

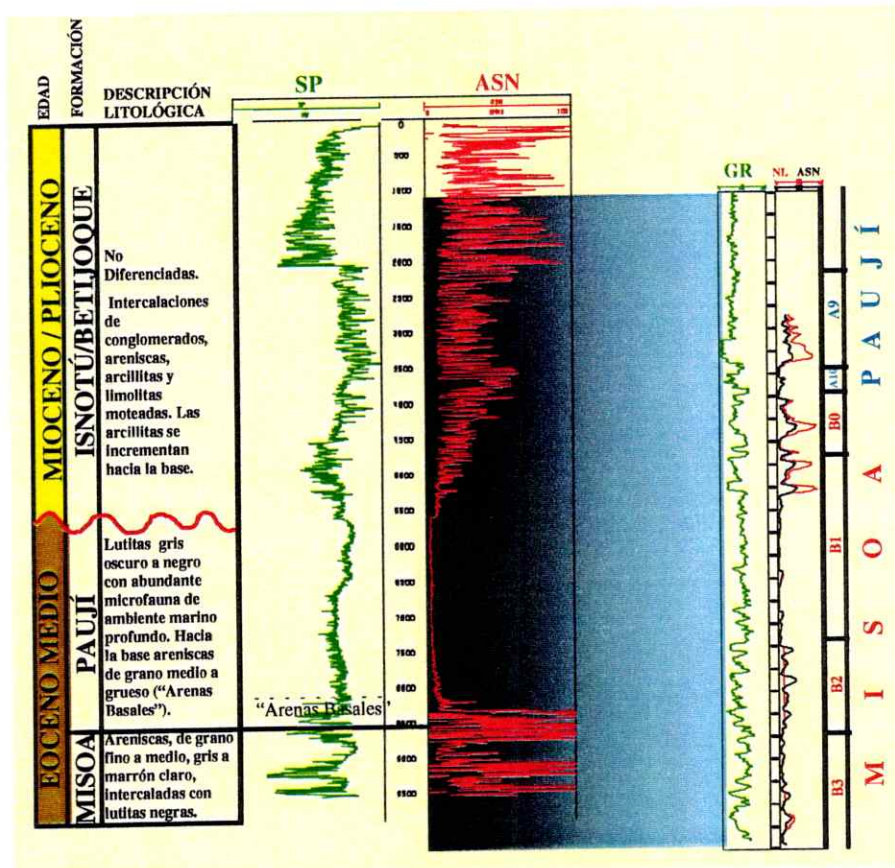


Figura 3: Estratigrafía generalizada del área bajo estudio.

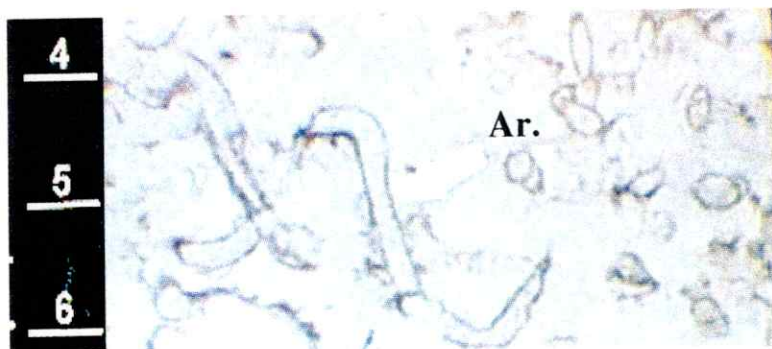


Figura 4: MOT-07, N-1, L-2.
Arenicolites (Ar.).

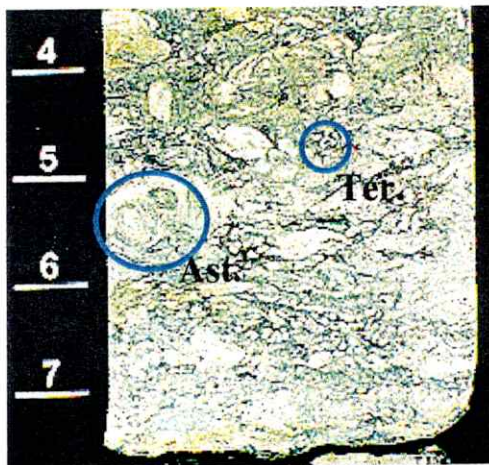


Figura 5: MGB-5X, N-20, L-2. *Asterosoma* (Ast.) y *Terebellina* (Ter.).

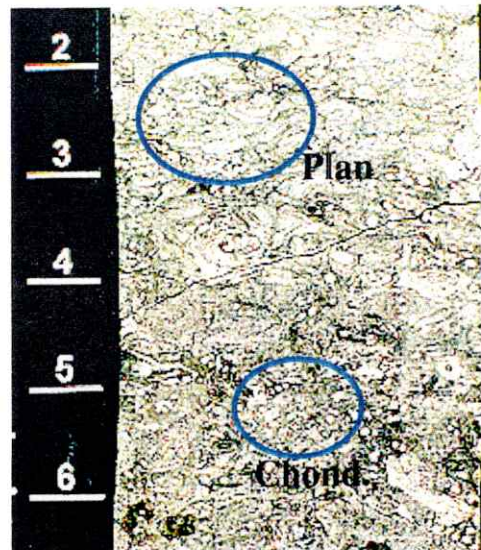


Figura 6: MGB-5X, N-20, L-1. *Chondrites* (Chond.) y *Planolites* (Plan.).

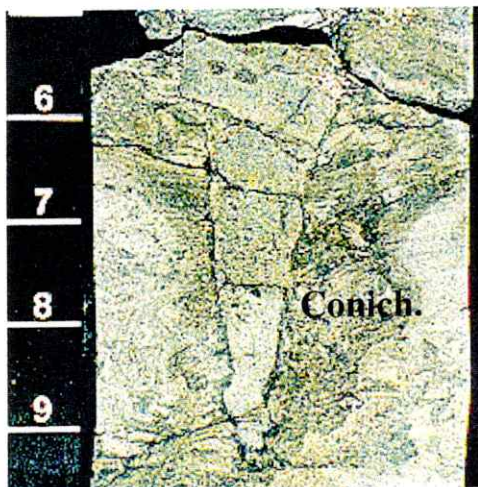


Figura 7: MOT-02, N-26, L-1. *Conichnus* (Conich.).

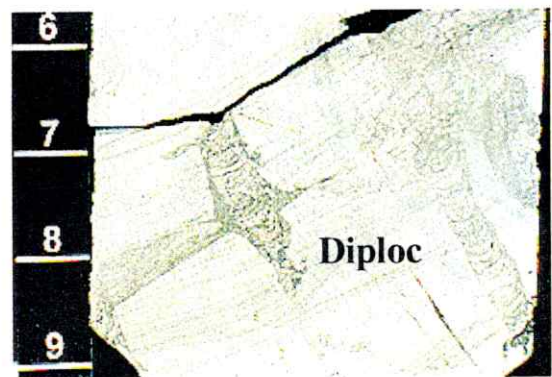


Figura 8: MOT-06, N-27, L-2. *Diplocraterion* (Diploc.).

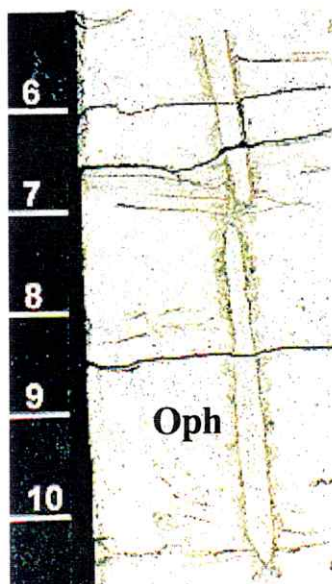


Figura 9: MOT-37, N-17, L-39. *Ophiomorpha* (Oph.).

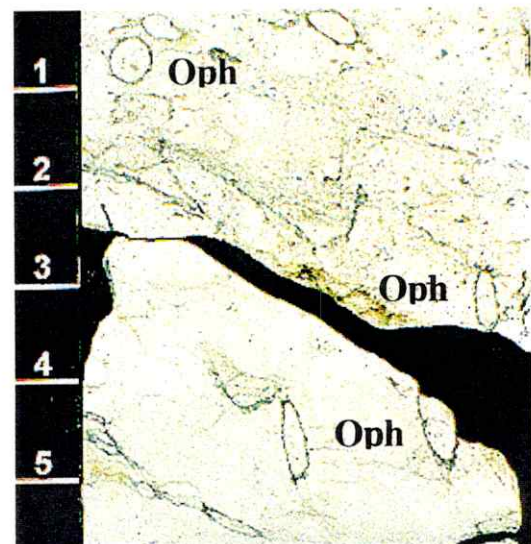


Figura 10: MOT-04, N-10, L-11. *Ophiomorpha* (Oph.).

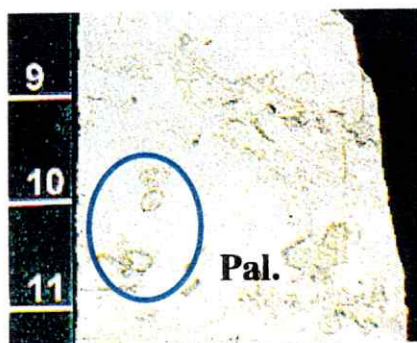


Figura 11: MOT-47, N-14, L-2. *Palaeophycus* (Pal.).



Figura 12: MOT-47, N-5, L-5. *Rhizocorallium* (Rhiz.).

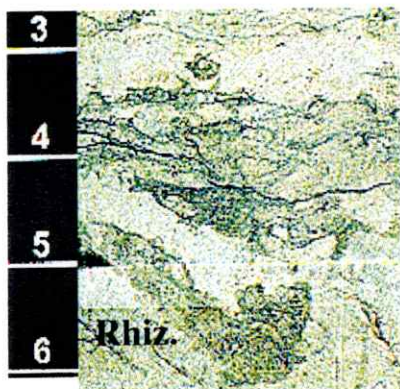


Figura 13: MOT-47, N-6, L-6. *Rhizocorallium* (Rhiz.).

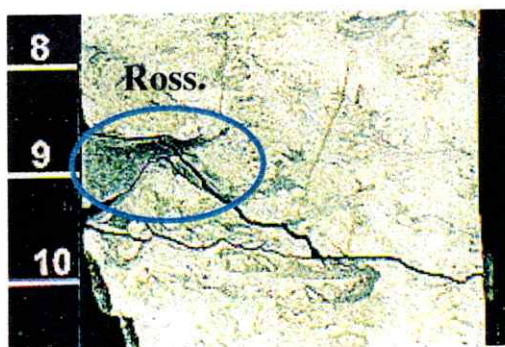


Figura 15: MOT-47, N-6, L-6. *Rosselia* (Ross.).

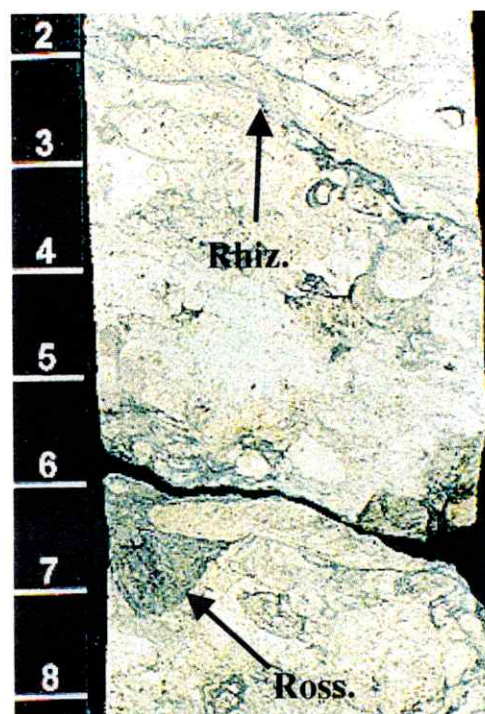


Figura 14: MOT-47, N-17, L-2. *Rhizocorallium* (Rhiz.) y *Rosselia* (Ross.).

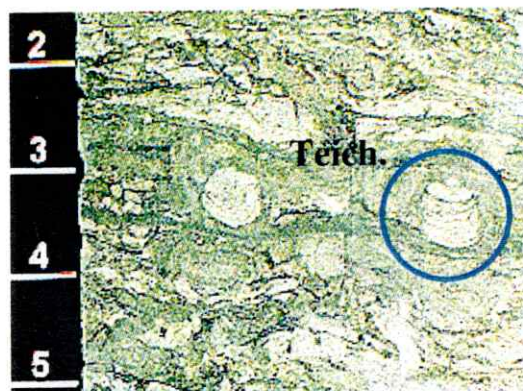


Figura 17: MOT-04, N-19, L-15. *Teichichnus* (Teich.).

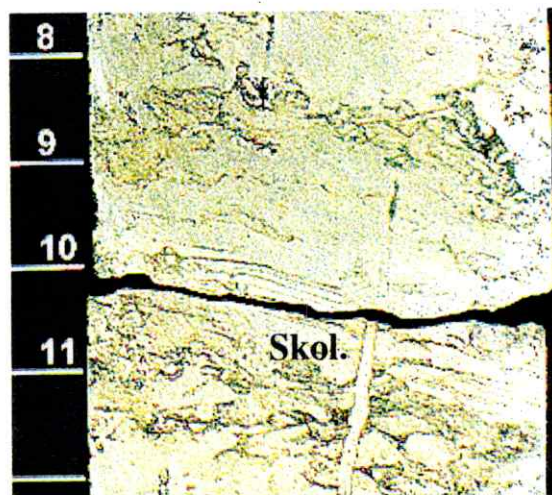


Figura 16: MOT-7, N-29, L-7. *Skolithos* (Skol.).

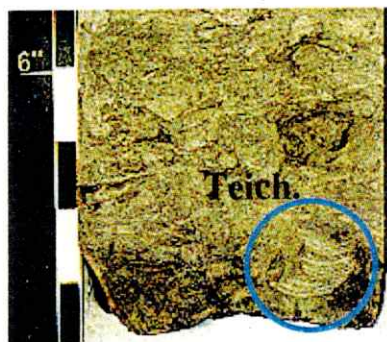


Figura 18: MOT-07, N-30, L-9. *Teichichnus* (Teich.).

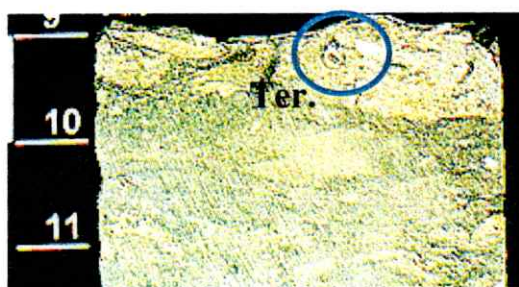


Figura 19: MGB-26, N-7, L-3. *Terebellina* (Ter.).

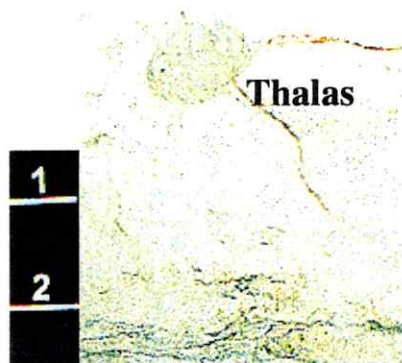


Figura 20: MOT-47, N-6, L-6. *Thalassinoides* (Thalas.).

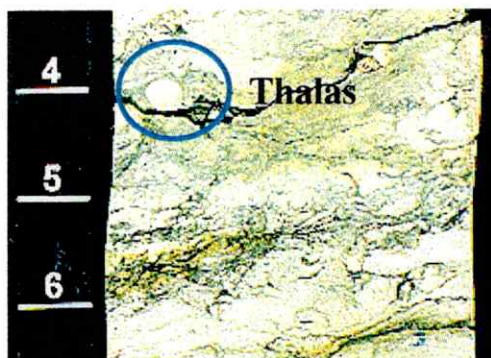


Figura 21: MGB-5X, N-20, L-3. *Thalassinoides* (Thalas.).

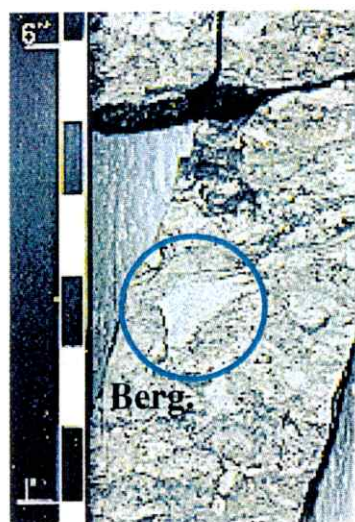


Figura 22: MOT-47, N-19, L-10. *Bergaueria* (Berg.).

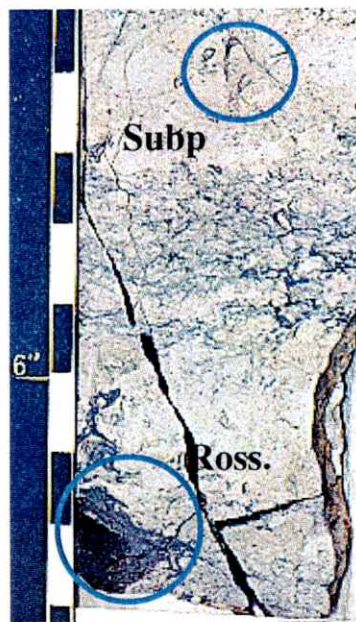


Figura 23: MOT-47, N-17, L-14. *Subphylochora* (Subp.).

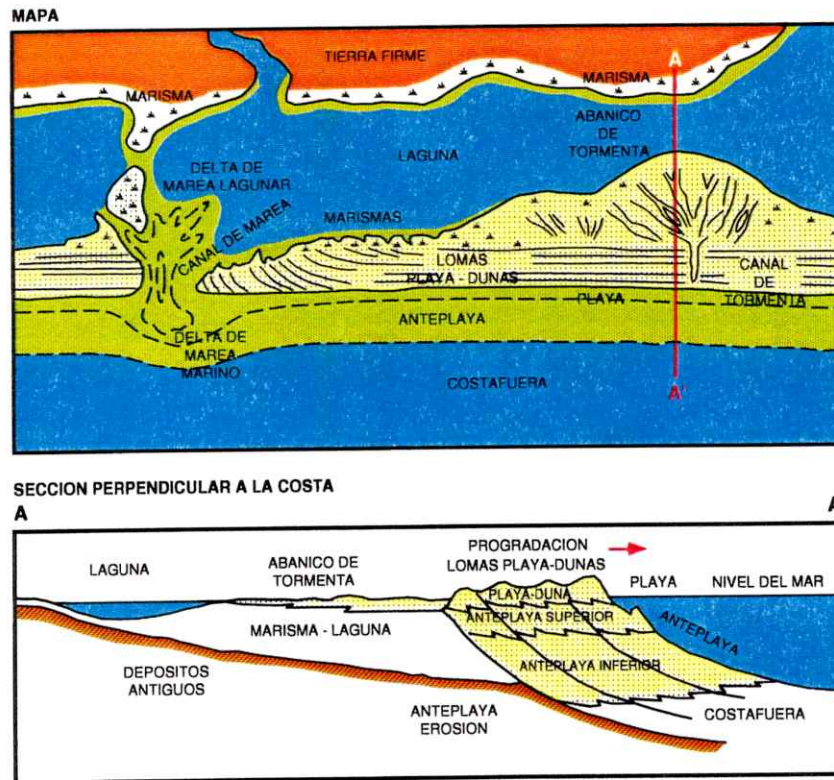


Figura 24: Modelo sedimentológico conceptual para las formaciones Misoa ("B Superior") y Paují ("arenas basales") en los campos Barúa y Motatán.

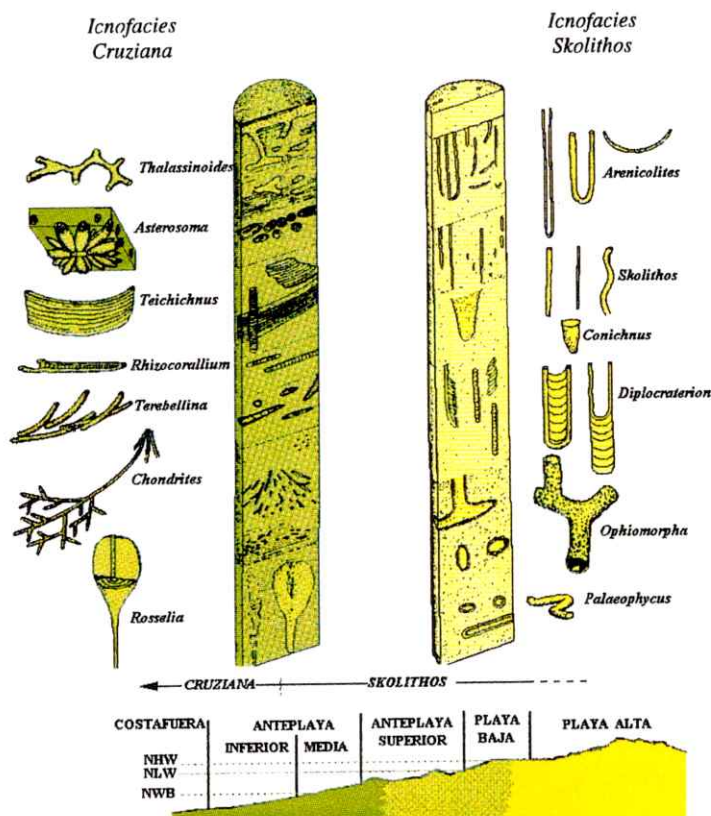


Figura 25: Diagrama esquemático de las iconofacies *Cruziana* y *Skolithos* en cortes de núcleos, y de los subambientes marinos en que se encuentran.

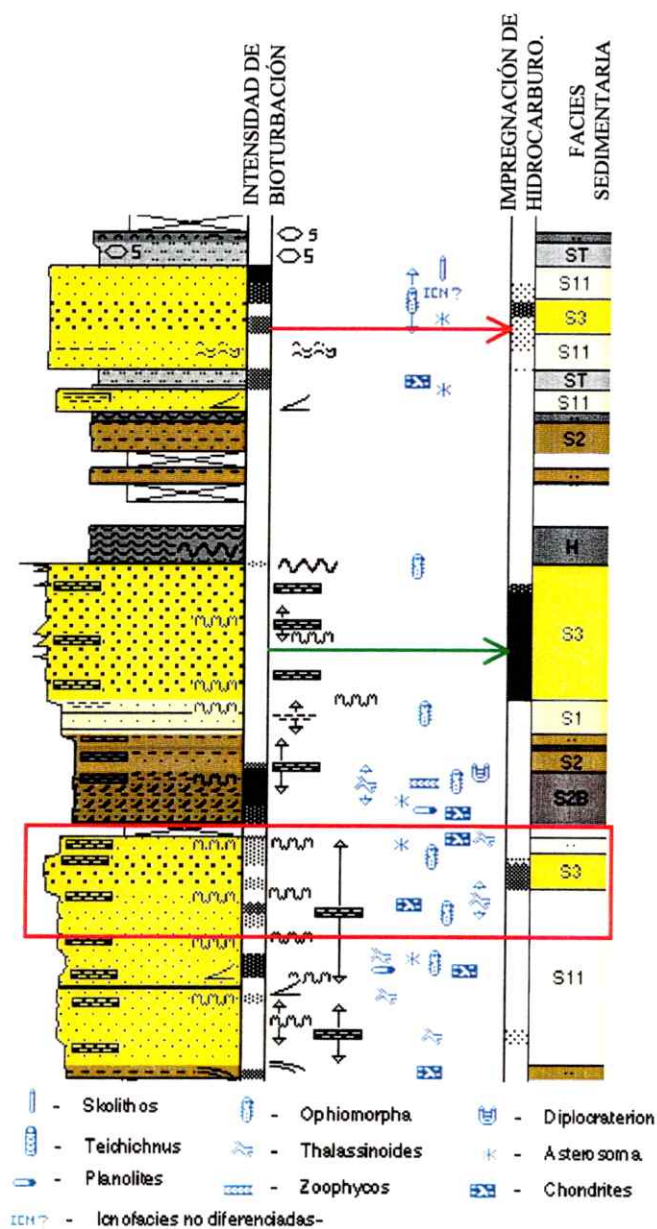


Figura 26: Columna estratigráfica representativa de los núcleos estudiados, mostrando como la bioturbación afecta las propiedades de la roca yacimiento. Las areniscas de las facies S3 poseen excelente impregnación de hidrocarburo (flecha verde), pero esta disminuye notablemente con la intensidad de la bioturbación (flecha y recuadro rojos).

Ichnología de las formaciones Neogeno-Cuaternarias en Venezuela Nororiental

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RESUMEN.

Las icnocenosis encontradas en los sedimentos neógeno-cuaternarios del noreste de Venezuela, están asociadas a las formaciones La Tejita (isla de Margarita), Cubagua y Tortuga (península de Araya e isla de Cubagua). Dichas icnocenosis pertenecen a las icnofacies Skolitos y Teredolites.

La icnofacies Skolitos está representada por las siguientes icnocenosis: *Gyrolithes* isp., *Ophiomorpha nodosa*, *Paleophycus* isp, *Teichichnus* isp., *Thallasinoides* isp.. La icnofacies Teredolites está representada por *Teredolites clavatus*.

La icnocenosis *Gyrolithes* isp. es una estructura muy regular en cuanto a su desarrollo vertical, llegando a alcanzar longitudes superiores a los 50 cm, sin que su forma varíe, no presentando codos ni conexiones con otro tipo de estructura biogénica.

Ophiomorpha nodosa presenta una sección que varía de circular a ovalada, su superficie exterior está formada por una cubierta de pellets individuales completamente oxidada y un núcleo central relleno del sedimento hospedador.

Thallasinoides isp., está conformada por una intrincada red de tubos horizontalizados, con bifurcaciones en forma de T y Y, completamente oxidada y sin estructura interna.

Teichichnus isp., íntimamente relacionada con la anterior, presenta la misma forma de desarrollo pero con una estructura de desplazamiento protusiva.

Paleophycus isp. Se presenta como una estructura cilíndrica sin ramificaciones y un patrón de distribución predominantemente horizontal.

La icnocenosis *Teredolites clavatus* se encuentra formando un profuso y apretado conjunto de perforaciones cilíndricas, de desarrollo sinuoso y paralelo al alargamiento del tronco perforado.

Palabras claves: Icnología, Neógeno-Cuaternario.

INTRODUCCIÓN.

En ambientes carbonáticos las evidencias de actividad orgánica pertenecen a tres categorías: a) bioturbación, b) bioerosión y c) formación de pellets, pseudoheces y coprolitos (Bromley, 1990). De éstas, la segunda es la mayormente estudiada, mientras que la bioturbación permanece aún con muchas lagunas.

La mayoría de los trabajos de icnología han sido realizados en sedimentos clásticos y la mayor parte de los estudios en sedimentos carbonáticos han sido hechos en secuencias mesozoicas y paleozoicas (Myrow, 1995; Frey & Bromley, 1985; Frey & Howard, 1986; Pickerill *et al.*, 1984; Narbonne, 1984; Crimes, *et al.* 1977, etc). Los estudios en el Terciario pertenecen, aparte de los estudios del Eoceno, mayormente a ejemplos Pleistocenos y recientes (Pemberton & Jones, 1988; Curran, 1984;

En la literatura geológica venezolana, hasta ahora., sólo habían sido mayormente reportados como "huellas de gusanos", por tanto su estudio desde el punto de vista sistemático y ambiental reviste gran importancia.

MARCO GEOLÓGICO.

Los sedimentos neógeno-cuaternario marinos estudiados, de la parte Nororiental de Venezuela, afloran en la península de Araya, e islas de Cubagua y Margarita. En esta última localidad afloran en una forma discontinua. Dichos sedimentos, que suprayacen discordantemente sobre un basamento metamórfico de rocas mesozoicas y eocenas, pertenecen a las formaciones Cubagua, La Tejita y Tortuga (Ibarra & Hernández, 1989 y Campos 1991).

La Formación Cubagua aflora extensamente en la porción más occidental de la península de Araya, y ha sido dividida en dos miembros: uno inferior de naturaleza lutítica, Miembro Cerro Verde y otro superior compuesto mayormente por carbonatos de mezcla (Zapata, 1995) denominado Miembro Cerro Negro. En las islas de Cubagua y Margarita solo aflora el miembro superior.

La Formación La Tejita solo aflora en la isla de Margarita, en las inmediaciones del aeropuerto, mientras que la Formación Tortuga, conocida por la mayoría como "terrazas marinas", aflora de manera discontinua en el perímetro de las tres localidades mencionadas.

Los mejores afloramientos de las tres formaciones citadas, que exhiben un abundante conjunto de icnofósiles, se encuentran en la localidad de la península de Araya, en los cerros Amarillo, El Macho, La Cantera y Pariche, en la ensenada Balandra y en las puntas La Caja y Arenas, en la isla de Cubagua, al sur de la ensenada de Charagato y en la isla de Margarita, en la localidad del aeropuerto (talud norte de la pista de aterrizaje) (Fig.1)

ICNOFACIES.

Las formaciones neógeno-cuaternarias marinas estudiadas están caracterizadas por un bien preservado conjunto de icnocenosis, las cuales incluyen: *Gyrolithes* isp., *Ophiomorpha nodosa*, *Paleophycus* isp., *Teichichnus* isp., *Teredolites clavatus* y *Thalassinoides* isp..

Estas icnocenosis pueden ser atribuidas tanto a grupos de organismos como a tipos de conductas, con lo cual las biocenosis originales pueden ser reconstruidas. Dichas icnocenosis están conformadas por estructuras producidas por bivalvos perforadores, crustáceos talasínidos y anélidos detritívoros principalmente. En la Tabla I se muestra la relación de las diferentes icnocenosis estudiadas y el organismo originador.

Icnocenosis	Clasificación etológica	Probable organismo originador
<i>Gyrolithes</i> isp.	Domichnia	Crustáceo talasínido
<i>Ophiomorpha nodosa</i>	Domichnia	Crustáceo talasínido
<i>Paleophycus</i> isp.	Fodinichnia	Anélido
<i>Teichichnus</i> isp.	Fodinichnia	Anélido o artrópodo
<i>Thalassinoides</i> isp.	Fodinichnia	Anélido o artrópodo
<i>Teredolites clavatus</i>	Domichnia	Bivalvo

Tabla I.- Clasificación etológica y probable organismo originador de las diferentes icnocenosis encontradas en las formaciones neógeno-cuaternarias del nororiente de Venezuela.

ICNOLOGÍA - Neógeno

ICNOLOGIA SISTEMATICA

Ichnogénero **GYROLITHES** Saporta, 1884

GYROLITHES ISP.1

Fig. 2a

Descripción.- Esta estructura biogénica, de desarrollo helicoidal regular, no presenta revestimiento externo, su sección transversal es ovalada con el diámetro mas largo de 2.3 cm y el mas corto de 1.9 cm. La espiral, con una altura de vuelta de 9 cm y un radio de 4 cm, está regularmente enrollada en sentido sinestral, no mostrando cambios de enrollamiento. Su largo alcanza tamaños superiores a los 50 cm sin que su forma varíe, no presentando codos ni conexiones con otro tipo de estructura biogénica.

Observaciones.- Esta icnocenosis está amplia y abundantemente distribuida en los sedimentos carbonáticos (limos arenosos) del Miembro Cerro Negro (Plioceno-Pleistoceno Inferior) de la Formación Cubagua, en la península de Araya (ensenada Balandra y cerros Amarillo, Negro, Barrigón, La Cantera y La Cruz).

GYROLITHES ISP.2

Fig. 2b

Descripción.- Estructura biogénica vertical y desarrollo helicoidal regular. Al contrario de la anterior presenta un recubrimiento externo de 0.5 cm de espesor de naturaleza limosa y de color amarillento y un relleno de color gris de granulometría mas fina.

Su sección es ovalada, con un diámetro mayor de 2 cm y el menor de 1.5 cm, su enrollamiento es sinestral, regular, con un radio de 3.3 cm y altura de vuelta de 6.6 cm. No muestra cambios en el enrollamiento, alcanza tamaños de hasta 40 cm y no presenta codos ni conexiones con otro tipo de estructura biogénica.

Observaciones.- Este tipo de estructura solo se observó en los afloramientos de la ensenada Balandra en sedimentos limoarenosos carbonáticos del Miembro Cerro Negro. Es posible que el revestimiento observado se deba a procesos de cementación alrededor de la estructura y no a la construcción de revestimiento por parte del organismo.

Ichnogénero **OPHIOMORPHA** Lundgren, 1891

OPHIOMORPHA NODOSA Lundgren, 1891

Fig. 2c

Descripción.- Perforaciones verticales y horizontales preservan relieve completo. Tienen sección mayormente circular con un diámetro que varía entre 4,5 y 5,5 cm, con una pared de revestimiento de 1 cm de espesor.

El interior de la mencionada pared es liso y externamente consiste de una densa y regularmente distribuida cubierta de pellets ovoides, regularmente espaciados y de 0.9 cm de diámetro, constituidos por material arenoso completamente oxidado.

El largo de las ramificaciones individuales llegan a alcanzar hasta 40 cm de largo.

El relleno interno es un limo arenoso de color amarillento, sin estructura, igual naturaleza al sedimento hospedador.

Observaciones.- *Ophiomorpha nodosa* es una estructura biogénica muy común en las localidades del sur de la península de Araya (cerro Pariche y sus alrededores), donde esta íntimamente asociada a *Thallasinoides* isp.

Ichnogénero **PALEOPHYCUS** Hall, 1874

PALEOPHYCUS ISP.

Descripción.- Perforación subhorizontal de superficie externa suave sin revestimiento, forma cilíndrica de sección circular con un diámetro de 1,5 cm. El relleno es de granulometría mas fina que la de la roca hospedadora. Está preservada como relieve completo.

Observaciones.- Esta icnocenosis se presenta en las areniscas calcáreas de la Formación Tortuga (Pleistoceno Superior) en la localidad de punta Arenas en la península de Araya.

Icnología - Neógeno

Icnogénero **TEICHICHNUS** Seilacher, 1955

TEICHICHNUS ISP.

Fig. 2d

Descripción.- Perforaciones horizontales con un "spreite" protusivo, apilado verticalmente. Su sección es ovalada, con un diámetro mayor de 3.2 cm y un largo de hasta 50 cm. No presenta recubrimiento externo o marca alguna sobre su superficie. Su desarrollo lineal es sinuoso presentado bifurcaciones en forma de T. Se preserva como relieve completo y el relleno, completamente oxidado, es de granulometría mas fina que el sedimento hospedador. Se preserva como relieve completo.

Observaciones.- Esta icnocenosis solo fue encontrada en la parte inferior de la Formación La Tejita, en la localidad del aeropuerto de la isla de Margarita, y está estrechamente asociada a la icnocenosis de *Thallasinoides isp.*

Icnogénero **THALLASINOIDES** Ehrenberg, 1944

THALLASINOIDES ISP.

Fig. 3a

Descripción.- Perforaciones horizontales de sección circular, con un diámetro de 4 cm y un largo de hasta 45 cm. Sus profusas ramificaciones, en forma de T y Y, no presentan revestimiento y su relleno, de naturaleza limosa y sin estructura, es de granulometría mas fina que la roca hospedadora. Se preserva como relieve completo.

Observaciones.- Abundantemente distribuida en los sedimentos limoarenosos del Miembro Cerro Negro en la localidades del sur de la península de Araya, asociada con la icnocenosis *Ophiomorpha nodosa*. En la localidad del aeropuerto de la isla de Margarita, esta estructura está asociada con la icnocenosis *Teichichnus isp.*

Icnogénero **TEREDOLITES** Leymerie, 1842

TEREDOLITES CLAVATUS Leymerie, 1842

Fig. 3b

Descripción.- Profuso y apretado conjunto de perforaciones cilíndricas, de desarrollo sinuoso y paralelo al alargamiento del tronco perforado. No presenta revestimiento. Su sección es ovalada, con diámetro mayor de 0.9 cm y menor de 0.7 cm. Su desarrollo lineal es sinuoso, cambiando algunas veces su dirección de perforación en 180° y con ramificaciones en forma de T (Fig.3b). El relleno pasivo es arenoso y sin estructura.

Observaciones.- Esta icnocenosis fue localizada en areniscas calcáreas del Miembro Cerro Negro en la localidad de la quebrada Lavandera, cerca del contacto con las rocas metamórficas. Esta estructura, comúnmente hecha por bivalvos, presenta cambios drásticos en la dirección de perforación y ramificaciones en forma de "T", lo cual estaría mas acorde con organismos vermiformes de cuerpo blando.

DISCUSION Y CONCLUSIONES.

Los organismos que producen huellas, en sus diferentes actividades de vida, son muy abundantes en los ambientes carbonáticos y paradójicamente los icnofósiles están mejor preservados y estudiados en los dominios clásticos (Basan, 1972). Debido a ello, los principios desarrollados en estos últimos ambientes, no han sido aplicados a la investigación en dominios carbonáticos, con todo rigor.

Los sedimentos neógeno-cuaternarios del nororiente de Venezuela, donde fueron localizadas las icnofacies estudiadas, pertenecen tanto a secuencias clásticas (Formación La Tejita) como a secuencias carbonáticas (Formación Cubagua, Miembro Cerro Negro y Formación Tortuga); observándose una excelente preservación tanto en los dominios limo-arenosos como en los de carbonatos de mezcla (Zapata, en prensa).

Las icnofacies estudiadas están distribuidas en ambientes que varían desde marino marginal (bahía, llanura de marea y playa) hasta plataforma interna (detrás de arrecife).

En la Tabla II se muestra la distribución ambiental y estratigráfica, de las diferentes icnofacies, así como el tipo de sedimento.

Icnología - Neógeno

Icnofacies	Tipo de sedimento	Unidad Estratigráfica	Ambiente
<i>Gyrolithes</i> isp.	Carbonático	Mbo. Cerro Negro	Plataforma interna
<i>Thallasinoides</i> isp. <i>Teichichmus</i> isp.	Limo-arenoso	Fm. La Tejita	Bahía
<i>Thallasinoides</i> isp. <i>Ophiomorpha nodosa</i>	Carbonático	Mbo. Cerro Negro	Llanura de marea
<i>Thallasinoides</i> isp. <i>Paleophycus</i> isp.	Carbonático	Fm. Tortuga	Playa
<i>Teredolites clavatus</i>	Carbonático	Mbo. Cerro Negro	Playa

Tabla II.- Ambientes y distribución de icnofacies en las unidades neógeno-cuaternarias del nororiente de Venezuela

AGRADECIMIENTOS.

El suscrito agradece al Consejo de Desarrollo Científico y Humanístico de la UCV por el aporte económico para la realización de este proyecto (09.13.1899/90)

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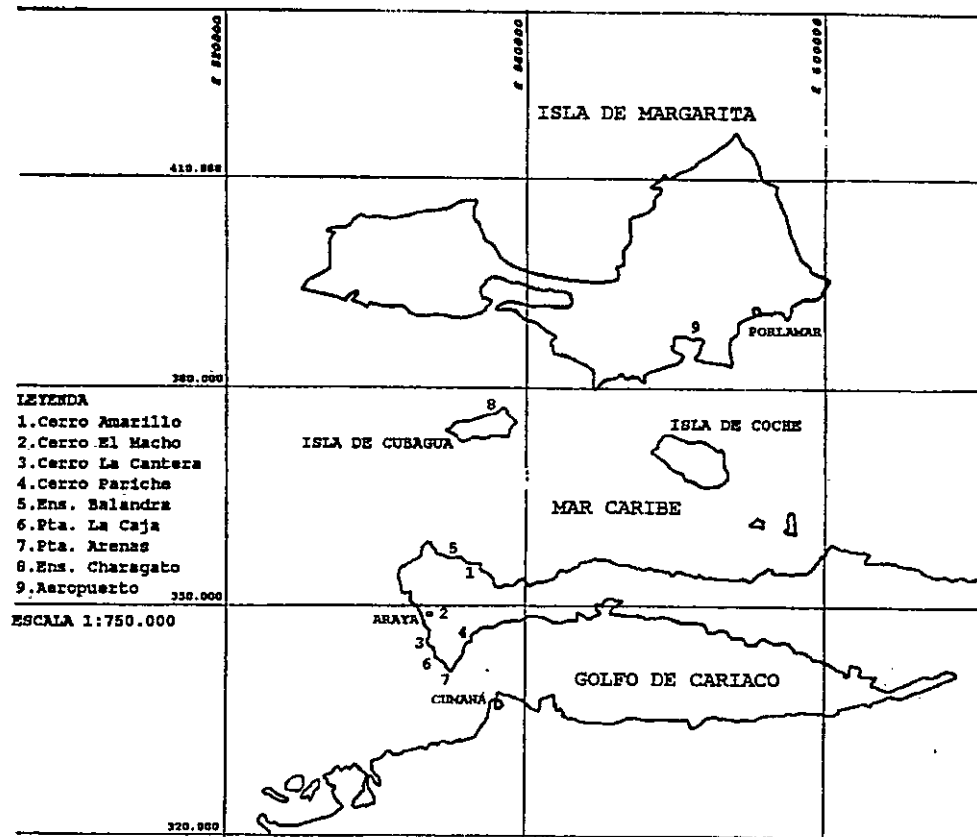


Fig.1: Ubicación geográfica de las localidades con icnofósiles.

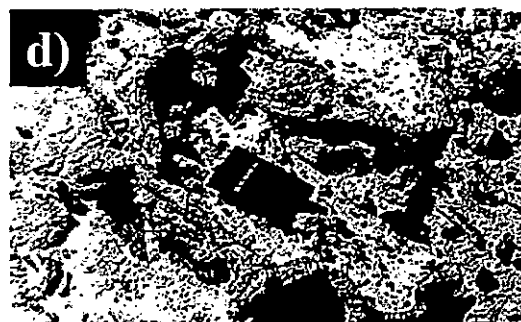
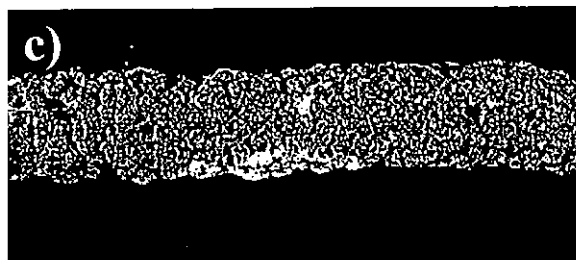
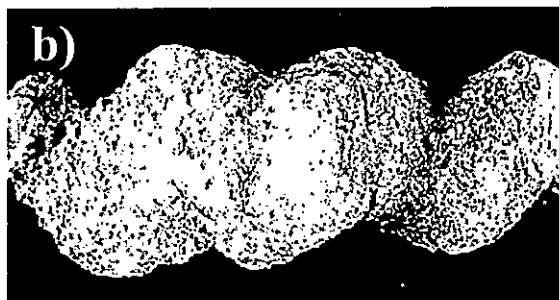
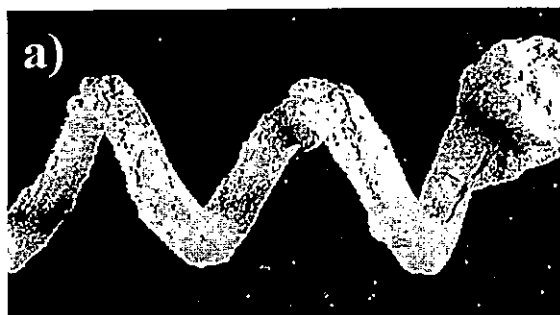


Fig. 2: a) *Gyrolithes* isp.1, b) *Gyrolithes* isp.2, c) *Ophiomorpha nodosa*, d) *Teichichnus* isp. Barra 5 cm.

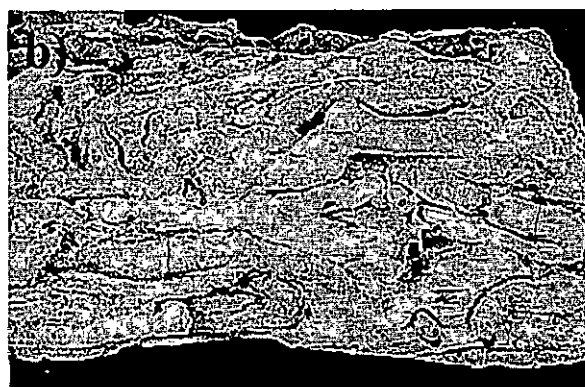
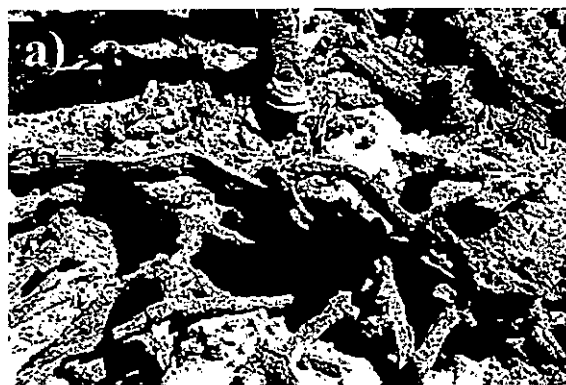


Fig. 3: a) *Thallasinoides* isp., b) *Teredolites clavatus*. Barra 5 cm

Análisis sedimentológico a los núcleos correspondientes al pozo PIC-7 entre los intervalos 16162' y 16092' (FM. Naricual)

Miguel Angel Briceño,

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ABSTRACT

This interval may be divided into two sedimentary units of 30 and 35 feet each, with similar characteristics. The lower unit comprises a fine dark brown sandstone; this colour is due to hydrocarbon impregnation. A yellowish and green coloration is also observed associated to cementation with iron oxides and processes of pyritization. Millimetric cross laminations with coal and stylolitic aspect in some cases are present. These laminations become more abundant up-section. Festoon and planar cross stratification are also present. The latter one in angles between 15° and 18° . These angles are also observed in parallel inclined stratification.

Pyrite is also common in nodules as well as in crystalline form. Layers with massive aspect and a subtle fining-up tendency are frequent in this unit.

Up-section there is a bed of fragmented coal (6 inches thick) underlying a sandy black siltstone with intercalations of white sandstone laminations.

The upper unit has the same sedimentary structures although with a predominance of coarse and very badly sorted sands. This interval is definitely more bioturbated.

These two units are separated by a siltstone layer of 2 feet which is very pyritized.

In both units, traces of Ophiomorpha and Thallasinoides are present, which are very characteristic of a transitional to shallow marine environment.

Biostratigraphic studies and sedimentological evidences, suggest that these two units were deposited in a transitional to internal neritic environment characterized by estuarine channels and paleosoils.

RESUMEN

El análisis de este intervalo constituye una parte de la evaluación geológica de 811 pies interrumpidos de núcleos correspondientes al pozo PIC-7, el cual se ubica en el área de Pirital al norte del estado Monagas (fig. 1). Corresponde al intervalos más joven de dichos núcleos, los cuales se muestran en la figura 2, y pertenecen litoestratigráficamente a las formaciones San Juan y Naricual (fig. 3). El objetivo principal fue el análisis sedimentológico a fin de determinar los ambientes sedimentarios y edades para conocer la calidad de las rocas-yacimiento. Esta sección e puede dividir en dos unidades sedimentarias, las cuales, poseen espesores aproximados de 30 pies la inferior y de 35 pies la superior, separadas por una intervalo lutítico-limolítico de 5 pies de espesor (Fig. 4). La unidad inferior corresponde a una arenisca fina con una coloración beige a pardo obscura, esto último se debe a una ligera impregnación diferencial de hidrocarburos debida a diferencias en las calidades petrofísicas de la roca. Se observa también una coloración amarillenta y verdosa debido a la cementación con óxidos de hierro y a procesos de piritización. Se pueden ver laminaciones cruzadas milimétricas limolíticas, en algunos casos formando pequeñas rizaduras marcadas por laminillas carbonosas discontinuas y bifurcadas con aspecto estilolítico, alineadas en ángulos de 10° (Fig. 5). Estas aumentan de espesor hacia el tope. Igualmente se observa abundantes restos de estratificación cruzada planar, la cual se hace más evidente a partir de 16156 pies en donde forma ángulos entre 18° y 20° disminuyendo a 10° y 12° sección arriba. Los mismos se conservan en estratificaciones paralela inclinada. También se puede ver aunque en menor proporción estratificación cruzada festoneada a medida que se sube en sección y un avance en la impregnación de hidrocarburos aportándole una coloración mas obscura a la roca. Igualmente se ve bioturbación leve y pirita (Fig. 6), tanto en clastos de pequeño espesor como en forma cristalina. En toda esta secuencia se detecta una ligera tendencia grano-decreciente. Hacia el tope de esta unidad se encuentra una capa de carbón fragmentado de 8 pulgadas de espesor, infrayacente a una limolita arenosa negra de 2 pies y medio de espesor con laminaciones de una arenisca blanca de grano fino intercaladas, con espesores que alcanzan los 0.5 cm hacia el tope, donde adquieren mayor potencia.

Suprayacentemente, se encuentra una capa de arenisca de 2 pies de espesor, de color marrón claro con un tamaño de grano muy fino. Hacia el tope se observan laminaciones arcillosas en algunos casos con aspecto estilolítico. En el resto del intervalo, se observan restos de estratificación cruzada festoneada.

La unidad superior esta formada por un paquete de areniscas de color marrón oscuro a negro, altamente impregnada de hidrocarburo, excepto los últimos 12 pies en donde se torna gris clara. Se presenta muy mal escogida aunque con una predominancia de granulometría gruesa. A través de todo el intervalo se observa muy claramente superficies de reactivación, estratificación cruzada festoneada, planar y paralela; con ángulos bajos en la parte basal del intervalo (menos de 5°), aumentando hacia el tope hasta llegar a los 18° a 20°

aproximadamente. Igualmente se aprecia granos de cuarzo azules con espesores de hasta 4mm., formación de pirita, fracturas subverticales rellenas en algunos casos de materia orgánica y restos fosilíferos que aumentan sección arriba. En este mismo sentido se aprecian laminaciones y capas lutíticas con espesores de hasta 2 cm. altamente bioturbadas. Entre 16098 y 16094 pies se observan trazas fósiles de *Thalassinoides* (Fig. 7), *Planolites* y *Ophiomorpha* (Fig.8). En todo este paquete se da una tendencia grano-decreciente, la cual se acentúa hacia el tope.

De acuerdo a los análisis bioestratigráficos y a las evidencias sedimentológicas, a éstas dos unidades se les asignó una edad Oligo-Mioceno y se depositaron en un ambiente transicional a marino somero (nerítico interno). Los paquetes arenosos fueron depositados en una costa de una cuenca subsidente en donde se desarrollan canales estuarinos con influencia de mareas, los sedimentos más finos (lutitas y limolitas) con paleorraíces y carbones son antiguos paleosuelos asociados a marismas.

La mineralogía de arcillas está conformada por cuatro especies que son: caolinita (Fig. 9), illita, illita-esmectita y clorita. Las dos primeras, determinan lo ya observado en pozos aledaños en relación a la predominancia de illita en el Cretácico y de caolinita en el Terciario. Esto último se corrobora con los resultados difractométricos asociados a éste intervalo. En relación a los daños de formación, la presencia de esmectita por ser un mineral expansible, pudiera acarrear inconvenientes en los procesos de recuperación adicional. Igualmente la caolinita al liberarse bajo condiciones de flujo turbulento, puede causar problemas de migración y taponamiento con reducción de permeabilidad. De igual manera la illita podría causar tortuosidad en el movimiento de los fluidos reduciendo igualmente la permeabilidad. La clorita pudiera estar presente como producto de alteración de la glauconita

En relación al análisis petrográfico, éstas areniscas son principalmente cuarzo-arenitas (Fig. 10). Las transformaciones diagenéticas que han actuado reduciendo la porosidad son: compactación (Fig. 11), fenómenos de presión-disolución, sobrecrecimiento de cuarzo, recristalización de arcillas autigénicas a partir de la matriz y formación de pirita. Los procesos que por el contrario han contribuido a mejorar las condiciones petrofísicas en estos reservorios son principalmente: disolución de granos y cementos y lavado de matriz (Fig. 12).

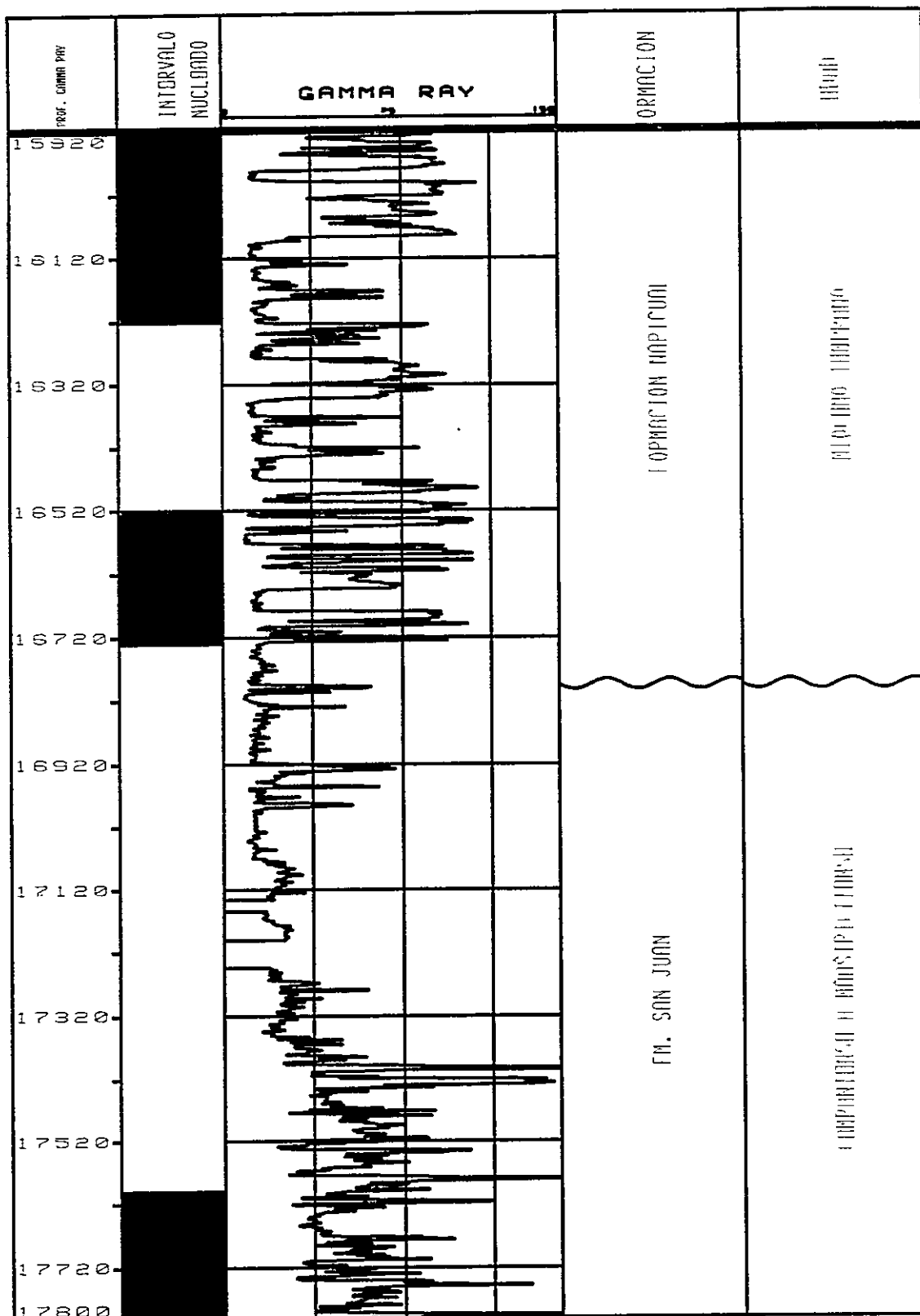


FIG. 2 UBICACIÓN DE LOS NÚCLEOS EN PROFUNDIDAD

ERA	PERIODO	EPOCA	PISO	FORMACION
CENOZOICO	CUATERNARIO	RECIENTE PLEISTOCENO		MESA
	TERCIARIO	PLIOCENO		LAS PIEDRAS
		MIOCENO	S	LA PICA
			I	CARAPITA
		OLIGOCENO		NARICUAL
		EOCENO	I	VIDOÑO
		PALEOCENO		
MESOZOICO	CRETACEO		MAESTRICHTIENSE	SAN JUAN
			CAMPANIENSE	SAN ANTONIO
			SANTONIENSE	QUERECUAL
			CONIACIENSE	
			TURONIENSE	
			CENOMANIENSE	
			ALBIENSE	CHIMANA
PALEOZOICO	CARBONIFERO			
			S	CARRIZAL
			I	
	DEVONICO			HATO VIEJO ?

FIGURA 3.-COLUMNA ESTRATIGRÁFICA REGIONAL
FLANCO NORTE DE LA CUENCA ORIENTAL

ESTUDIO DE NUCLEO

PERFIL SEDIMENTOLOGICO COMPUESTO

POZO: **PIC-7**

PIC-7

CAMPO: **PIRITAL**

PIRITAL

AUTOR (ES): MIGUEL ANGEL BRICENO

MIGUEL ANGEL BRICEÑO

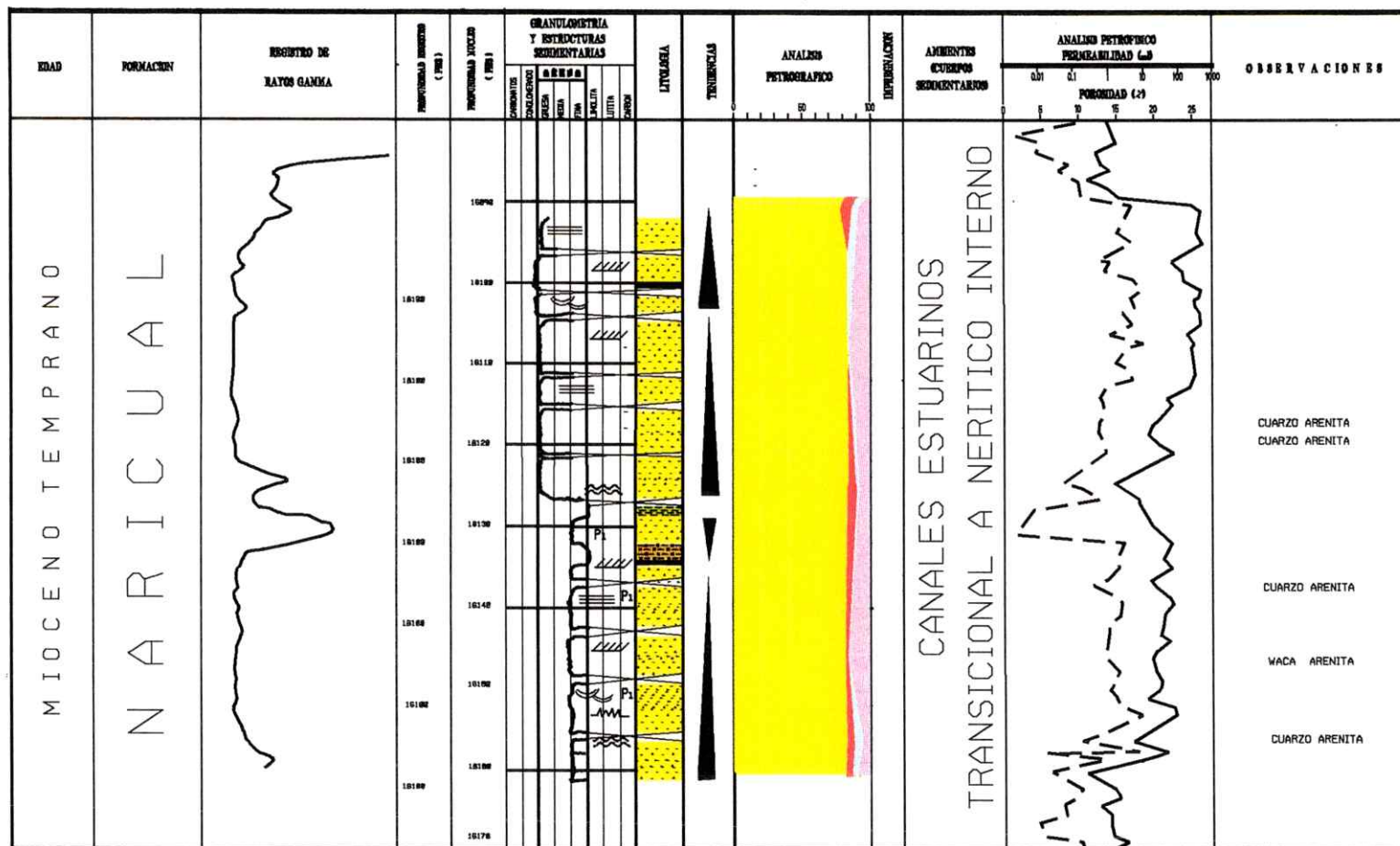
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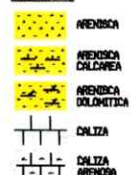
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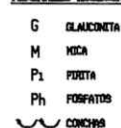
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STRUCTURE SUBSTITUTION



ADOLESCENT ADOLESCENTS



DISCUSSION

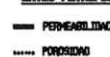
**DATING REFERENCES**

FIGURA 4

PIC-7
16165'5"



Fig. 5. Arenisca de grano fino. Nótese laminaciones carbonosas estilolitizadas y nódulo de pirita.

PIC-7
16112'5"

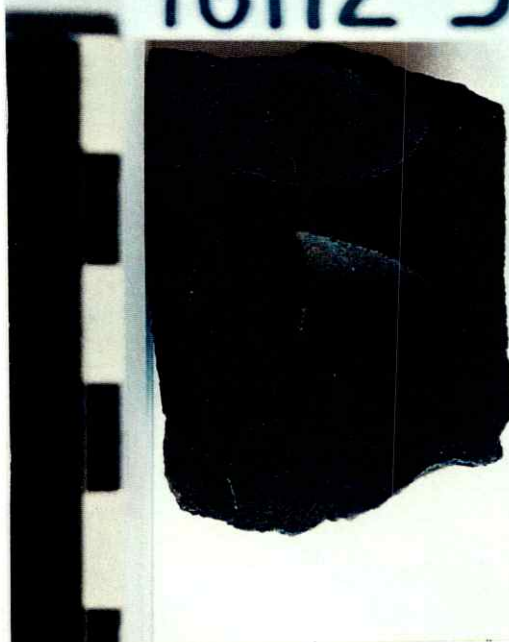


Fig. 6. Arenisca de grano muy grueso. Nótese presencia de nódulo de pirita.

PIC-7

16095'5"



Fig. 7. Arenisca de tamaño de grano grueso. Nótese presencia de Thalassinoides.

PIC-7

16097'2"

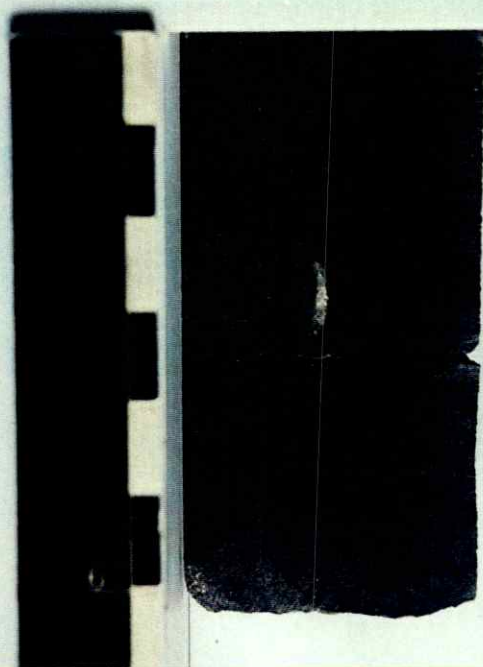


Fig. 8. Arenisca de tamaño de grano grueso. Nótese presencia de Ophimorpha.



Fig. 9. Vista SEM de arcillas tipo caolinitico autigénica en forma de hojas de libro (Booklets)

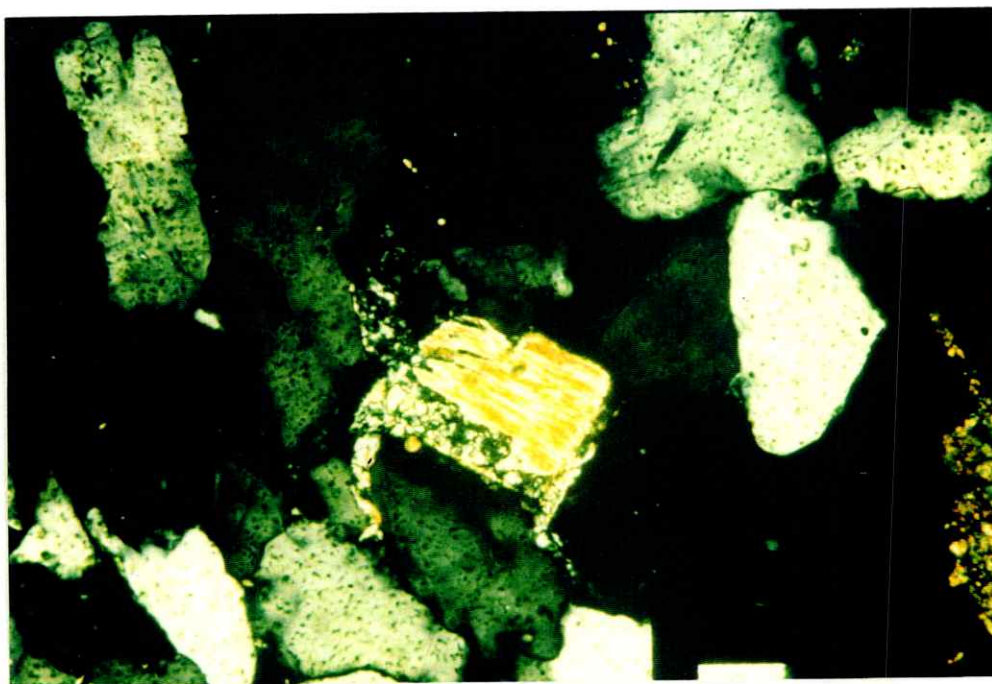


Fig. 10. Cuarzo-arenita. Nótese presencia de feldespato alterando la arcillas (20X).

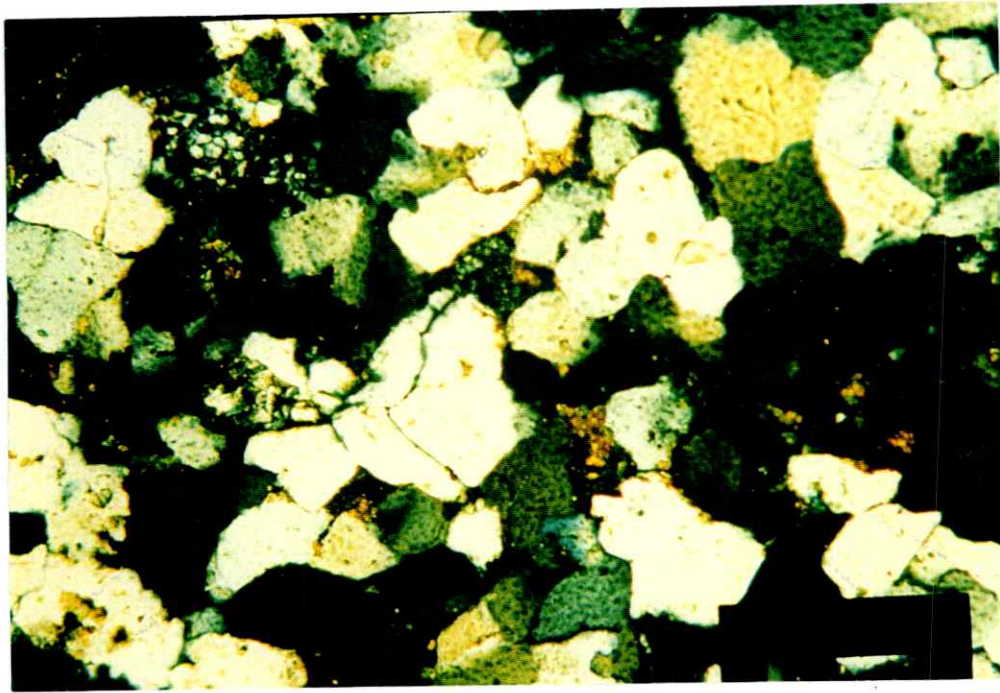


Fig. 11. Arenisca compactada. Nótese contacto del tipo concavo-convexo (20X)

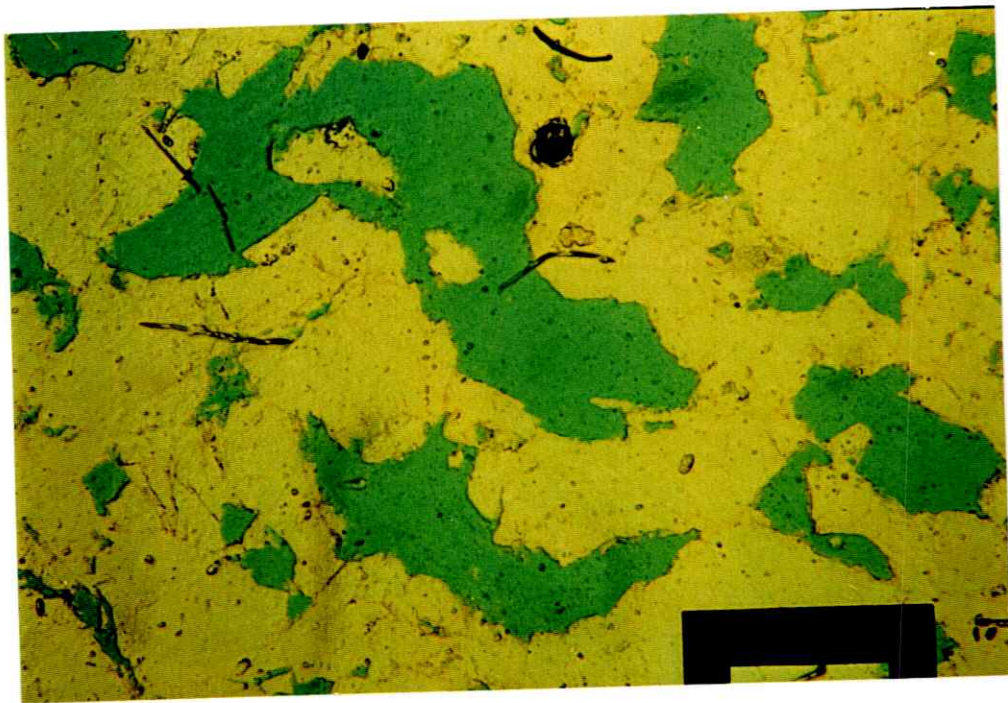


Fig. 12. Arenisca de tamaño de grano grueso. Nótese lavado de matriz, sobrecrecimiento de cuarzo y porosidad secundaria (2.5X)

Synsedimentary tectonic events revealed by palynology and core studies, the vital proof for a previously tentative model, El Furrial Field, Eastern Venezuela

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SUMMARY

A previous geological study on the El Furrial field has tentatively suggested a tectonic-sedimentological model, whereby tilting of blocks have induced local erosion and anomalous sedimentation patterns. The lack of a reliable stratigraphic framework has not permitted to validate this model. A quantitative palynological study of five wells was undertaken as part of an integrated reservoir study of El Furrial Field, in order to provide a fine correlation and depositional frameworks of the units informally called "Upper, Middle, and Lower Naricual, and the Areo" formations.

Based on the palynological data, five chronostratigraphic units were defined. A transgressive unit, considered to be of Early Maastrichtian-Campanian age, is observed in all studied wells and was used as the datum for the field correlation. The Late Maastrichtian unit is characterized by continental-coastal paleoenvironments and shows a relatively uniform thickness.

The effect of tectonism on the sedimentation is inferred to have started during the Paleocene. At least two transgressive events are determined. The first of Paleocene age, which was observed better in the eastern portion of the studied area, and the second occurring during the Paleocene-Middle Eocene, which was observed better in the western areas of the field. The thickness of the Paleocene-Middle Eocene unit decreases towards the west. The results indicate the influence of synsedimentary tectonic events during the Tertiary in the area.

1- Introduction.

Palynology has been extensively used as a tool for the exploration of the eastern Venezuelan Basin, especially in the El Furrial Field. Fasola and Paredes de Ramos (1991) reported Cretaceous miospore and dinoflagellate assemblages in intervals that were previously considered as Tertiary in age. This major discovery, significantly changed the geological framework for the exploration of the Maturín

sub-basin. Later on, palynological studies, were routinely used for determining a more definite biostratigraphic framework in the sub-basin (Ghosh et al., 1989; Isea et al., 1990, Paredes et al., 1992 and 1996).

More recently, biostratigraphy is becoming a rather useful tool not only for exploration purposes, but also for achieving more finer correlations of reservoir units. Kristensen et al. (1995) presented a multidisciplinary study on the subdivision of the Maastrichtian Chalk in the Danish North Sea. The study included the biostratigraphic subdivision into nine units based on the bioevents shown by the dinoflagellate cysts. At the local level (at field-sized scale), the correlation of these bioevents (first and last evolutionary occurrences, peaks of abundance) should be easy to correlate and follow from well to well. The integration of this information with seismic and well log information allows the subdivision of the reservoir section into reservoir units. Sawyer and Keegan (1995) reported the use of the characterization of palynofacies as a potential correlation tool during the horizontal drilling within the Brent Group.

As part of the characterization of the reservoir in the El Furrial Field, a palynological study was undertaken in order to:

- 1- Establish a palynostratigraphic correlation of the Tertiary-Cretaceous interval.
- 2- Determine trends regarding the distribution of the paleoenvironments of deposition of the studied interval.

2- Methodology.

A total of 150 samples (both core and cuttings) from six wells were studied by Laing (1996) and the results were integrated by Colmenares (1996). The study was eminently quantitative, and when the sample allowed, 250 or more specimens were counted. Samples were collected each 40 to 60 feet, depending on the lithology. Some core photographs of various types of shales sampled are shown in figures 1 to 3. Figure 4 summarizes the position of the cores relative to the Gamma Ray log of Well 5 and the display numbers used for the core workshop.

The results for the paleoenvironmental interpretation are presented as pie charts, with the relative frequencies (percentages) of the defined palynomorph groups: coastal vegetation, fern spores, pollen of palms, fungi palynomorphs, freshwater phytoplankton and marine phytoplankton. The variation of their frequencies, especially for intervals where one group become abundant, can provide information on the nature of the paleoenvironments of deposition (Muller, 1959; Frederiksen, 1985; Colmenares and Terán, 1993). The percentages were calculated for each of the units defined in this study, by averaging the percentages of samples included within each unit.

3- Results.

3.1 Palynostratigraphy

The studied interval corresponds to the wrongly named lithostratigraphic units upper, middle and lower "Naricual" and "Areo". The palynological studies have shown that a major stratigraphical revision of the subsurface is necessary in light to the age determinations of the referenced palynological studies.

Based on the information presented by Laing (1996) a total of four age units were inferred in this study (Figure 5):

- a) Oligocene or younger, characterized by the occurrence of species present in sediments of Oligocene or younger age. The lack of palynomorphs restricted to the Oligocene or to the Miocene, does not allow to narrow the age determination.
- b) Middle Eocene, characterized by the occurrences of the species *Echitriporites trianguliformis*, *Spinizonocolpites* spp., *Retistephanocolpites williamsi*, which have been reported in Eocene sediments in northern South America (Muller et al., 1987). The dinoflagellate species *Polysphaeridium subtile* (restricted to the early and middle Eocene by Williams and Bujak, 1985) and *Lingulodinium machaerophorum* were also reported by Laing (1996) to be present in these assemblages.
- c) Early Eocene, characterized by the occurrences of the dinoflagellate species *Apectodinium homomorphum*, *A. hyperacathum*, *Adnatosphaeridium multispinosum*, *Fibrocysta axialis*, *Homotryblum pallidum* and *Spinidinium sagittulum*. The co-occurrences of the first three species, restrict the age of the unit to the early Eocene (Williams and Bujak, 1985 and Williams et al., 1993).
- d) Paleocene: characterized by the last evolutionary occurrence of *Foveotriletes margaritae* and its association with *Longapertites vaneendenburgi*, *Mauritiidites crassibaculatus* and *Retidiporites magdalenensis*. The dinoflagellate assemblages were characterized by the presence of *Fibrocysta licia* and some species of the genus *Cordosphaeridium*.
- e) Late Maastrichtian; characterized by relatively impoverished assemblages and the occurrences of the pollen species *Buttinia andrevii*, whose topmost occurrence has been reported in the Maastrichtian (Muller et al., 1987; Fasola and Paredes de Ramos, 1991).

f) Early Maastrichtian to Campanian; characterized by the abundance of dinoflagellate cysts of the genera *Andalusiella*, *Palaeocystodinium*, *Cerodinium* and *Senegalinium* and the last evolutionary occurrence of the dinoflagellate species *Xenascus ceratioides*. The extinction of this species has been reported in the early Maastrichtian (Williams and Bujak, 1985).

Figure 6 shows the schematic correlations (approximately E-W and NW-SE respectively) of these five units in five of the wells considered in this study (the sixth well was not presented since it lied out of the El Furrial Field). The top of the Campanian-early Maastrichtian unit was used as datum for the correlation, since its top was determined quite precisely.

Overall, a significant thinning of the Paleocene and the early-middle Eocene units is observed in the northwesternmost well (Well 1). There were not significant differences in the thickness inferred for the late Maastrichtian unit. The upper and lowermost units studied (Oligocene or younger and Campanian to early Maastrichtian) were not considered since samples were not collected above and below these units in all the wells.

3.2 Paleoenvironments of deposition

Palynomorphs, unlike benthic foraminifera, are not precise indicators of paleobathymetry, since most are transported into the depositional environment. However, the distribution and ratios of palynomorph groups (marine vs. terrestrial, for example) have been used as indicators to proximity of the coast line. The increasing knowledge of botanical affinities of some palynomorph species found in the fossil record has also made possible to propose paleoecological inferences of their distribution in ancient sediments.) For example, Muller (1964) and Frederiksen (1985) have discussed about the botanical affinity and the distribution of extant and fossil pollen of the palm *Nypa* (included into the genus *Spinizonocolpites*. Colmenares (1988) and Colmenares and Terán (1993) showed the use of studying the frequency variation of palynomorph groups applied to the study of paleoenvironments of deposition in the Eocene of western Venezuela.

A total of six groups were defined or used in this study. The occurrence of abundant specimens of the marine phytoplankton group 'is, obviously, a clear indication of marine influence. The abundance of fern spores and fungi related palynomorphs can be related to deposition in swampy conditions. Therefore, the composition of the whole assemblage and the percentages of its components will reveal some light into the paleoenvironments of deposition to which they were related. Figures 4 to 7 show the distribution of the palynomorph groups for four of the age units under consideration in the five different wells. An evaluation of the assemblages revealed that they were consistent and uniform in all the wells.

Figure 7 shows the distribution of the palynomorph groups for the Campanian-early Maastrichtian. The predominance of marine phytoplankton (essentially of dinoflagellate cysts) indicates marine paleoenvironments of deposition in the area. The associated organic matter contained mainly marine amorphous organic matter. Terrestrial organic matter and palynomorphs were found in low counts. To the south, the percentages of terrestrial palynomorph show some increase, indicating increasing continental influence. The predominant dinoflagellates, mainly peridiniaceans proximate cysts might be an indication of marine environments not too distant from the continental areas. This type of cysts has been proposed to be abundant in marine environments near coastal areas.

A significant change in the distribution of palynomorph groups is observed in the unit corresponding to the late Maastrichtian (Figure 8). Marine phytoplankton is only observed in the easternmost well (Well 3; only at the based of this unit), whereas it is absent in all other wells. Fern spores predominate, with subordinate important amounts of coastal vegetation pollen (mainly of the genus *Spinizonocolpites*) and fungal spores. This association seems to suggest paleoenvironments of deposition located in swamps in or nearby coastal areas.

The marine phytoplankton group is present again in the Paleocene unit (Figure 9), with larger percentages in the easternmost well (Well 3). This trend seems to indicate that a major transgression took place during the Paleocene and that the paleoenvironments of deposition seem to be more marine to the easternmost area. This distribution is reverted during the early-middle Eocene unit (Figure 10), at which the larger percentages of dinoflagellates are detected in the western and southernmost area of the field.

4- Conclusions.

The palynological study undertaken in the El Furrial Field reveals a relatively complex stratigraphical picture. The geological model proposed as the result of this study and the tectonic-sedimentary study of the area (Chatellier and Colmenares, 1997) suggest the tilting of blocks within the field at the time of deposition during the early Paleogene. The inference of significant wedging of age units (such as the Paleocene to the western area of the field), and the observation on the existence of marine conditions at the base of the late Maastrichtian unit in the easternmost well, seem to indicate that the deposition was more continuous in the eastern area. Further detailed studies can reveal that tilting might have been reverted during the deposition middle Eocene or younger interval.

The study has shown the use of palynology in the characterization of reservoir units. Integrated studies with other microfossil groups will increase the resolution of the correlation of reservoir.

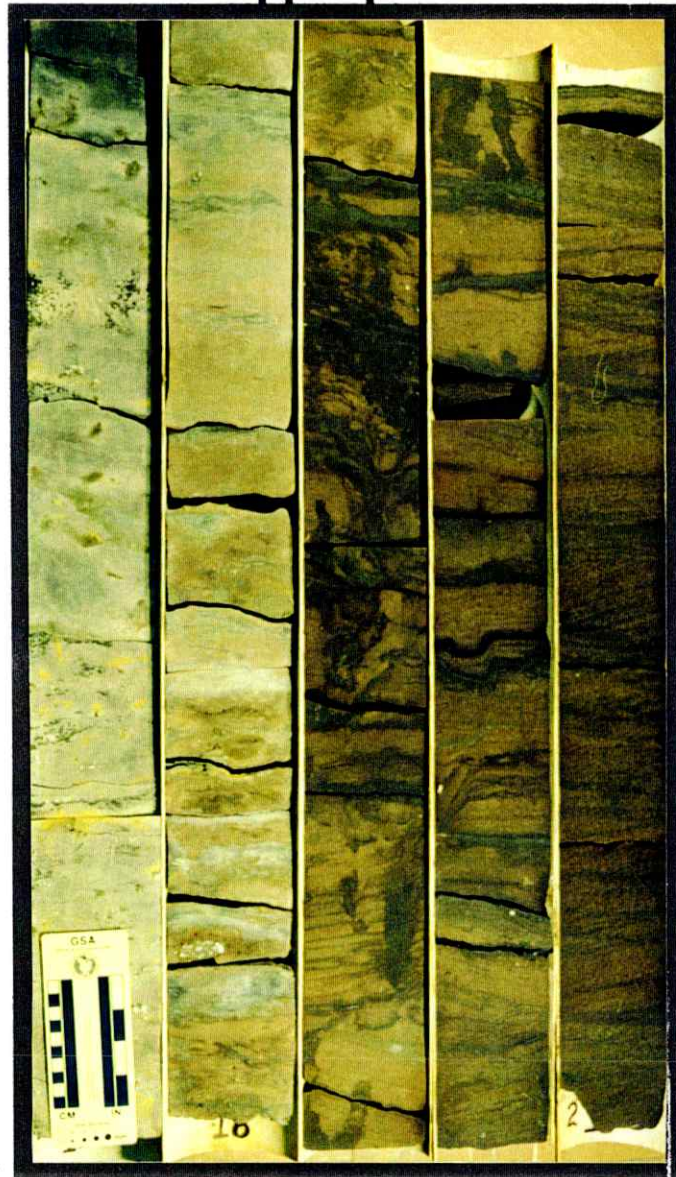
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Palynology - Furrial

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TRANSGRESSIVE SANDS
Upper part



A

TRANSGRESSIVE SANDS
Lower part



B

Fig.1 Shale sequences sampled for palynology and replaced in their paleoenvironment (part 1)

**CHANNEL
ABANDONMENT**



**TOP OF
MARINE BAR**

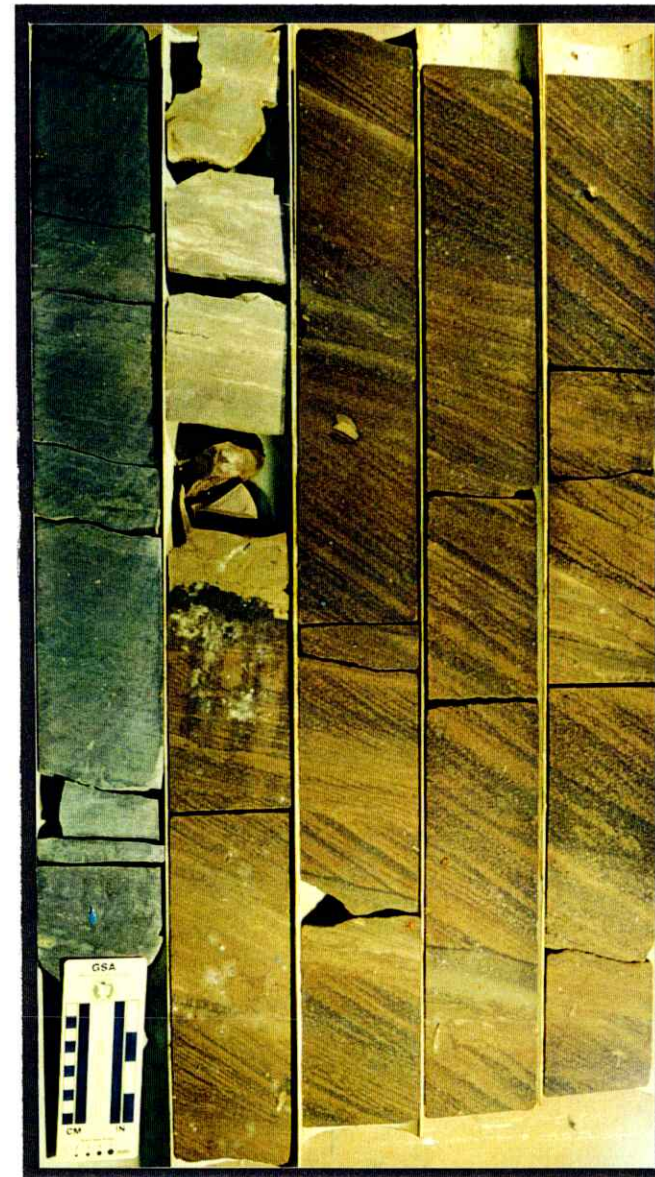
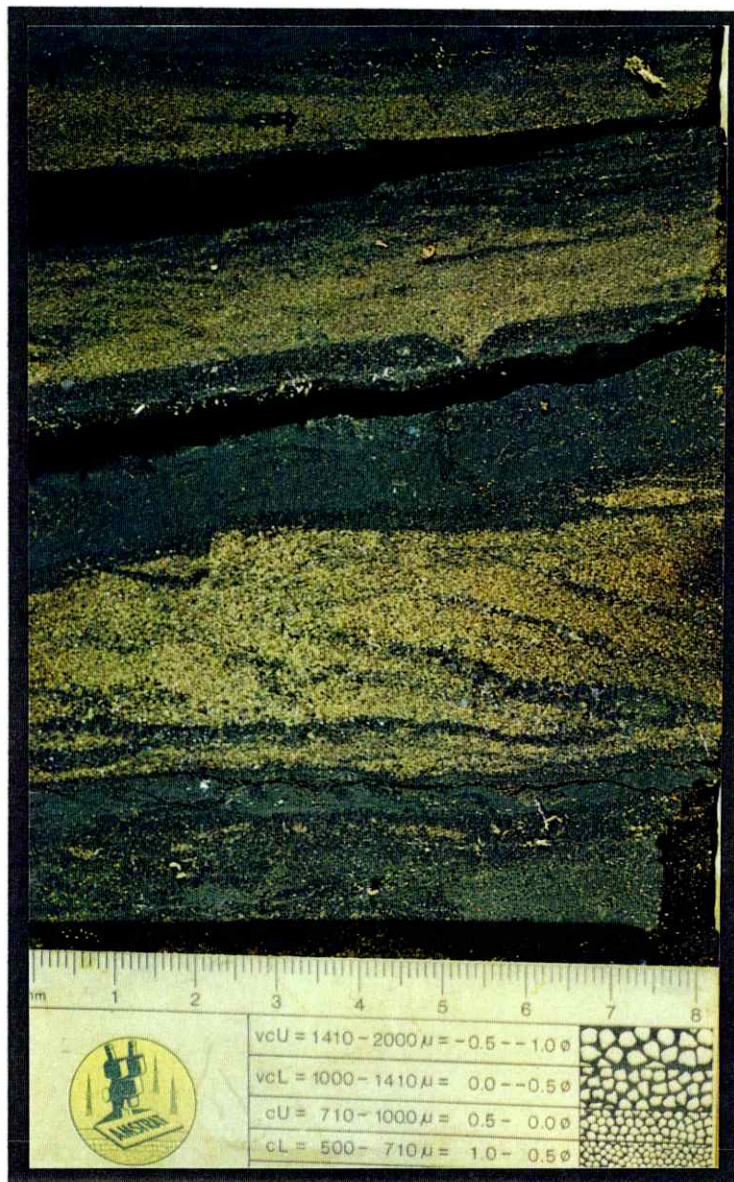


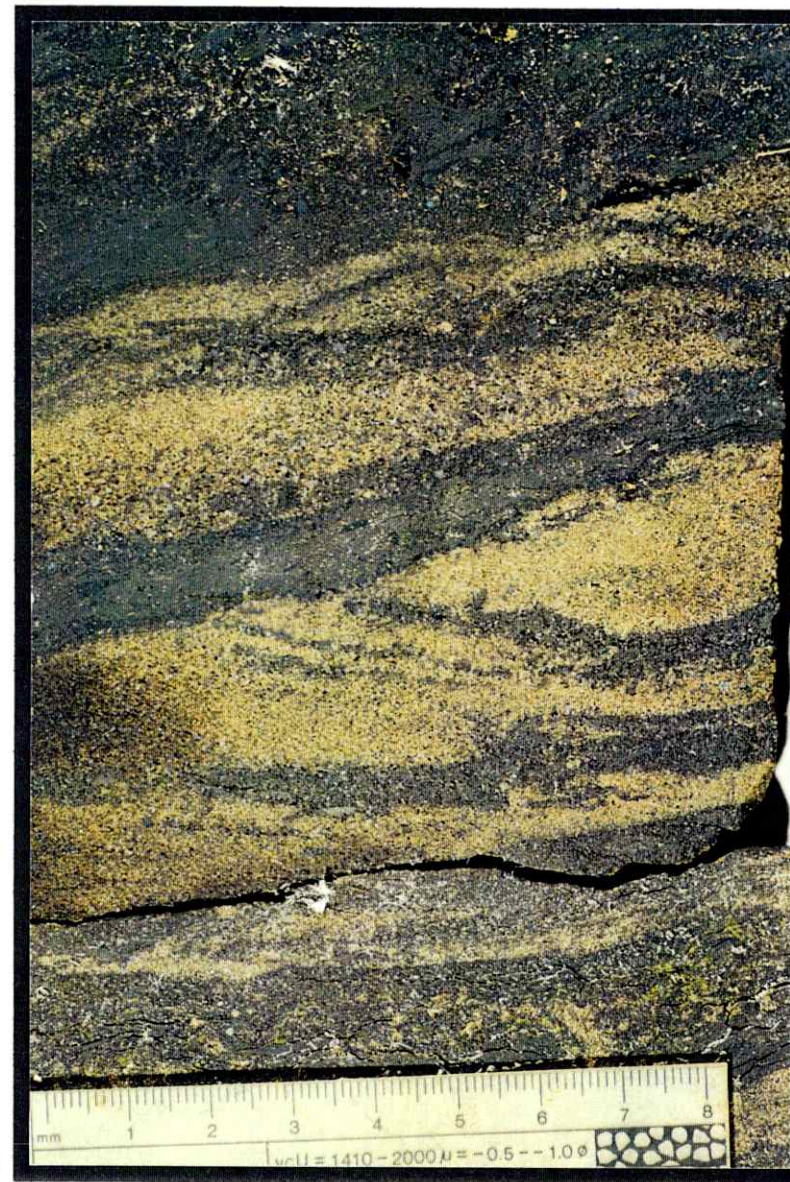
Fig.2 Shale sequences sampled for palynology and replaced in their paleoenvironment (part 2)



A

FUL-46 depth 14896.3'

Note the alternance of strong tidal current (cross beds and thicker) and weak tidal current)



B

FUL-46 depth 14898.4'

Fig.3 Shales and sands alternation in tidal rhythmites

Gamma Ray

WELL 5

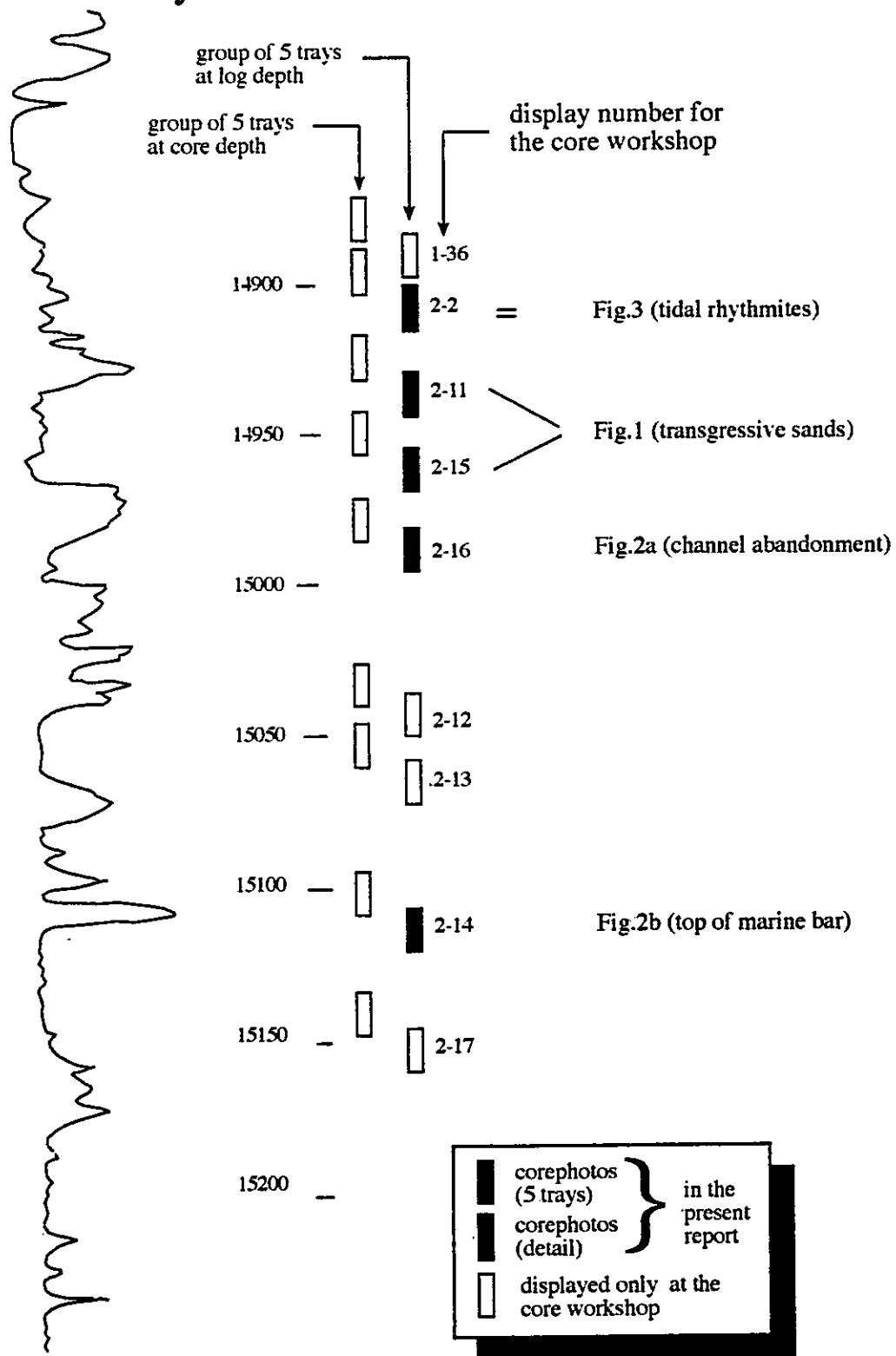


Fig.4 Distribution of the cores displayed at the workshop or reproduced in the proceedings

SERIES		LAING (1996)	Colmenares (1996)	LITHOSTRATIGRAPHIC UNITS
OLIGOCENE		P4	Oligocene or younger	"UPPER NARICUAL"
EOCENE	L	P3		"MIDDLE NARICUAL"
	M		Middle Eocene	
	E	P2	Early Eocene	
PALEOCENE		P1	Paleocene	
Maastrichtian		K10 - K8	Late Maast.	"LOWER NARICUAL"
		K7 - K6		
Campanian		K5 - K1	Campanian-early Maast.	"AREO"

Figure 5. Age units defined in this study based on the information of Laing (1996).

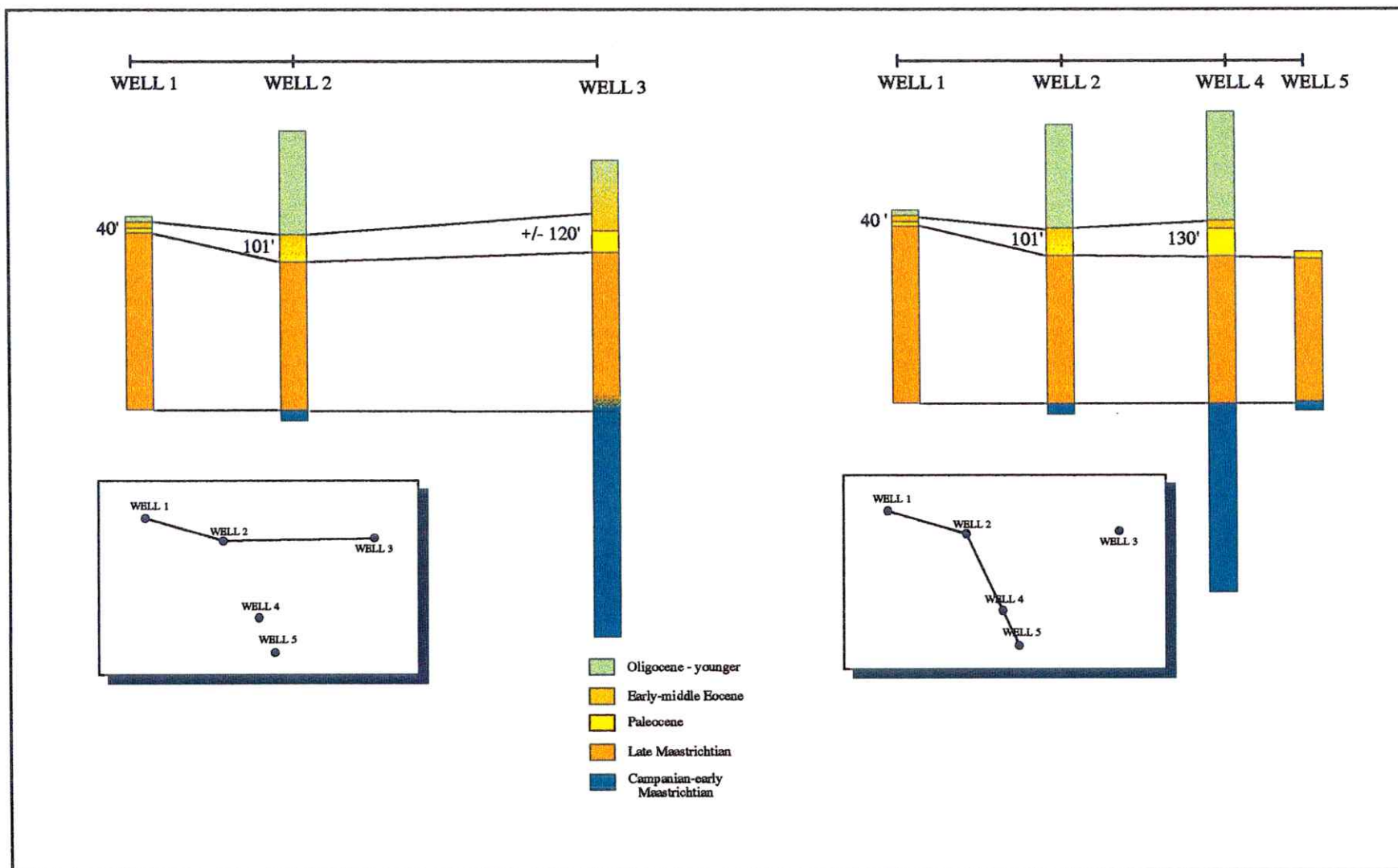


Figure 6. E - W and NS palynostratigraphic correlation, El Furrial Field

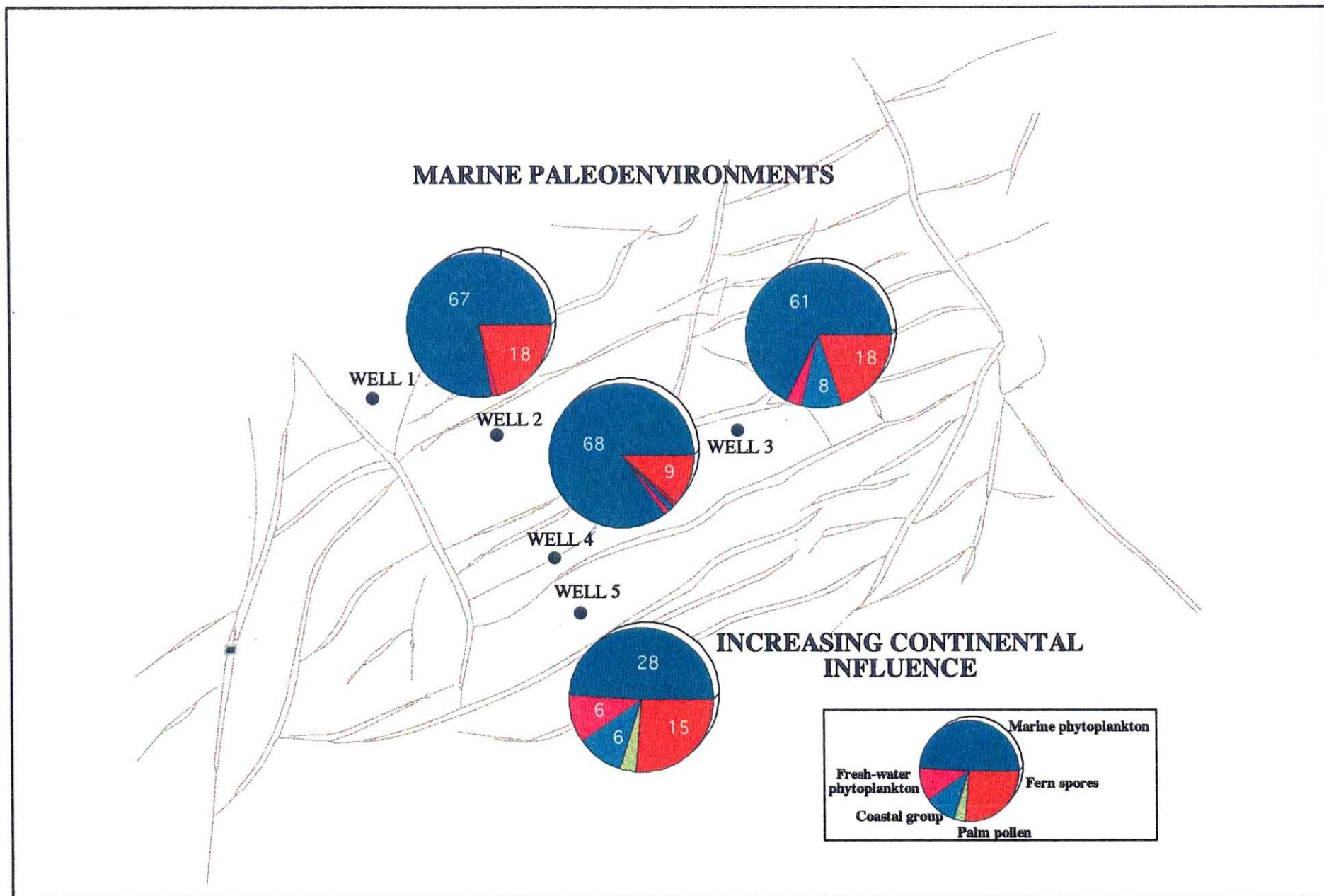


Figure 7. Paleoenvironmental Interpretation: Campanian - Early Maastrichtian

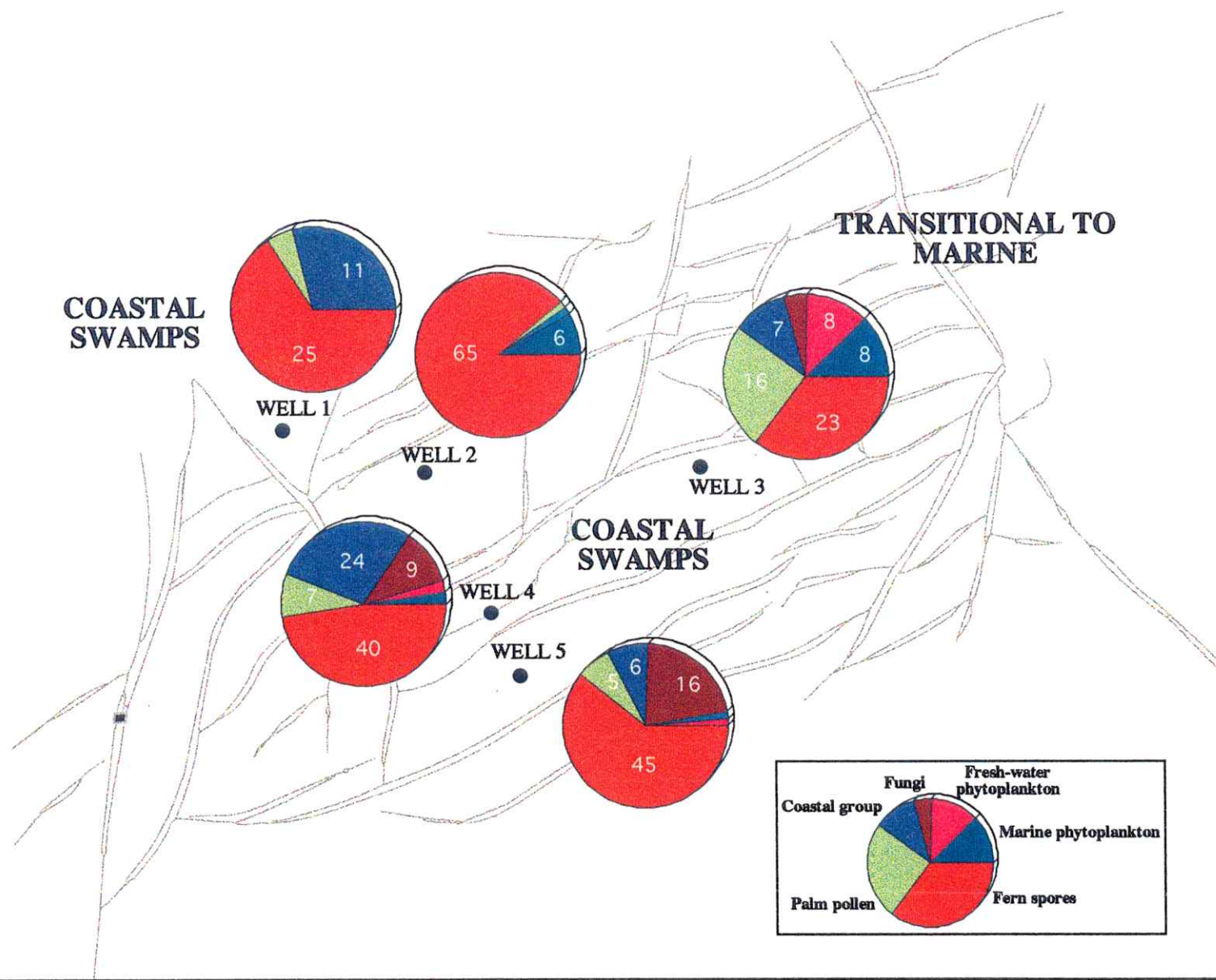


Figure 8. Paleoenvironmental interpretation: Late Maastrichtian

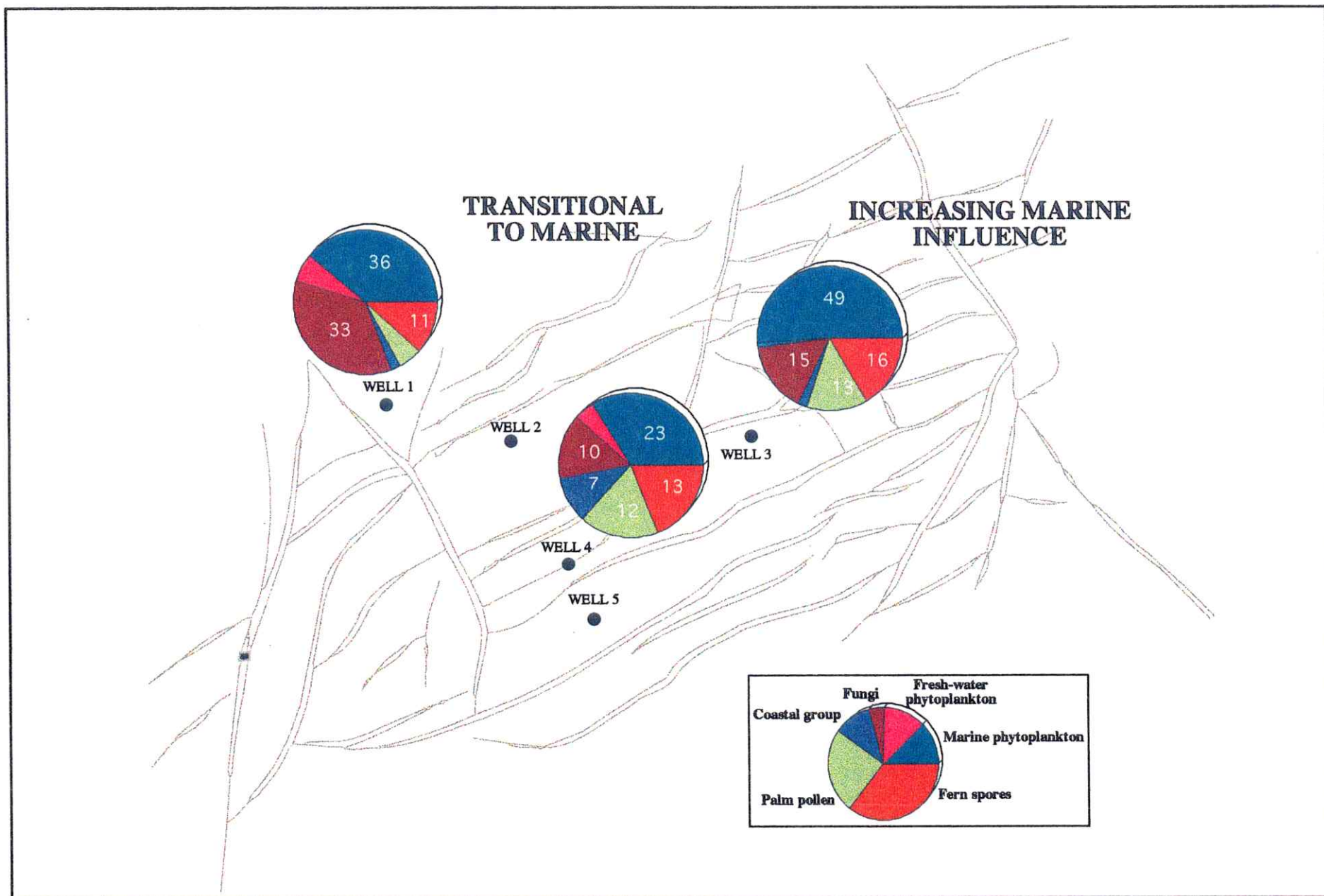


Figure 9. Paleoenvironmental interpretation:Paleocene

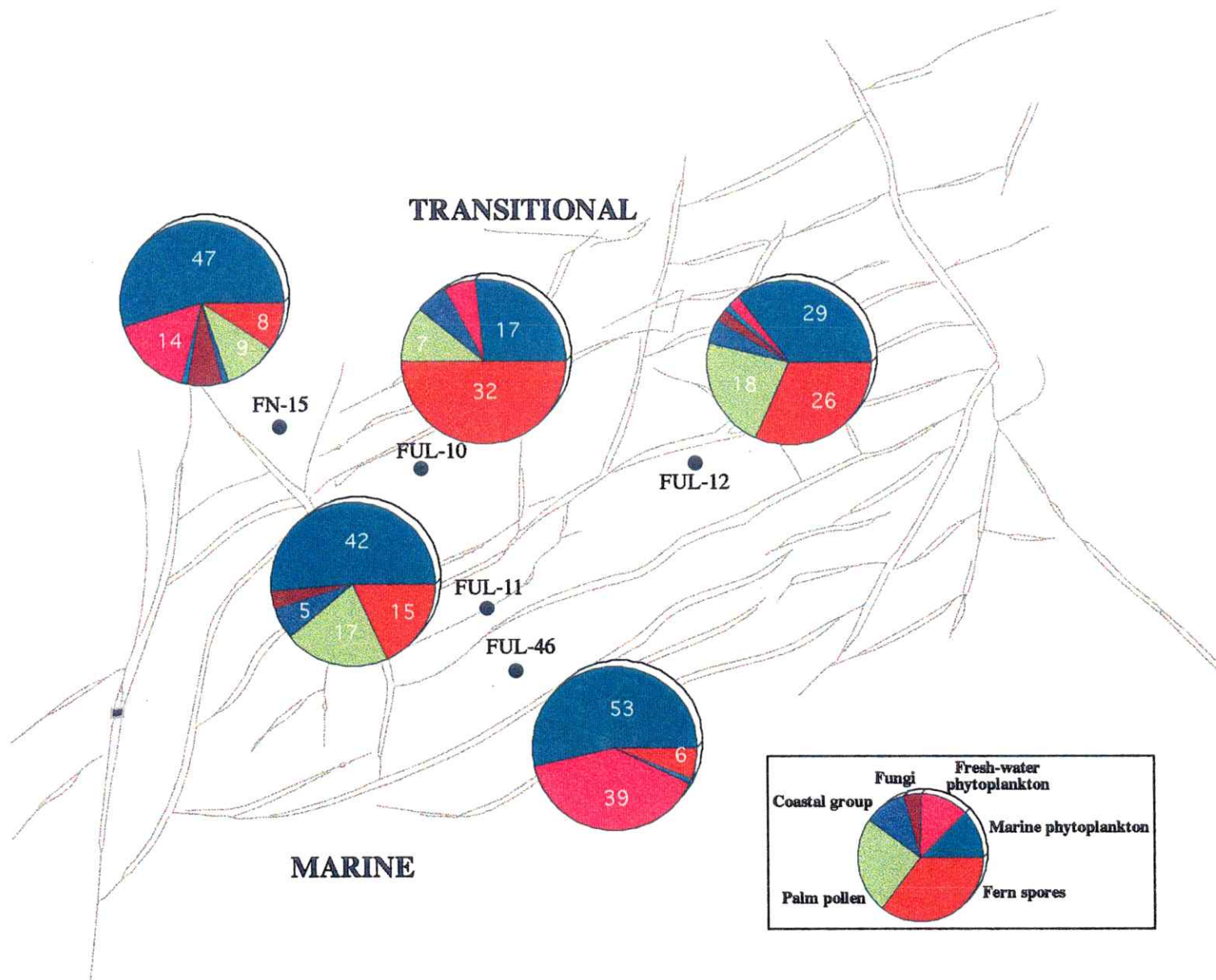


Figure 10. Paleoenvironmental interpretation: Early - Middle Eocene

Using core to assess the vertical permeability within individual marine sands of the Oligocene interval in the El Furrial field.

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Abstract

A probe permeameter survey on three sections of core has been used to estimate the vertical permeability within individual marine bar sand units of the "Naricual Superior" formation in the central region of the El Furrial field. The surveys allowed quantification of the significant heterogeneity within these sands, caused by bedding features, which had been not representatively sampled by one foot spaced core plugs, and was not evident on conventional wireline logs. The K_v/K_h ratio has been estimated in the range 0.01-0.05, giving little productivity advantage to highly inclined wells compared to vertical wells. The geometric average of the core plug data gives the best match to the horizontal permeability estimated from the probe permeameter. The arithmetic average of the plug data overestimates this value.

Introduction

Marine sands in the Oligocene section of the El Furrial Field are laterally continuous and well correlatable, they are commonly twenty to fifty feet thick and present good reservoir properties (porosity, permeability). A requirement to estimate the vertical permeability within individual sand bodies of the El Furrial field has recently arisen, due to a proposal for using high angle wells (70° deviation) as part of the depletion strategy. Analytical modelling has demonstrated the significant sensitivity of these wells to the vertical permeability, with a reduction in P.I. of 20% from an isotropic case, to a K_v/K_h ratio of 0.1. Importantly, the difference in productivity between vertical and high angle wells would probably be insufficient to justify the additional expense and risk in the latter case, unless a delay in injection breakthrough can also be achieved. Determination of sand body vertical permeability was thus established as a key factor in a feasibility study for a high angle "Naricual Superior" well in the central region of El Furrial.

Several methods exist for estimating vertical permeability. The most accurate involve flow tests, either partial penetration well tests, tests between two perforated intervals using straddle packers, or using a dual probe RFT type tool; considerable expense and risk would be incurred using these methods in El Furrial wells however. This paper shows the use of a probe permeametry method involving closely spaced permeability

measurements, with suitable upscaling, to estimate the vertical permeability from three representative sections of core.

Sedimentology of the selected horizons

A preliminary selection of sands suitable for high angle wells was made on the basis of wireline log characteristics and on petrophysical properties obtained from core plugs. The available core was reviewed, and it was determined that Naricual Superior intervals from Ful-2 and Ful-12, both in the central area of interest, would be most suitable for the probe-permeameter study (Fig.1). Sections of core covering complete sand units were chosen. Two intervals were taken from Ful-2 (13426'-13473' (upper) & 13688'-13729' (lower)) and one from Ful-12 (13654'-13717.5'), allowing the complete permeability distribution to be assessed for each sand unit (Figs.2 to 4). The generally good correlatability of shales above and below the units provide at least local, vertical seals, which do not impact greatly on the vertical permeability as seen by a high angle well.

At first glance these extensive marine sands appeared to be good candidates for high angle wells as the petrophysics performed on core material was indicating a Kv/Kh ratio close to 1. Nevertheless, although the wireline logs seem to indicate massive sands, the sedimentary features encountered in the cores showed a high degree of variability and heterogeneity. For the minipermeability study, we selected some of the intervals that seemed to be the most homogeneous on the basis of wireline log characteristics.

Examination of the cores showed a high diversity of sedimentary structures from tabular cross-beds to bioturbations and common internal changes in grain size from granule to clay (Figs.5 to 9). Clay rich laminae, detrimental to the vertical permeability, are common throughout the studied intervals except for some of the transgressive sands (e.g. FUL-2 between 13718' and 13723').

Probe Permeametry

Probe permeameter surveys were conducted on the three core sections, with probe spacing of approximately 0.1 foot. Care was taken to measure representative values for all fine scale laminations, since such laminations have a large impact on the vertical permeability.

The results of the surveys are shown in figures 2-4, where the data has been plotted with the core descriptions. It may be seen, particularly in the latter two figures, that fine scale bedding within the bar sands causes a two orders of magnitude reduction in permeability between the sand laminations. The probe permeameter captures this fine scale heterogeneity, which is completely missed by the conventional core plug analysis. It was also

noted that the conventional one foot spaced core plugs had been systematically sampled in the best quality sections of core. This plug sampling bias has lead to significant overestimation of horizontal permeability from core within the sand units.

Calculating correct values of horizontal and vertical permeability also requires that the interval in question has been adequately sampled. Following the method derived by Corbett and Jensen¹, the number of tests required to representatively sample a given interval can be calculated as:

$$\text{Number of samples, } N_o = (10 C_v)^2$$

where C_v = coefficient of variation (standard deviation / arithmetic average).

Table 1 shows the coefficient of variation and sample sufficiency figures for the core and probe surveys from the three intervals. Data has been taken from the top to bottom of the sand, ignoring values in the bounding shales. It may be seen that the conventional core plugs indicate the rock to be almost homogeneous (C_v around 0.6), whilst the probe data, generally with a C_v above 1.0, shows the high internal heterogeneity. The required number of samples to capture the internal variability has been calculated from the probe data, and it can be seen that while the probe permeameter data has adequate sampling, the core plugs undersample the interval. This implies care should be taken correlating petrophysical log data to this core information, as it is not representative of the formation.

Vertical permeability

The rationale behind calculating vertical permeability from probe permeameter data is that the test is essentially a point measurement, and at a small enough scale, rock may be considered to be isotropic ($K_x=K_y=K_z$). This means that provided sufficient data is taken, and that the fine scale heterogeneity has been captured, the localised vertical permeability can be calculated from the harmonic average of the data. The validity of the harmonic average as a measure of vertical permeability over a larger area depends on the geological features involved.

Geological description of the Naricual Superior interval shows that the litoral bar environment is laterally extensive over the majority of the study area, hence the sections of core chosen for the probe permeameter survey should be representative of the types of rock likely to be encountered by a high angle well. Additionally, examination of the available core shows the bedding features represented in these samples to be prevalent in the central part of the field. The low angle tabular bedding (5-10 degrees dip), is expected to be laterally continuous over 100's of feet in this environment. Figure 10 shows the high angle well trajectory, and flow regimes within the sand unit. It may be seen that for the high angle well, the important factor for productivity is the vertical permeability close to the well. The tabular bedding is likely to be continuous over

this interval, hence the harmonic average provides the correct upscaling technique. Over larger intervals however, a power law upscaling method, similar to that proposed by Deutsch², may be more appropriate.

The horizontal and vertical permeability's have been calculated from the arithmetic and harmonic average of the data respectively, and are shown in Table 2; the vertical permeability has been calculated both including, and excluding data from the small shaly units in the middle of the three data sets.

It may be seen that for the two sand units with a high proportion of bedding features, the probe data indicates a horizontal permeability approximately half of the permeability from the core plugs, due to non representative sampling. The geometric average of the core plug data, however, gives better agreement generally with the probe data, indicating that the use of this average may result in a more representative, horizontal permeability estimation.

It may be seen that the Kv/kh ratios calculated from the probe permeameter data are very low; this is indicative of the significant heterogeneity found within the sands. Excluding the values from the small shaly zone in the middle of the units makes a significant impact on the Ful-2 upper interval results, where, in general, the sands are of very good quality, and present less bedding; even so, the resulting Kv/Kh ratio is not particularly high considering the sand quality. There is very little impact on the other two zones however, where the bedding features hold the real key to the vertical permeability. It is felt that these latter units are more representative of the sands in the central area of El Furrial.

One impact of these results will be on perforation policy, where the abundance of sand laminations will favour the use of higher shot densities; the impact of the results on high angle well productivity is discussed below. It should be additionally noted that permeability reduction with compaction generally influences low permeability rock significantly more than rock with high permeability; it may be expected that in-situ vertical permeability is further reduced compared to the values calculated here.

High angle well performance

Using a published analytical model³, results have been calculated for high angle well P.I. versus Kv/Kh ratio, as shown in figure 11. The performance of a vertical well has been included for comparison.

It can be seen that with Kv/Kh ratios in the order of 0.01-0.05, there is little advantage in drilling a high angle well, with a P.I. increase of less than 3% compared to a vertical well. Even with the optimistic Kv/Kh of 0.14, the 7% increase in well productivity is probably insufficient to justify the additional well cost and risk associated with drilling this type of well, if the criteria is solely increase in production.

Conclusions

- ☐ The vertical permeability is significantly reduced by the extensive bedding features present within the litoral bar environment. The K_v/K_h ratio has been calculated in the range 0.01-0.05, with a possible upside of 0.14 for facies units where these bedding features are not predominant. It is planned to confirm these results using in-situ vertical permeability testing with a dual probe MDT tool, on a future cored well.
- ☐ There is little advantage in drilling a high angle well in this environment, from a purely productivity standpoint.
- ☐ The probe permeameter allows quantification of the significant heterogeneity seen within the cores. Reliance on conventional wireline logs alone in these intervals would have created a false impression of homogeneity.
- ☐ Conventional one foot spaced core plugs do not capture the variability in these cores, due to non representative and insufficient sampling.
- ☐ The geometric average of the core plug data gives the best match to the horizontal permeability estimated from the probe permeameter. The arithmetic average of the plug data overestimates this value.

References

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2. "Calculating effective absolute permeability in sandstone/shale sequences", Deutsch, C., *SPEFE*, p343, September 1989.
3. "The Skin due to Slant of Deviated Wells in Permeability-Anisotropic Reservoirs", Rogers, E.J., Economides, M.J., paper SPE 37068, 1996.

Permeability - Furrial

Table 1 Sample sufficiency

	Ful-2 (Upper) Probe	Ful-2 (Upper) Core plug	Ful-2 (Lower) Probe	Ful-2 (Lower) Core plug	Ful-12 Probe	Ful-12 Core plug
Coefficient of variation (Cv)	0.94	0.56	1.26	0.85	1.28	0.57
No. samples reqd. (No.)	88	-	160	-	163	-
No. samples taken	261	37	313	39	424	60

Table 2 Data upscaling

	Ful-2 (Upper) Probe	Ful-2 (Upper) Core plug	Ful-2 (Lower) Probe	Ful-2 (Lower) Core plug	Ful-12 Probe	Ful-12 Core plug
Kh (arithmetic average) md	1013.2	1278.6	329.2	635.2	334.2	639.2
Kv (harmonic average) md	10.8	365.6	8.9	11.2	1.68	95.8
Kv (excluding shaly unit) md	151.4		15.8		3.95	
K (geometric average) md		980.4		333.5		466.6
Kv/Kh	0.01	0.29	0.03	0.02	0.005	0.15
Kv/Kh (excluding shaly unit)	0.14		0.05		0.01	

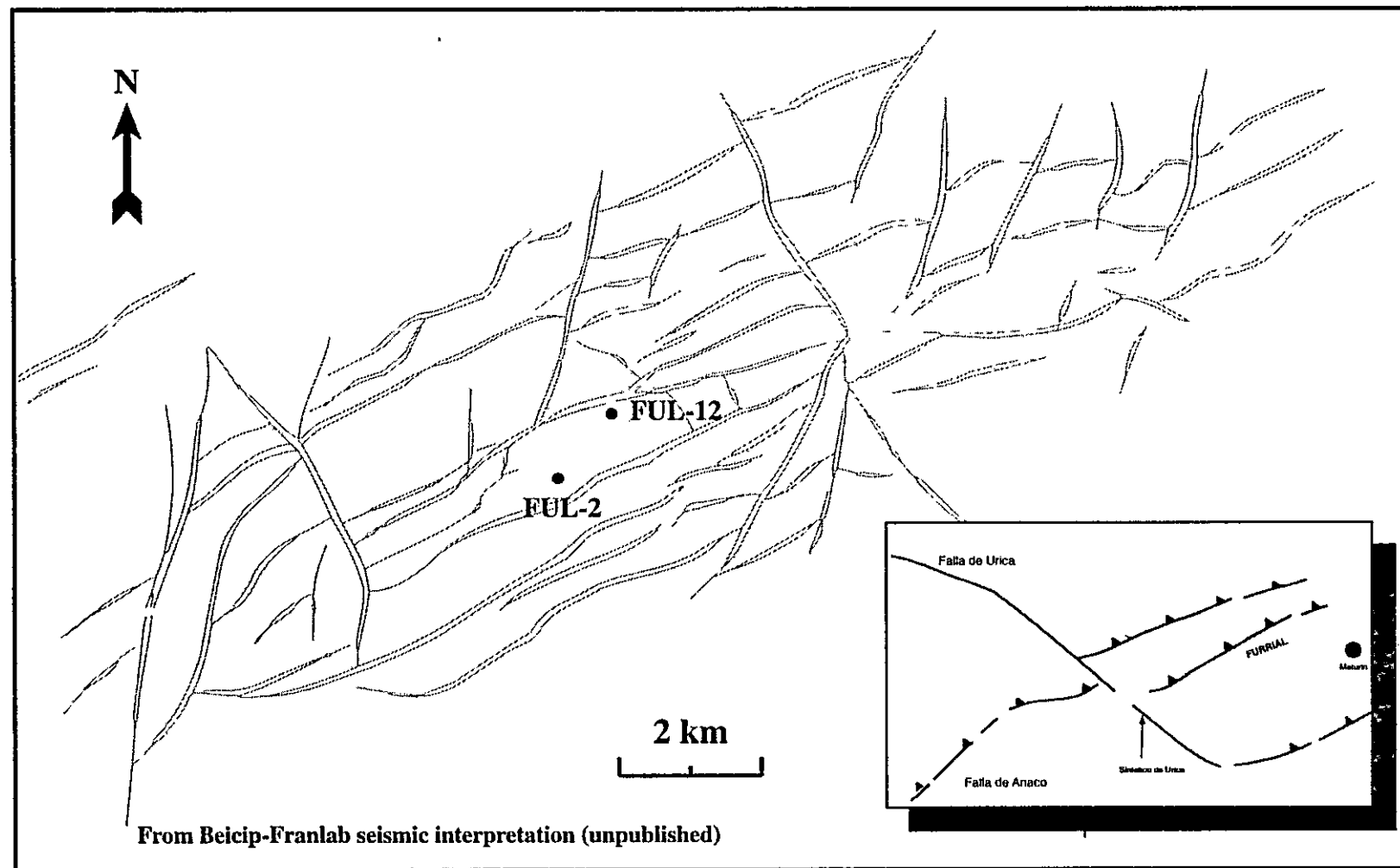


Fig. 1 Location map of studied wells

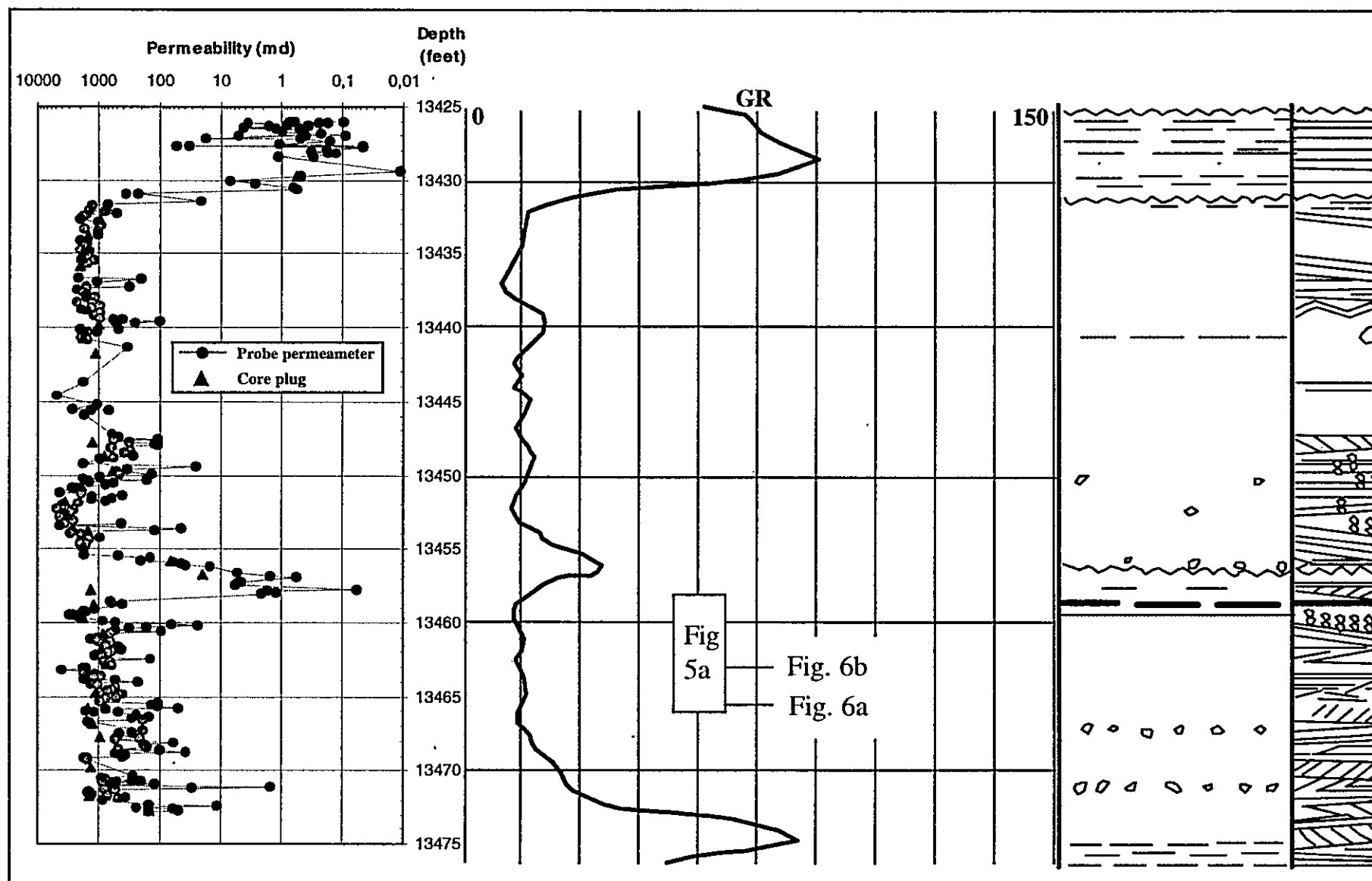


Fig. 2 Ful-2 (Upper) Probe permeametry & core description

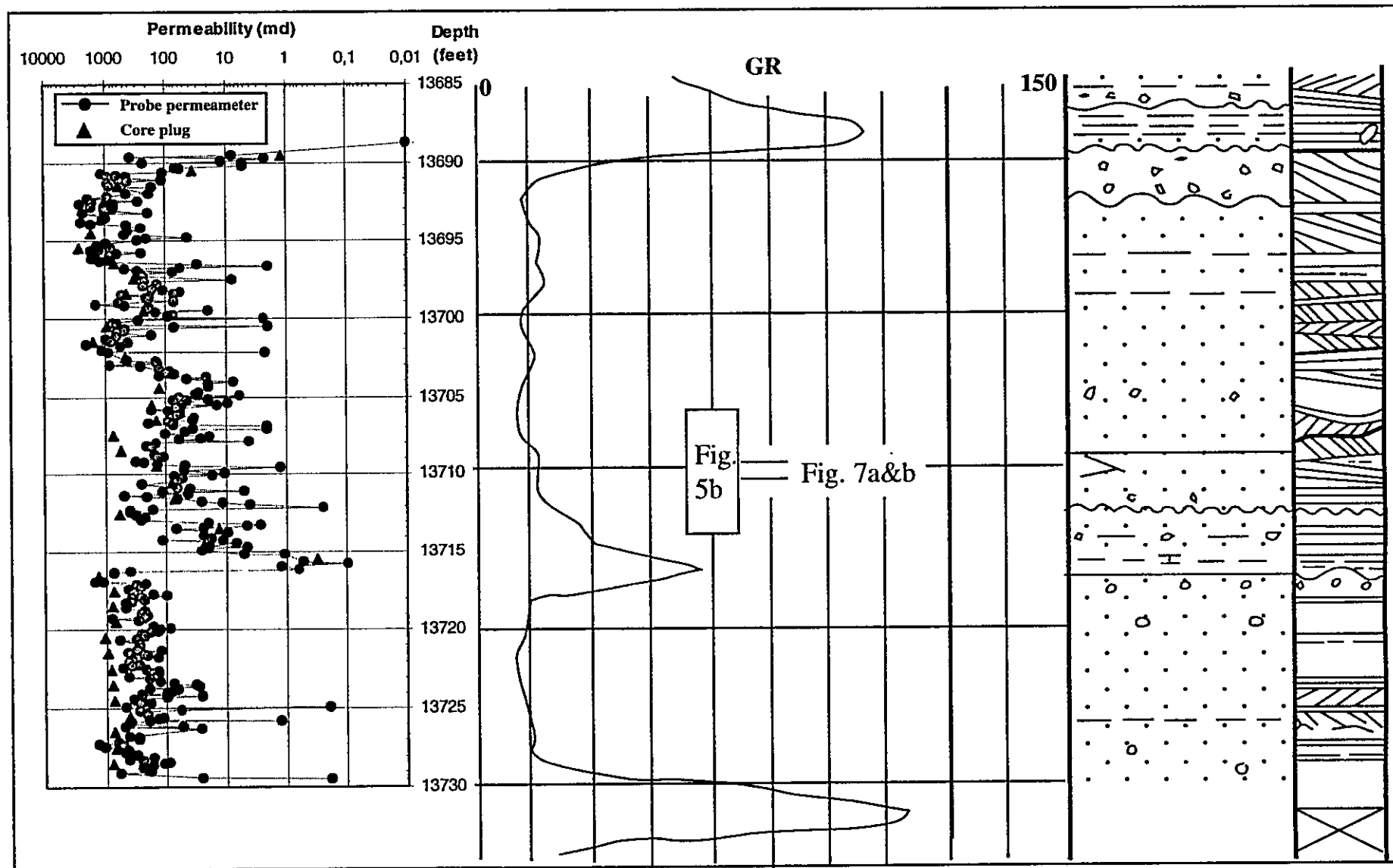


Fig. 3 Ful-2 (Lower) Probe permeametry & core description

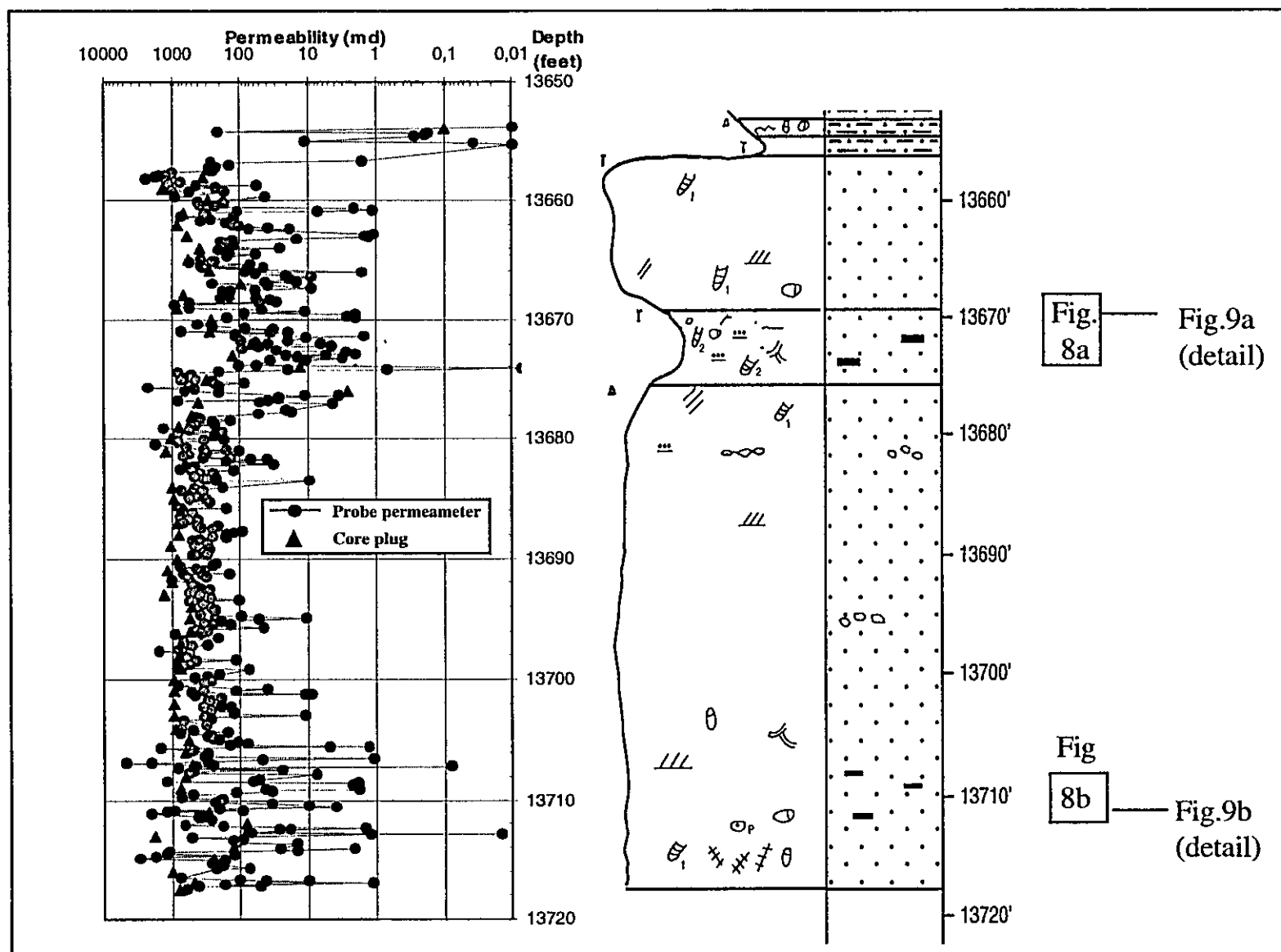
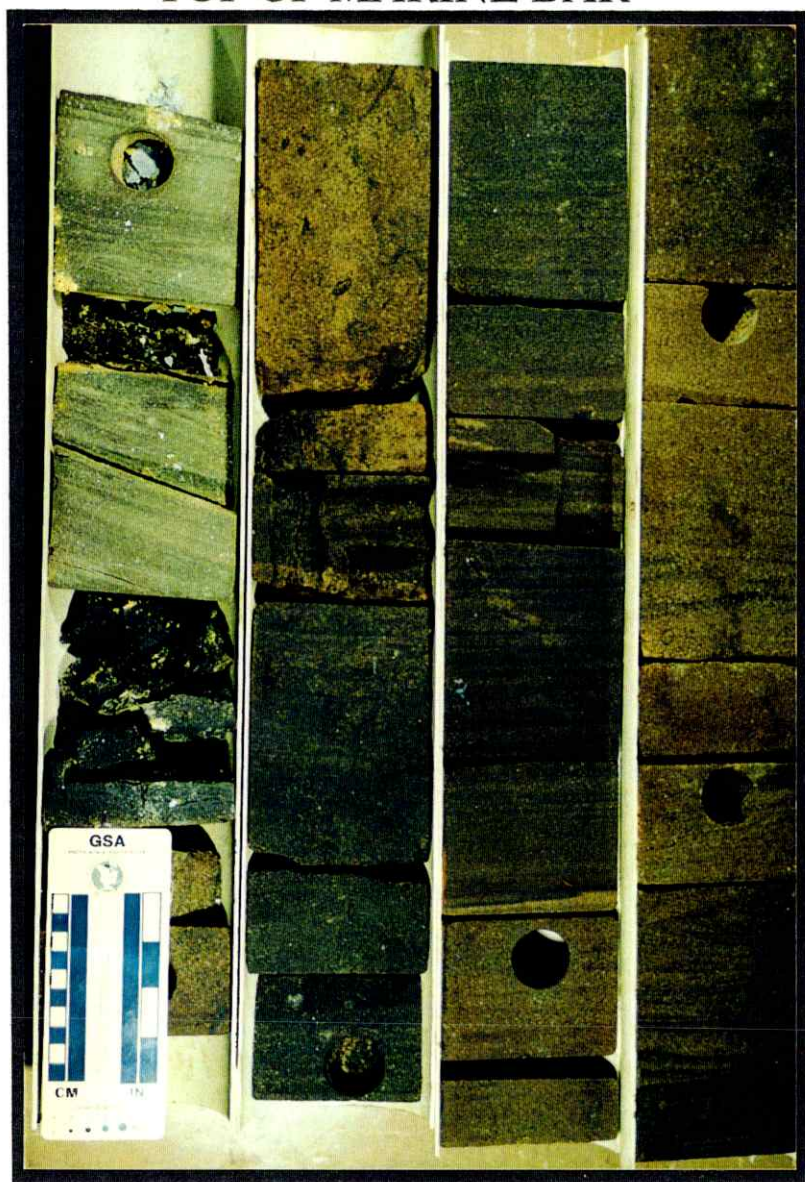


Fig. 4 Ful-12 Probe permeametry & core description

TOP OF MARINE BAR



A

BASE OF MARINE BAR



B

Fig.5 Heterogeneity and variability in marine bars (FUL-2)

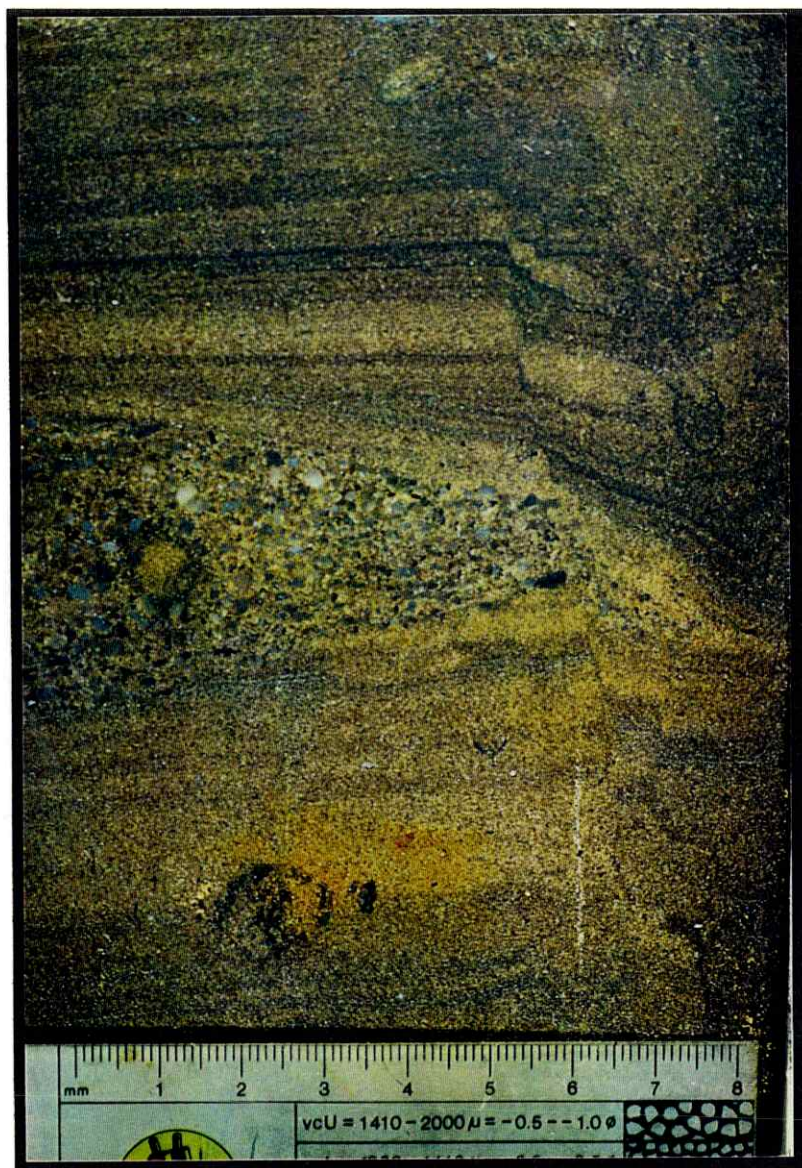


A 13465.7' Cross bedded sands; the increase in clay content in the lower third of the photo has a big impact on permeability (see Fig 2)



B 13463' Repeated change in grain size in horizontally laminated sandstone; relatively low impact on vertical permeability

Fig.6 Heterogeneity and variability in the upper part of a marine bar (details 1)



A 13709.7' High grain size variability and synsedimentary faulting are responsible for a low K_v/K_h ratio



B 13710.5' Repeated change in grain size and change in hydrodynamic regime are responsible for the vertical heterogeneity

Fig.7 Heterogeneity and variability in the lower part of a marine bar (details 2)

see
Fig.9a



A Variety of sedimentary structures in a rapidly deposited coarsening up sandy sequence



B Variety of structures towards the base of a marine channel

Note on Fig. 4,
the very high
variability in
permeability in
the two intervals
displayed

← see Fig.9b

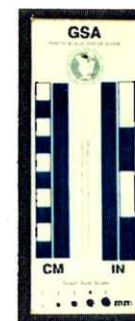
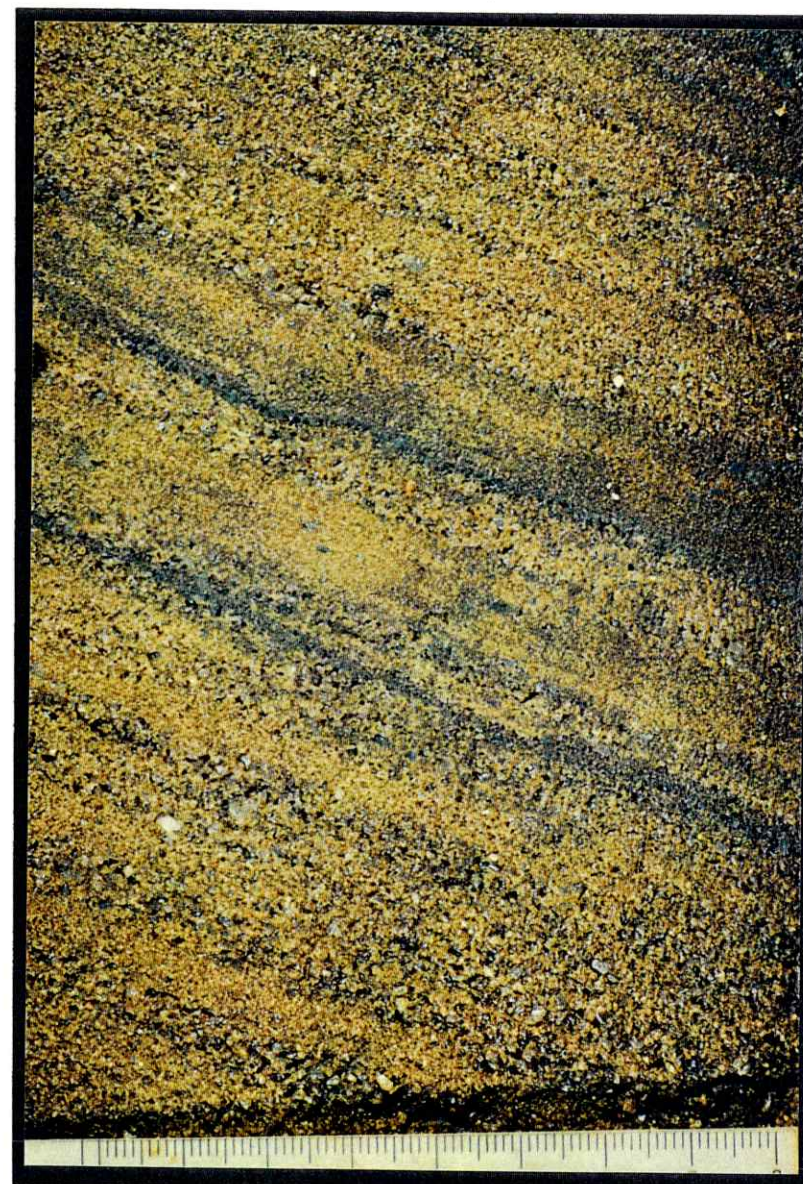


Fig.8 Heterogeneity and variability in marine sands from FUL-12



A 13669.7' Cross bedded sands with high clayey laminae and syndimentary faulting; very poor vertical connection



B 13711.2' Repeated change in grain size from clay to very coarse grain size highly affecting the vertical permeability

Fig.9 Heterogeneity and variability in marine sands of FUL-12 (details)

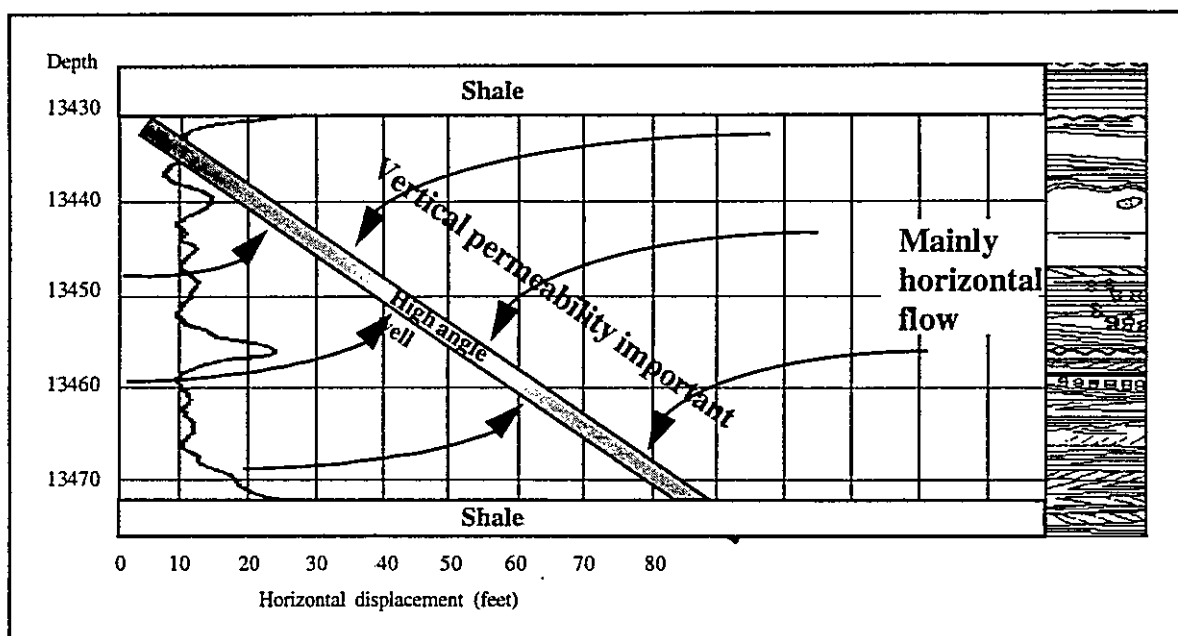


Fig.10 Flow regime influence around high angle wells

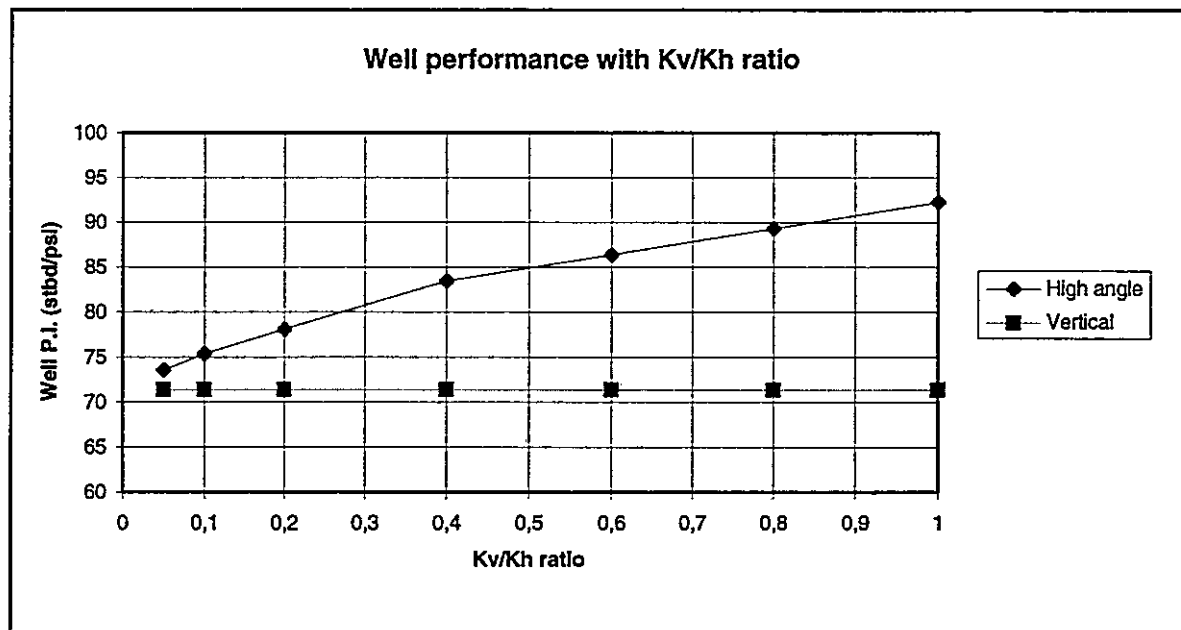


Fig.11 Well performance with K_v/K_h ratio