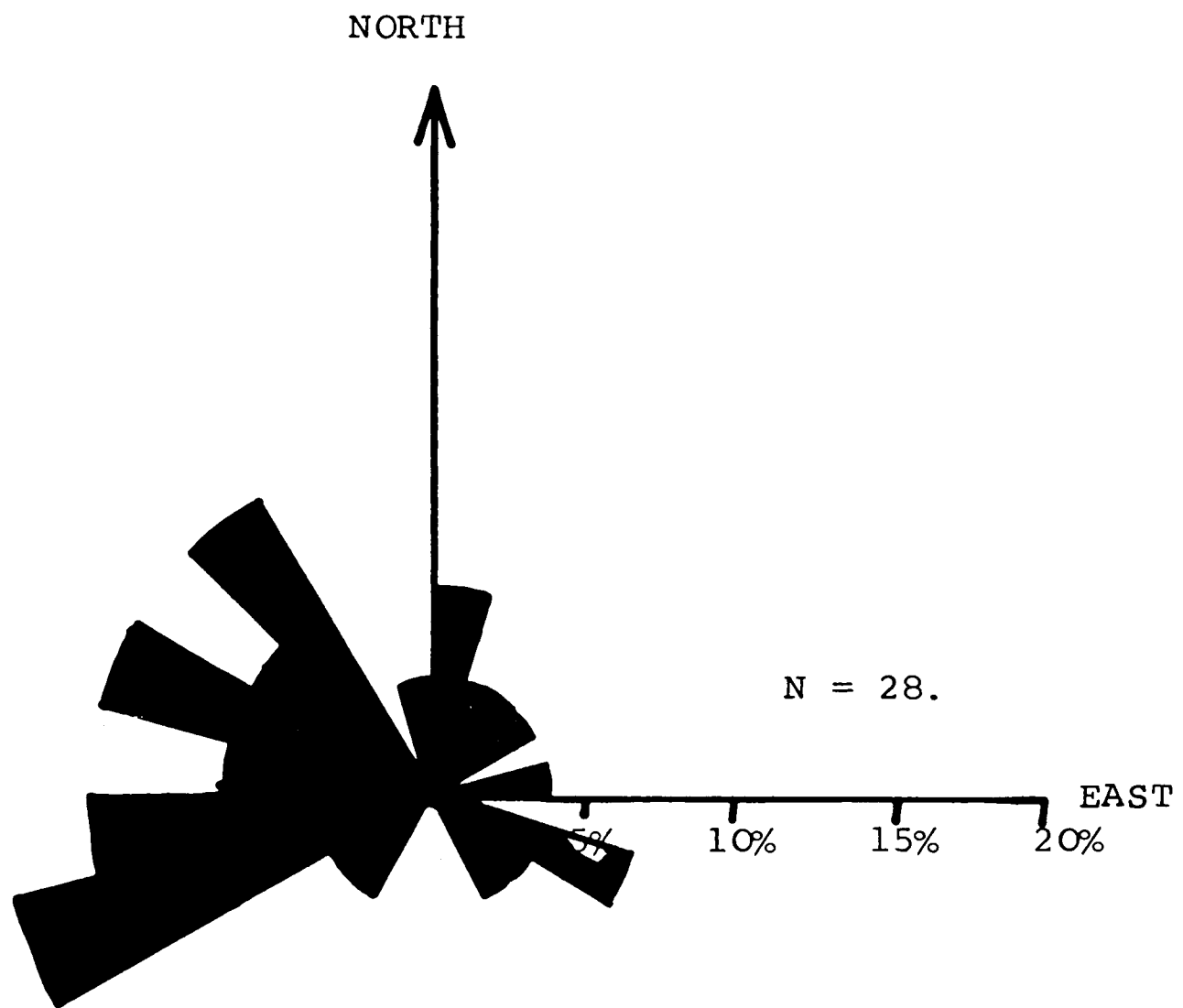


FIGURE 7-34B.

A rose diagram of the palaeocurrents from the crevasse splay and estuarine channel sands of the Las Penosas Fm. from the Comillas area. The greater spread in the data probably relates to the more variable direction that such channels and crevasses have further down the estuary than the feeder fluvial channels of Fig. 7-34A. Note the dominant orientation towards the WSW/W/WNW/NW which indicates that the estuarine channels had a tendency to turn in this direction, more in line with that of the inner shelf shore-parallel currents. This is common in estuaries with shore-parallel currents where the major spits that front the estuary have a strong tendency to grow longshore parallel to the dominant offshore current (here WNW - see Fig. 7-35). This is shown in Fig. 7-36.

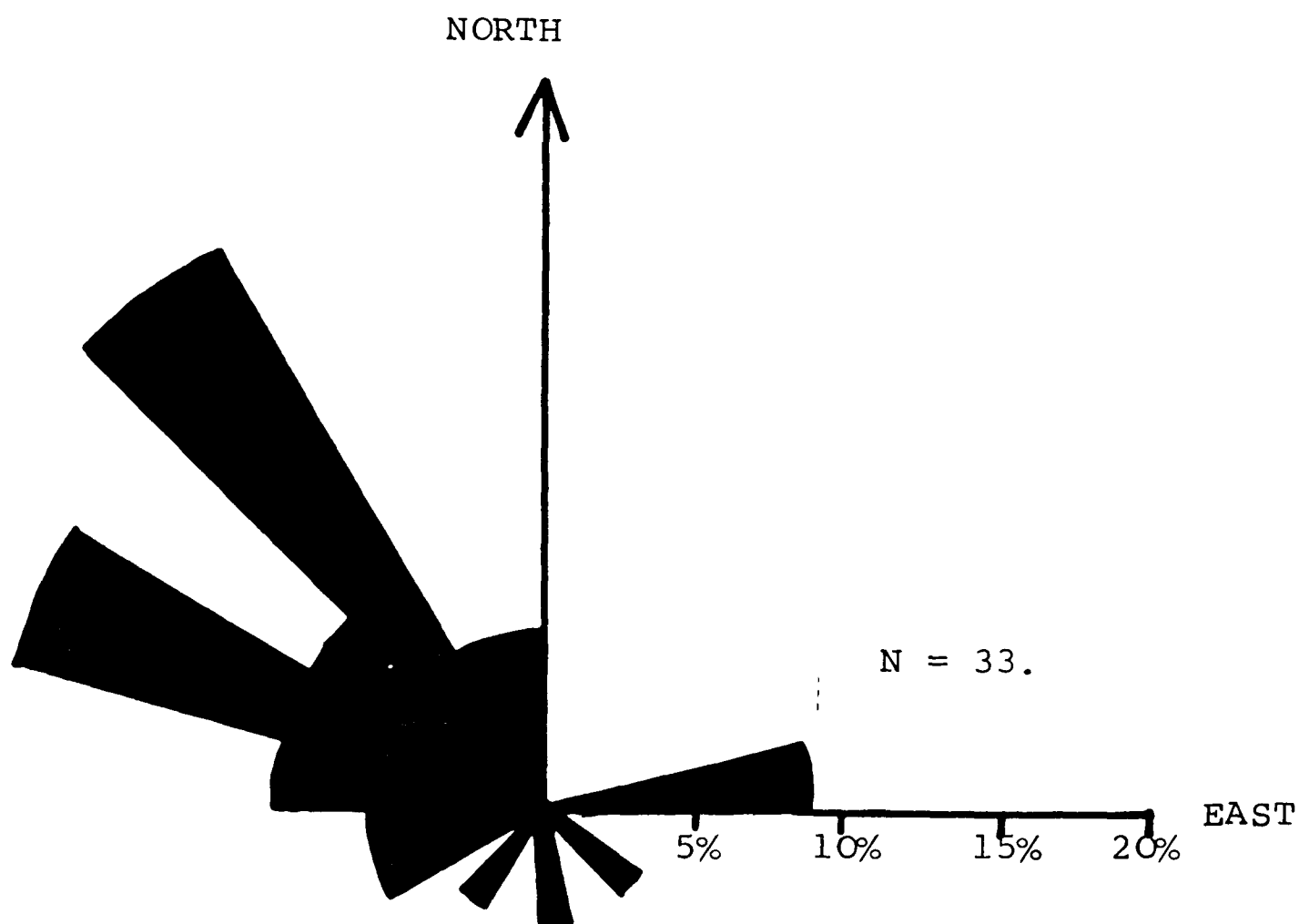
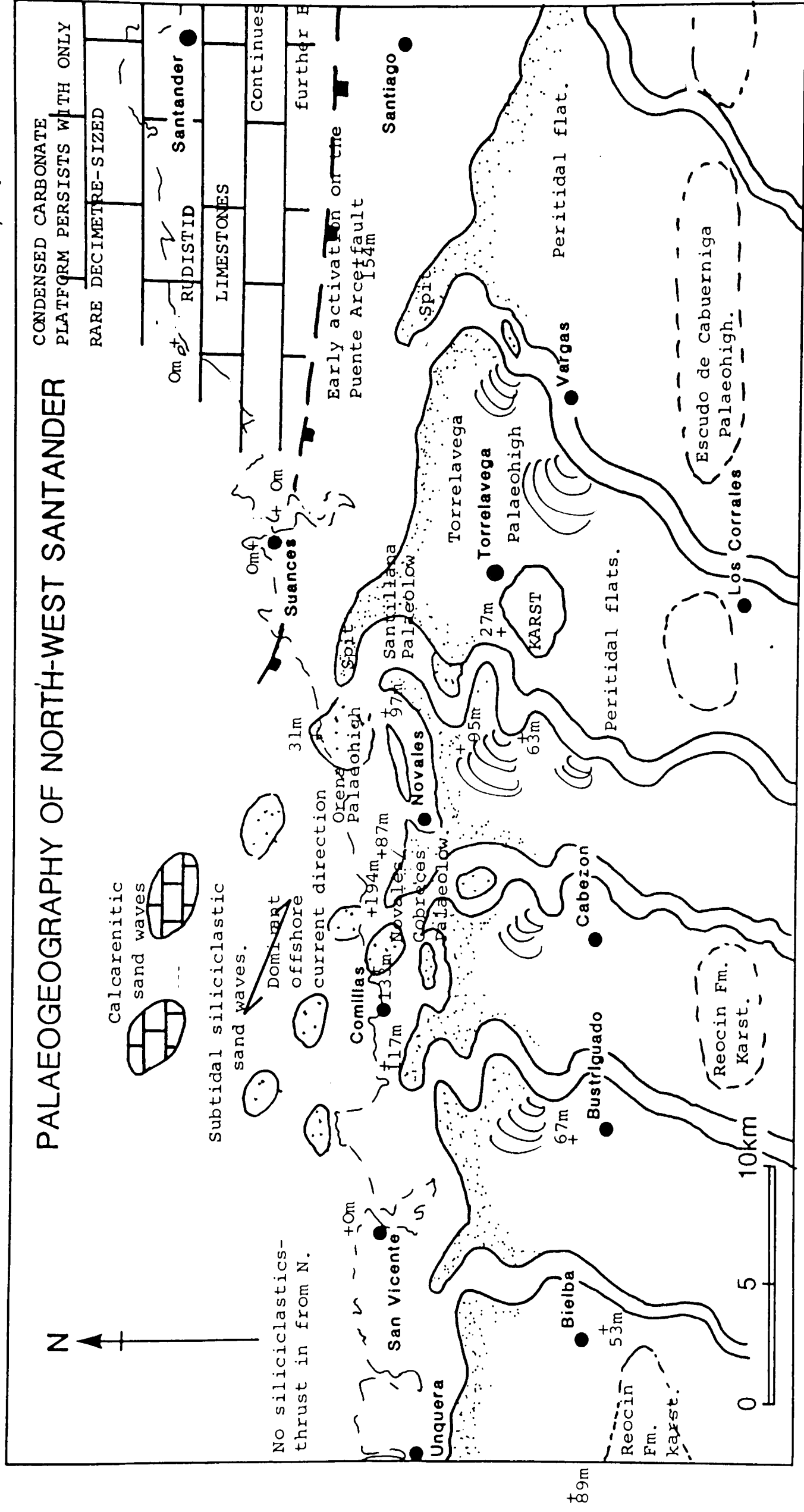


FIGURE 7-35.

A rose diagram of the palaeocurrents from the estuarine mouth bars/inner shelf tidal sand waves of the Las Penosas Fm. in the Comillas area. The strongly unidirectional flow towards the WNW/NW is due to the shore-subparallel, inner shelf ebb tidal current flowing in this direction. See text for details. These inner shelf tidal sand waves are shown in Fig. 7-36.

DEEPER WATER, DRIFTING OCEAN TO THE N/NE.



FLUVIAL SOURCE TO THE S/SW.
FIGURE 7-36.

A palaeogeography of the mid Lower Albian (Las Penosas Fm. times) of NW Santander showing the fluvial/estuarine/inner/middle shelfal sequence. + = Thickness of the Las Penosas Fm. in metres. ∴ = Palaeo-coastline. {{{ = Crevasse splay deposit in the estuary. ∴ = Sandy lithology. ⊥ = Rudistid platform limestone. Note the tendency of estuaries to flow towards palaeolows as well as a general offshore direction. Note the dominance of the W/WNW/NW current and it's effect on the spts of estuaries.

FIGURE 7-37.

A typical example of the clean, cross-bedded grainstones of the Santa Catalina Mb. of the Barcenaciones Fm. taken from the N 623 road section of the Puente Arce / Caserio de la Soledad section (Section 24 of Fig. 7-1). A description of this Facies 16 of Chapter 7 shows that the currents reworking the calcarenitic sand wave are dominantly tidal. The photograph is the right way up and the hammer is 25cm long (centre bottom).

FIGURE 7-38.

This is a good exposure of the high-energy calcarenites of the Santa Catalina Mb from the Punta de Ninera section, just north of San Vicente de la Barquera (Section 1 of Fig. 7-1). It shows the cross-bedded oolite of the tidal sand wave of the inner part of the middle / outer part of the inner shelf. The dominant palaeocurrent direction is to the right (WNW) and is the parallel-to-shore ebb tidal one. This is an example of Facies 16 of Chapter 7. The section shown is about 8m thick and the beds are younger to the top left.



FIGURE 7-39.

A view of the cross-bedded Santa Catalina Mb. from a fallen block of the basal calcarenitic tidal sand wave of the Punta Ninera section (Section 1 of Fig. 7-1). Note the multiple reactivations in the cross-bedding, characteristic of tidal deposition. Facies 16 of Chapter 7.7 gives a description of this rock. The block is the right way up and the hammer is 25cm long.

FIGURE 7-40.

This shows one of the larger cross beds of the second from base calcarenitic tidal sand waves of the Punta Ninera section (Section 1 of Fig. 7-1). It was taken from the same locality as Fig. 7-38. The main bedding is subparallel to the base of the photograph and the hammer is 25cm long. Note the mud-rich wacke/lime mudstone drapes to individual sets of this cross bed, again another characteristic of tidal deposition. The flow (to the right) is towards the WNW, the ebb tidal direction.





FIGURE 7-41.

A view of the large-scale tidal cross beds of the uppermost tidal sand wave of the Santa Catalina Mb. of the Punta Ninera section (Section 1 of Fig. 7-1). The main bedding is subparallel to the base of the photograph, the hammer is 25cm long and the large-scale cross-bed is about 2.5m thick. This is described in Facies 17 of Chapter 7.7. The rock is younger towards the top right.

FIGURE 7-42.

Refer to Figure 7-40.

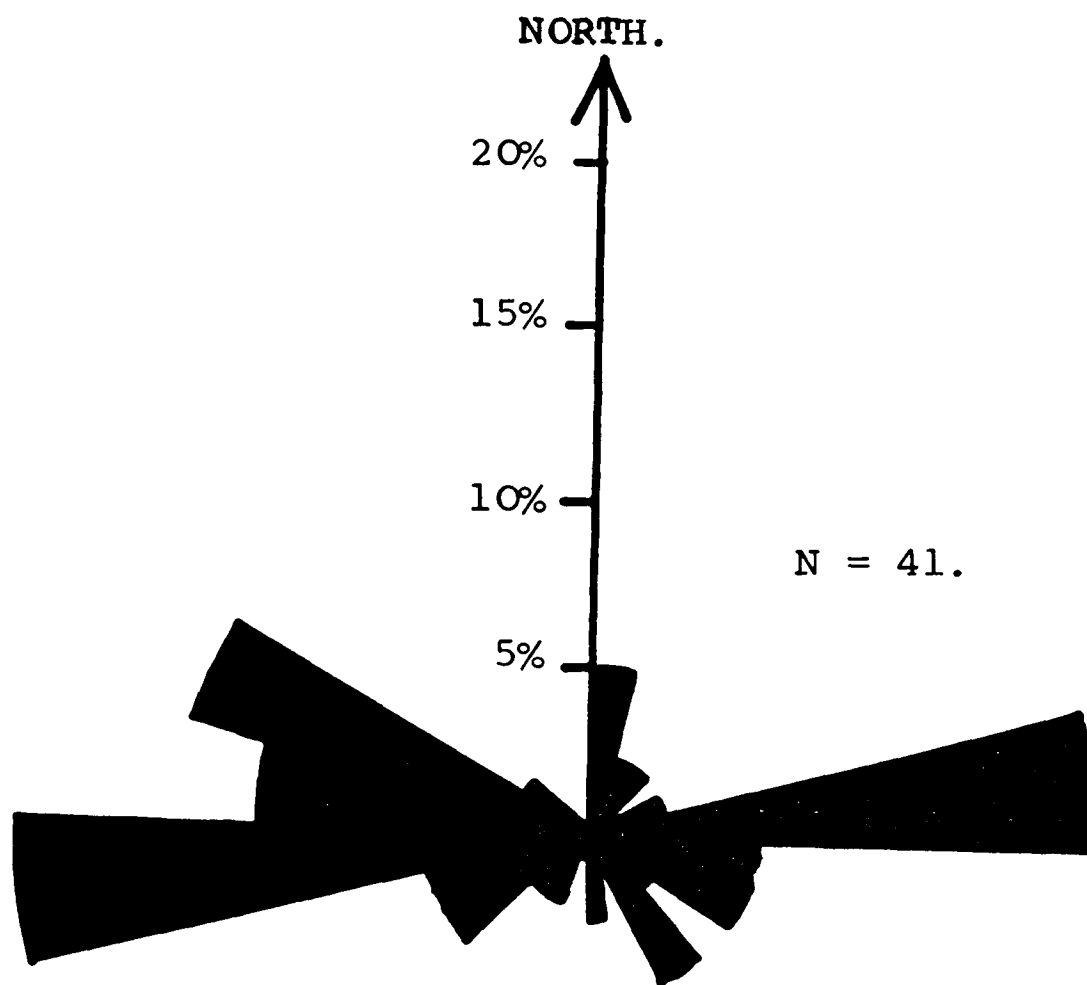


FIGURE 7-43.

A rose diagram of the palaeocurrents from the offshore calcarenitic tidal sand waves of the Santa Catalina Mb. (Barcenaciones Fm.) from mainly around the Punta Ninera section, just north of San Vicente de la Barquera. This strongly bipolar pattern clearly testifies to the essentially tidal origin of these calcarenitic sand waves, with the westerly-directed flow as the ebb one. Note the usual ebb (W) domination. Illustrated in Fig. 7-36.

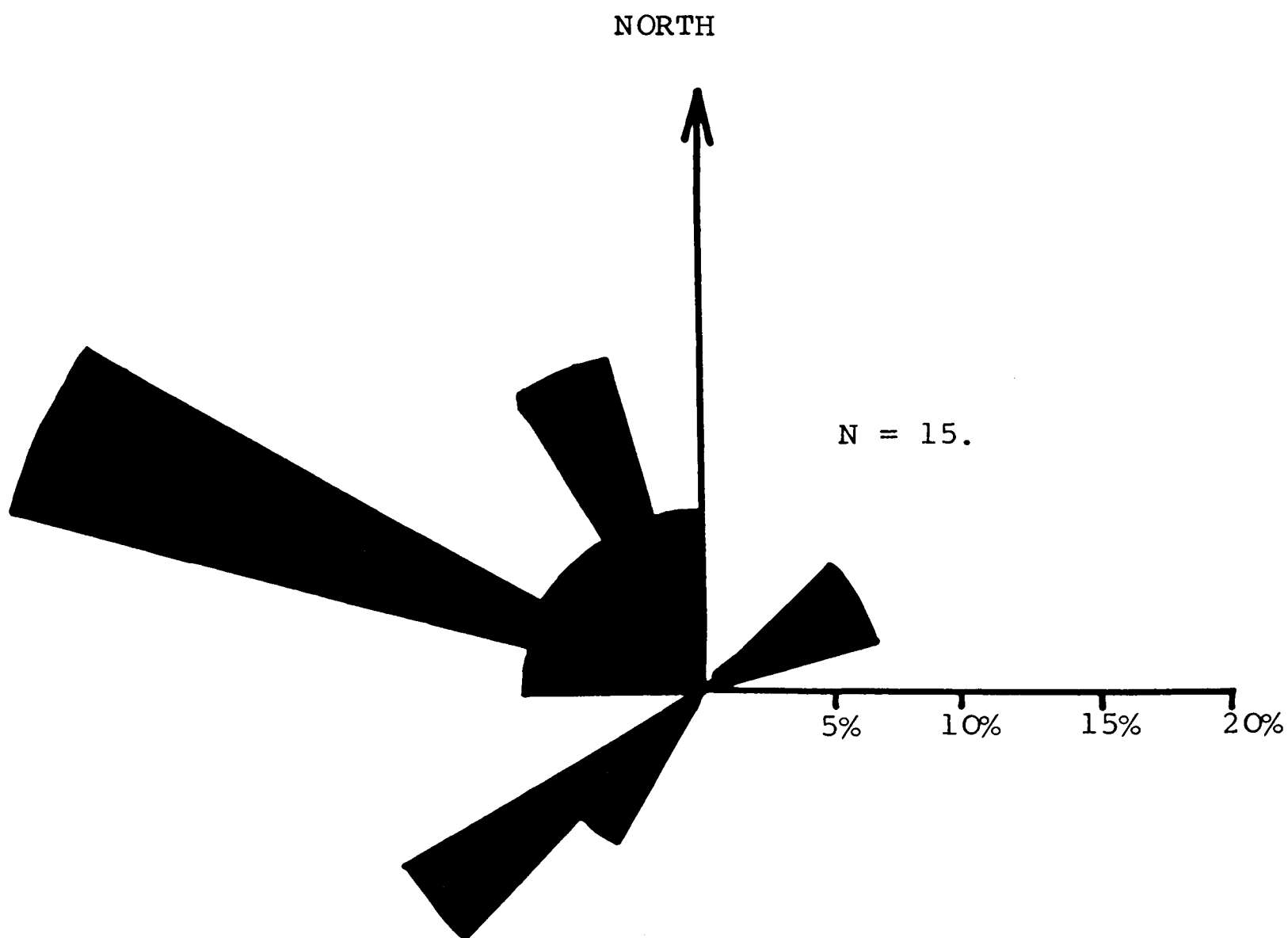


FIGURE 7-44.

A rose diagram of the palaeocurrents from the calcarenites of the Barcenaciones Fm. of the Miradorio area. Note the dominant WNW direction of flow, which is related to the major, shore-parallel ebb tidal current of these middle shelf shoals. A rather small data set could well be a problem in this grouping, though the general trend is consistent with other rose diagrams (Figs. 7-34 & 7-43).

FIGURE 7-45.

Refer to Figure 7-41.

FIGURE 7-46.

The interbar calcarenitic/marl facies of Facies 18 of Chapter 7.7. This shows the thin (cm-sized) quartz sand/silt-rich wacke/packstones (tempestites) in a marly matrix. Thicker bedded (decimetre-sized) wacke/packstones also occur, cf. the bed on which the lens cap is on. Note the moderate bioturbation of the more marly facies, and the presence of Chondrites burrows, characteristic of these middle shelfal environments. The lens cap is 5cm wide.

FIGURE 7-47.

A marly, nodular wackestone of Facies 20 of Chapter 7.7 of the Miradorio Mb. of the Barcenaciones Fm.. Note the preferential burrowing of the matrix as against the nodules, indicating that the nodular cementation was very early, probably within the top few 10's of cm of the sea bottom. The lens cap is 5cm wide and the top is at the top of the photograph.



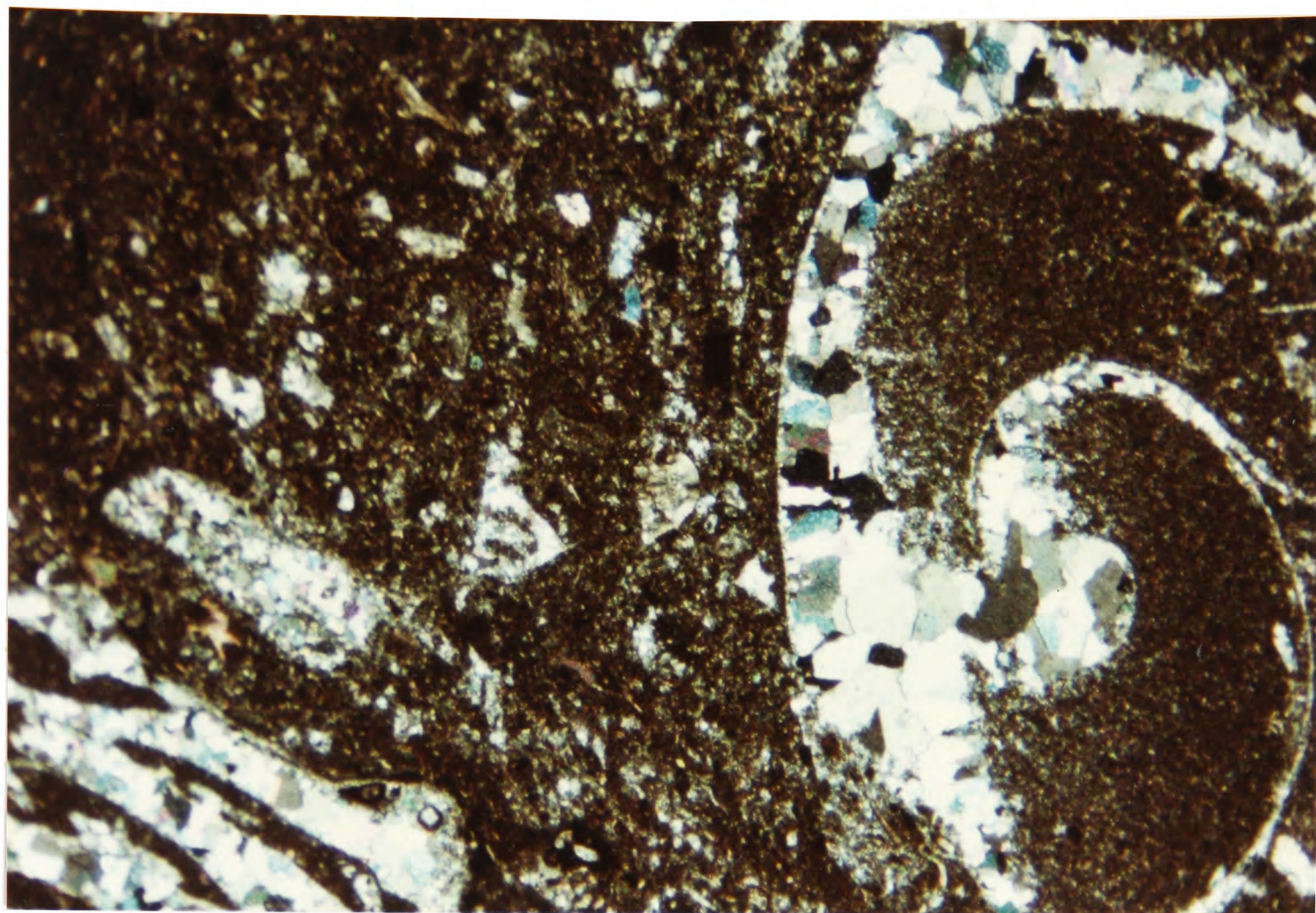


FIGURE 7-48.

This is a typical microfacies of the wacke/packstone of the Barcenaciones Fm. and shows the bioturbated micritic matrix to this rock. It has numerous gastropods whose shells have recrystallised to coarse spar. This was taken in cross-polarized light of an area 6mm by 9mm wide.

FIGURE 7-49.

A typical example of the Miradorio Mb. from the Punta Ninera section, just north of San Vicente de la Barquera (Section 1 of Fig. 7-1). This is the Marnes a Myacees of Mengaud, 1920 or Pascal, 1985. This marly limestone (wackestone/lime mudstone) to marl alternation in Facies 21 of Chapter 7.7. The photograph is correctly oriented and the hammer is 25cm long.

FIGURE 7-50.

This view of the Miradorio Mb. of the Barcenaciones Fm. comes from the section at Barcenaciones (Section 19 of Fig. 7-1). It illustrates the typical limestone/marl alternation (Facies 21 of Chapter 7.7) in the upper part of the photograph and nodular bedded limestone below. This probably relates to the clay content of the limestones. The photograph is the right way up and the hammer is 25cm long.



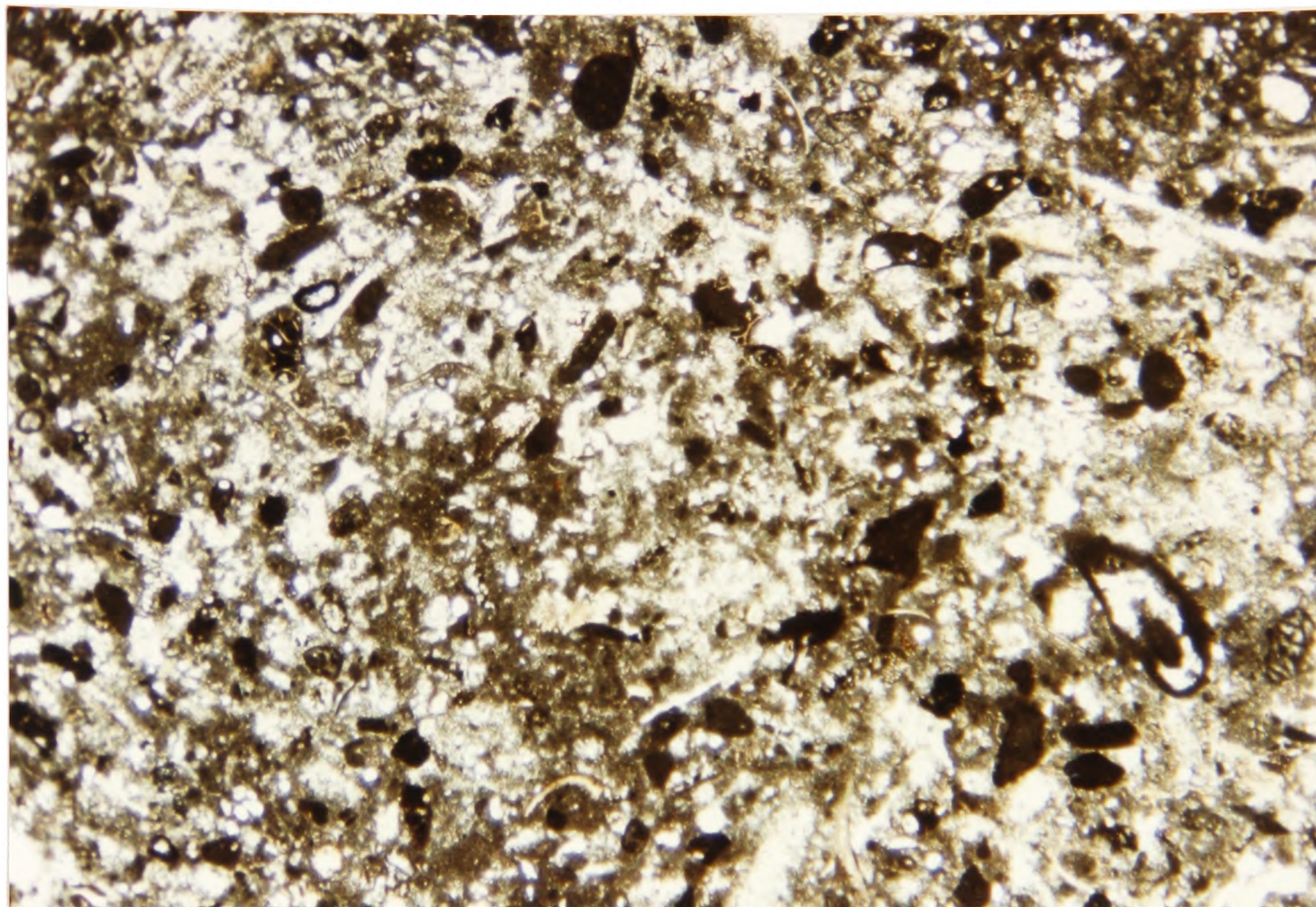


FIGURE 7-51.

A typical microfacies of a packstone from the Barcenaciones Fm.. It shows numerous peloids, bivalve cortoids, bryozoa, benthic foraminifera and other bivalves. There has been extensive recrystallisation of the micritic matrix to microspar, probably under active, meteoric conditions. This was taken plane-polarized light of an area 6mm by 9mm.

FIGURE 7-52.

This is a pair of skeletal (wacke)/packstone tempestites from the sequence above the Miradorio Mb. of the Barcenaciones Fm. from the east side of Casasolo Bay (Section 10 of Fig. 7-1). This is Facies 22 of Chapter 7.7. The lower sandy packstone has a rather swaly stratification and is bounded, above and below, by bioturbated calcarenite/marl-Facies 18 of Chapter 7.7. The upper packstone is rather strongly bioturbated. It has a typical red-weathering hardground surface at its top. The lens cap is 5cm wide.

FIGURE 7-53.

These are highly bioturbated beds of skeletal (wacke) /packstone from the basal parts of the Torriente Mb. (Barcenaciones Fm.) on the eastern side of Casasolo Bay (Section 10 of Fig. 7-1). Clear burrows can be seen with the calcarenitic packstones. The interpackstone beds are thin, rippled packstone laminae with slight to intense bioturbation. These are seen as tempestites-see Facies 22 of Chapter 7.7. The beds are the right way up and the lens cap is 5cm wide.



FIGURE 7-54.

A typical view of the Miradorio Mb. of Barcenaciones Fm. taken from the SW corner of the Comillas headland. It shows the marl/marly limestones of this member. The cliff is about 12m high.

FIGURE 7-55.

This shows the swaly cross stratification of the Torriente Mb.- Facies 24 of Chapter 7.7. Note the irregular antiformal swales that characterise this Facies. This was taken from the upper part of the Torriente Mb. of the Punta Ninera section (Section 1 of Fig. 7-1). The lens cap is 5cm wide.



KEY : (Barcenaciones section)

B : Barcenaciones Formation.
 R : Reocin Formation.
 SE : San Esteban Formation.

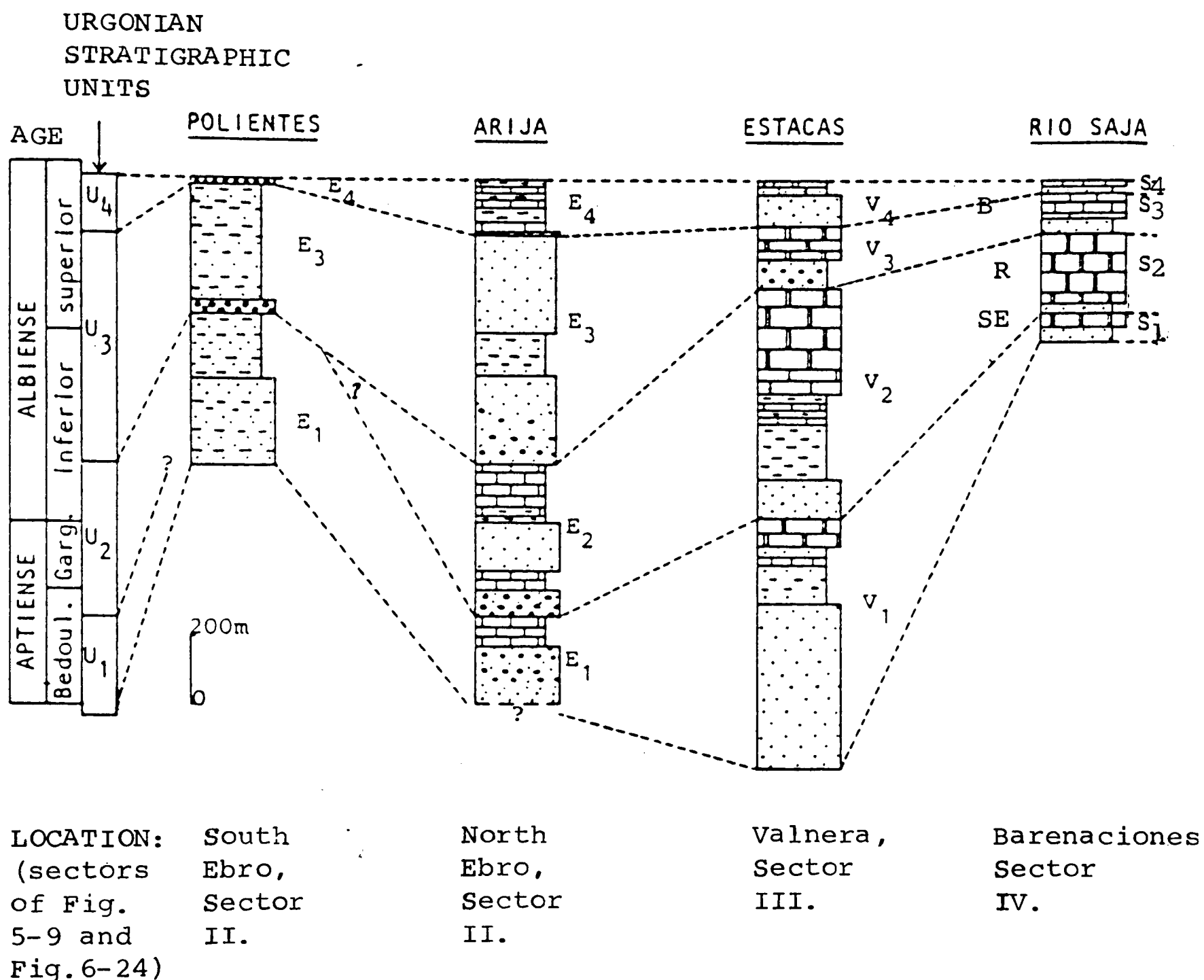


FIGURE 7-56.

A correlation of the sections through the Aptian/Albian of the western part of the Basco-Cantabrian basin from the south (Polientes) to the north (Rio Saja of the Barcenaciones section, NW Santander - Section 19 of Fig. 7-1). The sectors referred are those of Garcia Mondejar and are shown in Figs. 5-9 & 6-24. Note the relatively condensed sequence that occurs in NW Santander relative to those to the south in the Soba valley/Valnera area. The diagram shows the correlation of the U₁ etc. scheme of Urganian stratigraphy used by Garcia Mondejar and its coordination with the lithostratigraphy of NW Santander.

Adapted from Garcia Mondejar & Pujalte, 1981.

FIGURE 7-57.

The "Capa roja" bed of fine calcareous sandstone with reddish mottling as seen in the photograph. This is a typical example of Facies 26 of Chapter 7.7. This was taken from the eastern side of Casasolo Bay, Section 10 of Fig. 7-1. The mottling is due to intense bioturbation of the sandstone by marine benthos. The lens cap is 5cm wide.

FIGURE 7-58.

This is a typical example of the rather massive to decimetre-bedded, clean, skeletal wacke/packstone of the Torriente Mb. of the Barcenaciones Fm.. This shows the rather undulatory contacts between beds in Facies 28 of Chapter 7.7. (see text). The beds are the right way up and the hammer is 25cm long.

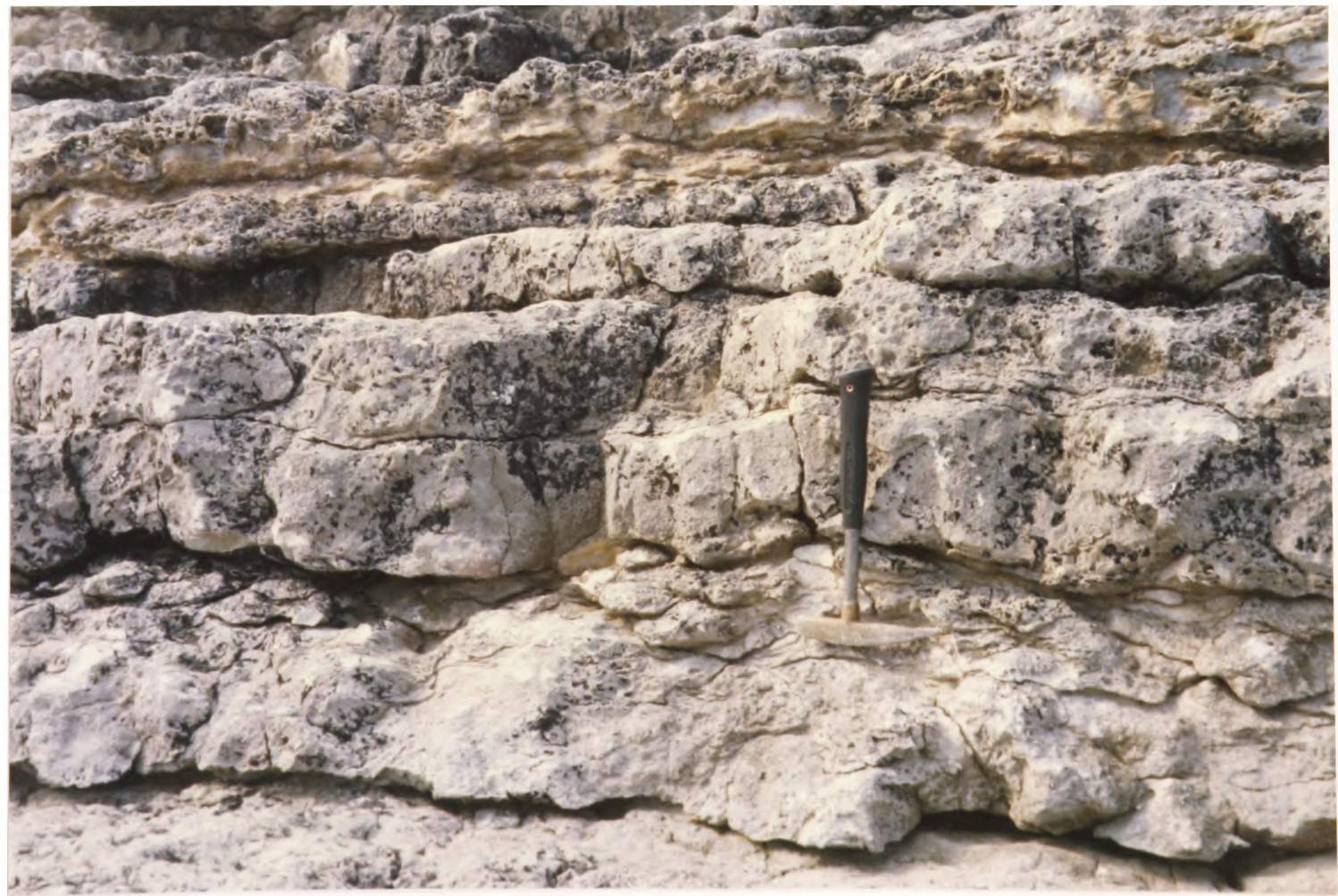


FIGURE 7-59.

A view of the Torriente Mb. of the Barcenaciones Fm. from the Punta Lambreras section (Section 6 of Fig. 7-1). It has a distinctly swaly stratification, as is typical of Facies 28 wacke/packstone of Chapter 7.7. Note the irregular, swaly antiforms and synforms of individual beds, suggesting a storm-influenced middle shelf environment of deposition. The beds are the right way up and the hammer is 25cm long.

FIGURE 7-60.

This is a Pseudotoucasia packstone bank from the Albian sequence at Rio Saja (Section 22 of Fig. 7-1 and Section 15A/33, 244m). It occurs in a several metre thick bank of such rudists and probably represents storm reworking of the middle shelf sea floor to form such banks. The matrix is micritic with abundant benthic foraminifera. This is a sectional view with the top towards the top and the lens cap is 5cm wide.



FIGURE 7-61.

The Caprina choffati beds of the uppermost Torriente Mb. (Barcenaciones Fm.) from the Punta Lambreras sequence (Section 6 of Fig. 7-1). This shows excellent examples of the above named rudist, though generally not in life position. This deposit probably represents a localized bank that was generated by storm waves moving the rudists only a short distance. The lens cap is 5cm wide and this is a plan view.

FIGURE 7-62.

This is an interdigitation of the Bielba Fm. siliciclastics into the horizons just above those with the Caprina choffati shown in Fig. 7-61. It is a muddy quartz sandstone with rare glauconite. Note the swaly stratification to this bed possibly linked to storm reworking of sea floor. The bed is the right way up and the lens cap is 5cm wide. The pebbles in the top left are Recent.



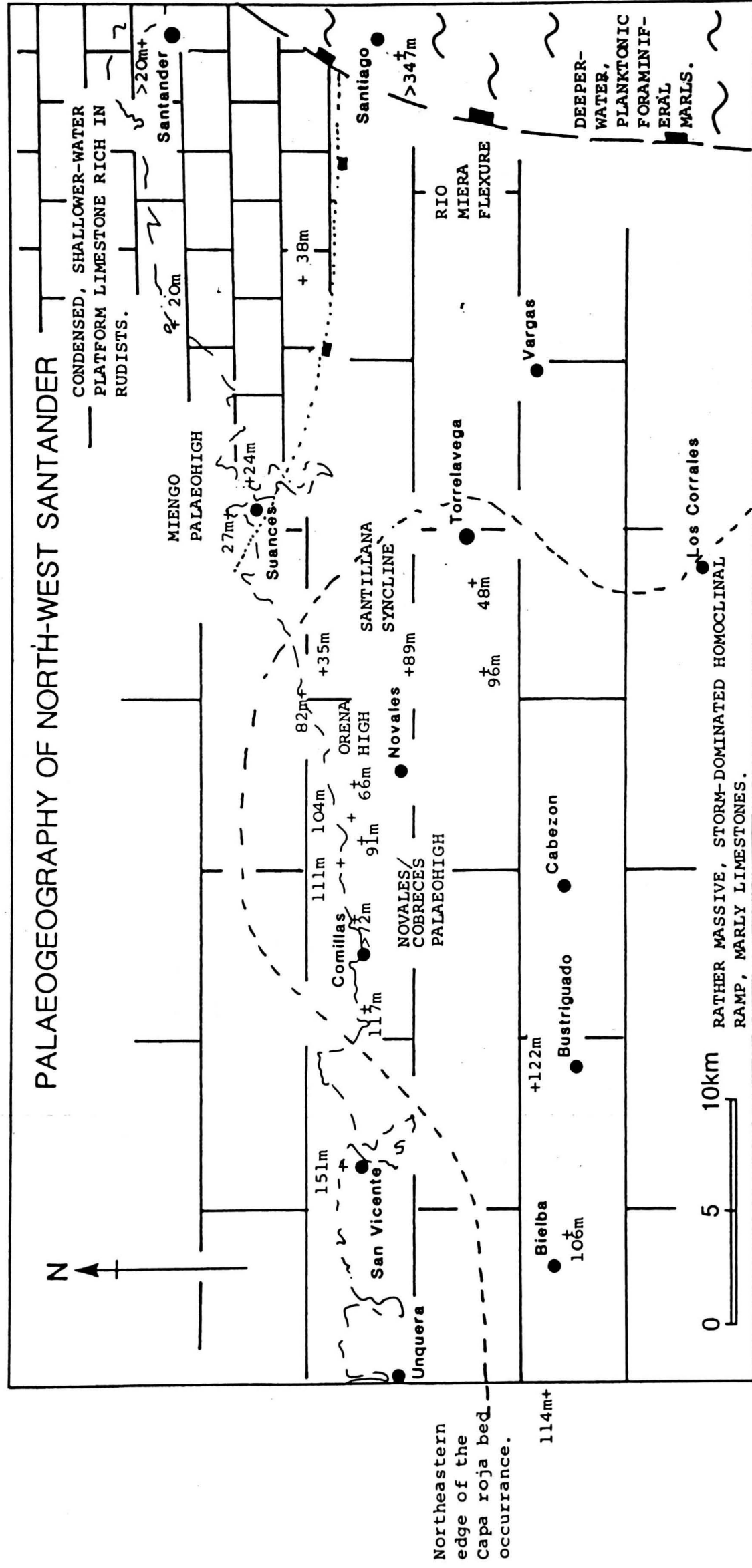


FIGURE 7-63.

A palaeogeography of the Upper Albian of NW Santander (Torriente Mb. of the Barcenaciones Fm. times). The area was dominated by rather massive, storm-dominated marl limestones deposited on a homoclinal ramp.

+ = Thickness of the Barcenaciones Fm. in metres:  = Wačke/packstones of the Torriente Mb.  = Condensed platform limestone sequence rich in rudists around Santander/Miengo;  = Deep-water marls east of the Rio Miera flexure.

FACIES 14 & 15 further offshore.

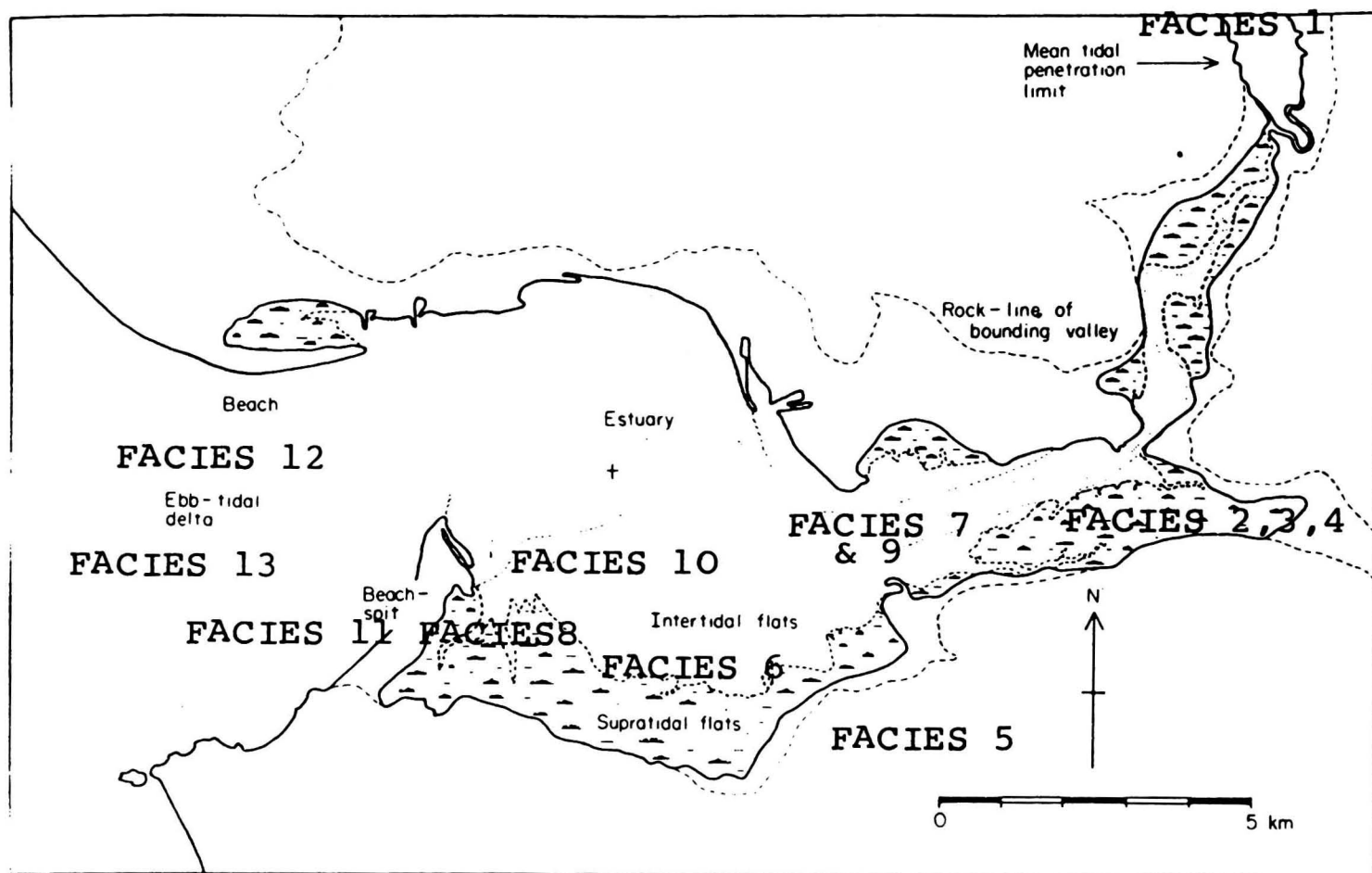


FIGURE 7-64.

A generalised model for the estuarine sequence of the Las Penosas Fm. showing the location of Facies used in Chapter 7.3. It is adapted from the Recent Loughor Estuary, S. Wales which is macrotidal and funnel shaped (Elliot & Gardiner, 1981).