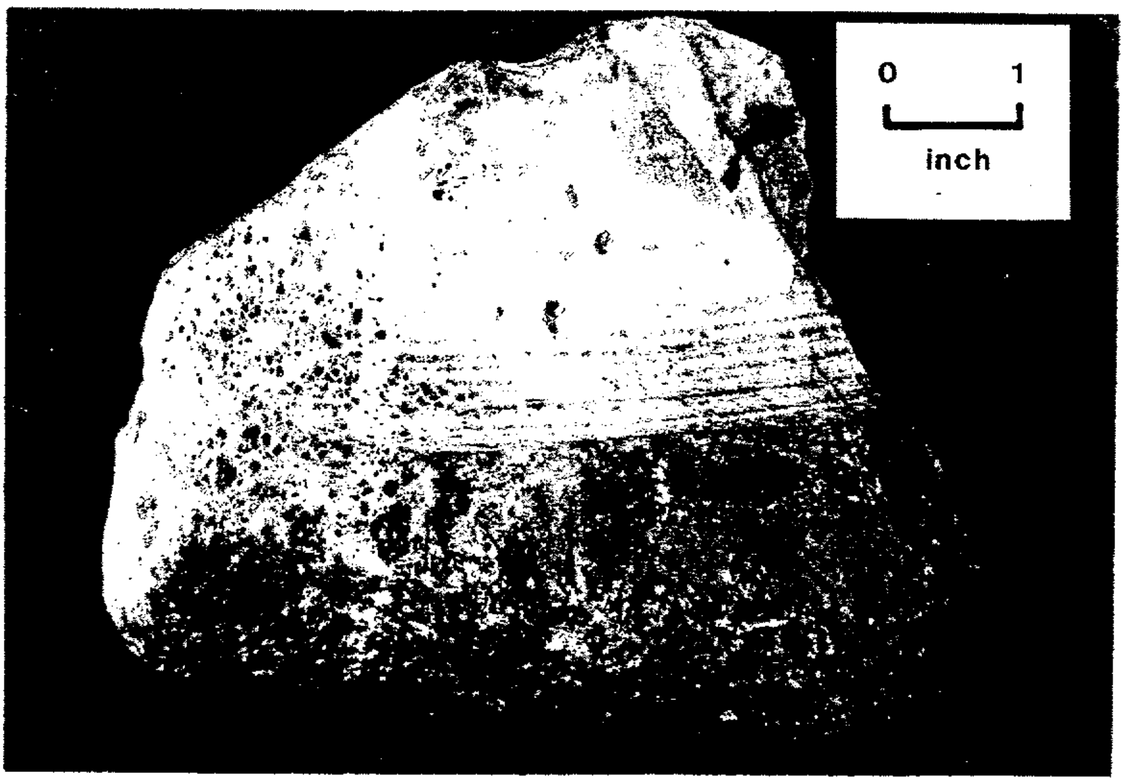
THE BOULDER ZONE DOLOMITES OF FLORIDA

Volume 1

PALEOGENE & UPPER CRETACEOUS ZONES OF THE SOUTHEASTERN PENINSULA AND THE KEYS



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Miami Geological Society

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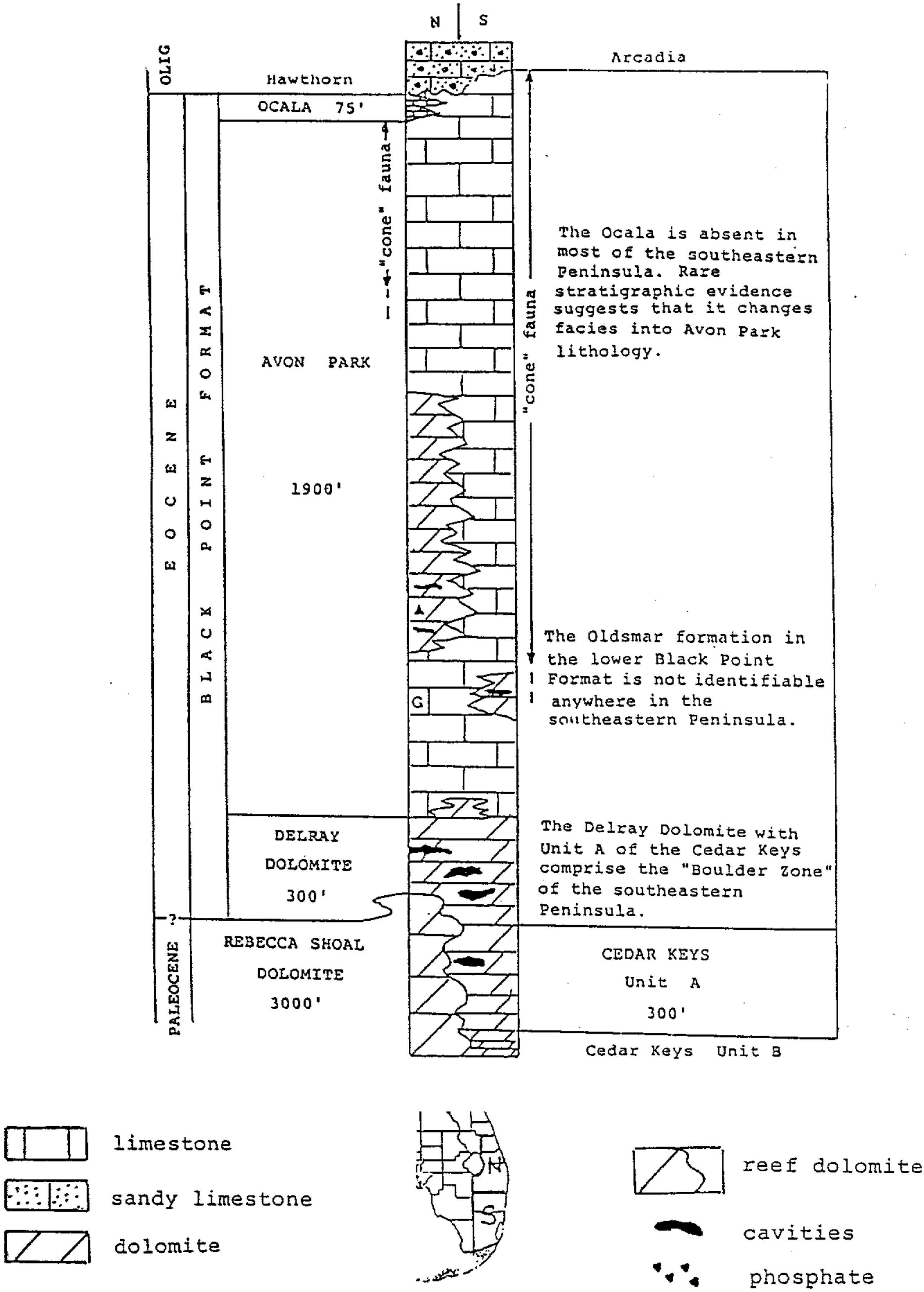
TABLE OF CONTENTS



Generalized Geologic Column of the
Black Point Format and Adjacent Units
in Southeastern Peninsular Florida

Fig. 1

EXECUTIVE SUMMARY

Of the three main sources of Boulder Zone geological data, the most useful is the borehole video-tape; lithology, caliper logs, and GR-Induction resistivity logs are of lesser value. The 1"=100' GR-dual induction-SFL log is essential for regional internal correlation of the entire Black Point Format-Floridan Aquifer section, and in some areas for establishing the top of the Cedar Keys A. Lithologic data are frequently necessary to establish formation tops.

Assuming that the drill cuttings represent the section drilled, dolomite texture appears to be unrelated to the type of wall features.

Major wall features include cavities, wall-collapse zones, vugs and solution-enlarged fractures. Thick wall-collapse zones appear to be associated with local faults. Where thick wall-collapse is present it suggests the possible nearby presence of an undetected fault. Wall-collapse is the only feature to show horizontal continuity in multiple well sites.

Cavities and megavugs are found in all units from the lower Avon Park dolomites into Cedar Keys A and the Rebecca Shoal. In Brevard County they are also present in Cedar Keys B. Large vugs and extensive vug fields, common in Rebecca Shoal and Avon Park dolomites, occur in other units in lesser quantities.

That reservoir continuity is present is evidenced by the immense volumes of fluid injected into Boulder Zone units. Much of this continuity is probably due to open channels and fractures, with subordinate continuity possibly provided by vug fields and occasional zones of intercrystalline porosity in

euhedral dolomite. Isolated cavities and vugs are probably not connected.

Reservoir characteristics vary widely between wells in the same site, but in general, the best developed reservoir occurs near faults or in the Rebecca Shoal reef. From very limited data, reservoir features appear to be less common inland away from the coast and the reef.

The Delray Dolomite tends to have better developed reservoir features than does the Cedar Keys A. Even so, it is desirable to take any single injection well through the Cedar Keys A to evaluate the maximum possible reservoir extent. At least the first well of a multi-well project should fully penetrate the Cedar Keys A, and if too little reservoir is present in that unit, subsequent wells can bottom at shallower depths. The Rebecca Shoal Dolomite reef section always contains good reservoir features.

From examination of video-tapes and lack of long bit-drops, I have concluded that most if not all of the black "cavern" features on video-tapes are the result of excessive wall-collapse hole enlargements and are not actual caverns.

In searching for fractures in the so-called "confining zone" in the Avon Park, the downhole video survey is a useful tool for their identification.

ABSTRACT

Boulder Zone boulders are man-made. They are produced by chunks of dolomite falling to the bottom of the drill hole where they are rolled around by the drill bit. If not drilled up, they must be fished out. Boulder-producing dolomites are characterized by the presence of wall features such as cavities and wall-collapse zones. Wall features are unrelated to dolomite textures, referred to herein as the Dolomite Triad consisting of euhedral, anhedral and cryptocrystalline types. Lithologic data in the southeastern Florida Peninsula are from injection wells drilled by the reverse air method.

The Delray Dolomite, averaging 250 feet in thickness, consists of a lensing or interfingering of the three textural varieties, anhedral being the most common. The Delray Dolomite occurs everywhere, but thins over the Rebecca Shoal Dolomite reef, suggesting that the basal Delray elsewhere is a lagoonal equivalent of the reef. In the Keys, limited data show the same Dolomite Triad to be present, but here there is a limestone bed in the middle of the unit. In one well this limestone directly overlies the Rebecca Shoal reef, further demonstrating the equivalence of the lower Delray Dolomite with the uppermost reef section.

Cedar Keys A, averaging 250 feet in thickness, consists of the same Dolomite Triad found in the Delray Dolomite. Cedar Keys A occurs everywhere except where the main body of the Rebecca Shoal reef is present. This absence of Cedar Keys A demonstrates that it is the lagoonal equivalent of the reef. The age of the Delray Dolomite and Cedar Keys A is indeterminate, but lies somewhere within the Lower Eocene-Upper Paleocene interval.

Continuity of the Dolomite Triads in the Delray Dolomite and the Cedar Keys A between closely spaced wells is virtually non-existent, but gross lithologic assemblages do extend laterally at multi-well sites. Regionally there is no continuity of the Dolomite Triad members.

Cedar Keys B consists mostly of fine microcrystalline euhedral dolomite. Only in Brevard County does it contain enough Boulder Zone wall features to be included in the Boulder Zone. Avon Park dolomites, when thick, also contain some Boulder Zone wall features.

The Rebecca Shoal reef is present in the Keys and in the area adjacent to St. Lucie County in the Peninsula. Sparse lithologic data in the Keys shows the reef and its Tavernier and Plantation Tongues to consist of euhedral and anhedral dolomite. Porosity is mainly intercrystalline with some vugs. Large caverns have been reported in the lower reef section in several wells. In the St. Lucie County area, injection wells penetrated several hundred feet of Rebecca Shoal reef. Here good lithologic data show the same reef lithology as in the Keys. By regional correlation, the age of the upper Rebecca Shoal (Tavernier) is essentially Paleocene and the middle Rebecca Shoal (Plantation) is Upper Cretaceous.

In the southeastern Peninsula, regional structure on top of the Delray Dolomite or Cedar Keys A dips southward from Brevard County into a large low area occupying most of Broward County. Dip reverses southward into Dade County. Faulting is present in Brevard, Palm Beach and Dade Counties, as shown by missing section or by structural anomalies between closely spaced wells.

Video tapes of injection well boreholes into Boulder Zones reveal the presence of cavities and vugs of various sizes, wall-collapse zones and wide vertical channels, all of which contribute to the reservoir permeability and capacity. Wall-collapse zones are created by intersecting open fractures, which when exposed by drilling, collapse into the hole due to the lack of support. Thick wall-collapse sections appear to be associated with faults. Cavities, large horizontal openings which frequently encompass the entire wall of the hole, may be several feet in diameter. There are no valid explanations for their origin, only speculations. Large vugs and vuggy zones occur sporadically. In the study area, true caverns have been identified only in the Rebecca Shoal reef. In the main body of the reef in the Keys they all occur some 2,000 feet below the top. This suggests a possible subaerial origin, but the absence of a significant sea level fall in the middle of the Upper Cretaceous mitigates against this explanation. The uncommon vertical channels are obviously solution-enlarged fractures. Continuity of Boulder Zone wall features between closely spaced injection wells is limited to wall-collapse zones.

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INTRODUCTION

Background

The study area is shown on Figure 12. Well control is shown on the structure and isopac maps (Figs. 30 & 31).

Boulders Zone boulders are man-made. They are produced by chunks of dolomite falling to the bottom of the drill hole where they are rolled around by the bit. If not drilled up, they must be fished out.

All lithologic and video descriptions used to prepare this study are original.

Prior to the early 1970's, cuttings from boulder-producing dolomites in oil tests using the conventionl hydraulic rotary drilling method were unavailable, due to loss of drilling fluids and cuttings into cavity-riddled dolomites. With the advent of reverse air drilling of injection wells (page 63), cuttings became available. Lithologic data are necessary to pick formation boundaries--geophysical logs alone are occasionally insufficient for this purpose.

Video tapes of injection well boreholes reveal the true nature of Boulder Zone features in the Delray Dolomite (herein formally introduced--see Appendix), Cedar Keys A, and locally in the Rebecca Shoal, Cedar Keys B and Avon Park dolomites. Lithology and video-tapes, backed up by geophysical logs, provide the basis for this study.

In the Keys, the Rebecca Shoal reef units have been penetrated only by oil tests. Due to partial or total loss of circulation, only limited lithologic data are available.

Injection well numbers on the various maps are those used by the Florida Department of Environmental Protection when this study started in early 1993. Oil tests (small numbers and dots on maps) are identified by Permit Numbers. Well numbers in the text are occasionally followed by the same two or three-letter county designations used on the maps to facilitate locating them.

As the well sections shown on the regional stratigraphic cross-sections (Fig. 32) are entirely dolomite, it was not necessary to show lithology. Showing the vertical distribution of dolomite textural varieties on these wells would have made the size of the cross-section unmanageable for publication. To show the local horizontal and vertical variability of dolomite textures, a lithologic cross-section of the Delray Dolomite at four-well site 51 is included (Fig. 5).

Boulders have been reported in zones which are known to be limestone. These boulders undoubtedly originate from higher dolomite beds that slough off and fall into the borehole during drilling.

The Oldsmar Formation of the northwestern Peninsula cannot be identified in the study area using the co-type criteria; therefore, in this project, the Avon Park Formation is extended down to the top of the Delray Dolomite (see Fig. 1).

There is no stratigraphic or structural evidence for unconformities between any of the Boulder Zone units or within the overlying Avon Park Formation. Interfingering of the units,as well as build-up of the Delray Dolomite into the Avon Park section, is demonstrable in several multiple-well sites.

Purpose

The purpose of this study was first to determine if there is any relationship between the dolomite textures of the Delray, Cedar Keys A, and Rebecca Shoal sections, and the occurrences of cavities, channels, wall-collapse zones, etc.

The second objective was to compare the lithologies and wall features, regionally and locally at multiple-well sites, to see if any trends were present to aid in predicting the occurrence of favorable injection zones.

Methods

To acquire lithologic data, drill cuttings were examined with a 10 power microscrope from sixty-seven injection wells in the southeastern Peninsula and five oil tests penetrating the Delray Dolomite and deeper beds in the Keys. The overlying Avon Park section (see Fig. 1) was also examined in selected wells.

Next, the euhedral, anhedral and cryptocrystalline percentages for each well were plotted on a 5"=100' scale (using caliper logs when available) to compare with caliper log anomalies and with other wells.

Video tapes of the Delray Dolomite and older units were examined and the wall features plotted on a scale of 1"=10' over a color plot of the three dolomite varieties when lithologic data were available. Five litho-video logs are included (Figs. 21-25). Their titles contain the map reference numbers.

PREVIOUS INVESTIGATIONS

The papers discussed below are the only ones that present either lithostratigraphic data or cavity and cavern occurrences. Papers which deal with hydrologic aspects of the Boulder Zone in the southeastern Peninsula are listed in the bibliography. Many papers mention or discuss the Boulder Zone, but present no data on lithologic or other geologic aspects. In use in the field since 1943, the term Boulder Zone was introduced into the literature by Kohout in 1965.

J. E. Banks (1950, Appendix 8) reported on Boulder Zone drilling difficulties. In Well 108MON (State Lease 363), Boulder Zones were encountered in the Delray Dolomite and the Rebecca Shoal Dolomite (Winston 1994a). Although no lithologic data were then available, many aspects of Boulder Zone drilling problems are discussed. Note that in Banks' discussion of the Rebecca Shoal intervals, the use of "limestone" is in error. At the time of writing, nothing was known of the true (dolomite) composition of these beds.

Puri & Winston (1974) mapped the occurrence of high transmissivity zones from limited lithologic data and driller reports of "Boulder Zone" or "cavity" occurrences. This study included what is now the entire Black Point and Rebecca Shoal units. In light of today's data, it is obsolete and of historical interest only. I since have described this investigation as "a study of nothing (cavities) with no data (lack of cuttings)".

Safko & Hickey (1992) describe wall features from video tapes of four wells in Brevard, St. Lucie and Palm Beach Counties. Written descriptions of features include those present in all or parts of the Delray Dolomite, Cedar Keys A, B, C, and the Rebecca Shoal.

STRATIGRAPHY

It is not within the scope of this project to compare and contrast the many different hypotheses for the formation of dolomite. The Bibliography lists a number of these, especially in regard to rocks involved in the Floridan Aquifer of which the Delray Dolomite and Cedar Keys A Boulder Zones are a part.

PRIMARY BOULDER ZONE FORMATIONS

DELRAY DOLOMITE

Southeastern Peninsula

Occurrence & Thickness

The Delray Dolomite occurs throughout the study area. It varies in thickness from 130 feet in the north (Well 81BRE) to 380 feet in Palm Beach County (Well 63). Farther south in Dade County, it thins to a minimum of 160 feet (Well 182). The average thickness is 250 feet.

The thickest Delray Dolomite occurs in an elongate trend just west of the Rebecca Shoal reef (Fig. 29a).

Lithology

Rarely preserved foraminifera and relic skeletal or oolite grains show that the Delray Dolomite was originally a limestone.

Today, the Delray Dolomite consists of three intermixed textures, euhedral (crystal faces visible), anhedral (crystalline but no faces visible), and cryptocrystalline (no crystalline structure visible) referred to herein as the Dolomite Triad. The euhedral variety is generally tan, orange/tan or cream, and fine to medium crystalline. Occasionally it exhibits intercrystalline porosity and a sucrosic texture. The anhedral variety is generally brown or orange/brown. Crypto-crystalline dolomite is usually cream or white. As it is typically lithographic in texture, this type has been mistakenly identified as chert.

In several wells, dolomite in the upper 100 feet of the Delray contains inclusions or thin beds of limestone. These are usually white, chalky micrite with dolomite crystal inclusions. On occasion, euhedral dolomites with white limestone inclusions are also present. In Well 26-1BRE limestone intercalations are skeletal grainstones with dolomite crystal inclusions. At site 37PB three of the five wells with sample data have occasional thin dolomite beds with limestone inclusions within the upper 150 feet. In Well 37-5 two dolomite beds in the upper Delray are glauconitic.

Correlation

Evidence from the following areas indicates that the lower 100 to 150 feet of the Delray Dolomite is equivalent to the uppermost Rebecca Shoal reef (Figs. 2 & 32).

In Martin County, in Well 53 the Rebecca Shoal reef is overlain by only 125 feet of Delray Dolomite. In Well 30STL near the lagoonal edge of the reef ten miles northwest, the Delray Dolomite is 200 feet thick. Away from the reef to the west and south (Fig. 29), thicknesses of 250 feet are the norm. Thus, over the reef the Delray Dolomite is 125 feet too thin.

In the Keys, Figures 3 & 4 indicate the same relationship. In the southernmost Peninsula, the Delray Dolomite averages 250 feet. In the Keys, where some aspect of the Rebecca Shoal reef complex is everywhere present, the overlying Delray Dolomite is some 100 feet thinner. Figures 3 & 4 show that the limestone bed overlying the Rebecca Shoal reef in Well 296 is the same limestone present in the middle of the Delray Dolomite in Wells 284 and 108, further demonstrating the relationship.

The Delray Dolomite is the basal section of the Oldsmar Formation in the northwestern Peninsula.

Age

There is no paleontological or other data to determine the exact age of the Delray Dolomite. Foraminifera in the overlying Oldsmar limestone (in the northwestern Peninsula) are Lower Eocene. Some 500 feet below the Delray Dolomite in Cedar Keys B, Paleocene foraminifera are present. As the Delray Dolomite and Cedar Keys A lie between these fossiliferous intervals, their age is in limbo.

If the upper Rebecca Shoal reef is entirely Paleocene, then Cedar Keys A and the lower part of the Delray Dolomite are also Paleocene, leaving only the upper Delray Dolomite as possibly Eocene in age. If the entire Delray Dolomite is Eocene, then the upper Rebecca Shoal reef is also Eocene!

Florida Keys

Occurrence & Thickness

The Delray Dolomite occurs throughout the Keys. Thickness ranges from 60 feet in Well 296 to 175 feet in Well 108.

Lithology

Among wells in the Keys, four contain at least a partial set of cuttings. Wells 295 and 284 contain complete but poor quality lithologic data. The Delray here contains the same Dolomite Triad lithologies found onshore, but here a persistent limestone bed is present in the middle of the unit.

In Well 296 (Figs. 2 & 3) this limestone consists of 15 feet of cream, coarse grain, skeletal limestone overlying Rebecca Shoal reef rock. The lower Delray Dolomite is missing. In Well 284 nine miles east, the middle limestone unit consists of 45 feet of micritic, cream, chalky limestone with inclusions of medium dolomite crystals. This limestone in turn overlies a basal Delray consisting of tan anhedral and medium to coarse crystalline euhedral dolomite overlying Rebecca Shoal reef rock.

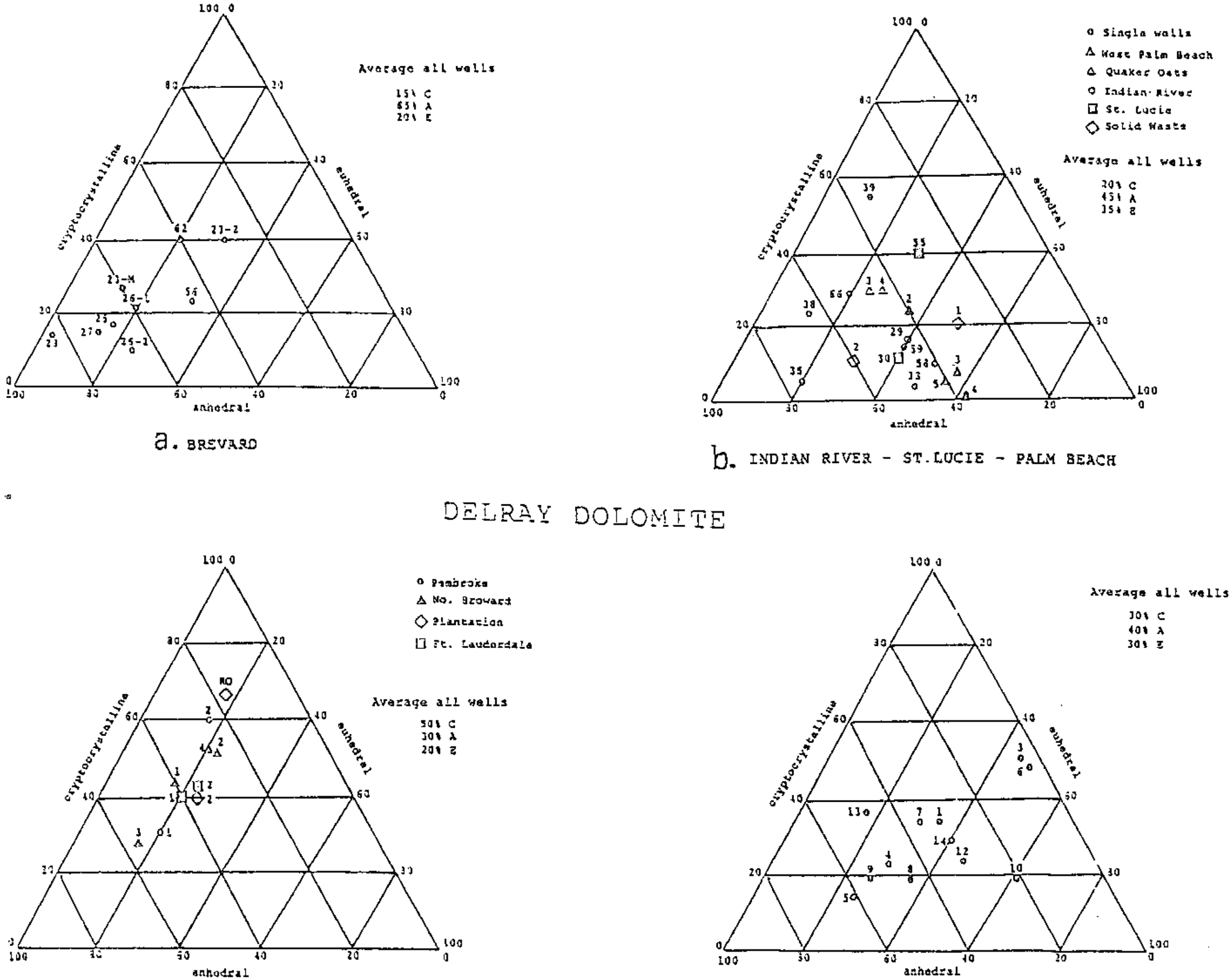
In the eastern Keys, Well 108 (Fig. 3) recovered samples only in the upper half of the Delray Dolomite. Here, 35 feet of dark brown and black cryptocrystalline and anhedral dolomite is underlain by 40 feet of the middle limestone unit, which is also micritic with inclusions of medium dolomite crystals, with masses of medium crystalline euhedral dolomite. Beneath this are two feet of blue-gray shale, which in turn overlies eight feet of gray cryptocrystalline dolomite. At that point, a cavern was reported and circulation was lost; no further cuttings were recovered.

Areal Distribution of the Delray Dolomite Triad

Figure A (page 15) shows how Dolomite Triad percentages are distributed over the study area from Brevard County in the north to Dade County in the south.

Percentage distribution of the Triad in counties north of Broward (Fig. 29 & Figs. Aa & b) are different from those within Broward (Fig. Ac), which in turn are also different from the distribution in Dade County to the south (Fig. Ad).

Individual beds of Triad members show little horizontal continuity between closely spaced wells (Fig. 5). Gross lithologic packages, however, do appear to extend horizontally. What geochemical processes formed these interbedded, interfingering, and intermixed textures cannot be determined from drill cuttings. Data from cores might provide some answers, but none have been taken in the in the study area.



a. BREVARD

b. INDIAN RIVER - ST.LUCIE - PALM BEACH

c. BROWARD

d. DADE
(Miami Dade Water & Sewer)
(South District)

Fig. A

Southeastern Peninsula

Occurrence and Thickness

Cedar Keys A occurs throughout this area, except where it is replaced by the Rebecca Shoal reef. Cedar Keys Units A, B, & C were correlated into the study area from the Cedar Keys Basin Reference Well in DeSoto County (Winston 1994b). Cedar Keys A, along with the lower Delray Dolomite, are lateral lagoonal equivalents of the upper Rebecca Shoal reef (see p. 10).

Thickness of Cedar Keys A vary from 70 feet in northern Brevard County (Well 25) to a maximum of 320 feet in Broward County (Well 46). It thins southward into Dade County to 150 feet. The average thickness in Brevard County is 150 feet; elsewhere it is 250 feet.

Lithology

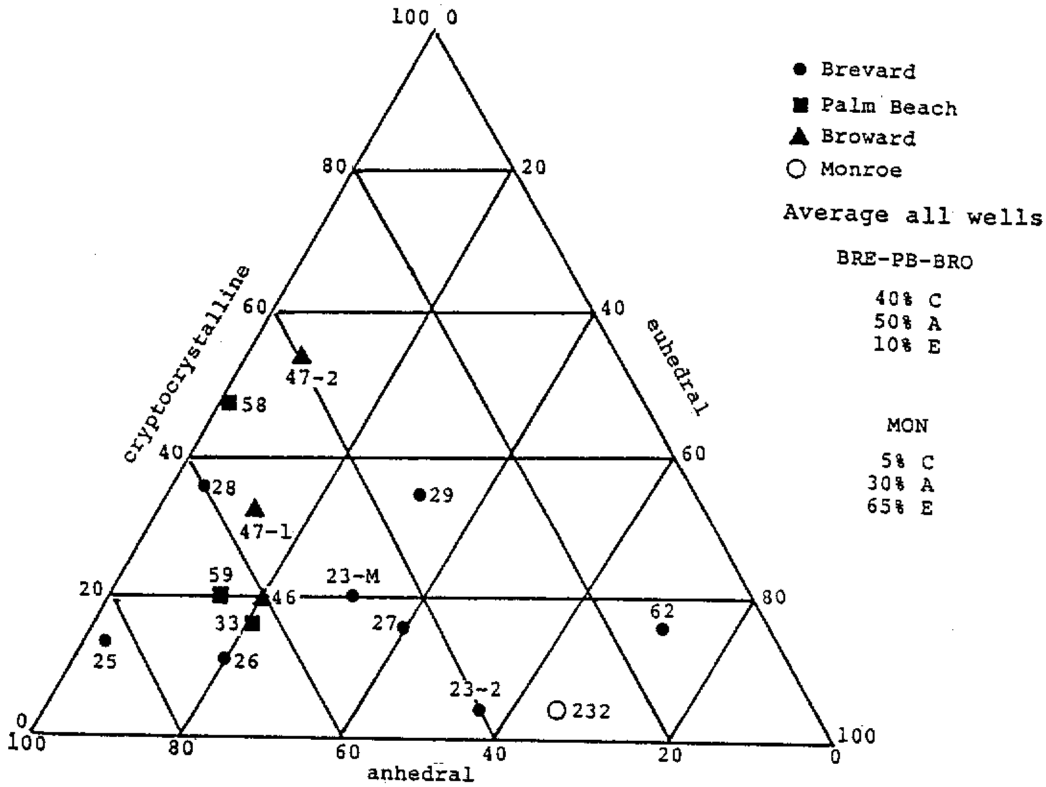
The regional distribution of the Dolomite Triad in the Cedar Keys A is shown on Figure B.

Fine microcrystalline dolomite occasionally interbedded with the Dolomite Triad in the basal Cedar Keys A is transitional between the evaporitic dolomites of the the older Cedar Keys Units and the non-evaporitic dolomites of the upper Cedar Keys A and Delray Dolomite.

Rarely preserved foraminifera and relic grain textures in Cedar Keys A suggests that it was originally a limestone.

No anhydrite occurs in Cedar Keys A in the study area, although anhydrite is present in the central basin. Regionally, Cedar Keys A is predominantly brown and tan anhedral dolomite with subordinate amounts of tan euhedral and tan to white cryptocrystalline dolomite.

Southward from Brevard County, euhedral dolomite percentages



Triangle Diagram of Cedar Keys A Dolomite Triad

Fig. B

decrease and crystal sizes become smaller. In Brevard and Indian River Counties, euhedral crystal size is very fine to medium, with little microcrystalline or fine microcrystalline dolomite. To the south in Broward County, fine crystal sizes are twice as common. No wells in Dade County penetrated enough Cedar Keys A to provide significant data.

Florida Keys

In Wells 108 and 148 where Cedar Keys A is interpreted to be present by E-log correlation (Figs. 3 & 6), no samples are available. In the other Keys wells, Cedar Keys A is absent, having been replaced in the section by Rebecca Shoal Dolomite reef rock.

Cedar Keys A is present north of the Keys in Well 232 (Fig. 4). Here it consists of tan, fine to medium crystalline euhedral dolomite, with subordinate amounts of tan to brown anhedral and cryptocrystalline dolomite. Vug and intercrystalline porosity is present in the euhedral variety. Here Cedar Keys A overlies Cedar Keys B.

SECONDARY BOULDER ZONE FORMATIONS

REBECCA SHOAL DOLOMITE REEF

Good data to determine the lithology of the Rebecca Shoal reef section and its Tavernier and Plantation Tongues is confined to Wells 259 and 772 in St. Lucie County, and to Wells 292 and 296 in the Keys. In Keys Wells 275, 284, 148, drill cutting recovery ranges from incomplete to practically nothing; no lithologic data are available from Wells 117, 108, 22, 280, 16, and 290. The only geophysical logs available on any of the Keys wells are electrical survey, laterolog or gamma ray neutron. A modern set of logs is available on Well 772STL, the only test drilled since 1962 to completely penetrate the Rebecca Shoal reef.

As no cavities were reported in the Card Sound Tongue of Rebecca Shoal (Well 148), it will not be discussed herein. For a full discussion of the Rebecca Shoal section, see Winston 1994a.

Occurrence & Thickness

In the Keys the Rebecca Shoal Dolomite reef occurs in a band some 20 miles wide (Fig. 6). It extends northward offshore up the east coast of the Peninsula, coming onshore in northeastern Palm Beach County. It continues onshore northward into St. Lucie County where it again goes offshore.

Maximum composite thickness of the Rebecca Shoal Dolomite reef is 3,000 feet.

Lithology

Florida Keys

In Wells 284 and 296, the Plantation and Tavernier Tongues are inseparable, either by lithology or on geophysical logs (Fig. 8). In these wells dolomite of the combined units is brown, tan, cream and white, anhedral, cryptocrystalline, and contains fine to coarse crystalline euhedral textures. Anhedral dolomite contains up to 15% pinpoint and vug porosity; euhedral dolomite contains up to 15% vug and intercrystalline porosity. The combined section overlies white, chalky Pine Key limestone.

The Plantation Tongue (Figs. 28 & 9) is present in Wells 108, 117, 22, 280, 16, and 298. Cuttings are available only on Well 298 where incomplete data show that it consists of anhedral, cryptocrystalline, and fine to medium crystalline euhedral dolomite. Colors are orange-tan, brown and gray. Vug porosity ranges up to 15% in anhedral dolomite, and 5% in euhedral dolomite. The gamma ray log of Well 292 (twin to 298) and regional knowledge, indicate that non-reef carbonates occur above and beneath the Tongue.

By E-log correlation, the Plantation Tongue is equivalent to Cedar Keys D through F and to the upper Pine Key Formation, and is therefore considered to be mostly Upper Cretaceous in age; no paleontologic data are available.

The Tavernier Tongue (Figs. 2, 8 & 9) is present in Wells F, 148, 108, 22, 280, 16, 275, 298 and 292. Again in Well 298 only incomplete cuttings are available. Here the dolomite is orange-tan and brown, anhedral and fine to coarse crystalline euhedral. Up to 25% intercrystalline porosity is present in the euhedral variety; 5% vug porosity is present in some anhedral dolomites.

E-log interpretation on Wells 16, 22, 292, and 148 where no lithologic data are available suggests that the Tavernier Tongue is overlain and underlain by normal Cedar Keys microcrystalline dolomite.

On geophysical logs of Well 275, the Tavernier Tongue appears to be overlain by the Delray Dolomite; sample data show the Tongue to be underlain by Cedar Keys microcrystalline dolomite. Anhydrite nodules in the underlying Cedar Keys lithology show Well 275's proximity to the basin evaporitic facies. The E-log on Well 108 suggests that here the reef is overlain by atypical Cedar Wells A lithology. In Well 148, E-log character indicates that the Tavernier Tongue is overlain by Cedar Keys B lithology, which in turn appears to be overlain by the same atypical Cedar Keys A lithology present in Well 108.

By regional E-log correlation, the Tavernier Tongue is essentially equivalent to Cedar Keys A through C, and is therefore mostly Paleocene in age. No paleontologic data are available.

St. Lucie-Palm Beach Area

In St. Lucie County, two oil tests (259 and 772) completely penetrate a combined Tavernier-Plantation Rebecca Shoal reef section (Fig. 10). In these wells, it consists mostly of cryptocrystalline and anhedral dolomite, with occasional beds of fine to medium crystalline euhedral dolomite. Vug porosity is characteristic in anhedral dolomite. Dolomite crystal linings of vugs or fractures are prevalent in cuttings. The core photographs from Well 259STL (Fig. 11) show the talus nature of the lower reef complex at 5034 feet.

In St. Lucie, Martin, and northeastern Palm Beach Counties, five injection wells with available cuttings penetrate several hundred feet of the uppermost Rebecca Shoal reef (Fig. 29). In these wells Rebecca Shoal colors are cream, orange-tan, and light gray. Euhedral dolomite is fine crystalline and occasionally sucrosic, with up to 15% intercrystalline porosity. Anhedral dolomite is prevalent and generally non-porous. The occasional cryptocrystalline dolomites are lithographic and white.

Notes on Rebecca Shoal Caverns

Data on Boulder Zone features (Table 1) in Wells 117 and 108 in the Keys and Well 259 in St. Lucie County are from the reports of well-site geologists. On all other wells, data consists of drillers' notations abstracted from Florida Geological Survey files. Caverns are the dominant reported large openings in the Rebecca Shoal in the Keys. Notations of boulders or "rough drilling" (Table 1) could either indicate cavities or the collapse of fractured wall rock.

The lack of driller notations of boulders, cavities or caverns does not necessarily mean that none were encountered, but only that the State received no reports. The first depth recorded for their occurrence on Table 1 is probably the depth of their origin--subsequent close boulder entries frequently reflect further caving from the original source, rather than new sources.

Reported caverns are all near the base of a Tongue or the continuous reef (Figs. 8, 9, & 10); no explanation is available for these basal positions. The possibility of subaerial origin seems unlikely as no major sea level falls are known for the appropriate intervals (see page 61).

In Well 290, a twist-off at 4686 feet, some 900 feet into the Rebecca Shoal reef, suggests the presence of a cavern there or within a couple of hundred feet up-hole. The depth of the twist-off would correlate with the base of the Tavernier Tongue in Well 296.

In Well 292 a 50-foot cavern was encountered. The well was

Reports of BZ Phenomena in Oil Tests

Co.	Per No.	feature: cav	feature: boulder	depth	FM	Remarks
Mon	290		X	4086-4338	RS-Tav	junked in RS - twist off
	285		X	3400	AP-ls	junked in top LK
						source of boulders unknown from available data
	292		X	4156	RS-Tav	junked - skidded to P 398
			X	4551-5410	RS-Tav-P	rough drilling
		X		5270-5320	RS-P	
	298	X		5210-52	RS-P	twist off
	16			3070	DD	bridge
				3267	RS-Tav	bridge
				3387	RS-Tav	bridge
	280		X	3163-285	RS-Tav	one mile west of P 22
			X	3602-73	RS-Tav	
			X	4705-83	RS-P	
	108	X		3610	DD	junked in top LK
		X		5615-22	RS-P	
		X		5648-58	RS-P	
		X		5705-15	RS-P	
			X	5740	RS-P	
			X	5780	RS-P	
			X	5830	RS-P	
			X	5950	RS-P	
	117			3570-80	RS-Tav	water flow
		X		4285-300	RS-Tav	
				4980-5000	RS-P	rough drilling - junked in lower UK?
Dade	182		X	3085-156	DD	
			X	3195-405	CKA&B	perhaps caving from DD
			X	3502-84	CK B	
	376		X	2618-910	AP	possibly from Avon Park stray dolomite
	386		X	2540-3224	?	from above AP stray dolomite into CK A -
						- source cannot be determined
St. L	254			3481-83	RS-Tav	cavity - data from geologist's log
				4230-31	RS-P	cavity
				5148-51	RS-P	cavity
				5173-78	RS-P	cavity - junked in base RS-P
	259	X		5277-94	RS-P	data from geologist's log (twin to P 254)

junked and skidded 790 feet southeast (Well 298). Here the cavern was again encountered but it was only 40 feet thick, and was 50 feet higher structurally.

Junked wells in the Keys are usually the result, directly or indirectly, of caverns in the Rebecca Shoal reef.

CEDAR KEYS B

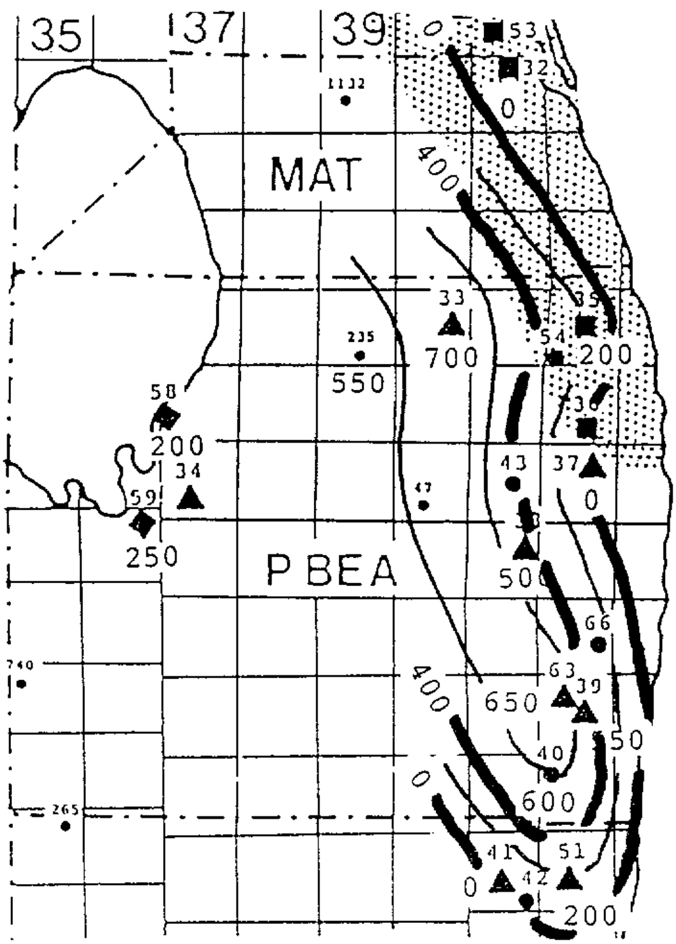
Five injection wells, four in Brevard County and one in Broward (Fig. 29) 120 miles to the south have complete data on Cedar Keys B. Video tapes show large differences in the type and frequency of wall features in this section.

In the four wells with samples, Cedar Keys B is almost universally brown, tan, and gray, fine microcrystalline to chalky dolomite. In Well 46-3BRO Cedar Keys B has numerous beds containing very fine to medium size relic skeletal grains with 5-15% inter-granular and moldic porosity. In contrast, Cedar Keys B dolomites in the Brevard wells, while identical in color and crystal size, lack relic grain textures and their accompanying intergranular porosities.

In southwest Dade County in Well 168, Cedar Keys B consists of cream and tan fine microcrystalline euhedral dolomite with occasional thin beds containing relic pellet and skeletal grains. No porosity was observed. Anhydrite nodules and selenite filling of former porosity is common.

AVON PARK FORMATION

In Dade and Broward Counties the Avon Park is predominantly a limestone, with a thin dolomite bed in the lower section (Fig. 1) occasionally containing Boulder Zone features. In Palm Beach County a thick dolomite is present (Figs. C & 1) extending



CI 200 feet

Isolith Lower Avon Park Dolomite

Fig. C

northwest from Well 40 through Well 33. Avon Park Dolomite in this trend is mostly euhedral with occasional anhedral and cryptocrystalline beds. The euhedral dolomite is microcrystalline to fine crystalline with much 5-20% intercrystalline and vug porosity. The few video-tapes to include the lower part of this thick dolomite reveal the presence of numerous large vugs and occasional cavities.

East of this trend, Well 37-27 in the West Palm Beach injection site (Fig. 14) has only minor dolomite in this interval. Limited data on field wells to the west show a rapid increase in dolomite westward toward the thick dolomite trend.

STRUCTURE

An occasional rapid change in facies between the basal Avon Park limestone and the upper Delray Dolomite makes the top of the Delray Dolomite an unreliable mapping surface at multiple-well sites. Unfortunately, at most sites, it is the only horizon available on all wells.

The top of the Cedar Keys A is a better mapping horizon, but it is less frequently penetrated (Fig. 29). Also, near the locale of the Rebecca Shoal reef, it is occasionally difficult to establish.

Regional Structure

Basins and arches of the Peninsula are shown on Figure 12. The Peninsular Arch plunges to the southeast into a broad low on top of the Delray Dolomite and Cedar Keys A centered in Broward County (Fig. 30). A ridge separates this low from the main South Florida Basin to the west.

The Delray Dolomite structure map (Fig. 30a) shows a gentle southward dip from -2500 feet in Brevard County to -3000 feet in central Broward County. Southward into Dade County, dip is reversed.

The Cedar Keys A structure map (Fig. 30b) shows essentially the same major features.

Faulting

All known or suspected faults are normal faults.

Duncan et al (1994) present data for the presence of at least one down-to-the-west fault in coastal Brevard County. With the additional material derived from my study of the Delray Dolomite-Cedar Keys C section in this county, I would place the faulted Wells 25 and 56 of Duncan, et al. (Fig. 13), on a fault to the east, with Well 24. Duncan et al connected Well 24 with Well 25 (Fig. 32). I place Well 25 on a parallel fault to the west. Bermes (1958) and Lichtler (1960) present evidence for down-to-the-<u>east</u> faulting along coastal Martin and Indian River Counties (Fig. 31).

Discovery of the following three new faults in this study was serendipitous. Their age is unknown; age determination would require large amounts of data on shallow horizons, the acquisition of which was beyond the scope of this project.

Contouring on the Delray Dolomite and Cedar Keys A structure maps (Figs. 30a & b) in northern Brevard County requires the presence of a down-to-the-<u>west</u> fault between well sites 62 and 23. Its presence is supported by the absence in well 62 of 150 feet of Cedar Keys B (Figs. 13 & 31). Cross-section A-B (Fig. 32) also shows an anomalous 100-foot thinning of the Cedar Keys A in Well 25. A similar thinning is present in Well 56 (Fig. 29a).

At the West Palm Beach site (Fig. 14), contouring also requires the presence of a fault. Structure cross-sections (Figs. 18a & b) support its presence.

One (and possibly a second) fault is present at Dade County Site 50 (Figs. 15 & 16).

Figure 31 shows faults, proven (in black) and suspected (in red), in the southeastern Peninsula. These faults and projections are controlled by various data from 17 wells and from publications by Bermes, Lichtler, and Duncan et al. The original fault projection of Duncan et al in Brevard County is shown by short dashes. The faults of Lichtler and Bermes and the one at Site 50 are down-to-the-<u>east</u>. The faults in Brevard County and at Well Site 37 are down-to-the-west. These opposite displacements suggests the presence of two regional fault trends with a horst in between.

Thick wall-collapse in Wells 33, 43, 39 and in 40 suggests another fault trend west of the horst. Projecting the suspected fault in Well 33 to the north encounters oil test well 1032, on which no shallow data are available. This well might have been drilled on an extension of this suspected fault.

The down thrown sides shown on suspected faults are interpreted from associated proven faults. No down thrown side is shown on the two short suspected faults west of the main trend in Palm Beach County as they are not on trend with known faults from which the down thrown side could be inferred.

Local Structure

A broad, elongate high is present on both regional structure maps (Figs. 30a & b) in the area of southwest Dade and southeast Collier Counties.

Local Structure at Multiple-Well Sites

Only at sites 50 and 37 does well spacing permit construction of structure maps (Figs 14, 15 & 16). The in-line position of wells at other sites makes construction of structure maps impractical.

Structure Maps

West Palm Beach (37) (Fig. 14)

The six wells at this site show steep (for Florida) north dip is shown with strong evidence for a down-to-the-west fault trending generally north-south.

Miami-Dade Water & Sewer (50) (Figs. 15 & 16)

This site has 17 injection wells some 700 feet apart in the shape of a distorted hemisphere approximately 1 mile by 1/2 mile in size. The two sets of structure contours shown on Figures 15 and 16 are on an Avon Park dolomite bed and the Delray Dolomite.

Using my premise that where there is thick wall-collapse there is a nearby fault, I have interpreted a down-to-the-east fault between Wells 2 and 6, both of which, along with parallel Wells 3 and 4, contain thick wall-collapse (Fig. 16). Displacement of this fault on the Avon Park dolomite bed is some 20 feet; on the Delray Dolomite map it is 35 feet. A fault in this position simplifies structure contouring and explains the presence of several anomalous subsea elevations on the eastern side of the site.

In the west part of the field, thick wall-collapse suggests the presence of a second fault in the vicinity of Wells 9 and 15. Only structural data on the Delray Dolomite supports its presence; data on the Avon Park dolomite bed map is indeterminate. Between the faults this map shows gentle dip to the northeast, while the Delray Dolomite map shows a syncline plunging gently to the northeast.

Structural Cross-Sections

In-line multiple-well sites (Figs. 17 & 18) are mapped on the Delray Dolomite. Where Cedar Keys A penetrations are available, structural profiles on that horizon are also presented. Cedar Keys A structure generally follows Delray Dolomite structure, except at the Plantation and SWA sites.

Steep dip is featured at Pembroke Pines (47, Fig. 18b), Margate (42, Fig. 17c), Palm Beach South (63, Fig. 17e), Harris (26, Fig. 18h), and the west side of Broward North (51, Fig. 18d). Moderate dip is shown at the other five sites with Plantation (45, Fig. 18e) showing no dip.

Plotting the dips in feet per mile from the Broward and south Palm Beach multiple-well sites on a map (Fig. 19). Dips are westward from the coast, and eastward from inland producing a linear trend which may or may not be significant.

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Appendix 1

GLOSSARY

<u>Dolomite Triad</u> - This term is used in this publication to include the three following dolomite texture varieties.

<u>Euhedral Dolomite</u> - Rhombic crystals are visible; sucrosic dolomite is always euhedral, but euhedral dolomite need not be sucrosic.

<u>Anhedral Dolomite</u> - Light reflections indicate a crystalline structure, but rhombic crystals are not visible. In this variety the crystals are interlocking.

<u>Cryptocrystalline Dolomite</u> - Has a smooth appearance with no crystal reflections; in some cases it is lithographic and may have conchoidal fracture, thus resembling chert.

<u>Boulder Zone</u> - A section of any dolomite interval in which, either from the breaking in of the roof of a cavity by the drill bit, or from the collapse of highly-fractured dolomite in the wall of the drill hole, large pieces of dolomite are deposited in the bottom of the hole. When drilled, these large fragments behave as if they were in-place boulders, hence the name bestowed by the early drillers in Florida.

<u>Dredging</u> - The term applied to re-drilling of rock which continually falls in the hole from wall-collapse zones. In large diameter injection wells, much more rock collapses than in the smaller hole of oil tests. In injection wells this process can take several days to deplete the zone of collapsing rock, and can produce truck-loads of cuttings and gravel.

<u>Floridan Aquifer System</u> - In the southeastern Peninsula includes rocks from the base of the Hawthorn into Cedar Keys B.

<u>Suite</u> - A vertical grouping of lithologies distinguished from adjoining vertical groups by a distinctive lithologic assemblage.

<u>Format</u> - Informal rock-stratigraphic unit bounded by marker horizons believed to be isochronous surfaces that can be traced across facies changes, particularly in the subsurface, and useful for correlation between areas where the stratigraphic section is divided into different formations that do not correspond in time value. (Dictionary of Geological Terms 1984)

APPENDIX 2

DELRAY DOLOMITE TYPE DESCRIPTION

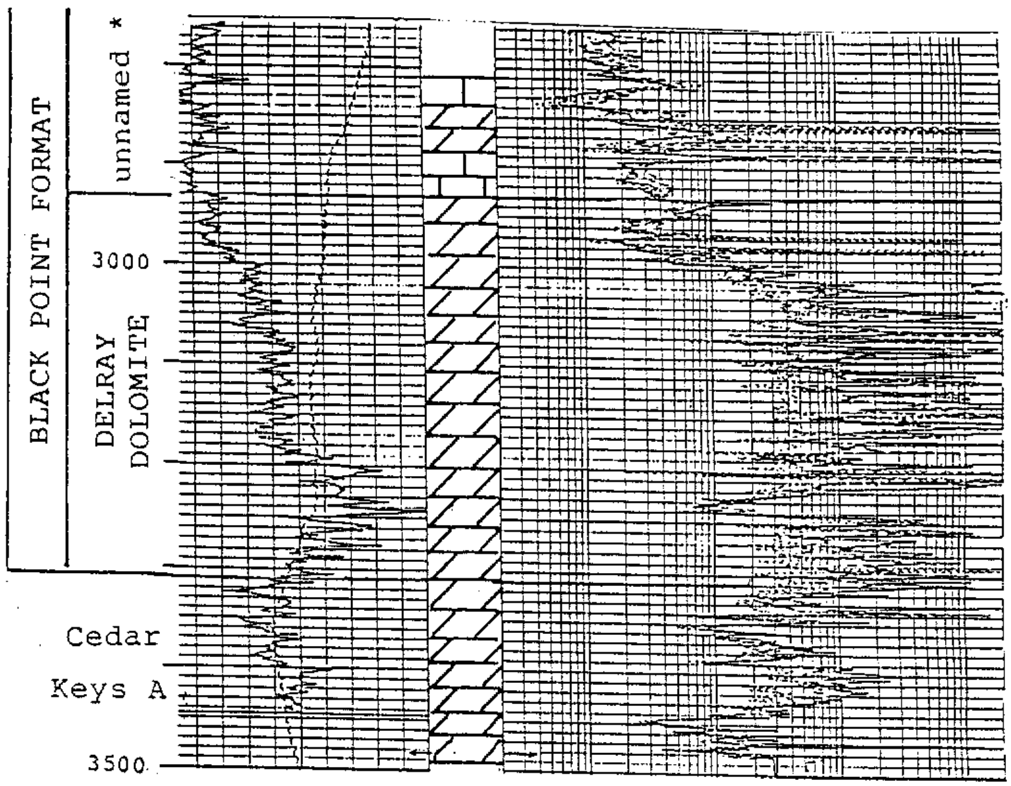
The type well for the Delray Dolomite is the Palm Beach Co. System 3 No. 1, Sec 10-T46S-R42E, Palm Beach County, Florida. The type interval is 2940-3315 feet in samples and 2930-3305 feet on the GR-DIL log. The name is derived from the adjacent village of Delray Gardens, 1 mile northeast of the type well. The maximum thickness is 350 feet in eastern Palm Beach County. The lithology is everywhere dolomite and consists of the three varieties - anhedral, euhedral and cryptocrystalline.

No age diagnostic fauna are present although occasional relic miliolids occur. No other age data are available. The Delray Dolomite could be of Early Eocene age, as is the overlying limestone, or Late Paleocene age as the underlying Cedar Keys Unit A is presumed to be. The upper boundary is conformable with and interfingers with overlying limestone except in the southwestern Peninsula, where occasionally it is contiguous with an overlying dolomite making identification difficult or impossible. The lower boundary is conformable and is defined by the change from brown and tan dolomite of the Delray Dolomite above to gray cryptocrystalline or anhedral dolomite of the Cedar Keys A Unit below. On rare occasions in the southeastern Peninsula the gray color is missing and the top of the Cedar Keys must be picked on geophysical logs.

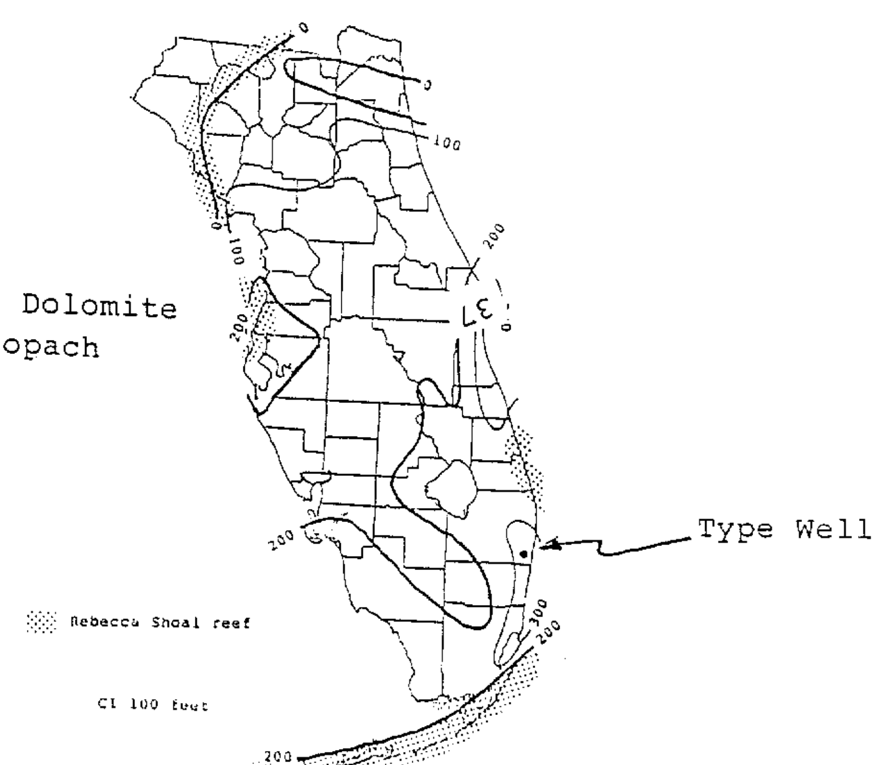
The type description of the Delray Dolomite follows.

2936-49	Ls	micrite, white, chalky
		DELRAY DOLOMITE
2940-50	Dol	cryptocrystalline, orange/tan, inclusions cream lithographic
2950-52	Dol	euhedral, orange/brown, fine crystalline
2952-54	Dol	anhedral, dark brown & orange/brown
2954-62	Dol	cryptocrystalline, orange/tan & cream
2962-68	Dol	anhedral, orange/brown & orange/tan
2968-3010	Dol	same with occasional inclusions of cream lithographic
3010-20	Dol	same with some gray
3020-30	Dol	euhedral, orange/brown & gray, medium crystalline
3030-35	Dol	anhedral, orange/tan
3035-40	Dol	cryptocrystalline, white, lithographic
3040-45	Dol	cryptocrystalline, light gray & orange/tan
3045-60	Dol	anhedral, orange/tan, mottled dark brown & gray/brown
3060-78	Dol	cryptocrystalline, light gray
3078-80	Dol	anhedral, orange/tan
3080-3115	Dol	cryptocrystalline, light gray & tan
3115-22	Dol	anhedral, orange/brown
3122-43	Dol	cryptocrystalline, light gray
3143-53	Dol	euhedral, orange/tan, very fine crystalline
3153-60	Dol	cryptocrystalline, orange/tan with cream inclusions
3160-74	Dol	cryptocrystalline, cream mottled with brown, relic skeletal texture
3174-83	Dol	anhedral, orange/brown with cream lithographic inclusions
3183-95	Dol	cryptocrystalline, light gray
3195-3205	Dol	cryptocrystalline, tan, lithographic
3205-10	Dol	cryptocrystalline, light gray, lithographic
3210-30	Dol	cryptocrystalline, orange/brown & orange/tan, occasional cream lithographic inclusions
3230-40	Dol	cryptocrystalline, cream, occasional breccia, tan, lithograhic fragments cemented with brown anhedral dolomite
3240-50	Dol	cryptocrystalline, same with more breccia; fracture linings of fine crystalline euhedral dolomite
3250-60	Dol	cryptocrystalline, tan mottled with gray, streaks of relic skeletal texture & miliolids
3260-85	Dol	anhedral, gray/tan & orange/tan
3285-90	Dol	cryptocrystalline, cream, skeletal, oolitic grainstone, medium to coarse grain
3290-94	Dol	cryptocrystalline, cream, lithographic
3294-98	Dol	cryptocrystalline, orange/tan
3298-3300	Dol	euhedral, orange/brown, medium crystalline, sucrosic
3300-10	Dol	anhedral & cryptogrystalline, orange/tan
3310-14	Dol	cryptocrystalline, cream with relic (skeletal?) texture, very vague; occasional breccia, cream, cryptocrystalline fragments cement with brown anhedral dolomite
3314-15	Dol	grainstone, tan, medium to coarse grain oolites
		CEDAR KEYS A
3315-22	Dol	cryptocrystalline, mottled gray & light gray, lithographic, inclusions of tan cryptocrystalline

PB County System 3 (39)



* The Delray Dolomite and the overlying section is the time equivalent of the Oldsmar Formation.



CEDAR KEYS

Considerable confusion is present in even identifying the type well for the Cedar Keys Formation. It was named by Cole (1944, p. 28) probably from a well in Levy County known at the time as "Cedar Keys No. 2", but which is now known as the Florida Oil Dev. No. 2 Scholtz Land. Cole did not specify a depth for either the top or the base of the unit in this well, and in his paper he only mentions a depth from the St. Mary's River 1 Hillard well across the state in Nassau County. Although there is some contention that the Hillard well is the type locality, Cole's selection of "Cedar Keys" as the name for the formation strongly points to the "Cedar Keys No. 2" well as the type locality. No one in the ensuing 32 years has seen fit to formally designate a type well or interval for the Cedar Keys, so I herein formally propose the Florida Oil Development No. 2 Scholtz Land well drilled in 1939 in Sec 9-T15S-R13E, Levy County as the type well. It is catalogued in the Florida Bureau of Geology files as W-355 (no permit). The type interval is designated at 1856 ft to 2490 ft.

Original Type Well Description

None was presented by Cole (1944). The Cedar Keys in his definition ". . . is designated to cover . . . (the interval) from the first appearance of the *Borelis* fauna to the top of the Upper Cretaceous" (depth or criteria unspecified).

Applin and Applin (1944) presented a description of the No. 2 Scholtz well on their graphic log illustration (p. 1752) and it is here presented . . . . as a substitute for the non-existent original description. (Winston 1977)

In the adjacent Section 16, Coastal drilled the No. 2 Ragland. As this well has an E-log, it was designated the co-type well (Winston 1977); the lithology is described below.

Co-Type Well: Coastal 1 Ragland, P 66, 16-15S-13E, Levy County

Co-Type Interval: (revised) 1805-2540 feet E-log; 1800-2565 feet samples

Co-Type Description: At the top is 20 feet cryptocrystalline tan dolomite with anhydrite nodules. Beneath is 60 feet of euhedral dolomite, tan and brown, medium crystalline and porous. This section is Rebecca Shoal Tavernier Tongue.

Beneath this section is 685 feet of interbedded euhedral, gray, chalky dolomite and very fine microcrystalline tan dolomite with relic skeletal grains. Anhydrite nodules are prominent in the lower 430 feet, and one anhydrite bed is present.

Basin Reference Well: Amoco 19-2 Knight, P 679, 19-36S-27E, DeSoto County

Reference Interval: 2880-5375 feet E-log; 2880-5400 feet samples

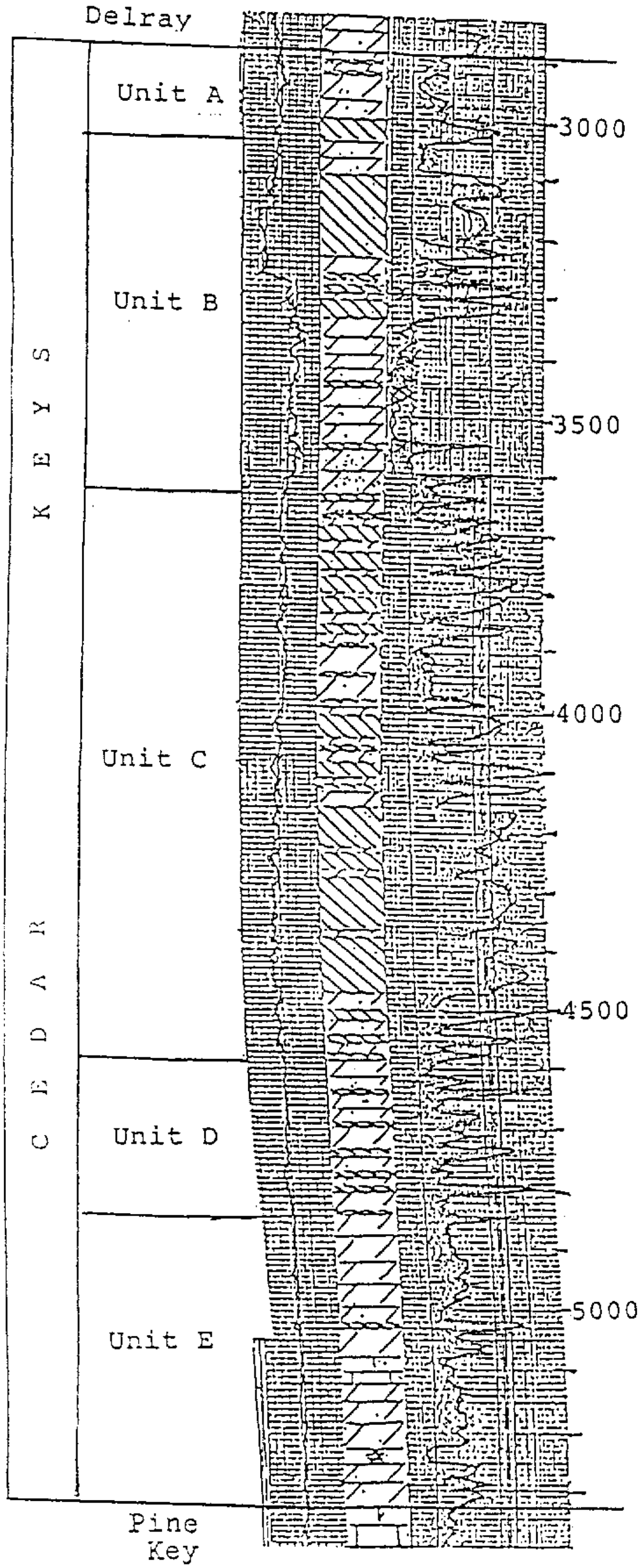
Reference Description: The Cedar Keys is subdivided (Winston 1994) into six units. Unit A consists of 170 feet of gray and tan, cryptocrystalline and microcrystalline euhedral dolomite with relic skeletal texture and bedded anhydrite. Unit B consists of 590 feet of gray and cream microcrystalline euhedral dolomite and anhydrite. Unit C consists of 925 feet of anhydrite with interbedded dolomite, tan, cream and gray euhedral microcrystalline to chalky with occasional relic skeletal texture. Unit D consists of 290 feet of gray and cream microcrystalline euhedral dolomite with interbeds of anhydrite. Unit E consists of 250 feet of cream and gray euhedral microcrystalline to chalky dolomite with one thin anhydrite. The underlying 250 feet represents an interfingering of Cedar Keys and Pine Key lithologies. The

P 679

BASIN REFERENCE WELL

&

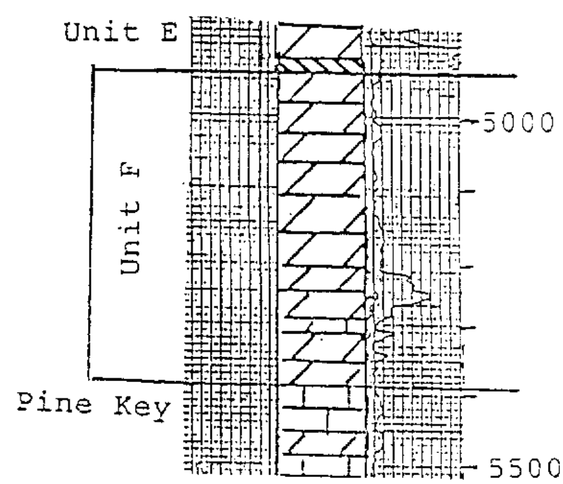
TYPE WELL FOR
SUBDIVISIONS A-E



P 167

TYPE WELL FOR

CEDAR KEYS UNIT F



basal unit has a 40-foot bed of skeletal limestone and another of white chalk.

Unit F is not present in the reference well. Well 167DAD is designated the type for the Unit F. It consists of 560 feet of anhedral, cryptocrystalline and microcrystalline euhedral dolomite. Relic pellet and oolite texture is common in the upper 300 feet. Interfingering with the Pine Key Formation is common in this unit.

Comments: Few oil tests penetrating the Cedar Keys recover samples from the top. Circulation is usually lost in the overlying Black Point Format rocks, and casing is not set until several hundred feet into the Cedar Keys, from which point samples are again recovered. P 679 was selected as the Basin Reference Well because it had samples across the boundary, and was in the thicker portion of the anhydrite development.

Thickness Range: 485–2470 feet

Age: Paleocene and Late Cretaceous by paleontology (Cole 1944), Applin and Applin 1944, and Vernon 1951). Vernon states that ..."the Upper Lawson [now incorporated in the basal Cedar Keys] is a transitional bed including fossils characterizing both Paleocene and Cretaceous."

Fauna: Borelis gunteri and B. floridana in Unit B. See Vernon 1951 and Applin and Applin 1944 for fauna in the now-abandoned Upper Lawson.

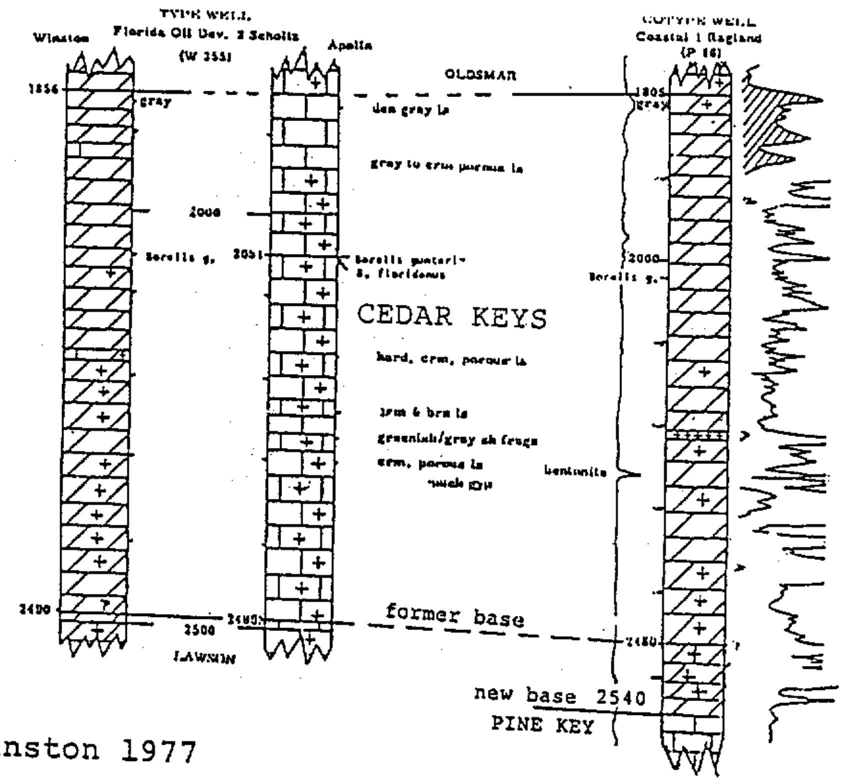
Upper Boundary: (conformable) Defined by the change from brown anhedral or euhedral dolomite of the Black Point Format above to gray cryptocrystalline or anhedral dolomite below. On occasion the gray color of the Cedar Keys is missing and the boundary must be established by the use of geophysical logs.

Lower Boundary: (conformable and interfingering) Defined by the change from tan, cream or brown, euhedral dolomite occasionally with relic oolite or skeletal texture above to cream limestone or white chalk of the Pine Key below.

Correlatives: Tavernier Tongue of the Rebecca Shoal Dolomite, lower MADco Suite (Winston 1993a) and Midway section of the western Panhandle

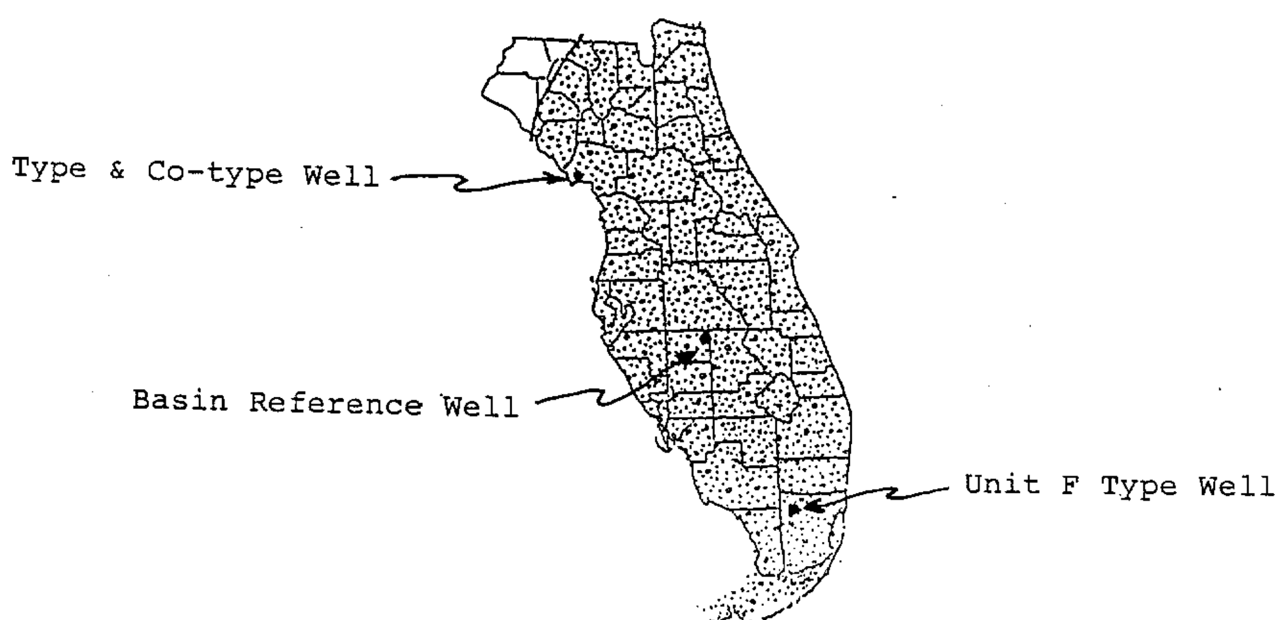
References: Cole 1942
Cole 1944
Applin and Applin 1944
Vernon 1951
Chen 1964
Winston 1977
Winston 1993
Winston 1994

TYPE & REVISED CO-TYPE WELLS



after Winston 1977

DISTRIBUTION OF CEDAR KEYS



Appendix 4

Black Point Format

Type Well: MDWS 5 Injection (W-13768, M57) 21-56S-40E Dade County

Type Interval: Top 1030 feet samples, 1035 feet GR log; base 3160 feet samples, 3165 feet GR log

Name Derivation: From Black Point on Biscayne Bay, one mile east of the type well

Thickness Range: 1170 to 2735 feet

Description of contained lithologies: Highly variable - includes light-colored chalky micrite, dense micrite, skeletal wackestone, packstone and grainstone, orange-brown and tan euhedral, anhedral and occasionally cryptocrystalline dolomite. Euhedral dolomite ranges from very fine microcrystalline to medium crystalline.

Comments: Used to refer to the carbonate interval between the base of the Miocene Hawthorn and the top of the Paleocene Cedar Keys regardless of Suite; includes Suwannee, Ocala, Avon Park, Oldsmar formations and their lateral rock equivalents.

The Black Point Format includes the LAFco, PINco, ORco, ChAco and DAco Suites.

Distribution: Entire Peninsula except for Madison and Taylor Counties.

Upper Boundary: Defined, when not outcropping, by the change from the phosphatic carbonates and clastics of the Miocene Hawthorne above to non-phosphatic carbonates of the Black Point Format below.

Lower Boundary: Defined by the change from orange-brown anhedral dolomite of the Delray Dolomite (Winston in prep) above to gray anhedral or cryptocrystalline lithographic dolomite of the Cedar Keys below. Identifying this boundary is aided by regional correlation using gamma ray logs. In the northernmost Peninsula, limestone instead of the Delray Dolomite dolomite overlies the Cedar Keys.

Age: Eocene and Oligocene (may include some Miocene in the Keys).

Reference: Winston 1993

Appendix 7

REBECCA SHOAL DOLOMITE

Type Well: Gulf-California OCS Blk 46 P 296, Monroe Co. 24 36'N, 82 36'W.

Type Interval: 3875-5648 feet E-log; 3890-5645 feet samples (revised 1989).

Name Derivation: From the bathymetric feature 11 miles north of the type well.

Type Description: "...is composed of gray, tan and white, very fine to fine crystalline euhedral and anhedral dolomite with numerous vugs, cavities and occasional caverns." (Winston 1971 p. 124).

Comments: Due to the poor quality of the cuttings in P 296 caused by loss of circulation in the very porous sections (particularly at the base), the boundaries are best determined by E-log character. Well 296 was the only one in the area with a reasonably complete set.

Thickness: A maximum thickness of 3120 feet was penetrated in Well 4950.

Age: Upper Cretaceous and Paleocene by stratigraphic position.

Fauna: None.

Upper Boundary: (conformable) Defined in the type well by the change from skeletal limestone of the Black Point Format above to cream and gray anhedral dolomite below. Elsewhere brown anhedral or cryptocrystalline dolomite may be present in the basal Black Point Format.

Lower Boundary: (conformable) In the type well, circulation was lost at or near the lower boundary. From the E-log, the rock below the base appears to be of low resistivity, probably chalky limestone. Underlying this section is a 200-foot high resistivity zone, possibly another Plantation Tongue of the reef. Beneath this, is another low resistivity section, probably the Pine Key chalky limestone. Where the Card Sound Tongue is present, the lower Rebecca Shoal boundary is defined by the change from tan anhedral or euhedral dolomite above to gray limestone of the Grassy Point below.

Correlatives: Pine Key and Cedar Keys.

Synonymies: Includes "deep Boulder Zones" of the oil industry.

Reference: Winston 1994a

Appendix 5

TAVERNIER TONGUE
of the
Rebecca Shoal Dolomite

Type Well: Coastal 1 State (363) P 108, 32-63S-38E, Monroe Co.

Type Interval: 3875-4660 feet E-log (no samples).

Name Derivation: From a town 1 mile from the type well.

Type Description: "Although no samples were recovered [from the type well] in the interval, data from other wells indicate a lithology similar to that of the main reef complex [Rebecca Shoal Dolomite]." (Winston 1978 p. 124). No other well with a well-developed section had samples.

Comments: None.

Thickness: Variable from 55 feet to 800+ feet, depending to the position of the well on the reef complex. In some cases the Tavernier Tongue is in contact with the underlying Plantation Tongue, and is thus indistinguishable from it.

Age: Paleocene by stratigraphic position.

Fauna: None.

Upper Boundary: (conformable) Defined by the change from brown anhedral dolomite of the basal Black Point Format to a cryptocrystalline or anhedral gray or tan dolomite of the Tavernier Tongue below. In Wells 108 and 148 E-log character and regional lithologic considerations suggest the presence above the Tavernier Tongue of Cedar Keys microcrystalline dolomite.

Lower Boundary: (conformable) Indistinguishable from the underlying Plantation Tongue in the main reef facies; elsewhere it is underlain by Cedar Keys microcrystalline dolomite.

Correlatives: Cedar Keys.

Synonymies: Part of the "deep Boulder Zone" of the oil industry.

Reference: Winston 1994a

Appendix 6

PLANTATION TONGUE
of the
Rebecca Shoal Dolomite

Type Well: Coastal 1 State (363) P 108, 32-63S-38E, Monroe Co.

Type Interval: 5010-5725 feet E-log (no samples).

Name Derivation: From the Key on which the type well is located.

Type Description: "Although no samples were recovered [from the type well] in the interval, data from other wells indicate a lithology similar to that of the main reef complex [Rebecca Shoal Dolomite]" (Winston 1978 p. 124-25). No other well with a well-developed section had samples.

Comments: The type well had drilling difficulties in this unit. Three cavity zones were recorded by the operator.

Thickness: Variable from 310 feet to 1275+ feet depending on the position of the well in the reef complex. When the Plantation Tongue is in contact with the overlying Tavernier Tongue or the underlying Card Sound Tongue, it is indistinguishable.

Age: Upper Cretaceous by stratigraphic position.

Fauna: None.

Upper Boundary: (conformable) Indistinguishable when in contact with the overlying Tavernier Tongue. In none of the wells where this tongue was separated from the Tavernier were samples recovered; from E-log character the overlying rock appears to be either Pine Key chalky limestone or Cedar Keys microcrystalline dolomite.

Lower Boundary: (conformable) Indistinguishable when in contact with the underlying Card Sound Tongue. In none of the wells where the Plantation Tongue was a separate unit were samples recovered; from E-log character the underlying lithology appears to be Pine Key chalky limestone.

Correlatives: Part of the Pine Key.

Synonymies: Part of the "deep Boulder Zone" of the oil industry.

Reference: Winston 1994a

WILDCATTING IN FLORIDA

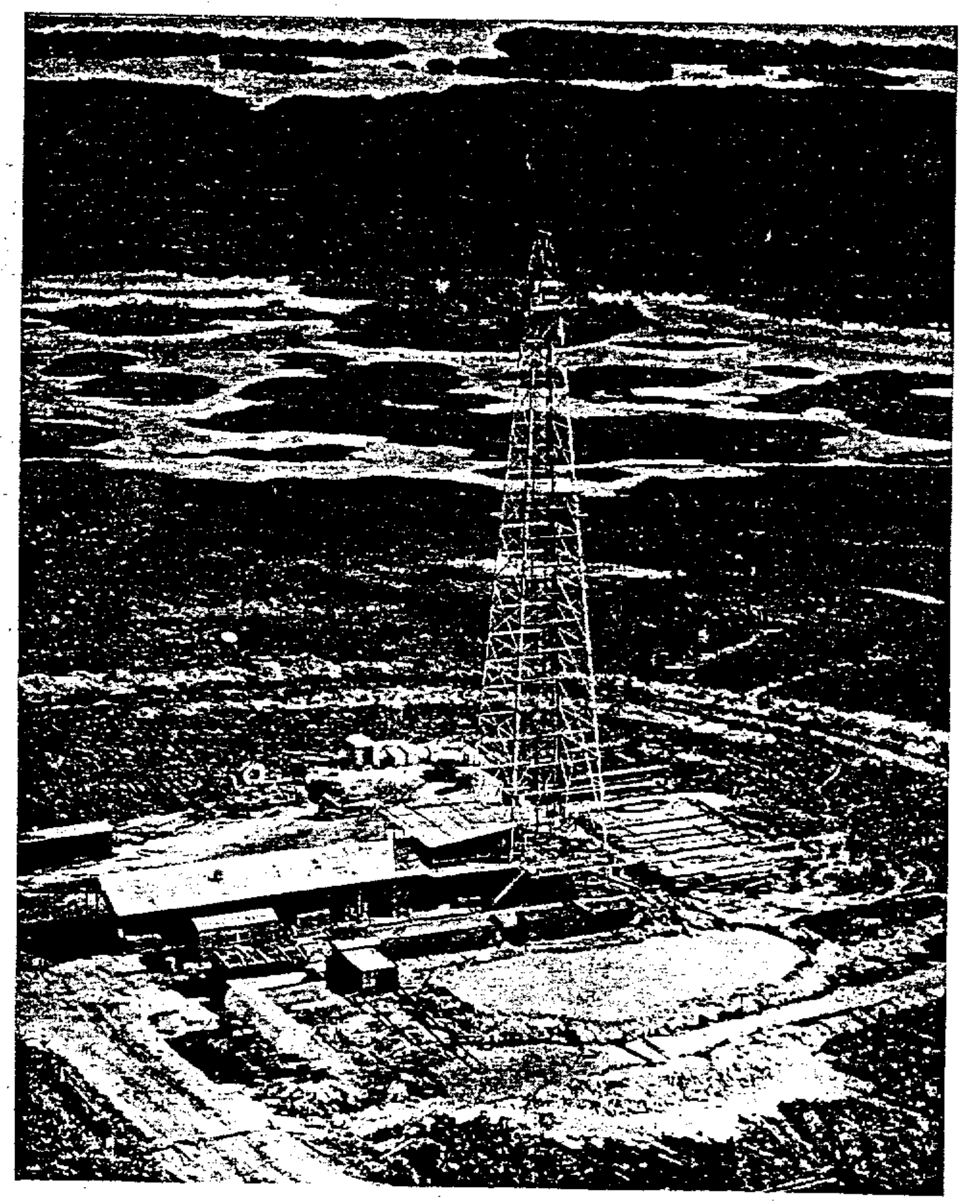
by J. E. Banks

THE frontier of the Gulf Coast oil business lies in Florida and extends from Pensacola to Key West, the longest tidelands belt of any state. This large, prospective oil territory has attracted attention because prolific limestone production might be found in South Florida as well as "Woodbine" production around the Ocala uplift in North Florida, and also partly because it is free from proration.

Geologically, Florida is part of the Cretaceous oil and gas belt which continues through Mississippi, northern Louisiana, southern Arkansas, Texas, and Mexico. Cretaceous sediments of northern Florida grade vertically from chalk to sand and shale; but in southern Florida the gradation is from chalk to lime and anhydrite. In both North and South Florida the maximum thickness of the Cretaceous is estimated to be in excess of 10,000 ft.; over the Ocala uplift the section thins to 1,500 ft.

In Florida, the wildcatter has not been assisted by oil and gas seeps or by surface indications of deep structures. Nature has masked the Cretaceous oil fields with a thick covering of "reef type" Tertiary limestone. So far only one deep anticline is known. This Cretaceous structure is productive from a thin limestone near the top of the Sunniland zone, of Glen Rose age, and which is the most persistent zone of oil and gas shows in Florida. The Sunniland zone in general is marine, thin bedded, and grades vertically from dolomite, to coquina, to chalky limestone, to marl. It is 250 ft. thick and is overlain and underlain by thick anhydrite beds.

The search for oil and gas in Florida has been difficult. The thick blanket of cavernous and irregularly bedded lime of Tertiary age greatly reduces the value of core drill and seismograph exploration. In addition, Florida has a Paleozoic "basement" complex of sedimentary and igneous rocks which obscures the interpretation of gravity and magnetic data. For the present the oil deposits of Florida are well hidden but the expected development of sharper exploration tools adapted to limestone areas may soon give renewed hope to the Florida wildcatters.



Drilling Costs for Florida

Florida oil activities are located 500 to 1,000 miles from most supplies and services. This factor alone greatly increases drilling costs. Typical examples of Florida drilling operations are the seven wildcats recently completed by Coastal Petroleum Co. at an average cost of $15.70 per foot. The individual well costs appear in Table 1.

East and south of Tallahassee the Florida wildcatter does not have the protection of the footage contract. Unusual drilling problems start at the surface and continue until the widespread zone of lost circulation or water flow is completely penetrated and cased.

Central Florida is covered with loose sand, in part resting on cavernous limestone and in part separated from the limestone by clay beds. For many years the surface sand has been sifting down into the cavernous limestone, leaving small and large sink holes at the surface. Drilling operations can easily speed up this natural process.

Cave-ins under the derrick foundations are common, necessitating quick cement jobs, more casing, or skidding the entire rig on very short notice. Operators usually provide two surface strings of casing. The first is set just into the limestone before circulation can be lost. The second is set a hundred feet or so into the lime-

The Coastal Petroleum Co. 1 Wright, located near Old Tampa Bay, 4 miles north of St. Petersburg, Fla., was drilled to a depth of 11,507 ft. in 137 days. Contractor for the wildcat was Parker Drilling Co. of Tulsa. All of the cavities in the hole could not be cased off because of the casing shortage of early 1948. As a result, the test was drilled to a total depth with salt water rather than mud.

The Author

J. E. Banks, chief geologist for Coastal Petroleum Co., St. Petersburg, Fla., received his bachelor of arts degree from Wabash College in 1935. He did gradua·: work at University of Iowa, receiving an M.E. degree in geology in 1937. Following college, Banks worked 3 years for The Texas Co. as a geologist in that firm's Barco concession in Colombia, S.A. From 1940 to 1942, he did further graduate work at Cornell University. He then spent a little over a year with the U. S. Engineers at Ithaca, N. Y., before returning to Texaco in Midland, Tex. Banks entered Florida geological work in 1945 as a geological scout for Stanolind Oil & Gas Co. in Tallahassee. He has been in his present position since 1947.

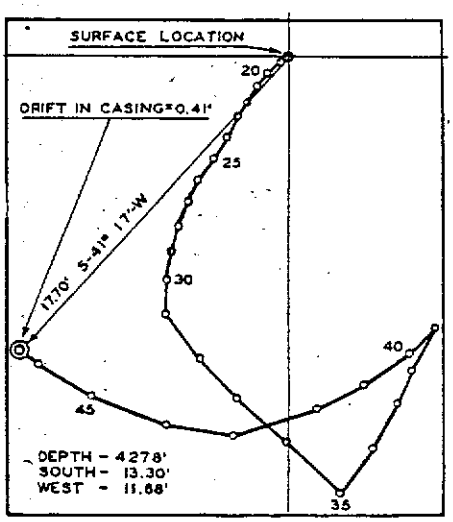


Fig. 1—This interesting directional survey shows that a Coastal well actually reversed direction in a cavernous limestone zone. This reversal occurred at about 3,600 ft. in a 10,500-ft. test, resulting in obvious drilling difficulties. State - Plantation

DRIFT IN ZONE OF CAVITIES

	Depth, ft.	Direction	Angle
30	2,743	S08W	0°45'
31	2,837	South	0°55'
32	2,931	S37E	1°30'
33	3,023	S40E	1°30'
34	3,135	S48E	1°50'
35	3,208	S47E	2°00'
36	3,301	N35E	1°30'
37	3,393	N28E	1°30'
38	3,486	N22E	1°00'
39	3,580	N30E	1°15'
40	3,673	S45W	1°00'
41	3,766	S55W	1°30'
42	3,859	S62W	1°30'
43	3,953	S72W	2°20'
44	4,047	N80W	1°50'
45	4,142	N69W	2°00'
46	4,236	N58W	1°40'
47	4,278	N51W	1°30'

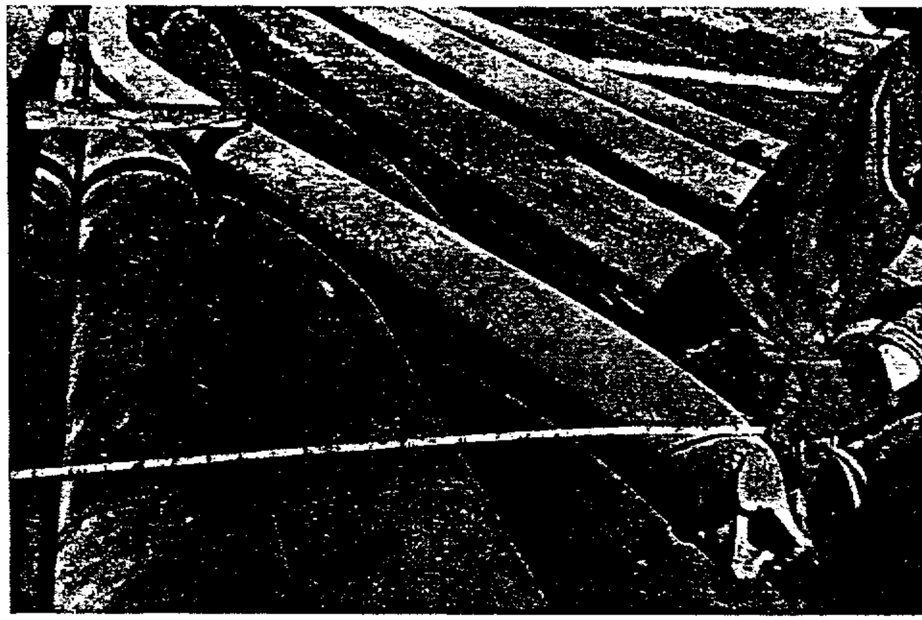


Fig. 2—This bent drill pipe resulted from insufficient wall support while drilling in cavernous limestone. The fish was recovered with difficulty through the 13⅜-in. surface casing in the hole.

stone or below any additional sand.

In South Florida the loose sand zone is covered by several hundred feet of younger limestone. If the derrick is built on these limestones there are no foundation problems; however, two surface strings of casing may still be needed because circulation may be lost in the limestones above the loose sand as well as in the older limestones below. In both North and South Florida, operators mud up to drill the sand zones of Pleistocene and Miocene ages.

The most common drilling hazard in Florida is loss of circulation in thick cavernous limestones. Drilling blind for 1,500 to 6,000 ft. is expected of the drilling contractors. In North Florida this zone of repeated cavities is thin and in places exposed at the surface. In South Florida the same zone of lost circulation is much thicker and is covered by 1,000 to 2,000 ft. of Miocene to Recent sediments. The individual cavities are characteristically thin and may not be noticed by the driller until the mud has disappeared.

Technically a cavity is a zone of

TABLE 1—FLORIDA WILDCATS DRILLED BY COASTAL PETROLEUM CO.

County, well and farm—	Footage	Drilling days	Date comp.	Contractor	Gross cost	Participation by others
Levy, 1 Ragland	5,850	65	10-19-47	Crow	$96,900	$50,000
Pinellas, 1 Wright	11,507	139	7- 8-48	Parker	192,800	65,000
Jefferson, 1 Larsh	7,913	60	1-13-49	Parker	100,700	46,000
Lafayette, 1 Sapp	*6,000	30	3-19-49	Parker	53,900	27,000
Monroe, 1 State Lse. 363	7,559	78	9-30-49	Parker	118,500	15,000
Dade, 1 State Lse. 340-A	11,520	77	12-18-49	Loffland	198,000	138,600
Monroe, 1 Williams	6,702	97	2- 5-50	Parker	136,000	22,300
Totals	57,051	546			$896,800	$363,900

*This test was actually bottomed at 3,507 ft. in Paleozoic basement but Coastal received 6,000 ft. credit toward its 60,000-ft. drilling obligation with the state of Florida on 4,800,000 acres of water bottom lands.

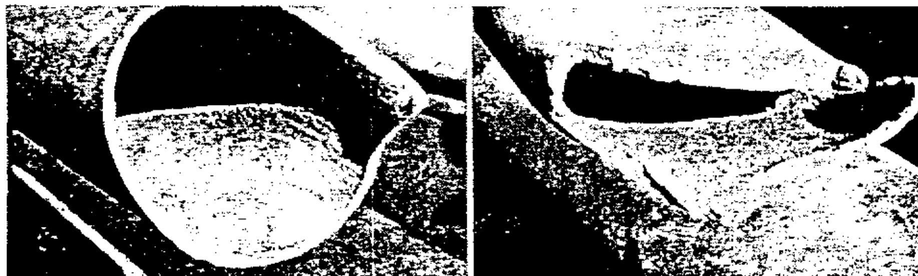


Fig. 3—In these two pictures can be seen the ends of the 1,387-ft. fish in Fig. 2. On the left is shown the initial twistoff. On the right can be seen the secondary break at the bottom end of the drill pipe.

excessive permeability and porosity formed in limestone by circulating ground water. Numerous small and large cavities are present throughout the zone of lost circulation. An individual cavity can usually be sealed off using cement and crushed rock, but the job of sealing off multiple cavities is at present uneconomic. Many of the cavities are large enough to permit the drill cuttings to escape into the formation. More numerous are the smaller cavities capable of taking fluid but not cuttings. The repeated loss of cuttings in large cavities is the ideal drilling condition. Also, chalk lends itself to drilling without returns because it disintegrates into the drilling fluid. Under ideal conditions the over-all drilling rate without returns in cavernous limestone or chalk can easily exceed that of conventional methods. On the other hand, if the cavities are small and the large cavities widely spaced, the problems of drilling without returns greatly increase and the drilling rate suffers.

Much Water Required

At Coastal Petroleum 1 State, Lease 363, located on Plantation Key in Monroe County, 600 ft. of cuttings accumulated in the hole while drilling 1,200 ft. before being flushed out in a large cavity at 5,620 ft. This required 2 to 6 hours' additional time to wash and ream to bottom with a new bit and 15 to 30 minutes to make each connection while drilling.

Usually a large volume of water is needed to keep the cuttings out of the way of the bit. Even then, large cuttings and cave-ins called "boulders" are continually wedging around the bit and drill collars. At times it is impossible to determine if the bit is drilling or reaming because the same amount of weight and torque may be required. Stuck pipe may occur when the drilling fluid flows into a cavity near the bit instead of lifting the cuttings. A plugged bit, pump failure, twistoff, or delayed connection can also stick the drill pipe.

Stuck pipe is the most common type of fishing job within the zone of lost circulation. Experience has shown that if fluid can be pumped through the bit the pipe can usually be worked loose. Freeing the pipe may take just a few anxious minutes or several long days. The Coastal Petroleum Co. 1 State Lease 363 penetrated the entire zone of cavities. In doing so, the pipe was stuck six times with a loss of 63 hours' drilling time, the longest single period being 2 days.

Cavities affect the drilling operations in other ways. For example, they may cause a sharp directional change in an otherwise normal drilling spiral. The bit on penetrating the floor of a cavity may not deviate appreciably from vertical but can reverse its horizontal direction, as shown in Fig. 1. Such sharp bends in the horizontal component of drilling spiral undoubtedly put an additional strain on the drill pipe.

Drilling-Time Curves

Cavities are associated with hard and broken drilling. The maximum weight of the drill collars is required to drill hard lime beds at a rate of 1 to 4 ft. per hour. Drilling-time curves within the zone of lost circulation correlate poorly at best and frequently not at all. The over-all drilling time for this zone also varies from well to well. In one well it will average 5 minutes per foot, whereas in another within 10 miles the average may be 15 minutes per foot. Apparently the local amount of rock hardening determines the drilling rate at each location.

Hole-size surveys indicate the position of large cavities, but more noticeable is the loss of gage resulting from drilling. Thirty days of drilling with water can double the original hole size opposite chalk and certain shales. Indurated limestone beds tend to remain in gage. A twistoff while drilling without returns through cavities and enlarged hole can be serious, because the drill pipe is not supported and centered by the walls of the hole at all points. A case in point is the Coastal Petroleum Co. 1 Williams located on Key Largo south of Miami. Here the operators set surface casing at 253 and 989 ft.; then attempted to drill 5,800 ft. of chalk and cavernous limestone with salt water using five 8-in. drill collars, 4½-in. drill pipe, and diesel-electric power.

To a depth of 6,702 ft., the hard lime formation dulled thirty-three 12¼-in. rock bits. Time lost in reaming to bottom amounted to 168 hours and freeing the pipe 25 times took 119 hours. At this depth, while reaming preparatory to running casing, the bit stuck 18 ft. off bottom and the drill pipe twisted off at 2,200 ft.

Fishing operations revealed that the drill pipe had dropped, bent into the large cavities, and sheared off at several places. The first 1,387-ft. piece of drill pipe was recovered from 3,028 ft., indicating that it had dropped 828 ft. and bypassed the second piece by 122 ft. Photographs of this fish are shown in Figs. 2 and 3. The top of the second fish was located in a cavity at 4,293 ft. but could not be recovered.

Hole-Size Variations

Hole-size variations also affect the casing program. Running one string of casing completely through a long interval of enlarged and tight hole is obviously difficult and hazardous. An intermediate mud string proved very successful in the Coastal 1 Ragland in Levy County because the remainder of the Tertiary section was drilled without loss of circulation, and the hole was completed to basement without the usual long mud string.

Since large quantities of water are used in drilling without returns, it is fortunate that in most parts of Florida there is an abundance of fresh water within a few feet to a few hundred feet of the surface. On the Florida Keys, however, fresh water is not available and drilling costs are therefore greater. Not only is the bill for pump parts excessive but the mud lines and drill pipe can be worn out in one or two locations.

On the bright side of the Florida drilling picture is the almost complete absence of problems after the mud string has been cemented below the cavernous limestone section. Expensive mud treatment is not required. At the Coastal 1 Larsh in Jefferson County, 2,500 ft. of chalky limestone and 4,500 ft. of sand and shale were drilled successfully, using thin bentonite mud and no chemicals. At the 1 Sapp in Lafayette County untreated bentonite mud was used in wire-line coring 200 ft. of sand and shale, resulting in 87 per cent recovery. The Coastal 1 State Lease 340-A in Dade County west of Miami was drilled below the mud string to a depth of 10,600 ft. with fresh water before mudding up. To this depth the water cuttings gave reliable mud-log readings for oil and gas, the formation changes were sharp, and the hole below the chalk section remained in gage.

BENT PIPE at troublesome well in Sunoco field shows extent of drilling problems. This drill pipe, pulled from the hole at Sun Oil Co.'s 32-2 Red Cattle Co., was twisted while trying to drill through a 90-ft cavern.

DOWNHOLE SHOT of 32-2 Red Cattle, taken at about 2,800 ft, shows cavernous rock. Cavities on each side of the hole spilled loose rocks and boulders to bottom which caused the bit to stick at times.

Sun whips Florida's boulder zone

On-the-spot improvisation helps Sun Oil Co. drill through cavernous dolomite as it brings Sunoco field into production. Getting through cavernous section with loose rock taxed ingenuity of drillers, but operator cut hole costs significantly.

Robert G. Burke
Southwest Editor

DEVELOPING Sunoco field in South Florida taught Sun Oil Co. how to cope with the unusual problem of drilling straight through large rock-filled caverns.

While this certainly isn't a common drilling problem, the knowledge picked up by Sun might come in handy again.

Florida operators had encountered the trouble zone before so Sun had an inkling of what to expect. As it turned out, the contract drillers found the situation worse than anticipated.

The problem has not been well-known because so few fields have been discovered in Florida. Before Sun completed its program, its engineers minimized a tough situation. After a few months, drilling time shrank from 35 to 22 days for an 11,500-ft well. Per-well costs fell from $220,000 to $145,000.

The problem. Significant advances such as these did not come easily. Working in the field, Sun engineers had to improvise on the spot. A down-hole camera took remarkable stereoscopic photographs that revealed the zone. Toolmakers were consulted, and special equipment was flown to the site. Using this information, Sun conducted a school that showed drill crews precisely what they were dealing with and how best to handle it.

Between 2,500 and 3,000 ft at Sunoco-Felda and throughout the southern half of Florida, is a troublesome dolomitic section. The zone is filled with cavities ranging from 4 to 8 ft thick. Some are much larger. The largest Sun drilled into was a gigantic 90-ft cavity with no estimate of how wide it might be.

Not much is known about the zone except it outcrops in northern Florida. Nowhere else in the country has Sun encountered a similar problem. When American companies were drilling in Cuba, some reported the same sort of situation. Humble Oil & Refining Co., which operates Sunniland field, 20 miles south, had to master the same zone.

How it was handled. Drillers on the job were Larco Drilling Co., Jackson, Miss., and Empire Drilling Co., Dallas. At times four rigs were running. Testimony to the drillers' success is the 24 wells now producing in Sunoco, which stands as the third discovery in Florida and only the second field now producing in the state.

Loose rocks, tumbling from roofs of cut caverns and from unconsolidated strata, fell in the hole. Enough of them could stick the pipe and keep it from rotating.

Small rocks on the bottom could be washed up the hole with fresh water or charges of mud. But the bigger boulders just had to be ground up.

Since any fluid pumped in the hole would be lost, Sun used fresh water which was plentiful in that region. At the same time, the lighter drilling fluid increased the penetration rate. This cut costs further.

Grinding rock. Due to some experimentation in the field, Sun actually ended up drilling both above and below the bit.

Two stabilizers were installed in the drill stem. One was just on top of the bit, and the other was 60 to 90 ft up the pipe. As rocks fell on the bit and drill collar, the metal blades of the rotating stabilizer chewed them to gravel-sized pieces which could be washed out of the way.

Grinding up the big boulders and washing them up the hole helped Sun get through the zone. Probably the rock particles were washed up into cavities very much like the ones from which they had fallen.

The tools. Once Sun got through the boulder zone, drilling time was fast. To isolate the zone, Sun ran 9⅝-in. casing to below the zone and cemented it. From then on it was relatively easy. One rig made 2,200 ft in 24 hr, good time for any location at this depth.

Size of the hole drilled through the cavernous section was 12¼ in. The casing program included 70 ft of 20-in. pipe predriven into the loose subsoil, 1,100 ft of 13⅜-in. casing, and 5½-in. casing set to the bottom for a production string.

Sun made sure it had a good bit when it entered the zone. Toward the last it was using a special insert-type bit. All efforts were directed toward reducing agitation in the hole, such as slower rotary speed, reduced pump pressure and circulation rate, and larger drill-collar sizes.

As a rule, the company could get through the zone in 4 days. Some wells took less. Of course, others took much longer.

Worst encounter. Sun's biggest surprise came on 32-2 Red Cattle Co. where the drill bit penetrated a 90-ft cavern.

Two strings, including the bit and drill collars, were lost in the hole.

Abandoning the hole Sun moved 500 ft to the west and came up with a producer. The driller went through the boulder zone without hitting any signs of a cavity this large.

Drilling aids. Sun now feels that two of the biggest steps it took in handling the cavernous zone were training the drill crews with a downhole camera and employing proper tools and drilling techniques for the conditions encountered.

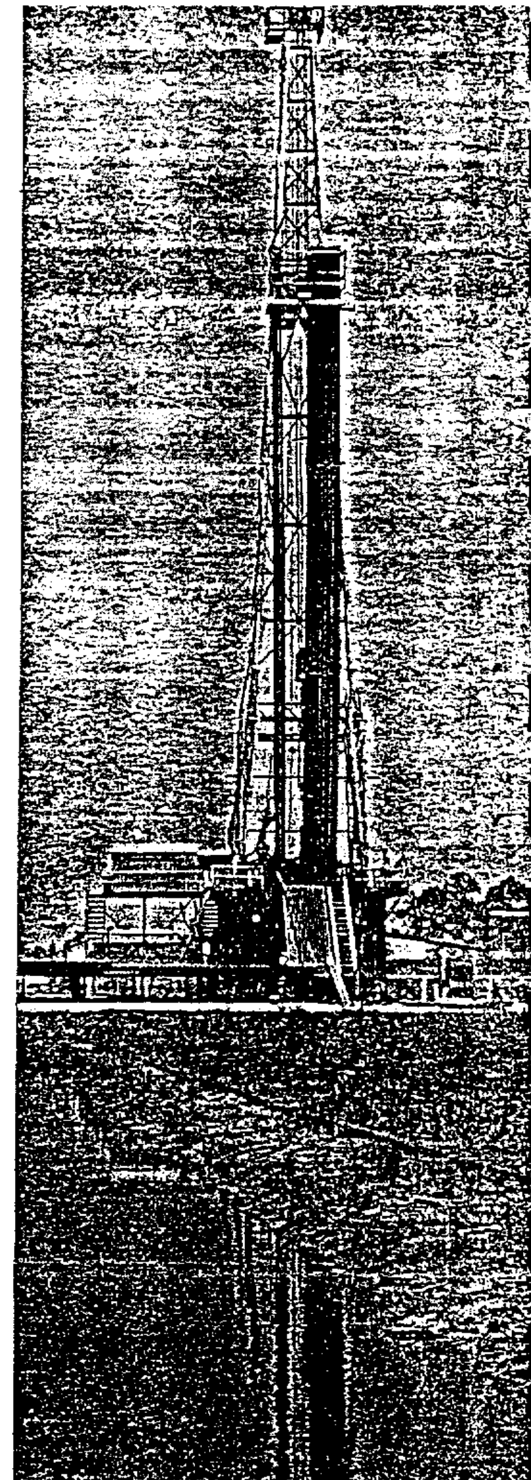
Stereoscopic photographs, which are much in demand for geology classes and other drillers, are of excellent quality. They were taken by Lane Texas Co., a water driller who developed the camera.

Color film shows the trouble zone to be a brown vugular rock. Cavities appear almost round, and many seem to have a dark-colored ring around them (see photos).

Quick solution. One way of getting out the boulders didn't crop up until toward the last.

Using an open-ended junk basket, Sun was able to recover big rocks right off the bottom of the hole. As an experiment, this basket was fastened to the bottom of an 8-ft section of 8⅝-in. casing. Rotating to the bottom of the hole caused the rocks to be trapped in the basket assembly.

In one hole the 8-ft casing length was entirely filled with debris. From that time on, Sun reports, the hole was drilled without further trouble from boulders in that hole.



RIG, operated by Empire Drilling Co., drills one of 24 producers in Sun's Sunoco field of South Florida. Despite tough drilling conditions, the operator whipped the cavernous rock section that is found in most of the lower part of the state.

Future drilling in the area will benefit from the many lessons learned. And Sun is armed with good information on handling the boulder zone just in case it turns up another discovery in Florida.

End

APPENDIX 10

WELL LIST

INJECTION WELLS

Well Map No.	Name
SdLk	Sand Lake
23	Merritt Island
24	West Melbourne
25	D.B.Lee
26	Harris
27	Port Malabar
28	South Beaches
29	Hercules
30	North Port
31	South Port
32	Stuart
33	Pratt & Whitney
34	Quaker Oats
35	Encon
36	Palm Beach SWA
37	West Palm Beach
38	Acme
39	PB System 3
40	PB System 9
41	Coral Springs
42	Margate
43	Royal Palm Beach
44	Sunrise
45	Plantation
46	Ft. Lauderdale
47	Pembroke Pines
48	Sunset Park
49	Kendall
50	MDWS
51	North Broward
53	DeBartolo
54	Seacoast
55	Ft. Pierce
56	Grant Street
58	Pahokee
59	Belle Glade
62	Rockledge
63	PB South
66	Boynton Beach RO
67	Plantation RO

OIL TESTS

ONSHORE

Permit No.	Well Name
IIF	Humble 1 IIF
8	Humble 1 Carroll
31	Humble 1 Hayman
47	Humble 1 Tucson
81	Hunt 1 Wilson
91	Hunt 3 CNS
115	Coastal 1 State 340
167	Commonwealth 1 Wiseheart
182	Gulf 1 State
230	Warren 1 Terry
235	Amerada 1 Southern States
237	Amerada 1 Swenson
243	Amerada 1 Mitchell
254	Amerada 1 Cowles Magazine
259	Amerada 2 Cowles Magazine
265	Humble 1 State 1004
740	Shell 7-4 Gulf & Western
1032	Kanaba 21-1 Allapatta
1063	Hughes 20-3 Oleum

FLORIDA KEYS

Permit No.	Well Name
16	Gulf 1 State 374
22	Gulf 1 State
108	Coastal 1 State
117	Coastal 1 Williams
232	Gulf 1 State 826G
280	Calco 1 State 1011
275	Gulf 1 State 826Y
284	Gulf-Cal 1 OCS Blk 28
290	Gulf-Cal 1 OCS Blk 44
292	Cal 2 State 1011
296	Gulf-Cal 1 OCS Blk 46
298	Cal 3 State 1011

BOULDER ZONE PHENOMENA

VIDEOTAPE WALL FEATURES

Definitions and size limits of wall features used in this study are for application only to borehole videotape examination.

Symbols are used to present a more complete representation of wall features than can be done by verbal descriptions. The symbols were devised to be as close as possible to the actual appearance of the features.

Due to the difficulty in determining the exact depths of features on the videotape, those shown on the litho-video logs should be considered as being within one foot plus or minus of their true position on the tape. In one well, two video runs showed a five foot difference in feature location; depths, therefore, can only be considered as approximate.

On the litho-video logs, vug size is shown graphically as small or large. The density of symbols indicates whether they occur in small quantities or in large fields.

Major openings include cavities, megavugs, tunnels, caverns, wall-collapses, and channels. In the study area, vugs, wall-collapse zones, and cavities are the most common features. True caverns are confined to the Rebecca Shoal reef. Major features are most prevalent in the Delray Dolomite, Cedar Keys A, and the main body of the Rebecca Shoal Dolomite reef and its Tavernier and Plantation Tongues. Cavities and megavugs are more prevalent in the Delray Dolomite than in Cedar Keys A.

Lesser occurrences of wall features are present in various Avon Park dolomites and in Cedar Keys B. From limited lithologic data, most Avon Park Boulder Zone features occur in euhedral dolomite.

In Brevard County the Cedar Keys B contains numerous thin cavities, occasional large vug fields, megavugs, and rare wall-collapse zones. As this section appears capable to some extent of accepting injection fluids, much of it is shown on litho-video log 27 (Fig. 25). South of Brevard County, Cedar Keys B is not considered to be part of the Boulder Zone, as it contains only an occasional thin cavity or vug field.

The five included borehole video surveys were selected for image quality plus full penetration of the Delray Dolomite-Cedar Keys A section, and a substantial penetration of the Rebecca Shoal Dolomite and Avon Park dolomite. Their videologs are shown in the front of the Illustrations section.

The five color litho-videologs (Figs. 21-25) are included to illustrate the lack of relationship between lithology and wall features.

WALL FEATURE DEFINITIONS & DESCRIPTIONS

a. VUGS

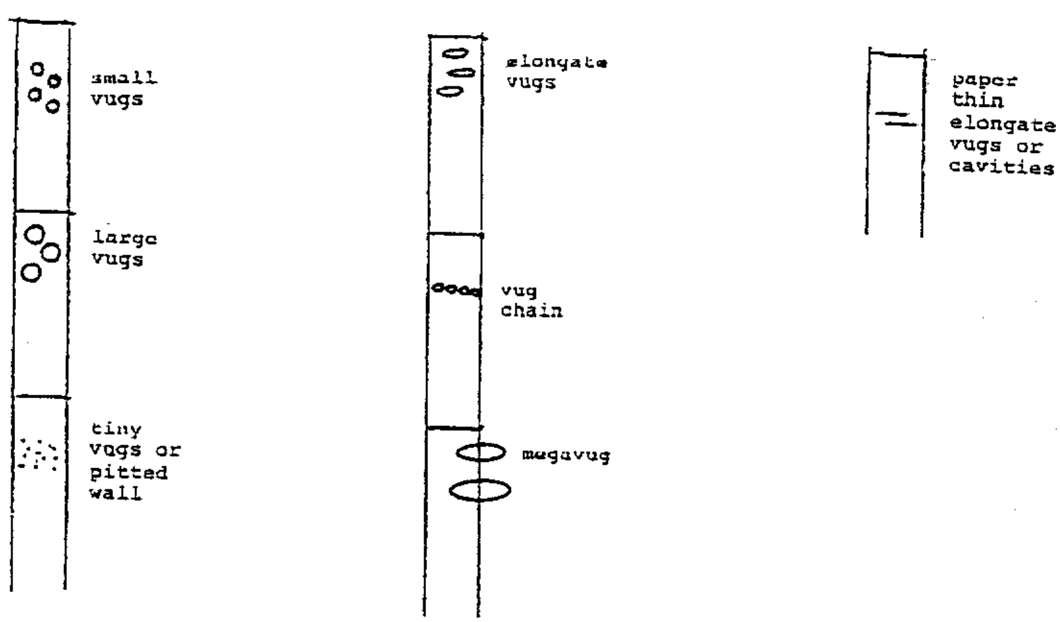
The lower limit of vug visibility on the tapes is probably on the order of one-half inch. Vugs are either round in shape, or elongate in a horizontal direction. Occasionally elongate vugs occur at various vertical angles. Elongate vugs are usually some one inch high and may be up to six inches in length. Occasionally small vugs of either shape occur as a horizontal chain.

In Well 47-2BRO at a depth of 3383 feet (see accompanying videotape) a rare phenomenon of unknown origin was observed. It can only be described as a chain of "bleeding vugs". Ten tiny vugs had short black marks several inches long running down the wellbore wall. This same cluster of vugs was also present on the opposite side of the hole, indicating that the phenomenon extends at least several feet in a horizontal direction.

Very large openings (six to twelve inches) which are round or oval are classed as megavugs. Although their size is in the cavity range, their ovoid shape relates them to vugs rather than to the discoid cavities.

Occasionally small vugs occur in horizontal chains. Rarely small vertical vugs are present around the entire wall as a "chain".

When vugs (large and small) are densely packed, they are referred to as a "vug field".



c. "CAVERNS"

Observed "caverns" could be large wall-collapse zones, where the wall has moved back beyond the range of the camera.

"Caverns" are seen (or rather not seen) on the video tape as a black picture with no wall visible and having a thickness of over two feet and not positioned near wall-collapse zones.

In the Cedar Keys A, only one "cavern" was observed (Well 59). In the Delray Dolomite, true caverns are exceedingly rare or may not exist at all. Three "caverns" were observed in Wells 50-4, 50-5 and 50-7 in Dade County, all located at widely different levels.

For the purposes of this study, and until the newly-introduced side-looking video camera shows otherwise, an opening is labeled a cavern when no wall is visible, and neither the top nor the base are visible on the tape at the same time.

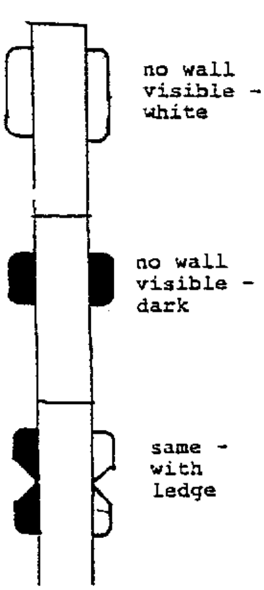
Although "caverns" are seen usually as black pictures, occasionally a white picture without visible wall is present.

Occasionally an apparent "cavern" (black or white) may have a ledge protruding into the range of the camera, suggesting that it is actually wall-collapse.

"Caverns" are shown graphically with rounded corners, whereas cavities are shown with square corners.

When a "cavern" appears juxtaposed to a wall-collapse zone, that is probably what it is.

Drillers' reports of bit drops are generally lacking in the consultant's engineering reports. No one I spoke with knew of any bit drops in the Delray Dolomite or Cedar Keys A of more than a few feet. Major caverns would therefore appear not to be present in these units in the study area. Major caverns are present in the Rebecca Shoal reef. In the southwestern Peninsula (see Vol. 2) major caverns are present in the Avon Park Formation.



d. WALL-COLLAPSE ZONES

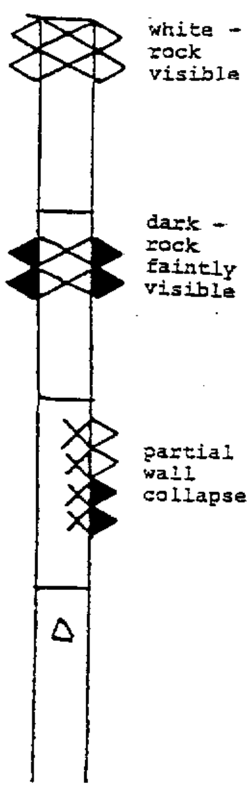
Wall-collapse is identified by a blocky appearance and enlargement of the borehole wall. The presence of numerous open, intersecting fractures, when penetrated by the bit, cause large blocks of rock to lose support and fall into the hole. This feature is the source of most of the "boulders" in the southeastern Peninsula, and causes considerable "dredging" (see Glossary).

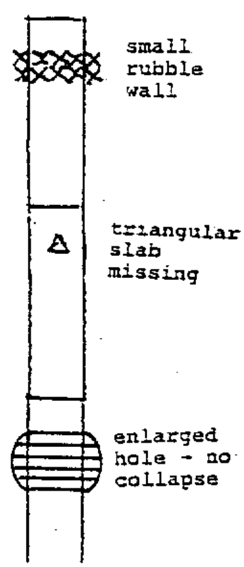
Thick hole enlargements on caliper logs seem to be almost always the result of wall collapse, not the presence of caverns. Wall-collapse zones can span several scores of feet, or as little as one foot. They can encompass the entire borehole wall, or occupy only part of the wall; here a wall segment shows the round drill hole.

Wall-collapse zones taper out at the base, whereas cavities are defined as ending abruptly with a flat base.

Occasionally a zone, usually measured in inches, consists of a very fine lattice of small fractures. These zones usually produce a small hole enlargement.

Rarely, wall-collapse zones are dominated by vertical open fractures, producing long slabs of rock, rather than the usual squarish blocks (see Video I).





b. CAVITIES

As used in this study, a cavity ranges from six inches up to two feet in height, and is discoid in shape. Both its top and base must be visible on the tape at the same time. Cavities have a large horizontal dimension, probably on the order of several feet.

On videotapes large cavities are occasionally difficult to separate from wall-collapse features. To separate them in this study, the criterion used is that cavities have a flat base, whereas wall-collapse zones taper out at the base.

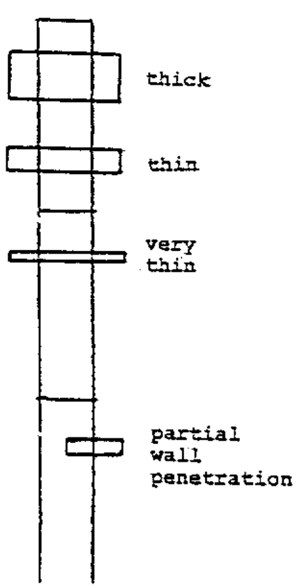
In diameter cavities are probably three to six feet and from a few inches to several feet in thickness. In three out of four instances, the borehole cuts only part of a cavity. In the other case, the cavity completely encircles the wellbore.

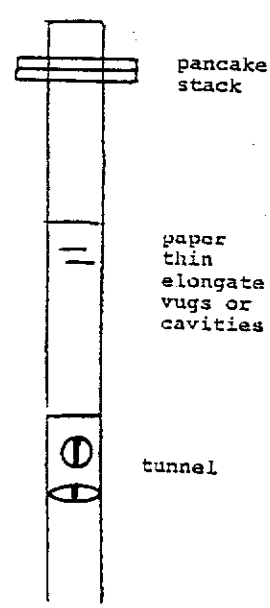
Where cavities occur inches apart, the group is referred to as a "pancake stack".

Occasionally a full hole cavity may exhibit interruptions or "posts". This phenomenom may represent a chain or field of cavities with the "posts" suggesting a room-and-pillar coal mine.

A tunnel is a round or occasionally ovate hole some six to twelve inches in diameter which enters the borehole on one side, and exits on the other.

Cavities are shown graphically with square corners, whereas caverns are shown with rounded corners.



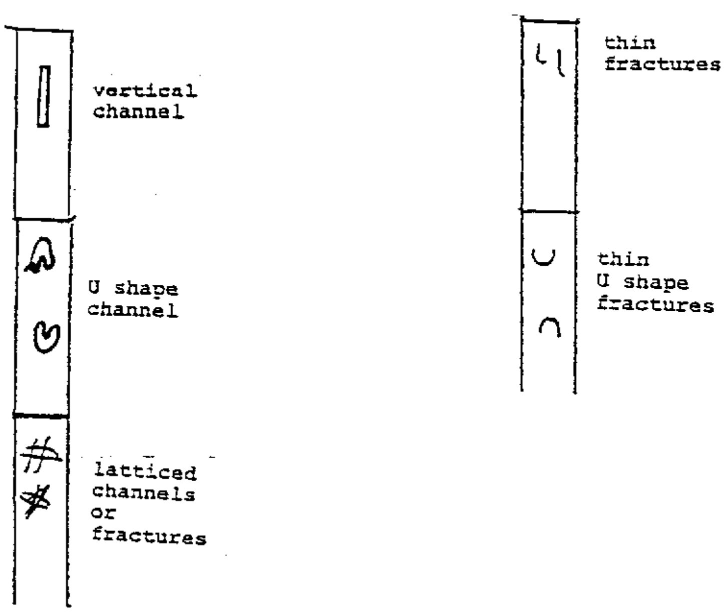


e. LINEAR OPENINGS

Channels are more or less vertical openings from one-half inch to several inches wide. They can be several feet long. Most channels penetrate both sides of the hole. Drill cutting data suggest that some are lined with coarse crystalline euhedral dolomite. Channels are frequently oriented up to 30 degrees off vertical. When these terminate in the wall of the wellbore, they appear as a "U" or an inverted "U". Wide channels frequently connect closely-spaced cavities, and are also involved in wall-collapse zones. What are seen as independent channels could be intersecting unseen cavities beyond the borehole. Channels are solution-fractures.

Fractures as used in this study refer to vertical dark lines visible on the borehole wall, but without obvious openings.

Intersecting open fracture systems cause wall-collapse.



f. MISCELLANEOUS FEATURES

Banding is frequently visible on the wall of the hole, particularly in the lower Delray Dolomite, in Cedar Keys A and Cedar Keys B Units. These may be caused by color differentiation, linear chains of tiny vugs, or bands of softer and harder rock. Banding can occur in any of the three dolomite varieties. Most likely, differing hardness in response to the drill is the main cause, with color differences responsible for the wider bands.

Occasionally an inch-wide color band has the appearance of an incipient or filled-in cavity.

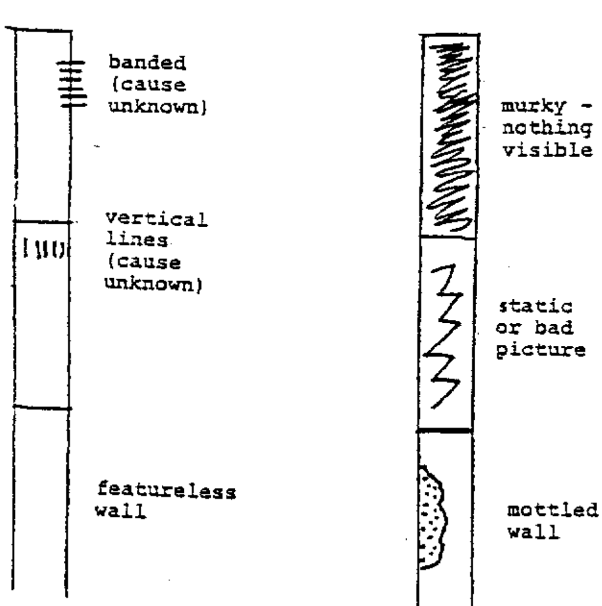
Vertical parallel lines are rare and occur mainly in the lower Delray Dolomite and in Cedar Keys A. They are usually closely packed and encircle the entire hole. As these lines are vertical, it is hard to see how they would be caused by the drill bit, which should produce spiral marks. Rare vertically oriented lines which do occur with a right-hand twist are probably a drilling effect.

Heavily mottled wall is a rare occurrence, probably due to a mixing of euhedral and one of the other dolomite types.

In Broward County wells, and particularly in the wells at site 50 in Dade, dark areas are present on the bore hole wall. About 70% of these have shapes and dimensions of megavugs, cavities or vertical channels. Indeed, they could be features filled in with secondary dolomite, as occasionally seen in cuttings, or alternatively, incipient features not yet dissolved out. When viewed on a cloudy video tape, these can be mistakenly identified as openings.

On rare occasions shallow triangular or round openings in the bore hole wall appear to extend only an inch into the rock, as if a slab of rock had been removed. The triangular openings appear to be bounded by a set of locally intersecting fractures.

On rare occasions the borehole shape appears to be in the form of a low angle helix extending for several feet. This is probably a response to the drilling process.



RESERVOIR PROPERTIES

Reservoir as used in this publication pertains to the ability of a rock section to accept or give up appreciable volumes of fluid. Unless they occur in dense fields, small and large vugs are probably not connected.

Intercrystalline porosity in euhedral dolomite is probably of minor importance in the injection and storage of wastewater.

When present, channels provide superb permeability between cavities or in wall-collapse zones. Isolated channels contribute little pore space to the reservoir capacity.

Cavities add up to as much as 50 feet in some wells. If connected, they would form a major reservoir. As nothing is known about their connections (except in isolated cases, see above), their reservoir capacity cannot be accurately evaluated.

Caverns, if present, obviously would contribute considerably to reservoir capacity and permeability.

Thick wall-collapse zones probably contribute as much to reservoir capacity as all other features combined. They obviously have great permeability, and when wide would have a high volume of fracture porosity. In oil fields, highly fractured rock is known to be an excellent reservoir.

At multiple well sites, zones of well-developed wall-collapse occasionally extend to adjacent wells.

Table 2 shows the average thickness of potential reservoir rock in each of four formations as a percentage of total formation thickness. In order to balance out the effect of varying formation thicknesses, percentage rather than total thickness of potential reservoir is presented. As most cavities and megavugs are on the order of one-half foot thick or less, the

Table 2

Average Percentage of Potential Reservoir
(wall-collapse, cavities, megavugs & vug fields)

FM	Wells	Dade	Wells	Broward	Wells	P Beach	Wells	St.Lucie	Wells	Brevard
Delray Dolomite	13 1	av 30% (short)83%	13 2 w/	av 25% max 33	12 1	av 40% (short)90%	4 2	av 55%	6 2	av 50% (short)80%
Cedar Keys A	0	minor penetration	14	av 25%	1	25%	0	fm.not present	3	av 30%
			2 w/	max 60%	1	75%			1	60%
Cedar Keys B	0	not reached	2	av 10%	1	av 10%	0	fm.not present	4	av 50%
Rebecca Shoal	0	fm.not present	0	fm.not present	2	av 35%	4	av 80%	0	fm.not present

Note: Short tapes penetrate less than 100 feet into the unit.

total numbers of these features were divided by two to arrive at a rough approximation of their thicknesses.

Thicknesses of potential reservoir in the Delray Dolomite increase from 25 to 30% in the Dade-Broward County area to 50 to 55% in Brevard County to the north. Cedar Keys A contains an average of 25% potential reservoir in the southern counties and 30% in Brevard County, not a very large change. Cedar Keys B in the few wells in the south to penetrate enough of the section to be significant shows 10% potential reservoir, while to the north in Brevard County it is 50%, a very large change.

Neither Cedar Keys A nor Cedar Keys B are present in the St. Lucie-Martin County injection wells. Here these units are replaced by the Rebecca Shoal reef which contains 80% potential reservoir, the highest average figure for any unit.

A video-tape of the lower part of the Avon Park in Well 40PB shows the presence of wall-collapse zones, cavities, megavugs and vug fields, similar in size and quantity to those in the primary Boulder Zone formations. Well 40PB contained 52% potential reservoir in the 280-foot taped interval. The major difference in Boulder Zone features between the Avon Park dolomite and the other four units is the occurrence of a much larger number of large vugs. Although video tape data are not available on other wells in the thick Avon Park dolomite trend (Fig. C, p. --), similar Boulder Zone features are probably present.

From the statistical data, Boulder Zone feature development improves northward from the Dade-Broward County area. Although there is no obvious explanation for this, examination of the triangle diagrams of the Delray Dolomite Triad (Fig. A, p. 15) reveals that Dade and Broward Counties have less anhedral and more cryptocrystalline dolomite than do the counties to the north. Although wall features appear to be unrelated to dolomite tectural variety, dolomite texture might subtly influence the development of Boulder Zone features.

SPECULATIONS ON THE ORIGIN OF BOULDER ZONE FEATURES

General

With available data, how and why many of the wall features were formed cannot be determined. Wall-collapse, cavities and channels as typically seen on video-tapes of the Delray Dolomite and Cedar Keys A are not, to my knowledge, found outside Peninsular Florida. If this is so, the diagenetic and depositional environments on the Peninsula must have been significantly different from those producing dolomites elsewhere.

Drill cutting data in the southeastern Peninsula indicate that Boulder Zone features occur indiscriminately in crypto-crystalline, anhedral, and euhedral dolomites; therefore, their origin would seem to be independent of the original dolomitization processes, and must have appeared afterward.

Cavities

The horizontal orientation of cavities, vug chains, and most ovoid vugs, points to horizontal water movement as an important contributing factor to cavity origin. The large size of some cavities requires that they be formed in lithified rock, as in soft sediments such features would have collapsed. The numerous occurrences of horizontal banding suggest that bedding planes directed water in a horizontal direction.

As demonstrated in Well 59PB, cavities, megavugs, and vug fields must be connected, as demonstrated by the large volumes of fluid injected into a section which has only five feet of scattered wall-collapse.

Several modes of cavity formation by horizontal water movement come to mind.

1. If pockets of limestone survived initial dolomitization, later movement of formation water could have

dissolved the more soluble limestone.

2. The shape and orientation of many dark areas seen on video-tapes resemble cavities and megavugs. These could represent a different form of dolomite from that of the host rock. Such dark areas could be proto-cavities filled with a more soluble form of dolomite which was never dissolved out.

3. Another concept is that these dark areas are cavities or megavugs which have been filled in by a later episode of dolomitization. The presence of at least a second period of dolomitization is indicated by drill cuttings with dolomite crystals lining fractures or vugs.

4. Solution of originally deposited anhydrite lenses or nodules is very unlikely, as the dolomite textures of both the Delray Dolomite and Cedar Keys A in the study area are not those associated with evaporites. In addition, I have never seen even a trace of anhydrite in these units in the 67 Boulder Zone sections examined in the southeastern Peninsula.

5. Solution by movement of "modern" (i.e. Late Cenozoic to Holocene) formation waters in the Floridan Aquifer (see Glossary) cannot have formed the dolomite and contained cavities for the following reason. At the Sunniland Oil Field in Collier County, a cavern once existed in a mid-Avon Park Dolomite (see Vol. 2). This cavern collapsed shortly after its creation as shown by the thickening of overlying beds, and the presence of a sinkhole in the Suwannee-Ocala section. This event demonstrates that the dolomite, its contained cavern, and probably the other major Boulder Zone solution features were all primarily formed in the Eocene. Post-Eocene enlargement of these by moving formation waters may have taken place.

6. Candor (1991) shows an Eocene age for Avon Park

dolomitization. Kohout, Henry, and Banks (1977) propose ongoing dolomitization accompanying the movement of Floridan aquifer water up to the present. Hanshaw, Back, and Deike (1971) discuss the pros and cons of Floridan aquifer waters (up to the present time) as the dolomitizing medium.

Wall-Collapse Zones

These features are formed by the presence of a latticed pattern of open fractures which, when drilled through (particularly in the large-diameter injection wells) permit the loosely held blocks to fall into the hole.

Some very thick wall-collapse zones occur in areas of known faulting. Where thick zones occur elsewhere, they might indicate the presence of a nearby undetected fault (Fig. 32).

Another explanation for wall-collapse zones is the subsidence of the coastal area due to Post-Eocene faulting (see p. --). The only inland well with video-tape data (59PB) has a total of five feet of scattered collapse zones; if more inland well data were available, they might support the faulting-subsidence hypothesis.

Channels

These appear to be solution enlarged fractures. They range up to several inches across and are frequently associated with, and intersect wall-collapse zones and pancake stacks of cavities. These associations give additional credence to the hypothesis of fracture enlargement for their origin.

Caverns

The only confirmed caverns in the study area are in the Rebecca Shoal reef (Figs. 8, 9 & 10, & Table 1). These all occur near the base of the main reef body or a Tongue. With the exception of the cavern in Well 117MON, all caverns are found about two thousand feet below the top of the Rebecca Shoal, suggesting that they might have been formed at about the same time. In Twin Wells 292 & 298MON, 790 feet apart, the same cavern was encountered (see p. 21), suggesting that other Rebecca Shoal caverns might be of comparable extent.

Although there is no evidence in the drill cuttings for a subaerial origin for these caverns, the apparent coincidence of their structural positions could support that hypothesis.

DRILLING TECHNIQUES AND PROBLEMS

Banks (1950) and Burke (1967) present details on Boulder Zone drilling problems and remedial techniques in Appendices 8 & 9.

Conventional Drilling

In this method, water or drilling mud is pumped down the pipe, with returns containing cuttings rising up the borehole outside the drill pipe to the surface. If highly permeable zones are encountered, the drilling fluid and its load of cuttings are lost into these zones. As this "lost circulation" results in failure of cuttings to reach the surface, a long interval without samples occurs until casing is set below the Boulder Zone, around 4000 feet.

All deep oil tests are drilled by the conventional method.

Reverse Air Drilling

This method, also referred to as "airlift" drilling, is used on injection wells. To put it simply, it sucks the formation water and drill cuttings up the drill pipe. To achieve this, a one-inch air line is run through the swivel into the kelly, and down into the drill pipe about 300 feet below ground surface. Pumping compressed air down the one-inch air line decreases the density of water in the top of the drill pipe. The reduced pressure then causes the water and suspended cuttings at the bottom of the drill pipe to move up the pipe to the surface. The cuttings settle out and the produced water is returned to the borehole outside the drill pipe. These cuttings are therefore not lost in highly permeable zones in the borehole. This system eliminates the problem of lost cuttings and circulation, which in conventional drilling methods frequently resulted in stuck pipe and "twist-offs".

BOULDER FORMATION AND RECOVERY

Boulder Formation

Prior to 1967, conventional drilling techniques in the Avon Park Boulder Zones of Collier and Hendry Counties emphasized speed of penetration. This included both heavy weight on and rapid rotation of the bit. These practices produced boulders by breaking off the roof of a cavity, particularly if fractures were also present. The roof fragment would fall to the bottom of the cavity where it was rolled around rather than being crushed by the bit. Unless pushed back into the cavity or fished out, the inability to drill up a large boulder would result in abandoning the hole and skidding the rig to a nearby location. Wall-collapse zones presented even more intractable problems, as there was no cavity into which a boulder could be nudged.

In the large-hole injection wells boulders are usually ground up, as their small size in relation to a 16 to 30 inch multi-headed bit prevents them from rolling around excessively. Bit marks on the boulder, pictured in Figure 27a from an oil test, show that it changed position several times before being fished out. Figure 27b pictures 14 boulders recovered from Well 574 outside the study area in Lake County.

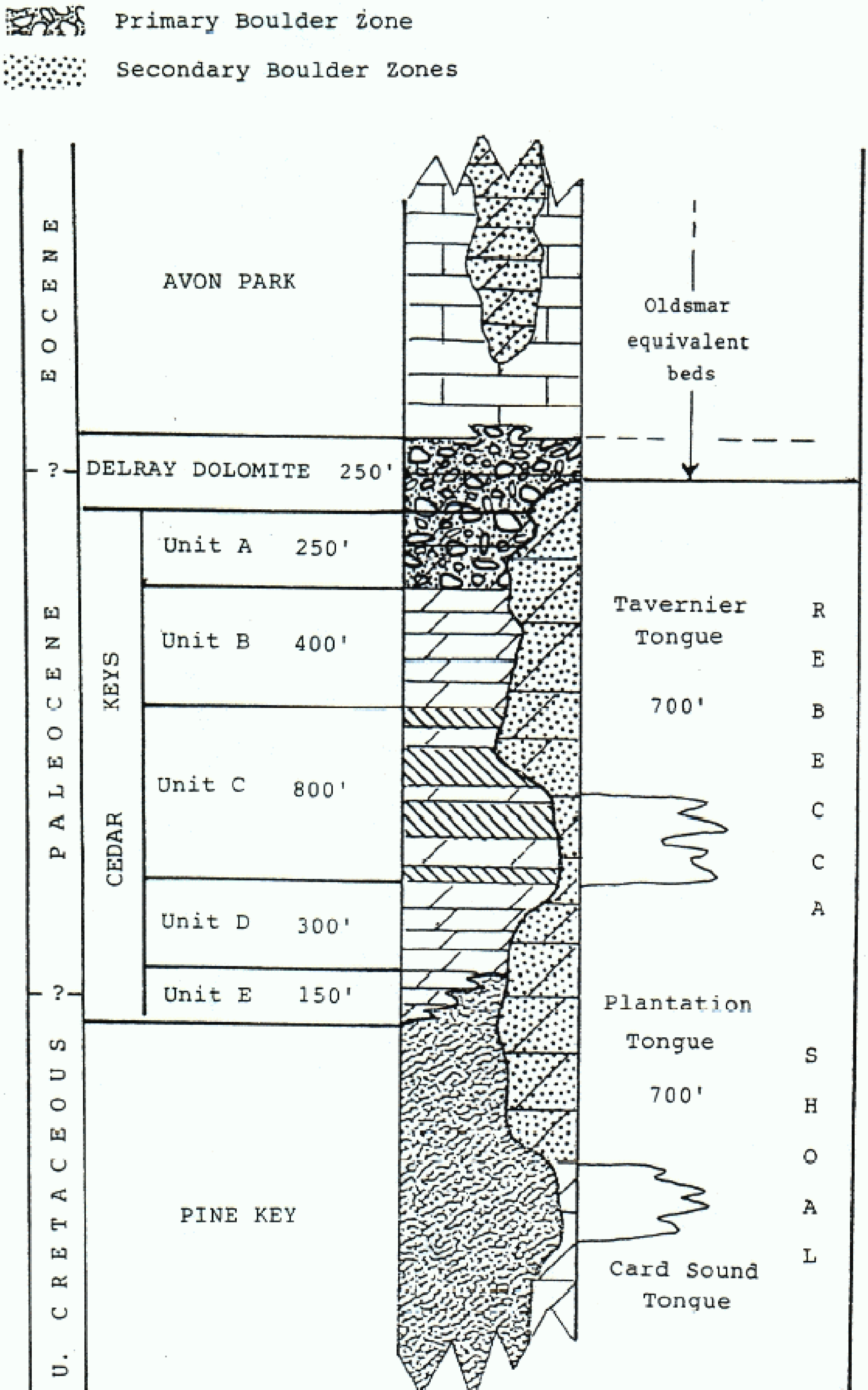
In the smaller hole of oil tests wall collapse was probably less frequent. In the large holes of injection wells it is more of a problem. In a small hole the curve of the wall provides more support for the fractured rock than the wider arc of the large diameter injection wells.

In small diameter holes, the bit has on occasion been key-seated by a large rock fragment falling in from up hole. Trips occasionally cause an unstable boulder resting on the edge of a cavity to fall.

Recovery

In oil tests, if a boulder could not be drilled up, attempts would be made to get it out of the hole by use of one of the devices, shown on Figure 28. One device, known as a junk basket, consists of a piece of drill pipe with a cylinder of casing six to eight feet long welded to it at the top and bottom. Two slots measuring two to three feet high and six inches wide are cut in the casing. The device is held off the bottom of the hole on the end of the drill string and fluid circulated to lift the boulder or boulders up, where they eventually fall into the slots and are captured.

The other device consists of a joint of casing with teeth cut into the end. These are slightly bent inward to direct their closing beneath a boulder when the weight of the drill string is put on the pipe.



Geleralized Geologic Column

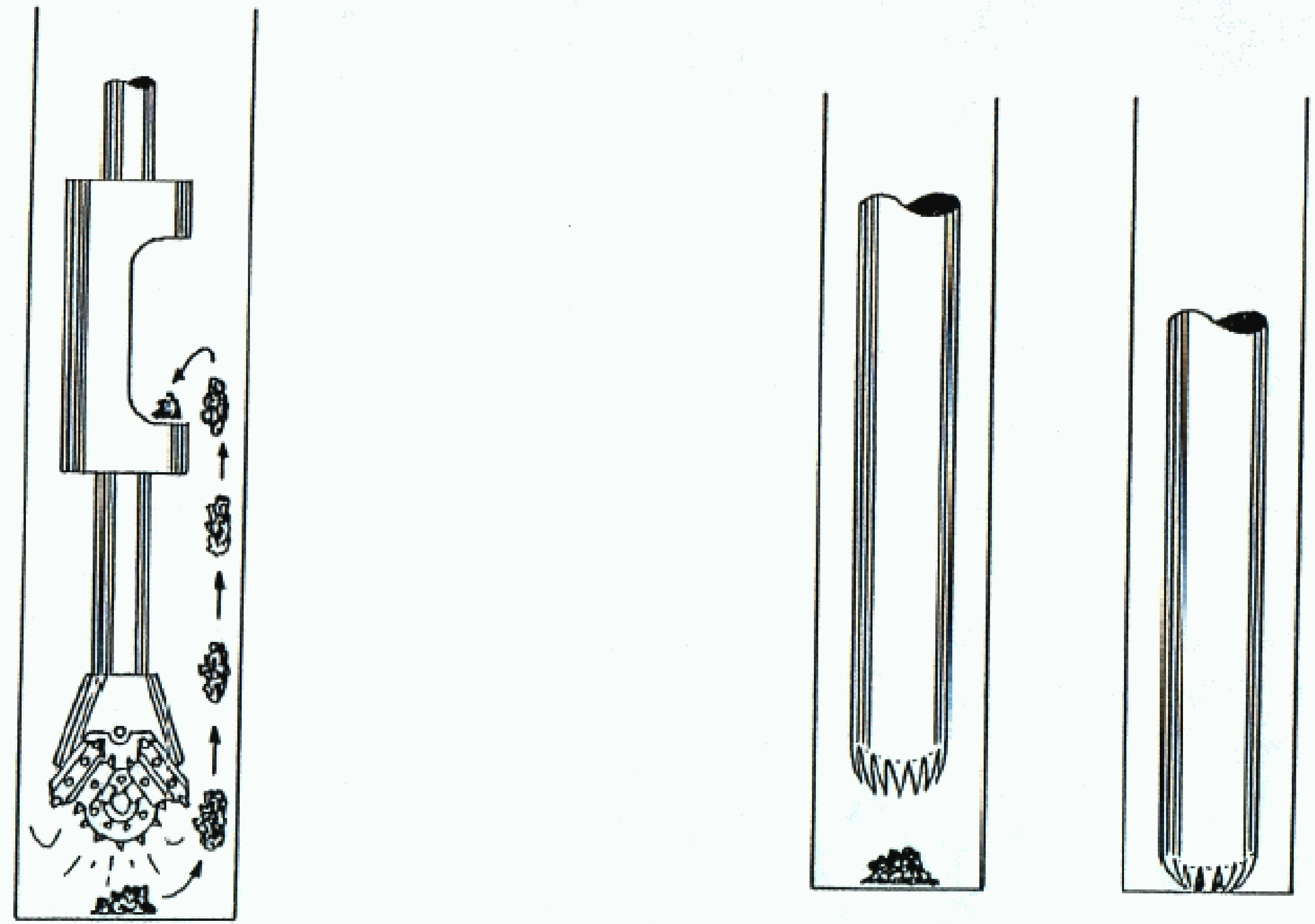
Boulder Zone Units & Lateral Equivalents

Fig. 2

ILLUSTRATIONS

NUMBERED FIGURES

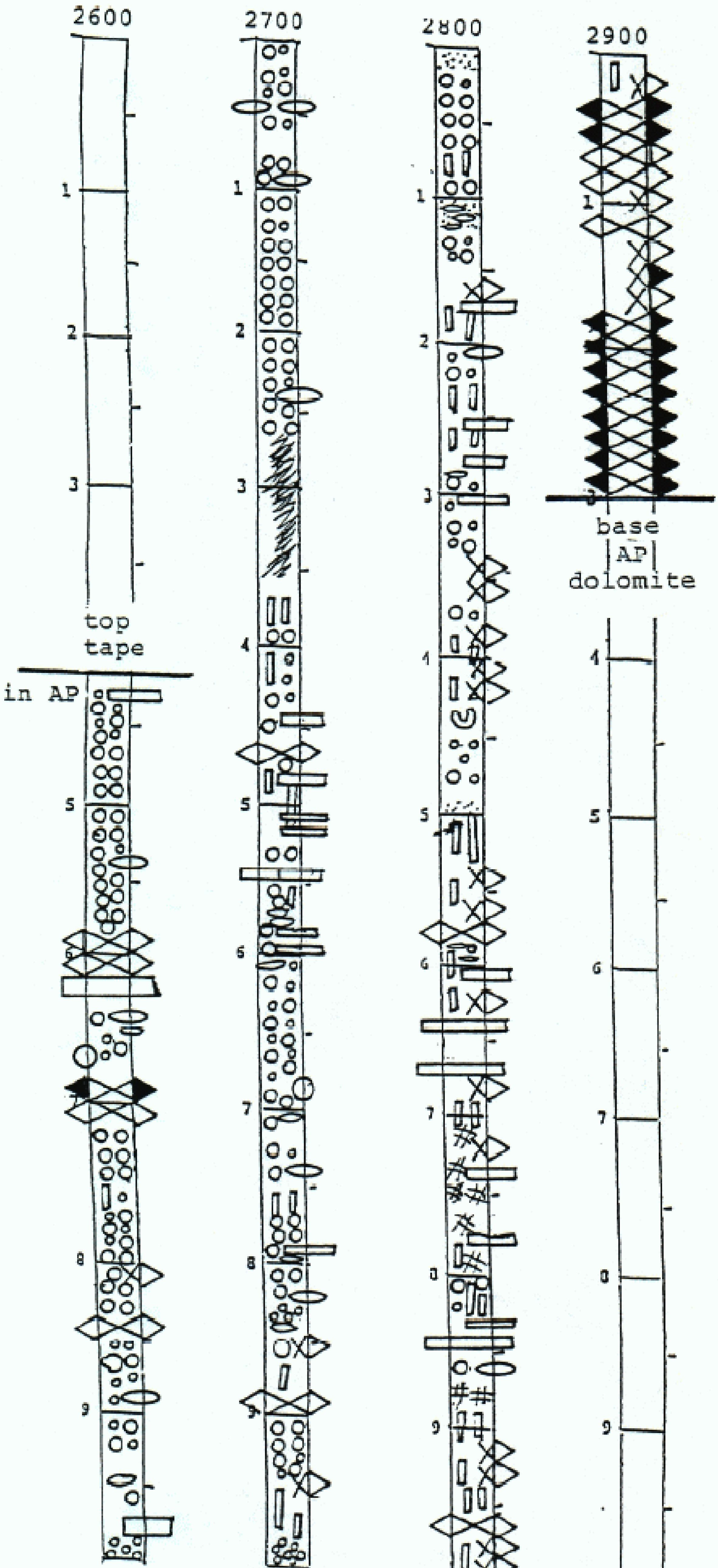
FIGURES BOUND IN TEXT



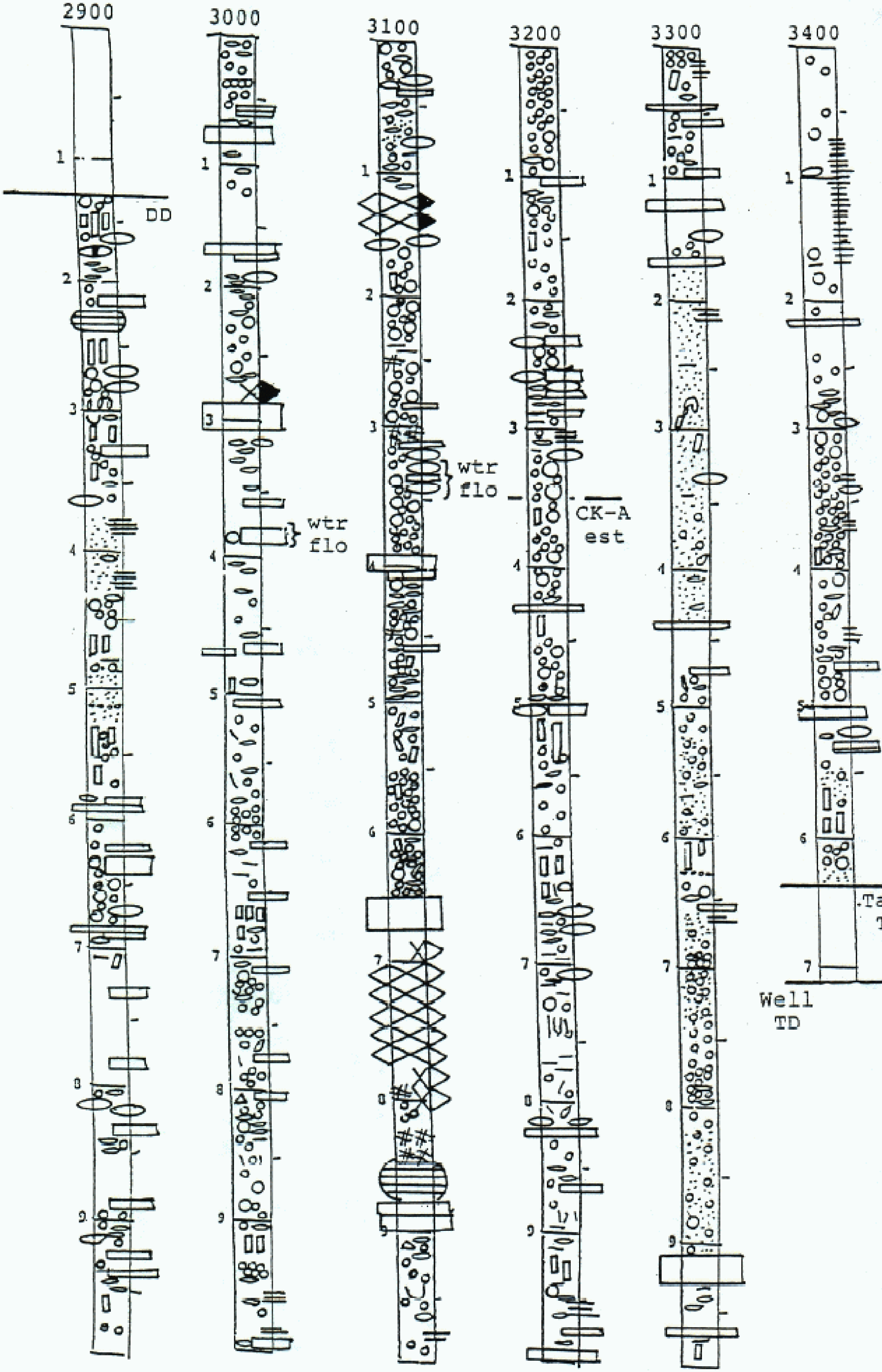
Devices used in Boulder Recovery

Fig. 28

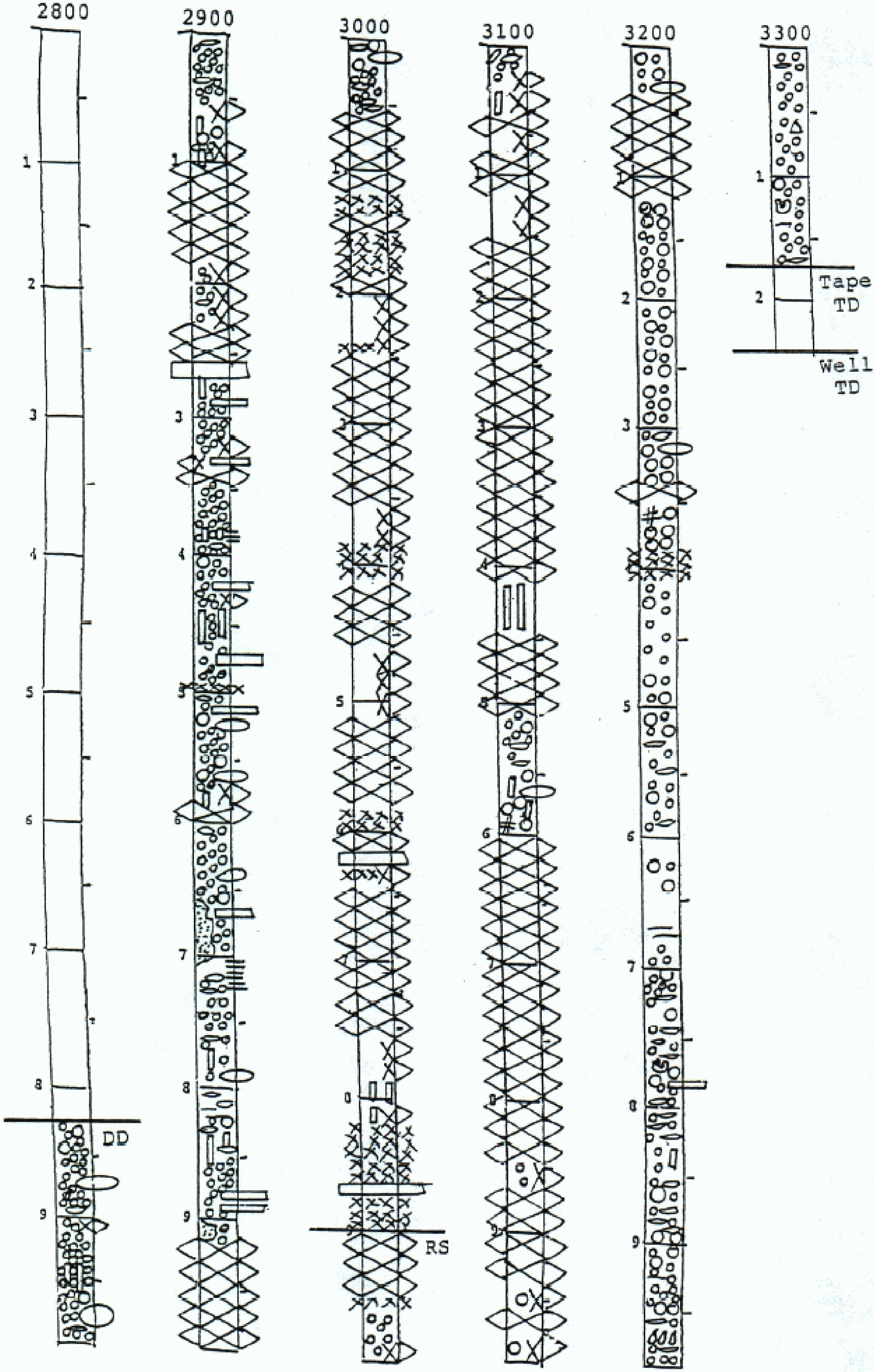
The following pages contain
graphic presentations (videologs)
of down-hole video surveys
included in this publication


2600
2700
2800
2900
top
tape
in AP
base
AP
dolomite

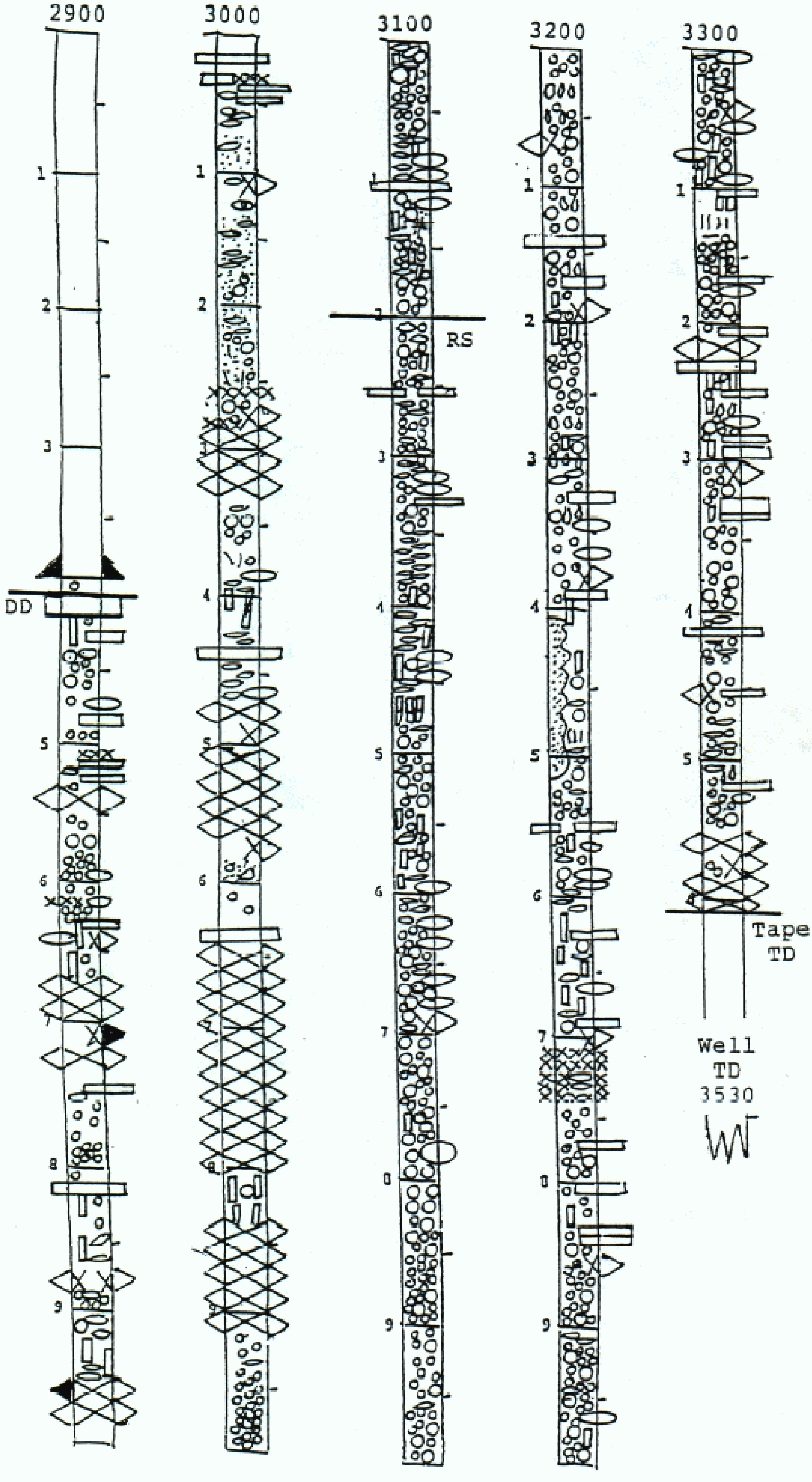
Ft. Lauderdale 46-5

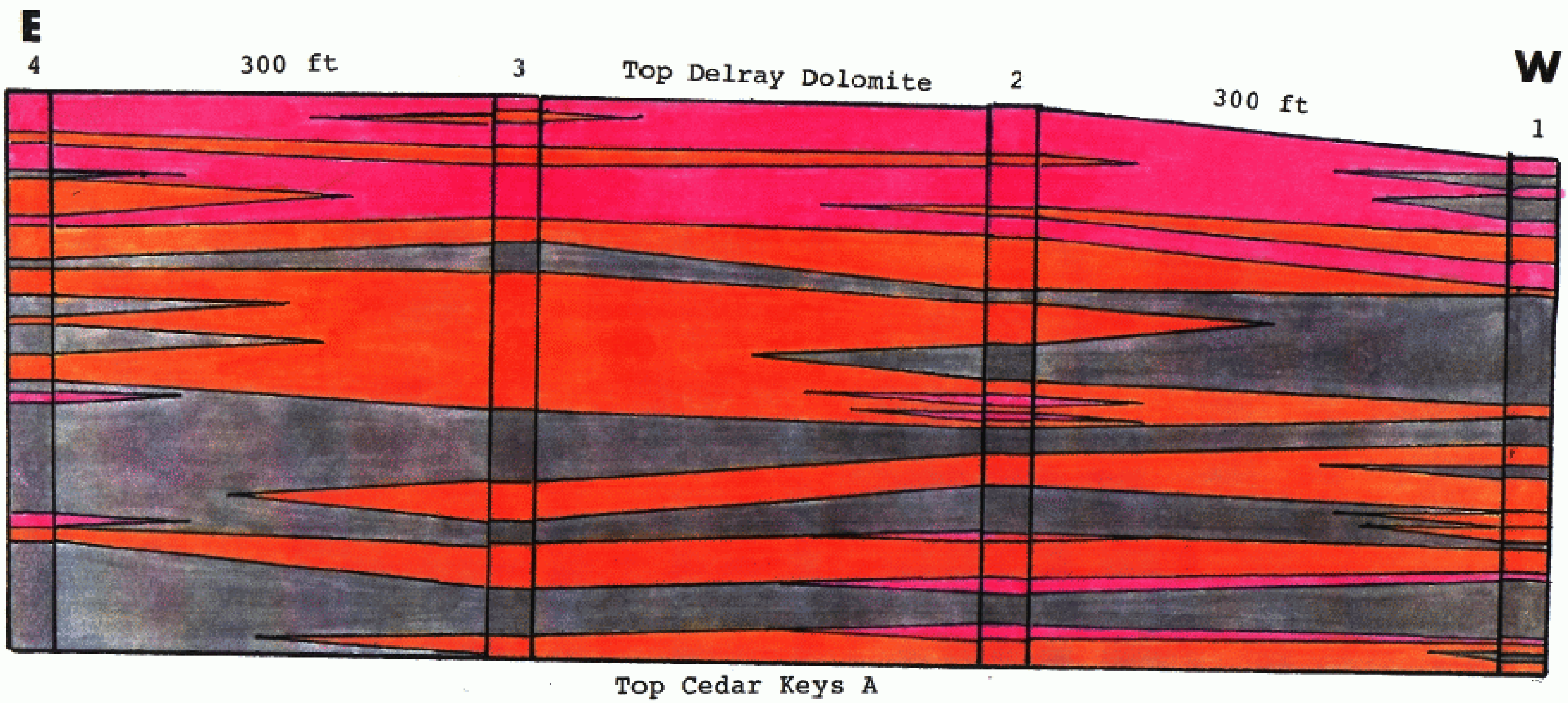


North Port 30



DeBartolo 53





100 feet

Natural Scale

0

100 feet

euhedral

anhedral

cryptocrystalline

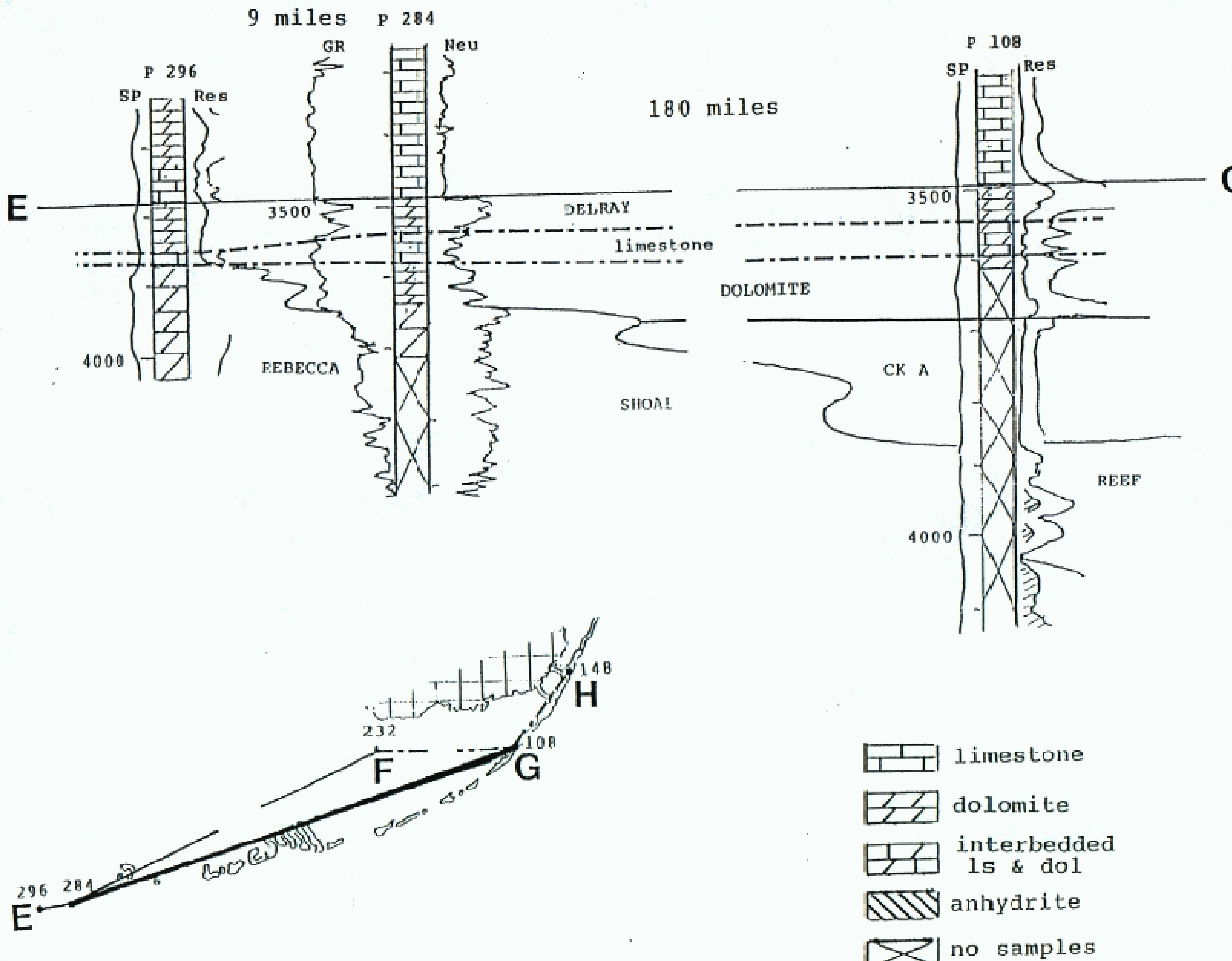
Lithologic Cross-section

showing

Dolomite Textures

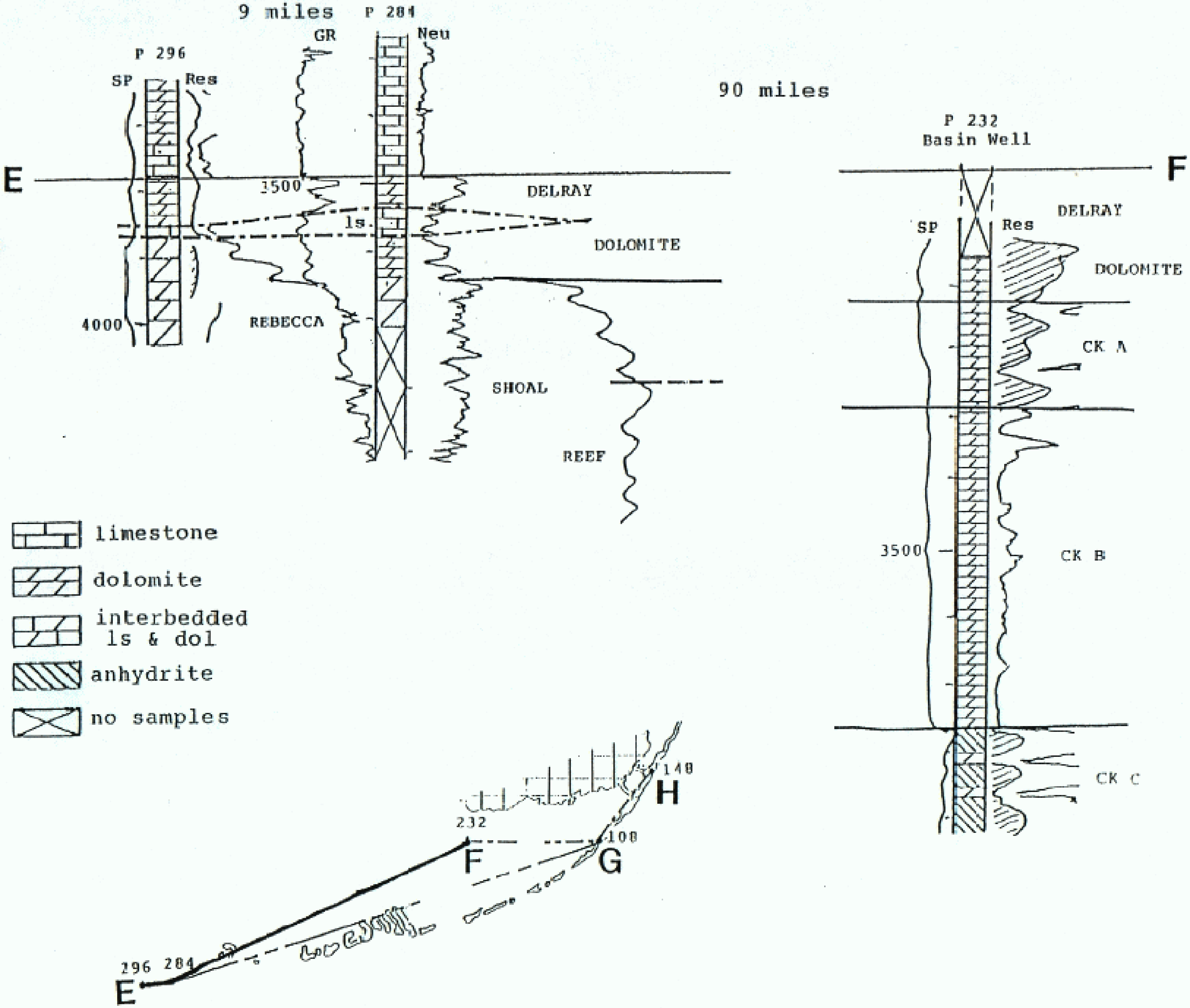
Broward North Site (51)

Fig. 3



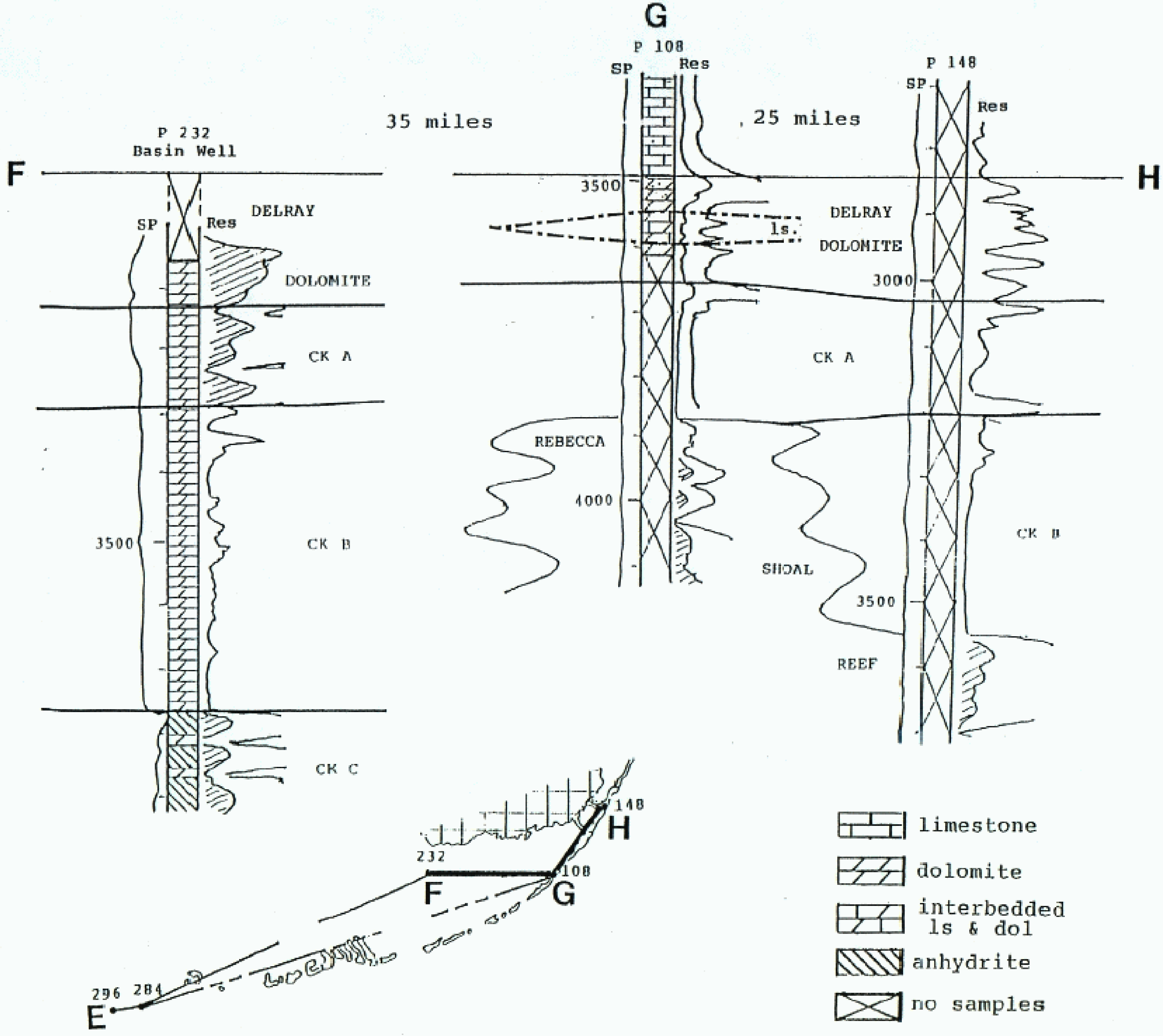
Keys Delray Dolomite Cross-section E-G

Fig. 4



Keys Delray Dolomite Cross-section E-F

Fig. 5

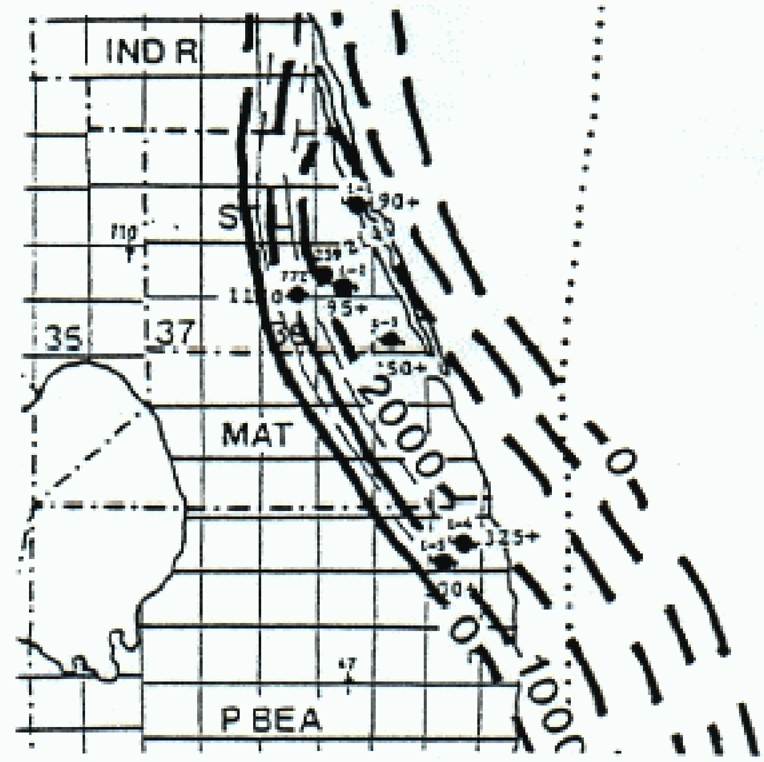


Keys Delray Dolomite Cross-section F-G-H

Fig. 6

Injection well
number translator

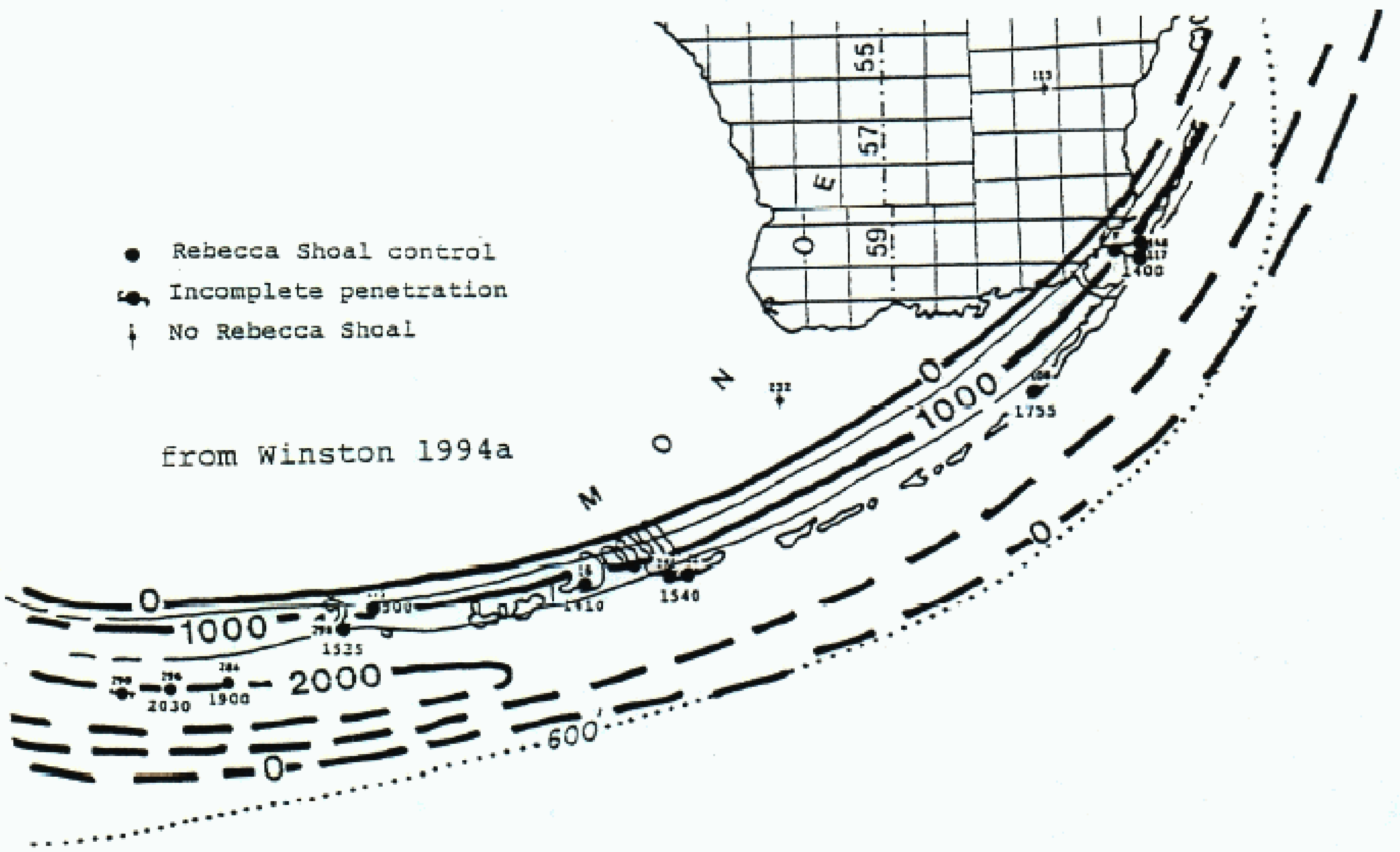
i-1=55
i-2=30
i-3=53
i-4=35
i-5=54



from Winston 1994a

- Rebecca Shoal control
- Incomplete penetration
- No Rebecca Shoal

from Winston 1994a



Isolith Rebecca Shoal Reef Rock

Fig. 7

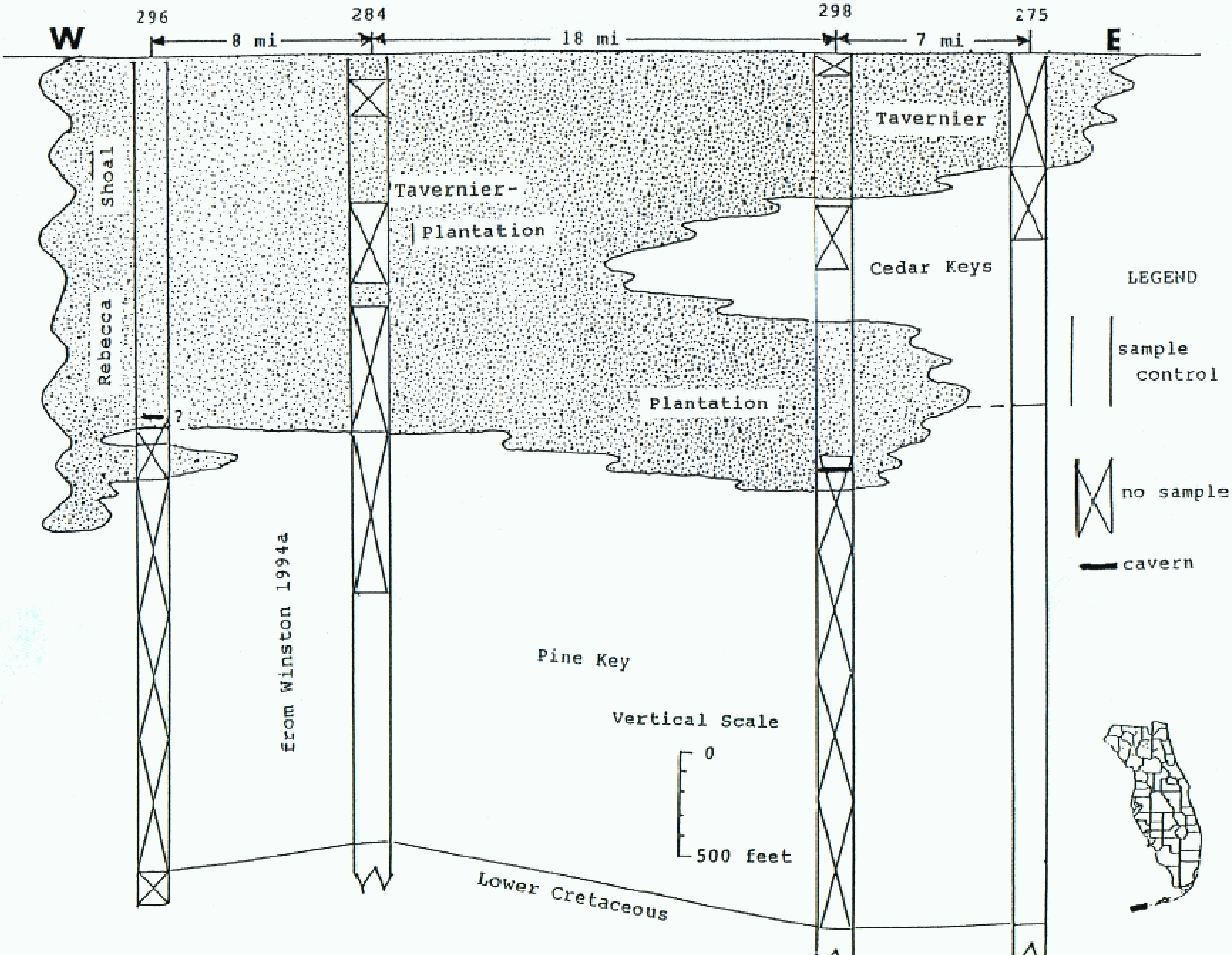


Fig. 8

Rebecca Shoal Cross-section Showing Cavern Location
Marquesas Keys

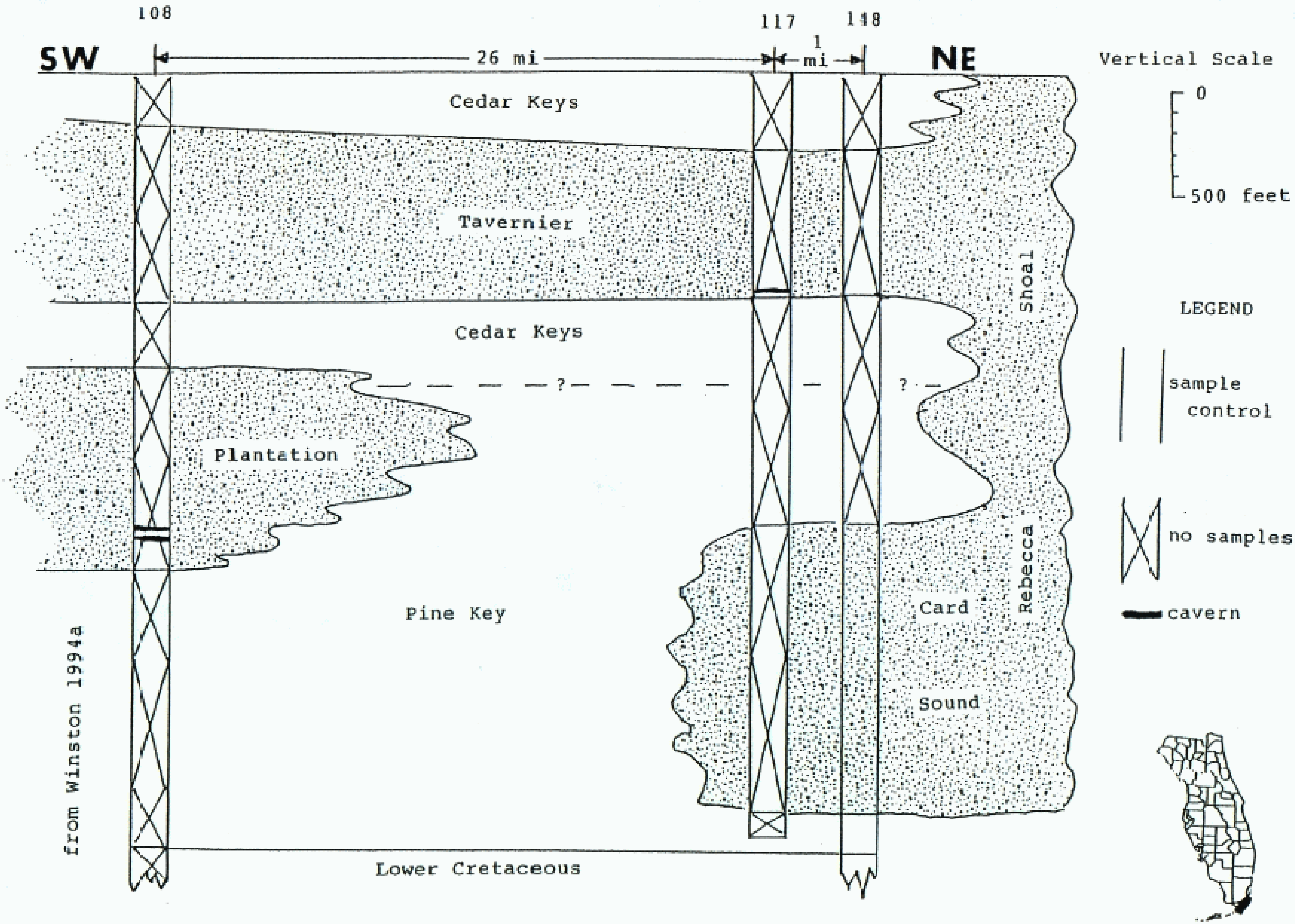


Fig. 9 Rebecca Shoal Cross-sections Showing Cavern Location Upper Keys

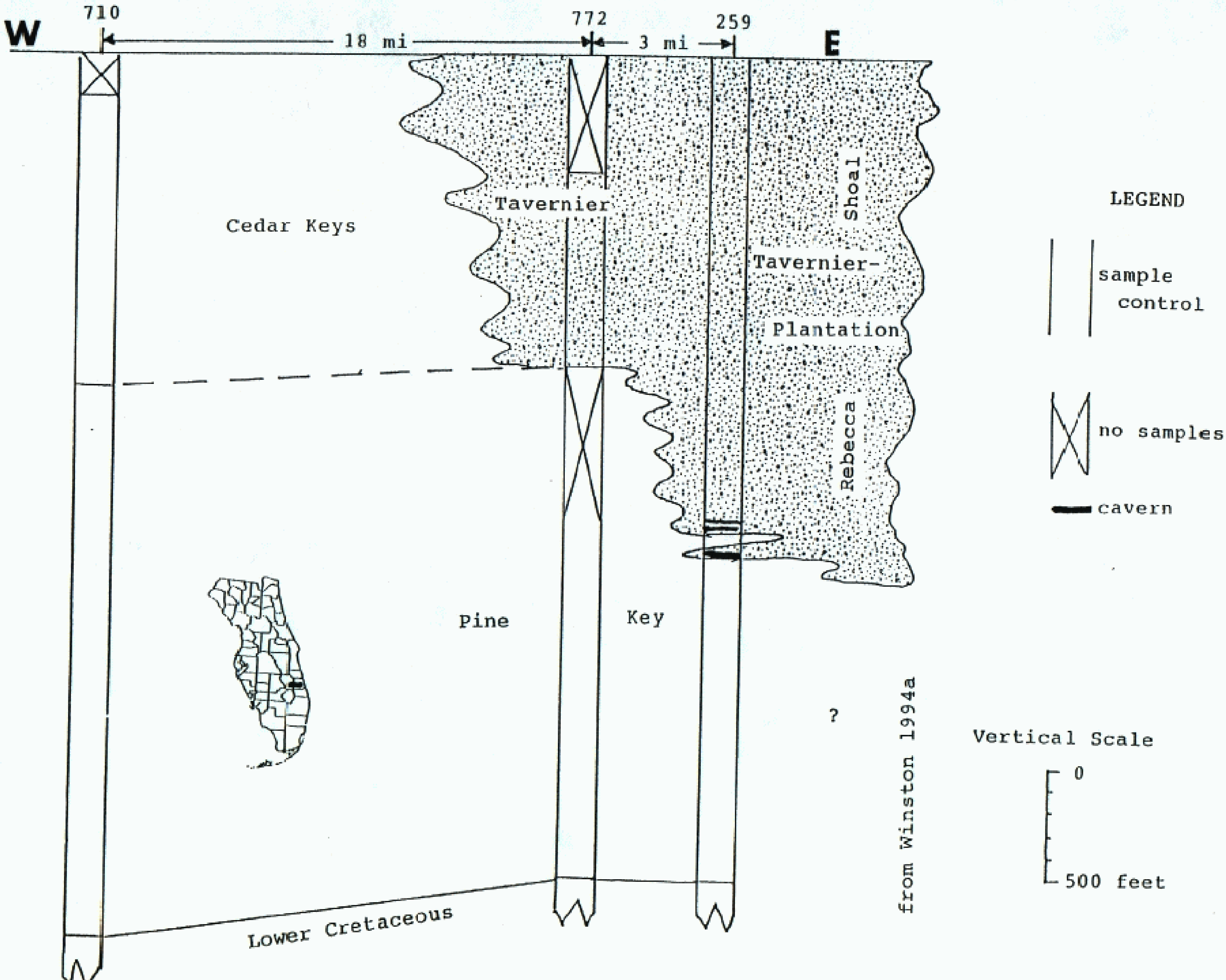
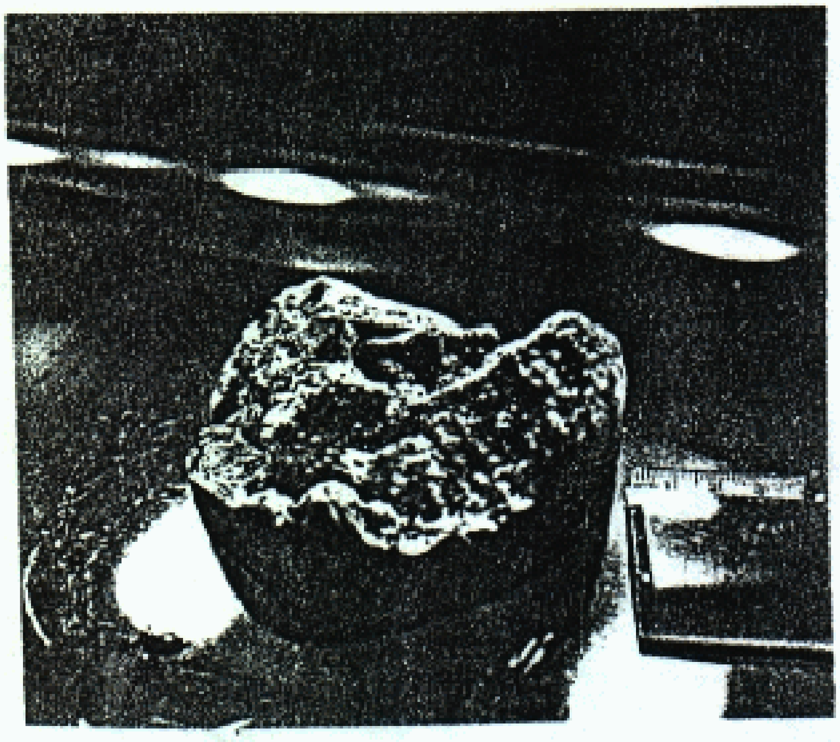


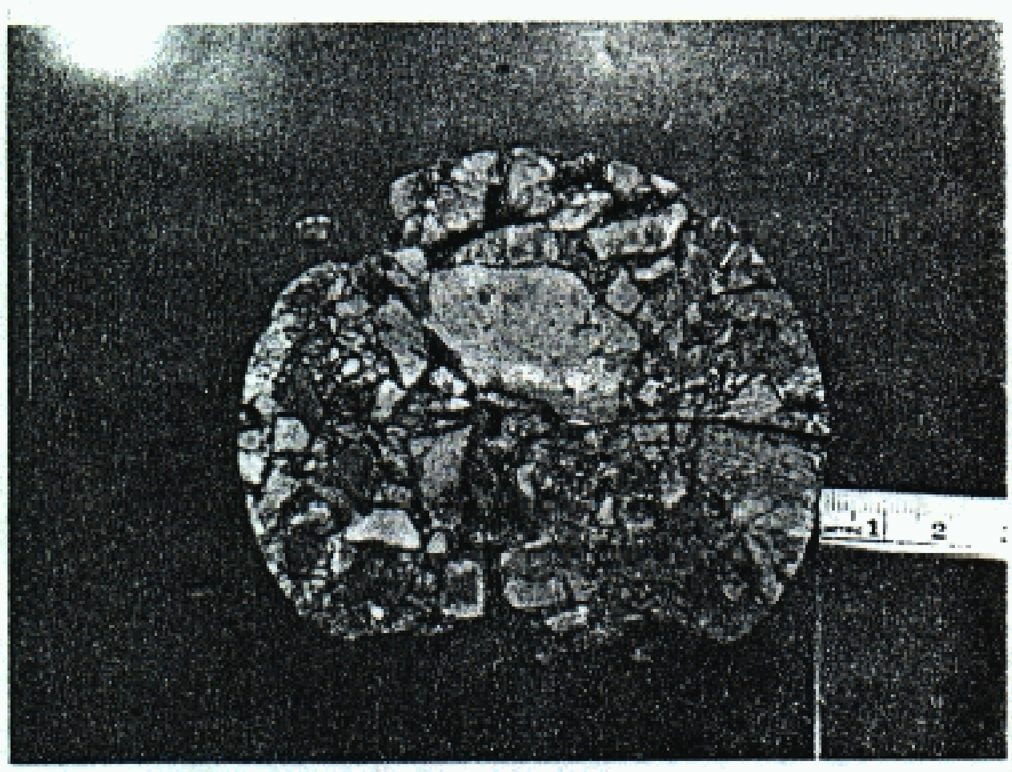
Fig. 10 Rececca Shoal Cross-section Showing Cavern Location
St. Lucie County



Oblique View

Overhead View

from Puri & Winston 1994

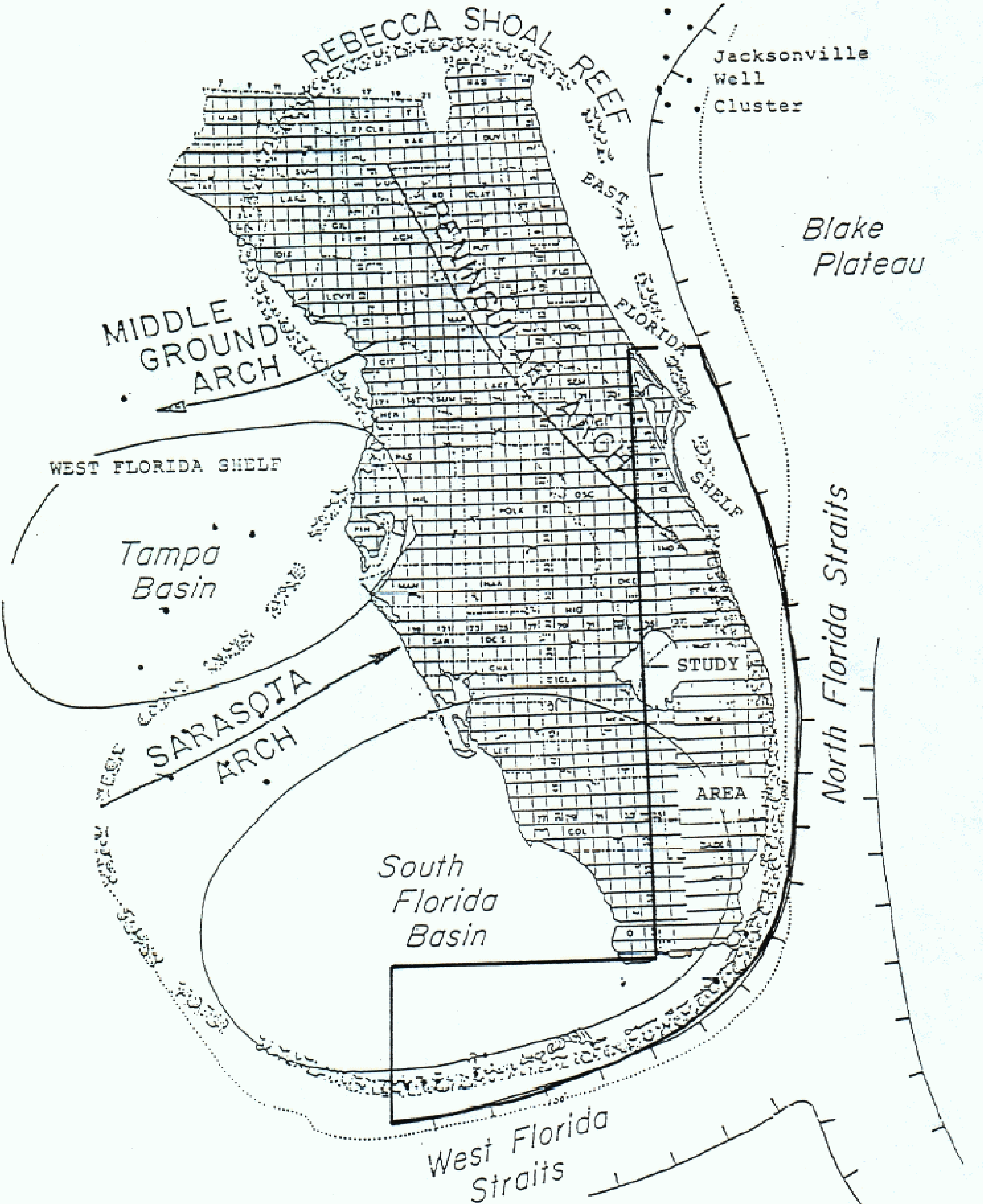


A sawed face of core from Upper Cretaceous 5034 - 40½ in Amerada No. 2 Cowles - Magazine (259), St. Lucie County (top); Other side of the same core (bottom).

Photographs of Talus in Core

from Basal Rebecca Shoal

Fig. 11



Regional Structure and Study Area Location

Fig. 12

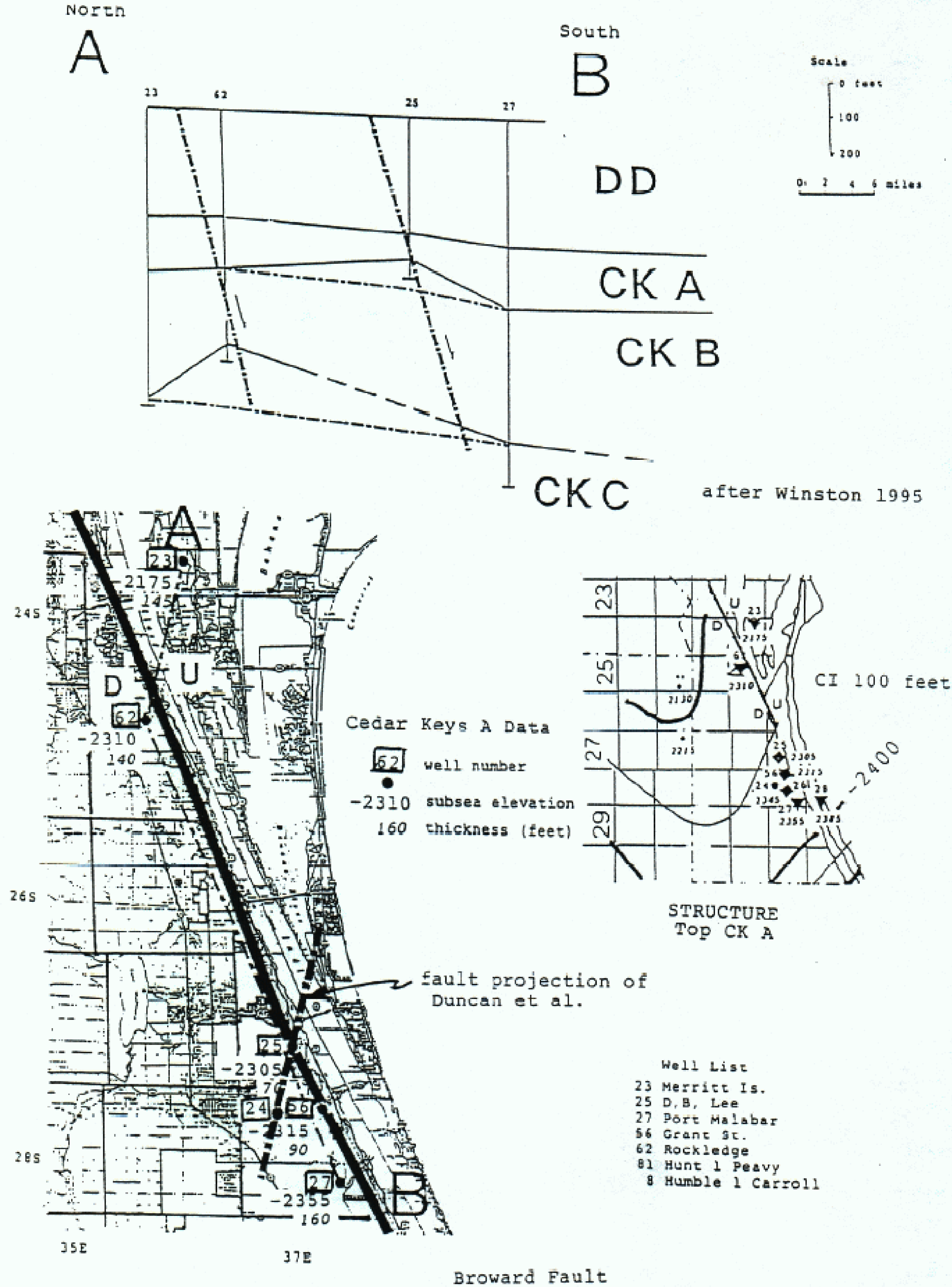
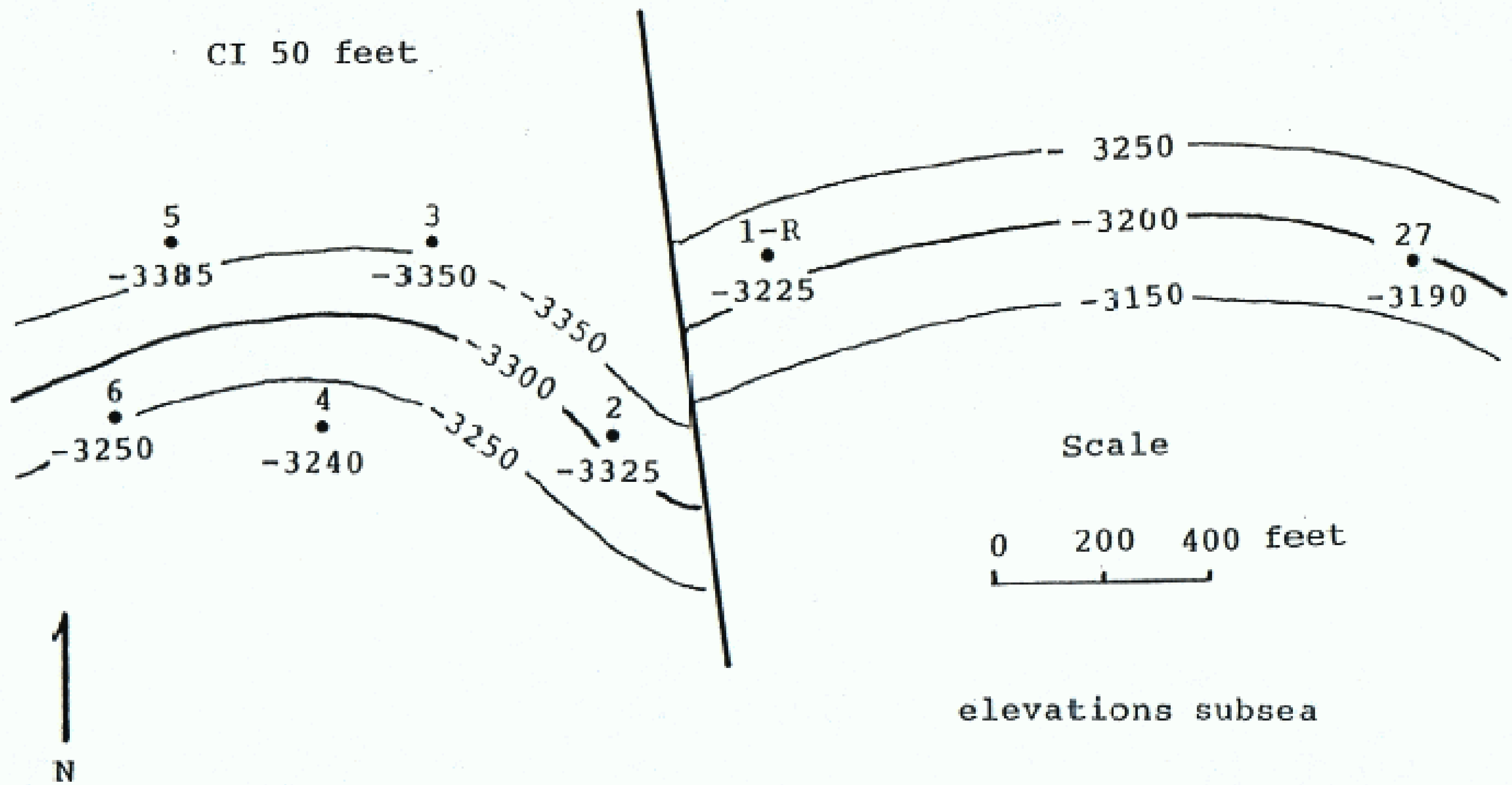

North
A
South
B
23
62
25
27
Scale
0 feet
100
200
0 2 4 6 miles
DD
CK A
CK B
CK C
after Winston 1995
D
U
2175
145
24S
62
-2310
140
26S
25
-2305
24
56
-2315
90
28S
27
-2355
160
35E
37E
Cedar Keys A Data
62 well number
-2310 subsea elevation
160 thickness (feet)
CI 100 feet
-2400
STRUCTURE
Top CK A
fault projection of
Duncan et al.
Well List
23 Merritt Is.
25 D,B, Lee
27 Port Malabar
56 Grant St.
62 Rockledge
81 Hunt 1 Peavy
8 Humble 1 Carroll
Broward Fault

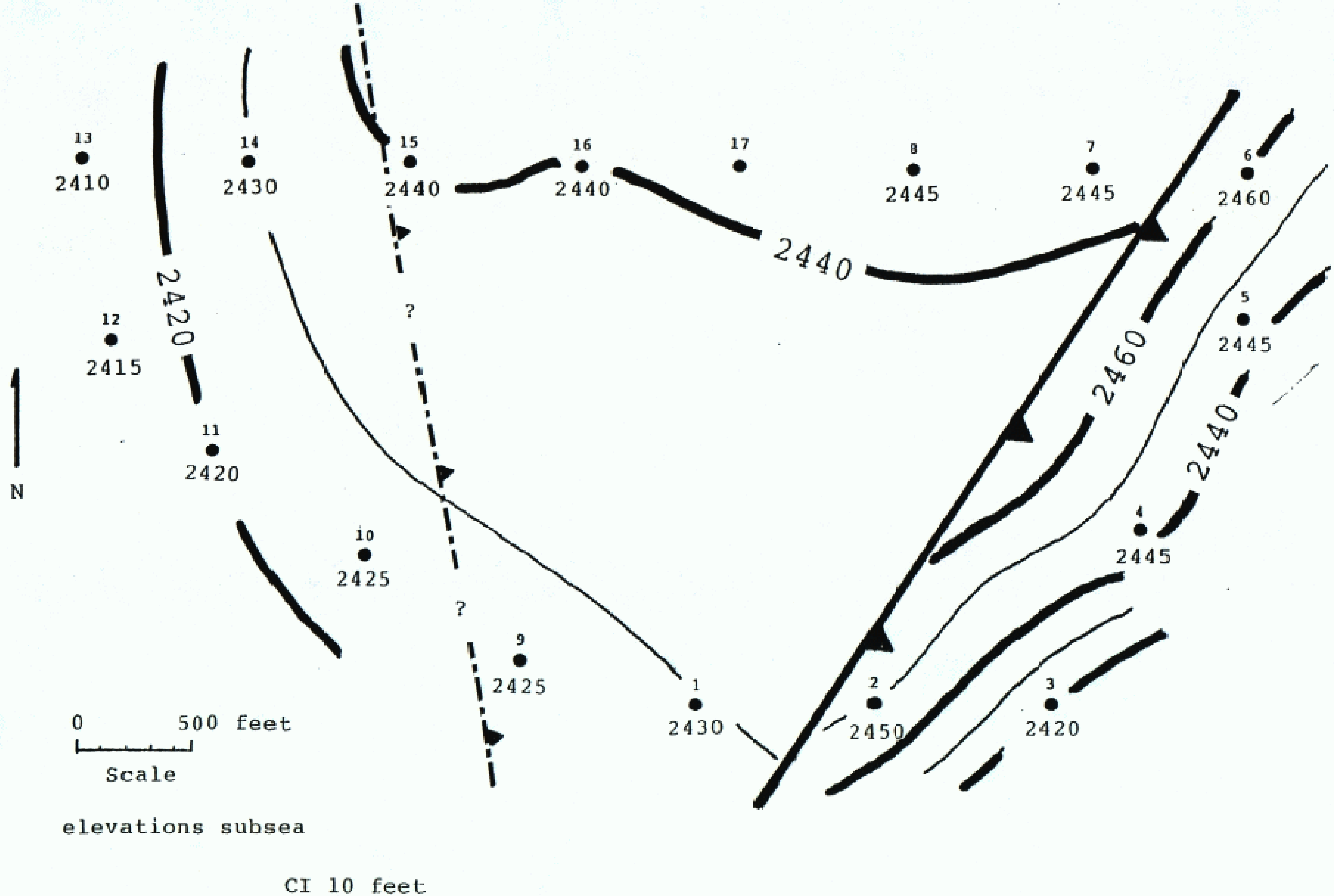
Fig. 13



Delray Dolomite Structure

West Palm Beach Multiple Well Site (37)

Fig. 14

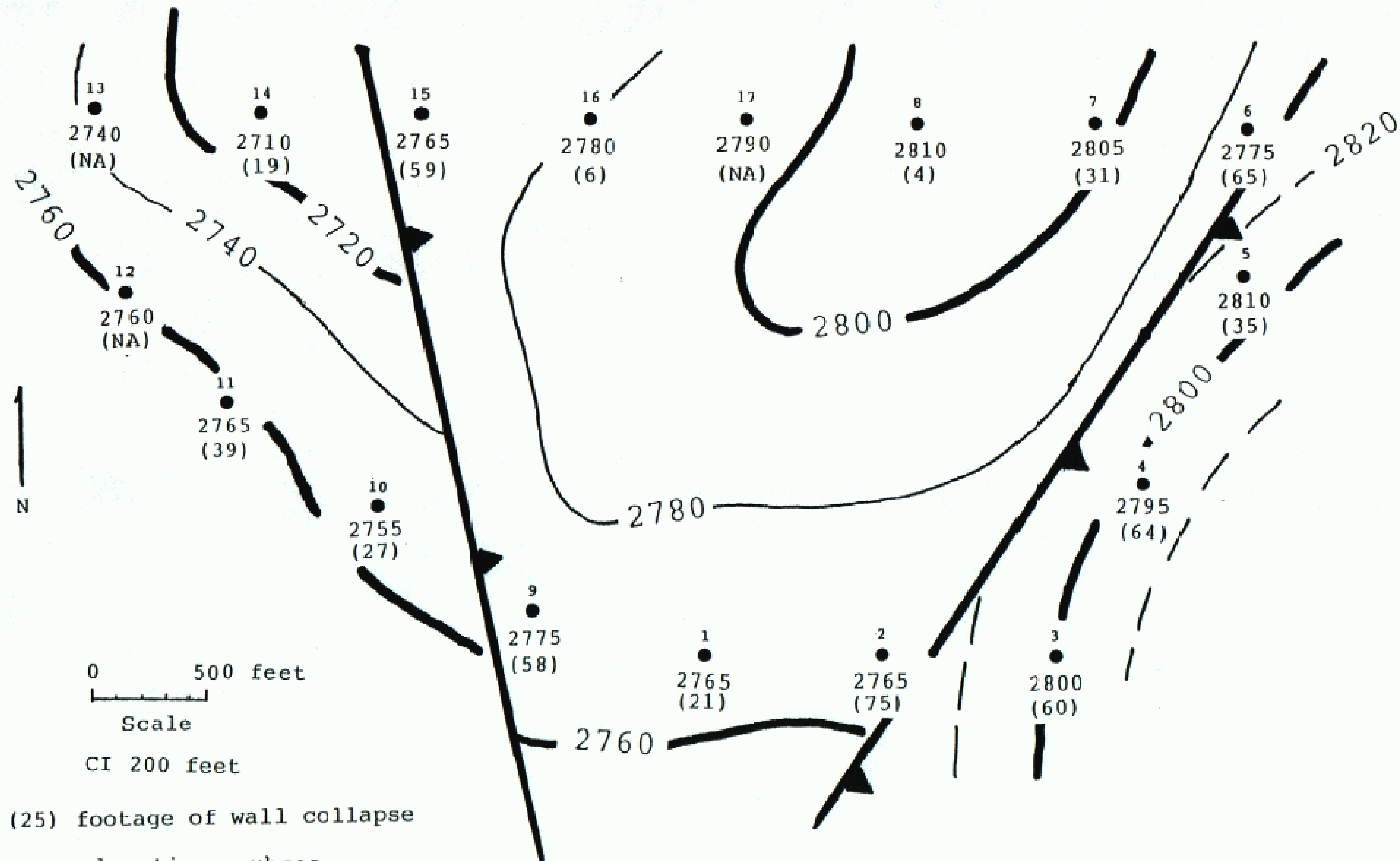


Structure - on an Avon Park dolomite

Miami Dade Water & Sewer (50)

(South District)

Fig. 15

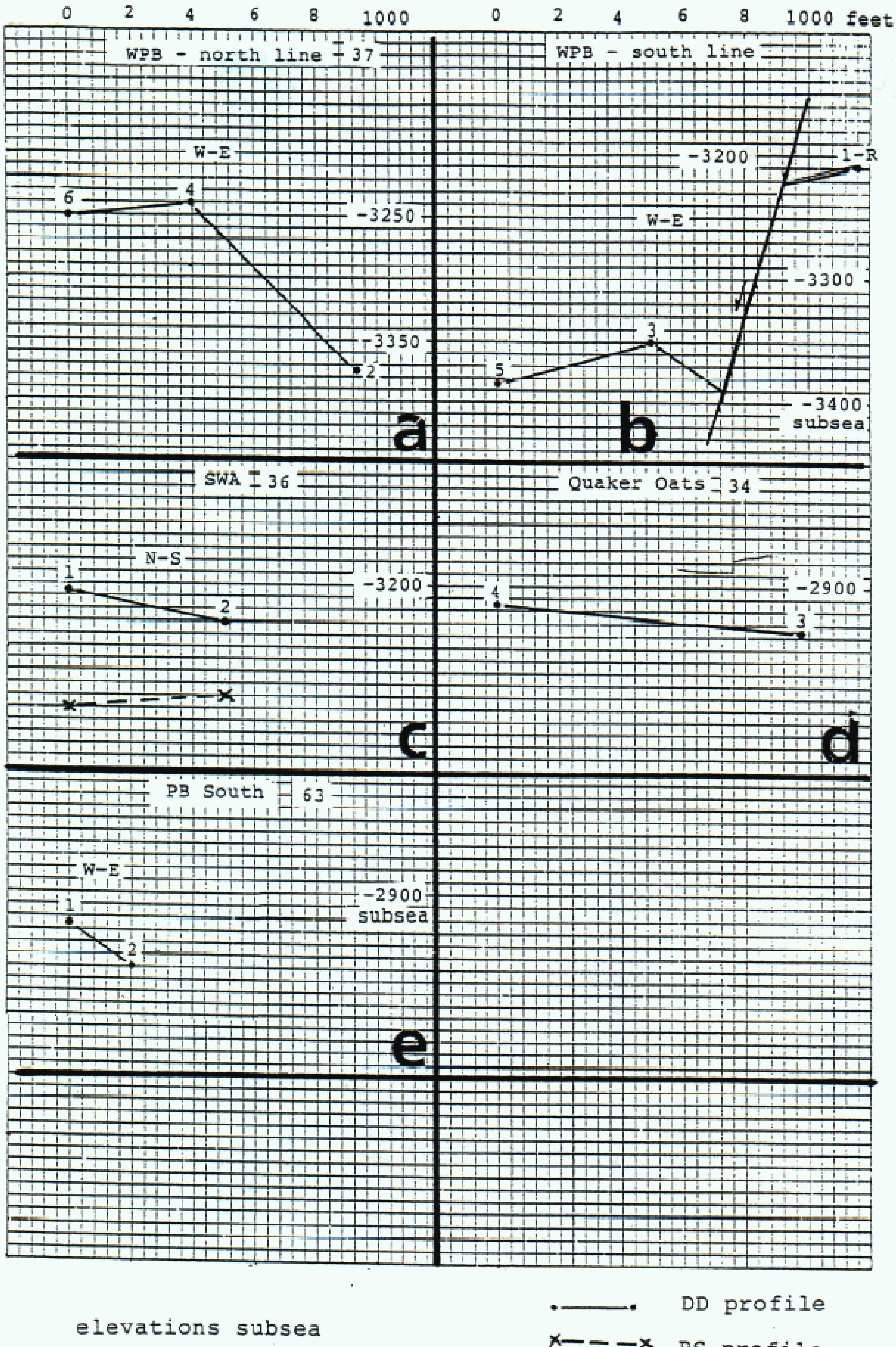


Structure - Delray Dolomite

Miami Dade Water & Sewer (50)

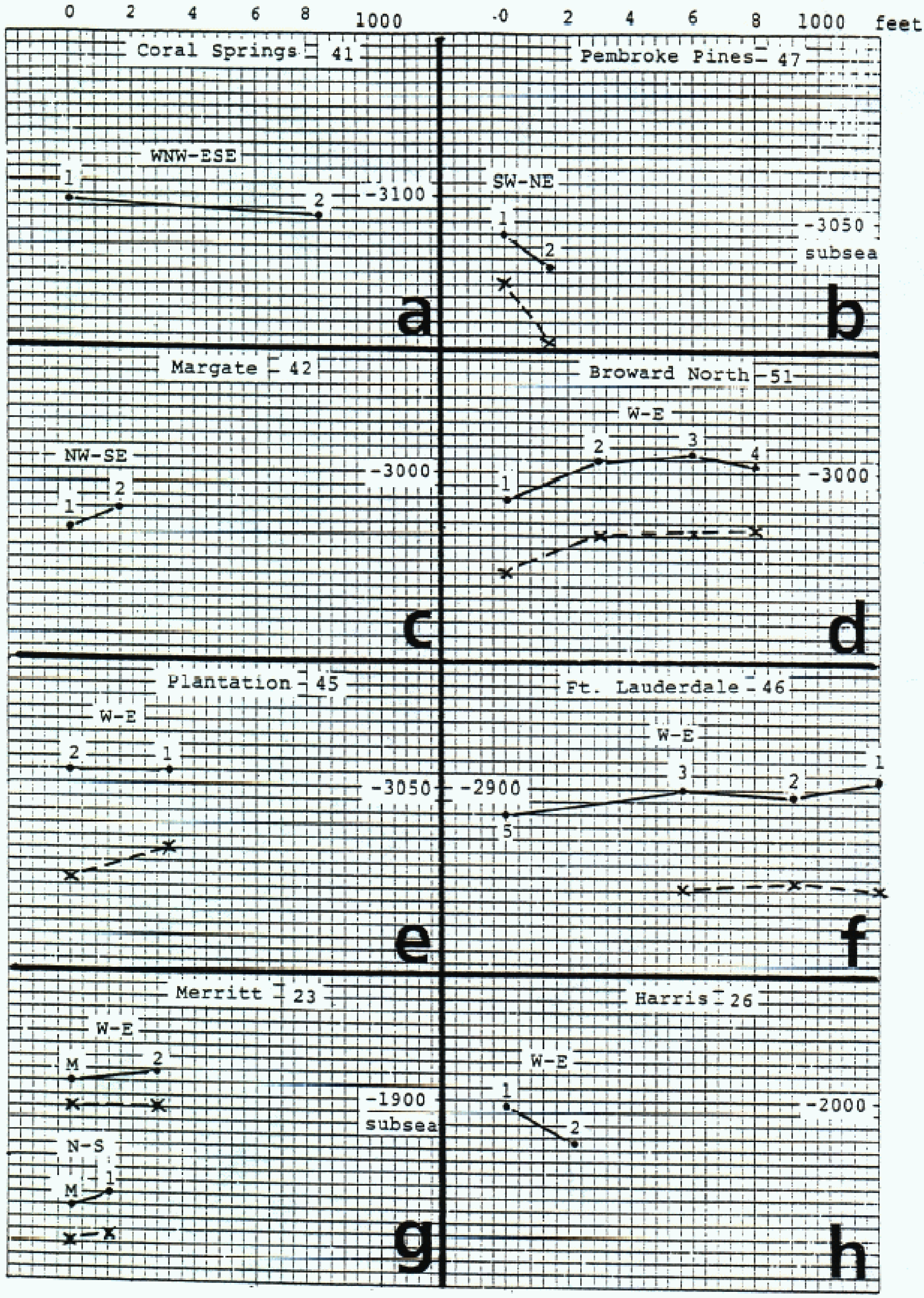
(South District)

Fig. 16



Structure Profiles at Multiple Well Sites

Fig. 17



elevations subsea

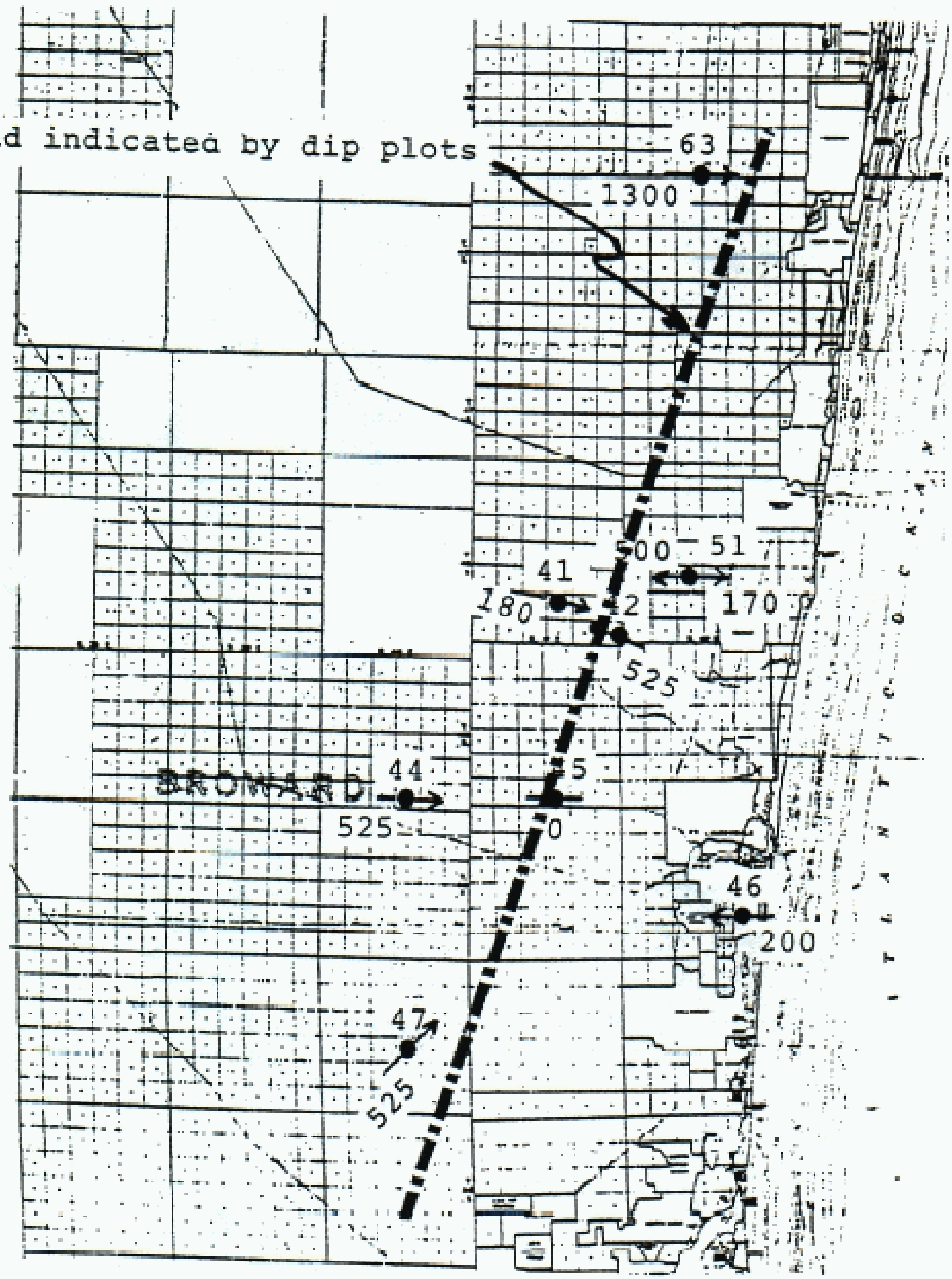
DD profile

CK A profile

Structure Profiles at Multiple Well Sites

Fig. 18

low trend indicated by dip plots



Dip Plots in Feet per Mile

Broward & Palm Beach Counties

Fig. 19

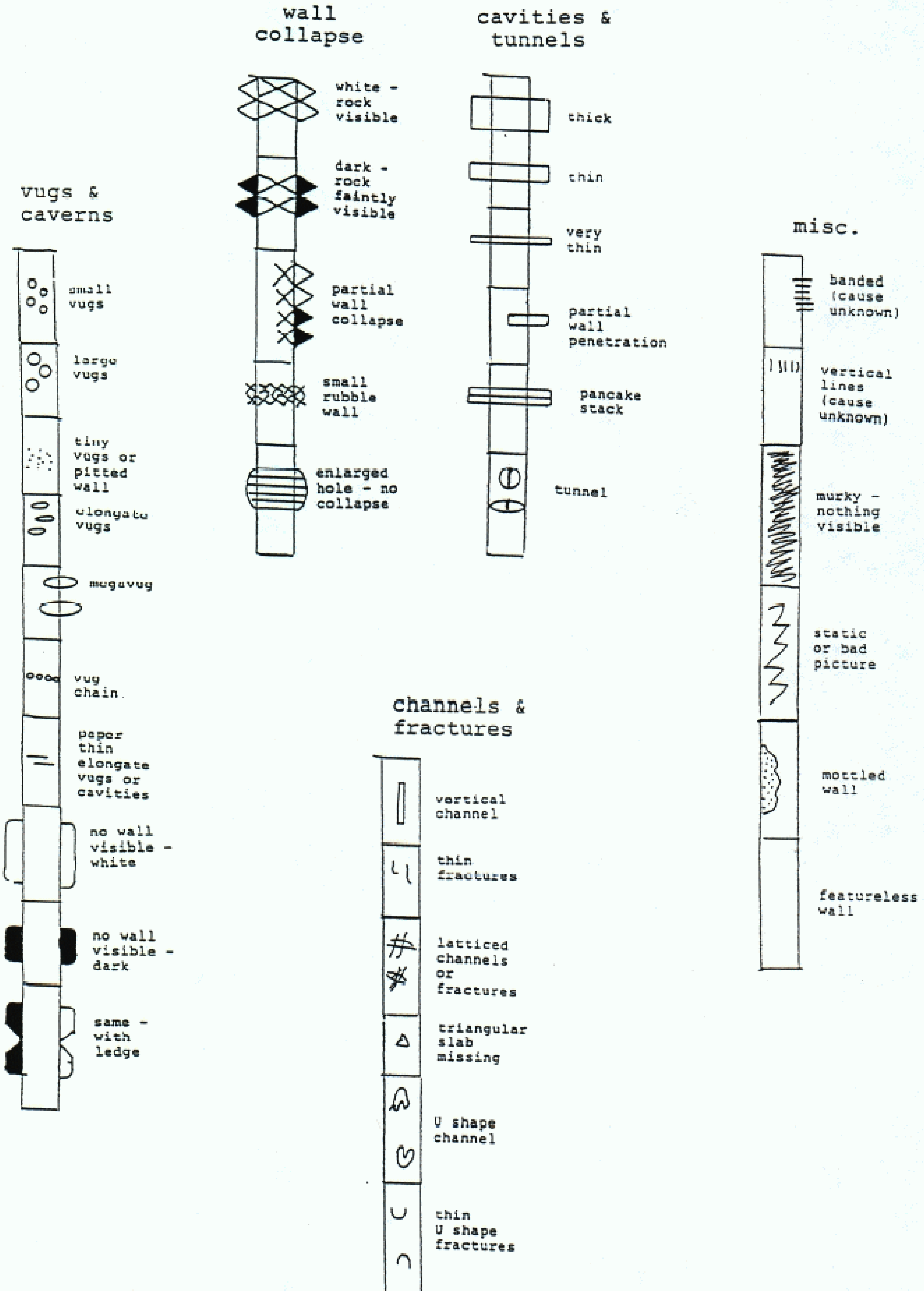


Fig. 20

Symbol Key

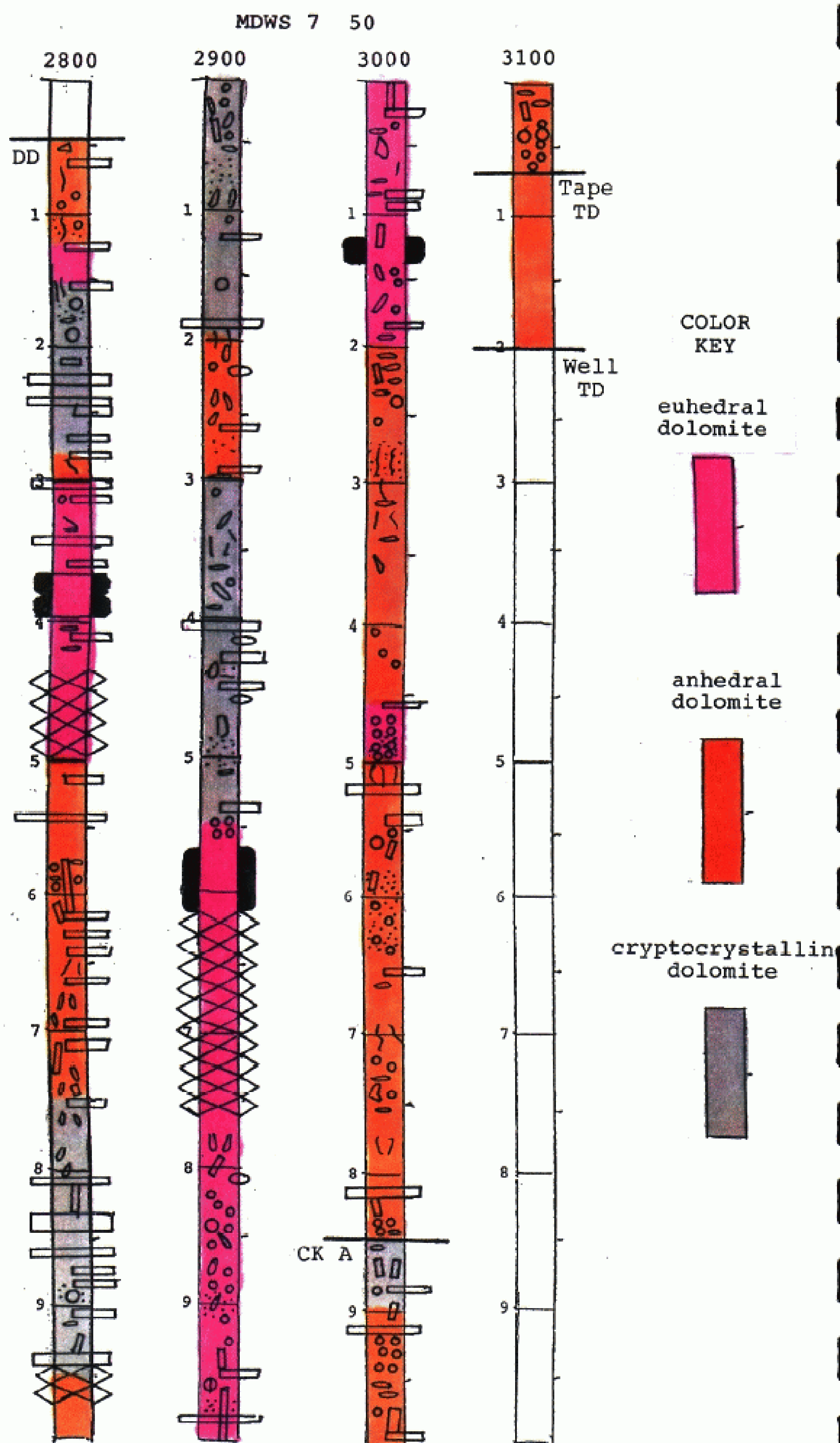
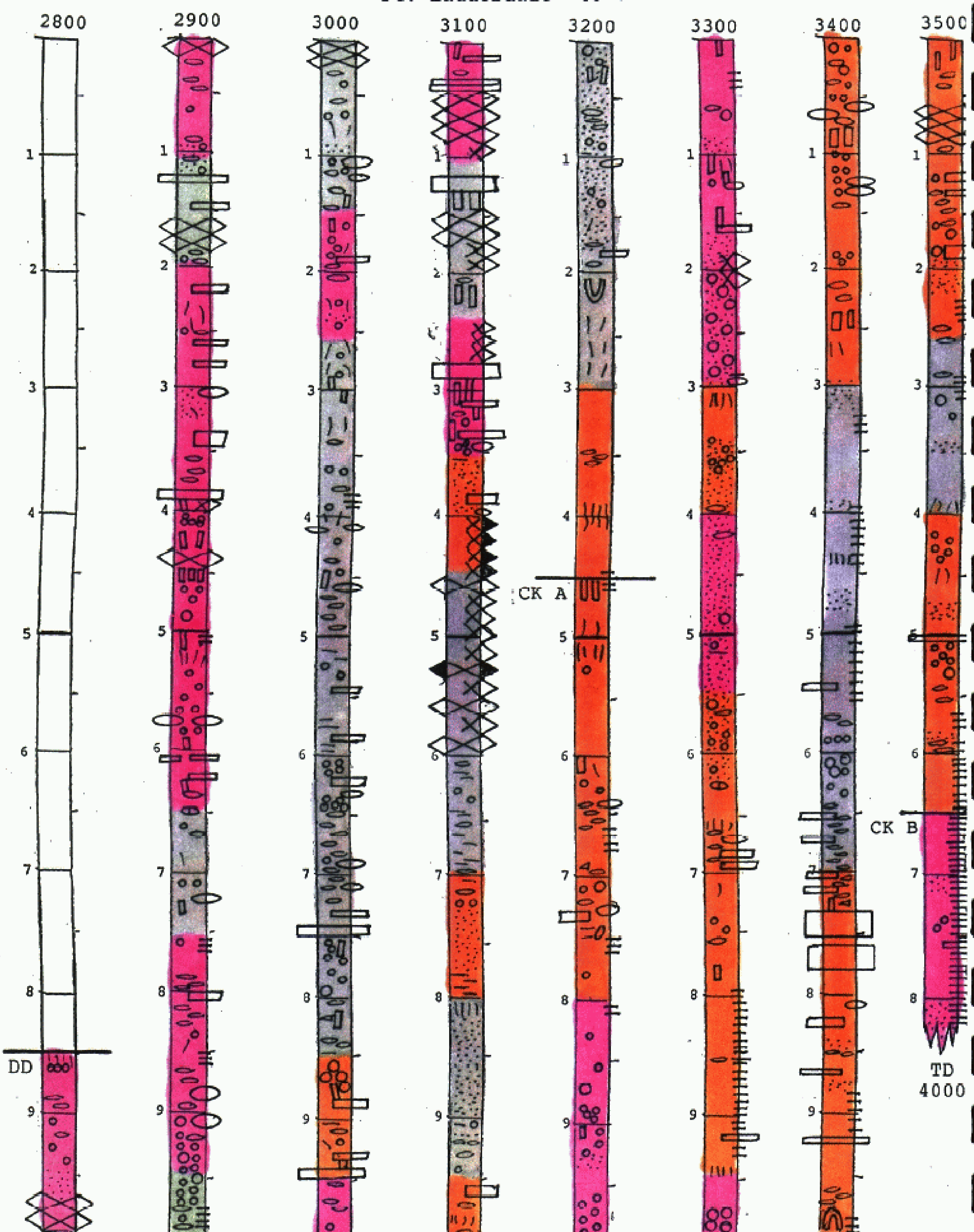

MDWS 7 50
2800
2900
3000
3100
DD
Tape TD
Well TD
CK A
COLOR KEY
euhedral dolomite
anhedral dolomite
cryptocrystalline dolomite

Fig. 21

Ft. Lauderdale 46-3



Belle Glade 59

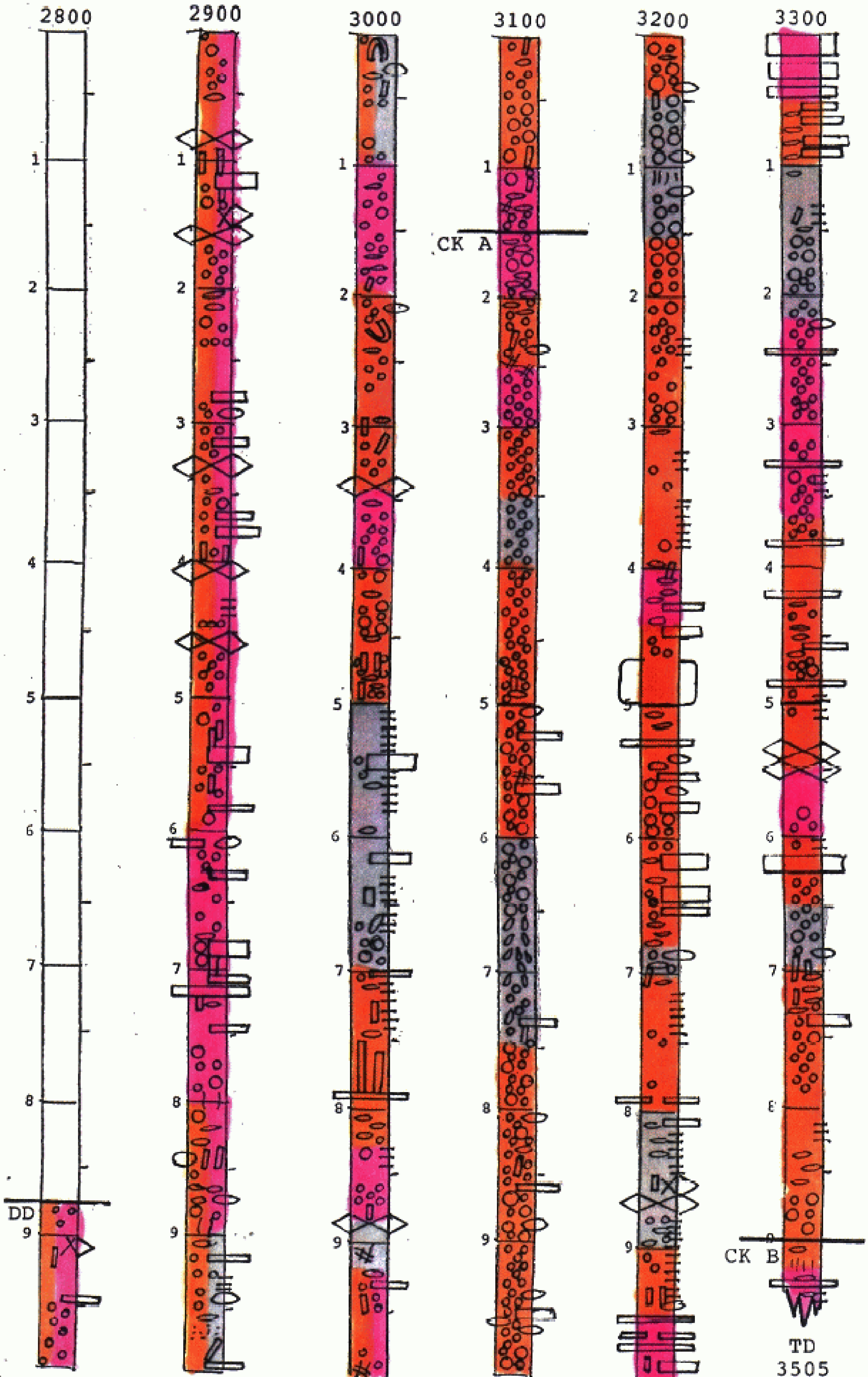


Fig. 23

Encon 35

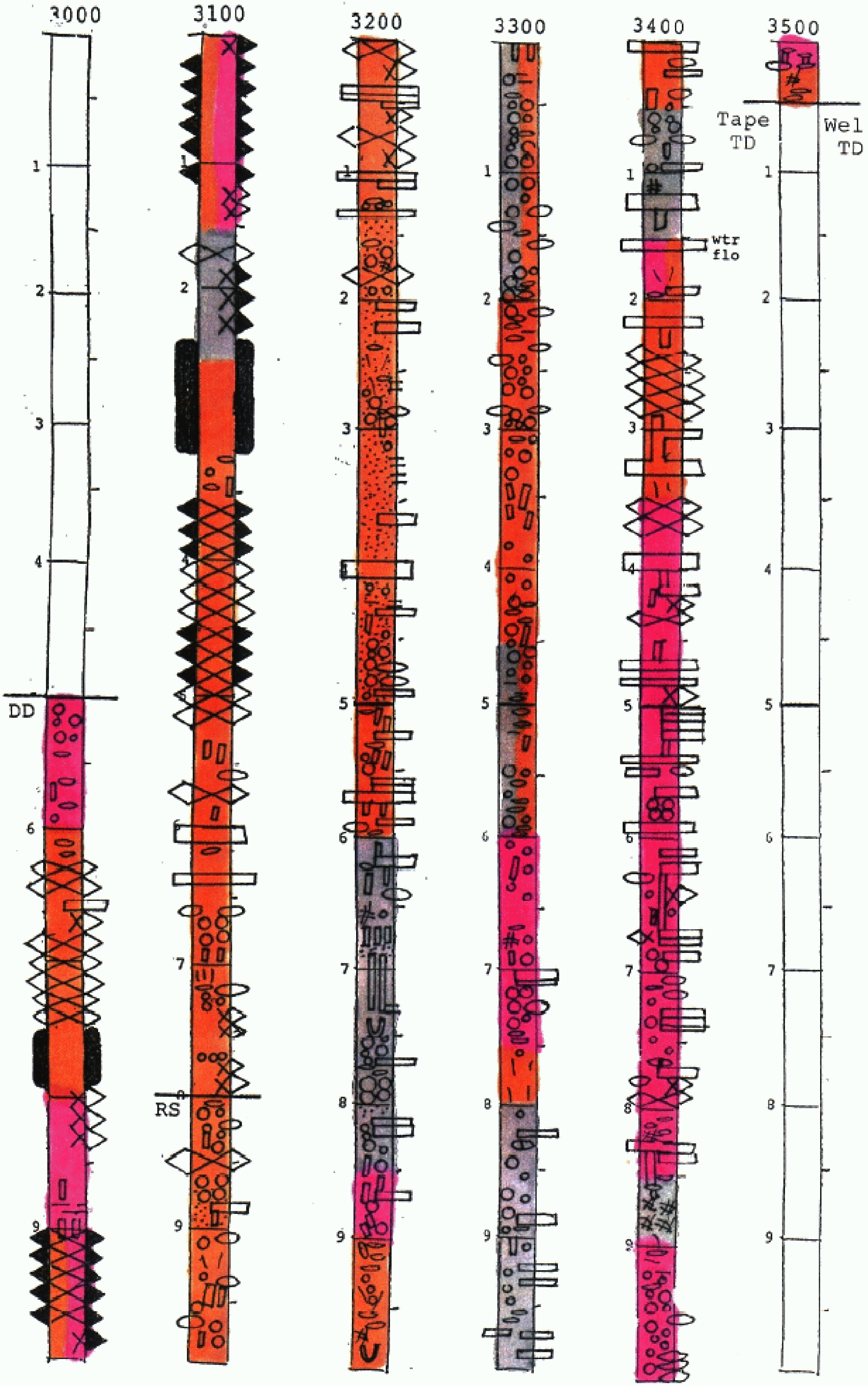


Fig. 24

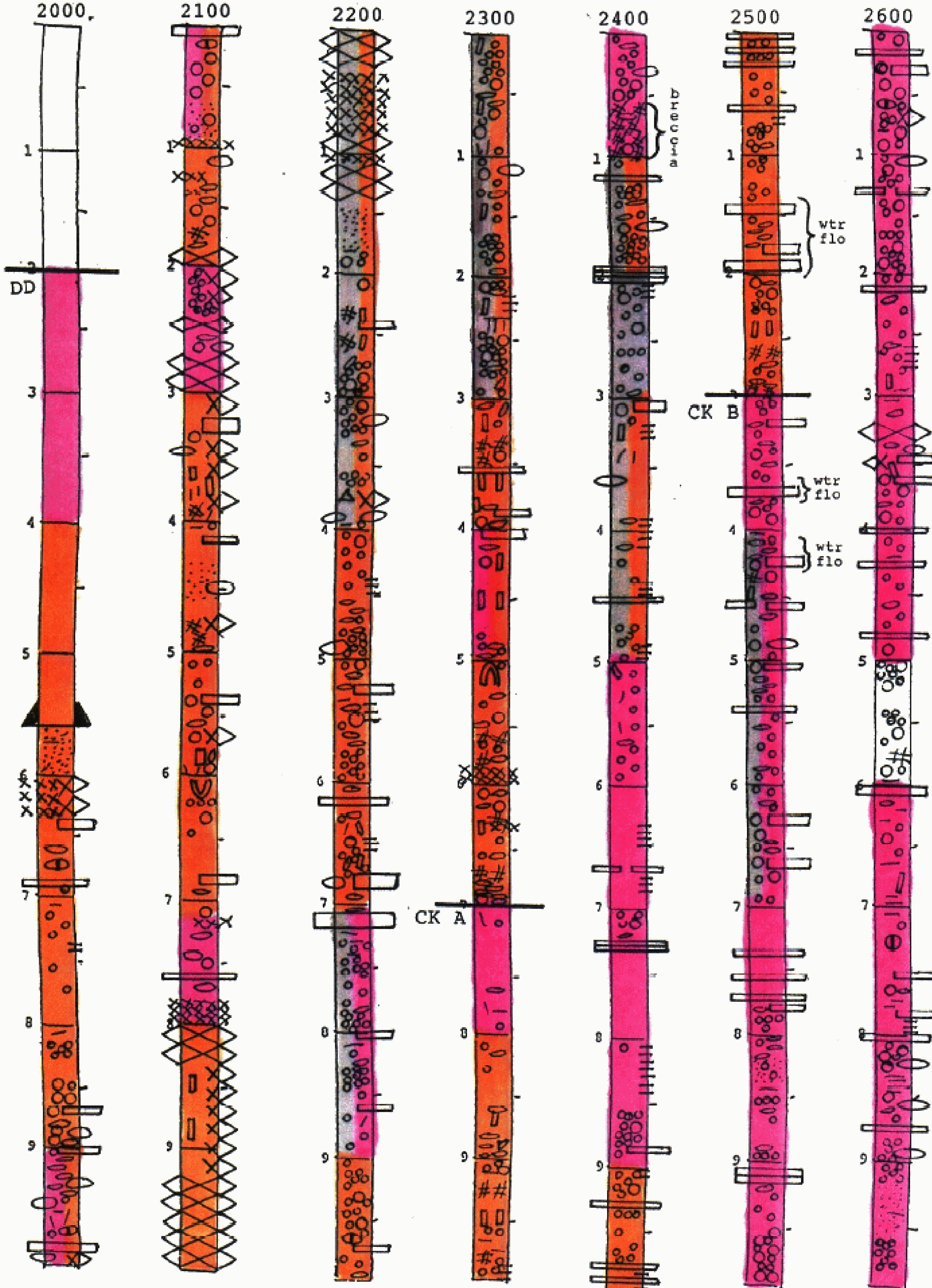

2000
2100
2200
2300
2400
2500
2600
DD
CK A
CK B
breccia
wtr flo
wtr flo
wtr flo

Fig. 25

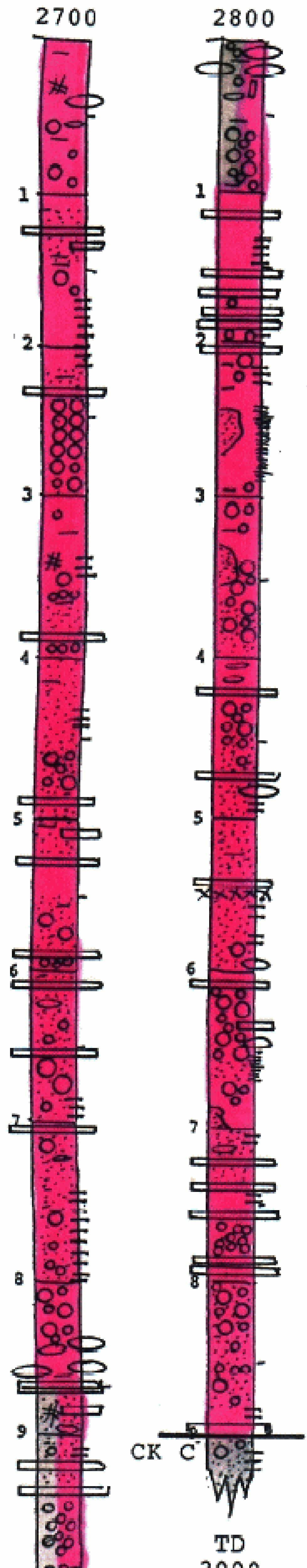
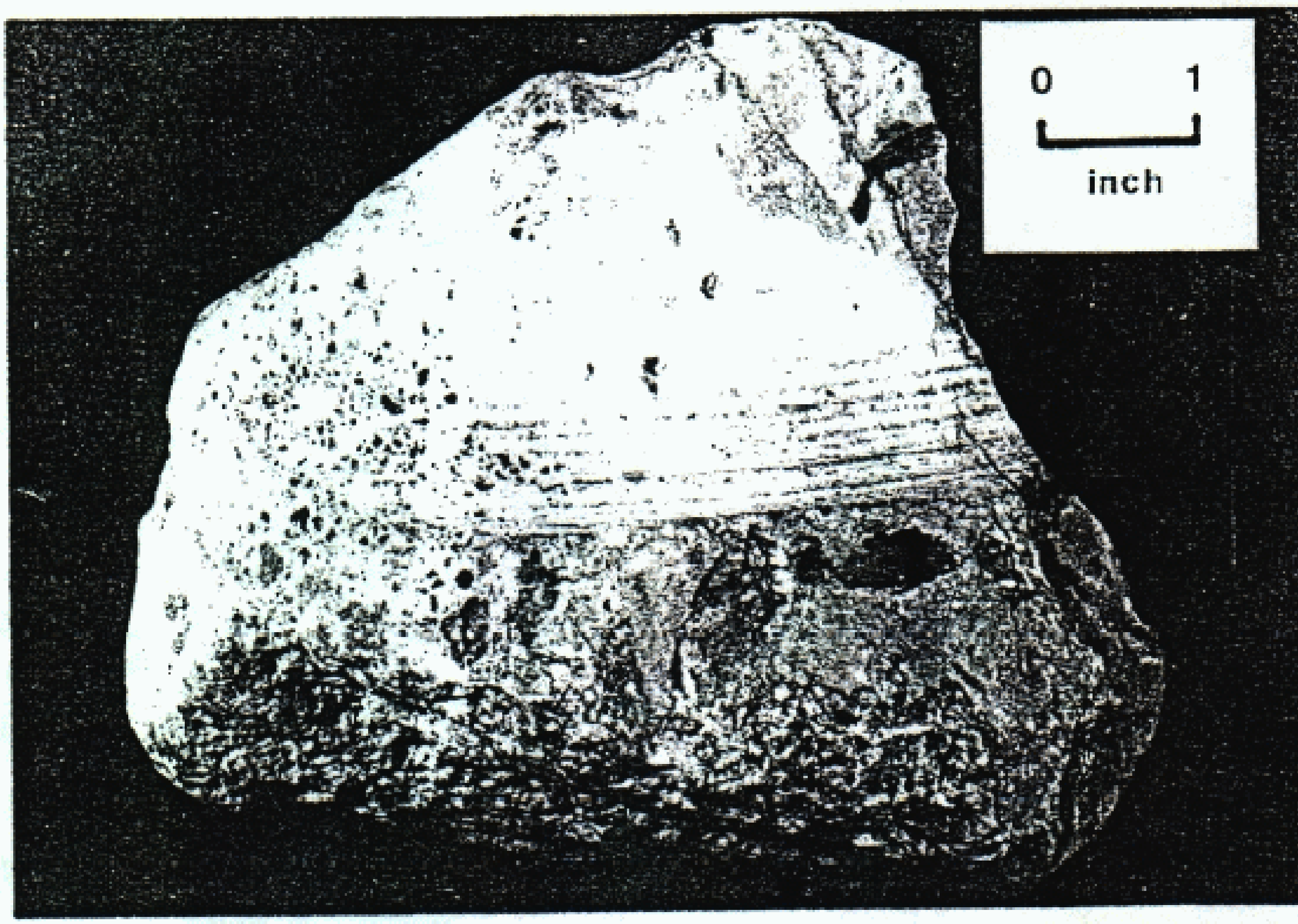


Fig. 25a

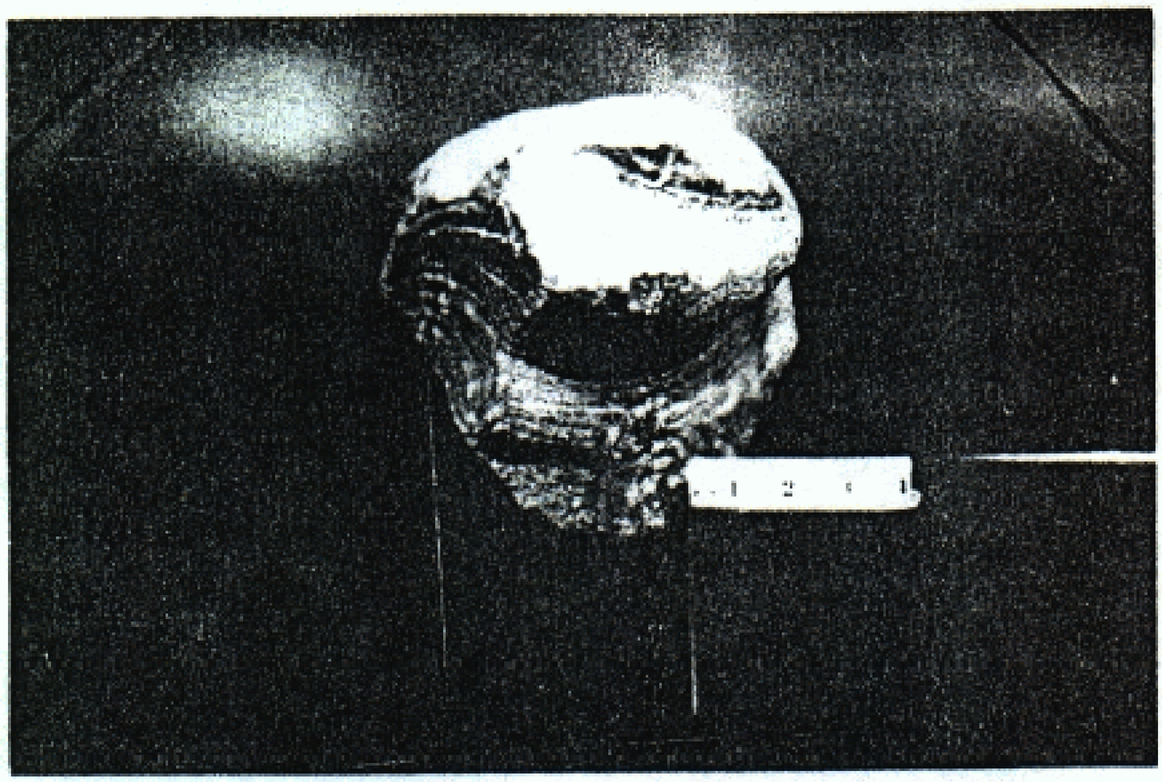


Porous dolomite "boulder" broken off a cavity's wall by a diamond drill bit. Note the vugs and pores, which are lined with micro-crystals of dolomite. The striated collar was cut in the rock by the rotating drill bit before the "boulder" broke off the cavity's wall. Florida Geological Survey photo.

from FL Geological Survey SP 29

Boulder Photograph

Fig. 26



"Boulder" with two sets of tool marks from an unknown depth between 2200 and 2500 feet on the Amerada No. 1 Southern States (235) Palm Beach County.

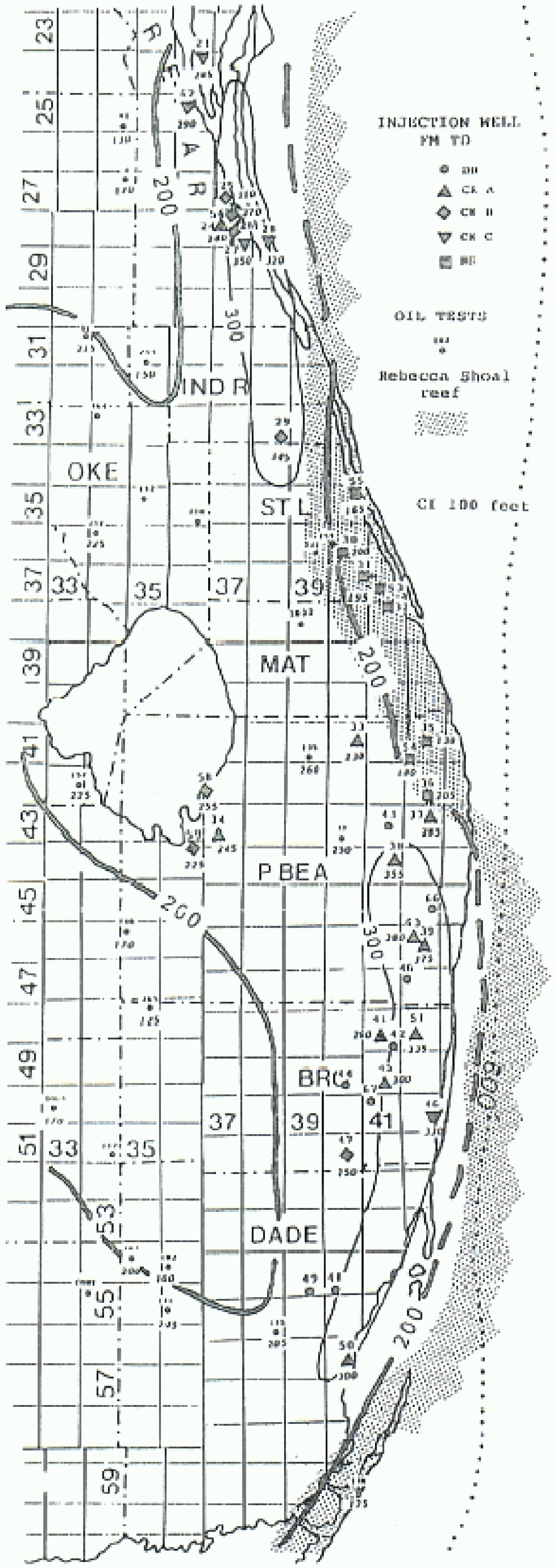
Hamilton 1 Keen
Lake County
(outside study area)

(no depth given)

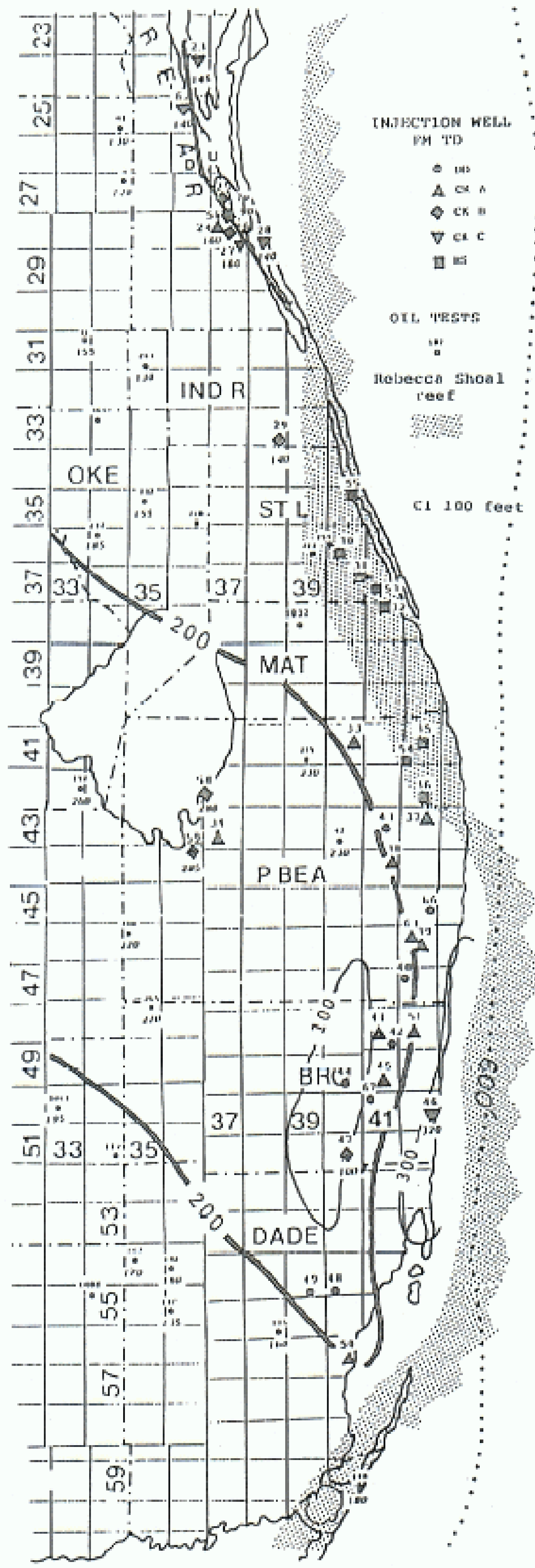
Boulder Zones noted between
1100 (AP) and 1900 (DD)

Boulder Photographs

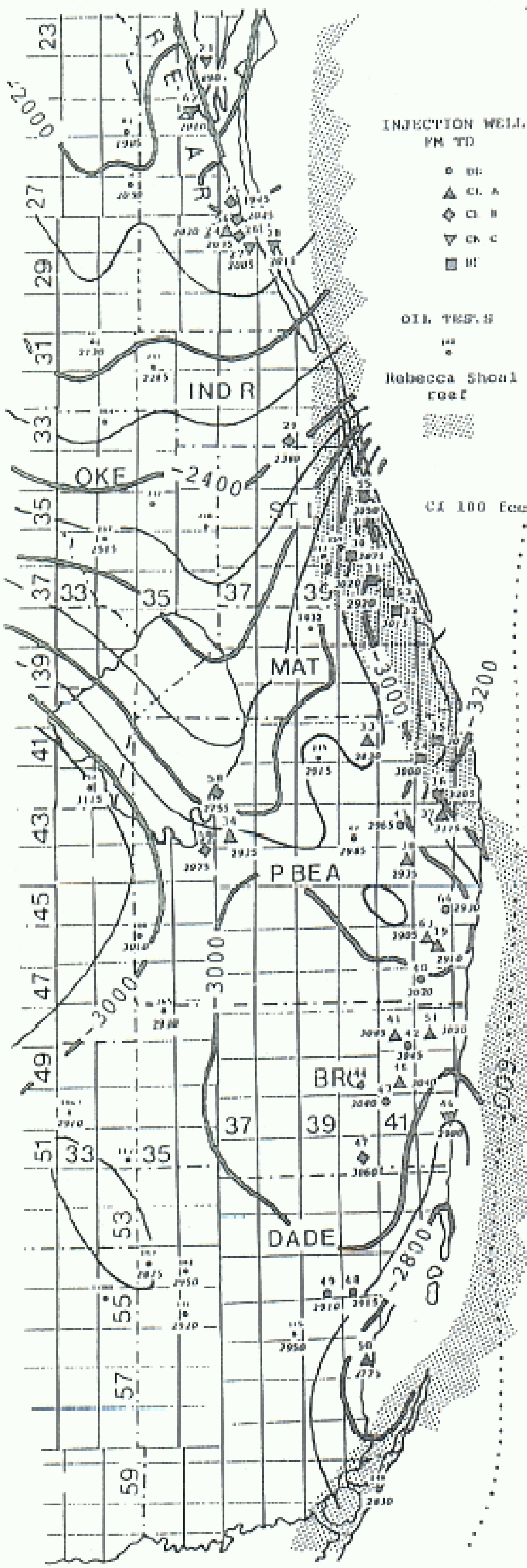
Fig. 27



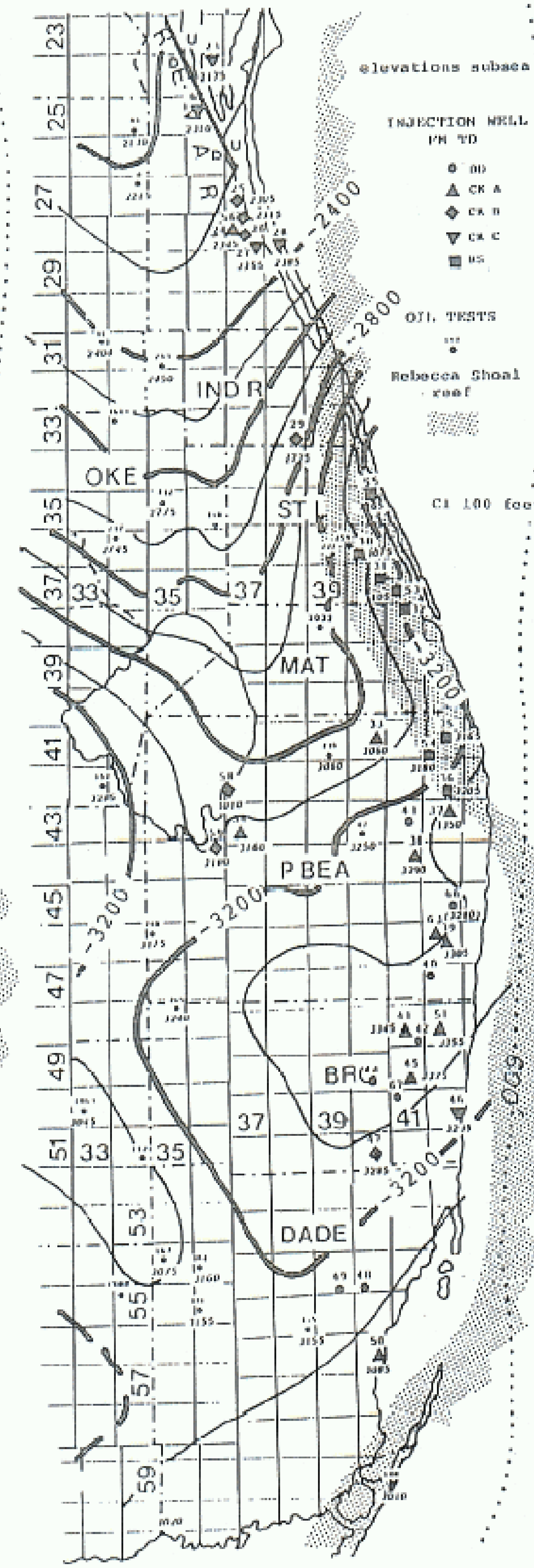
Delray Dolomite



Cedar Keys A



Delray Dolomite



Cedar Keys A

Structure Maps

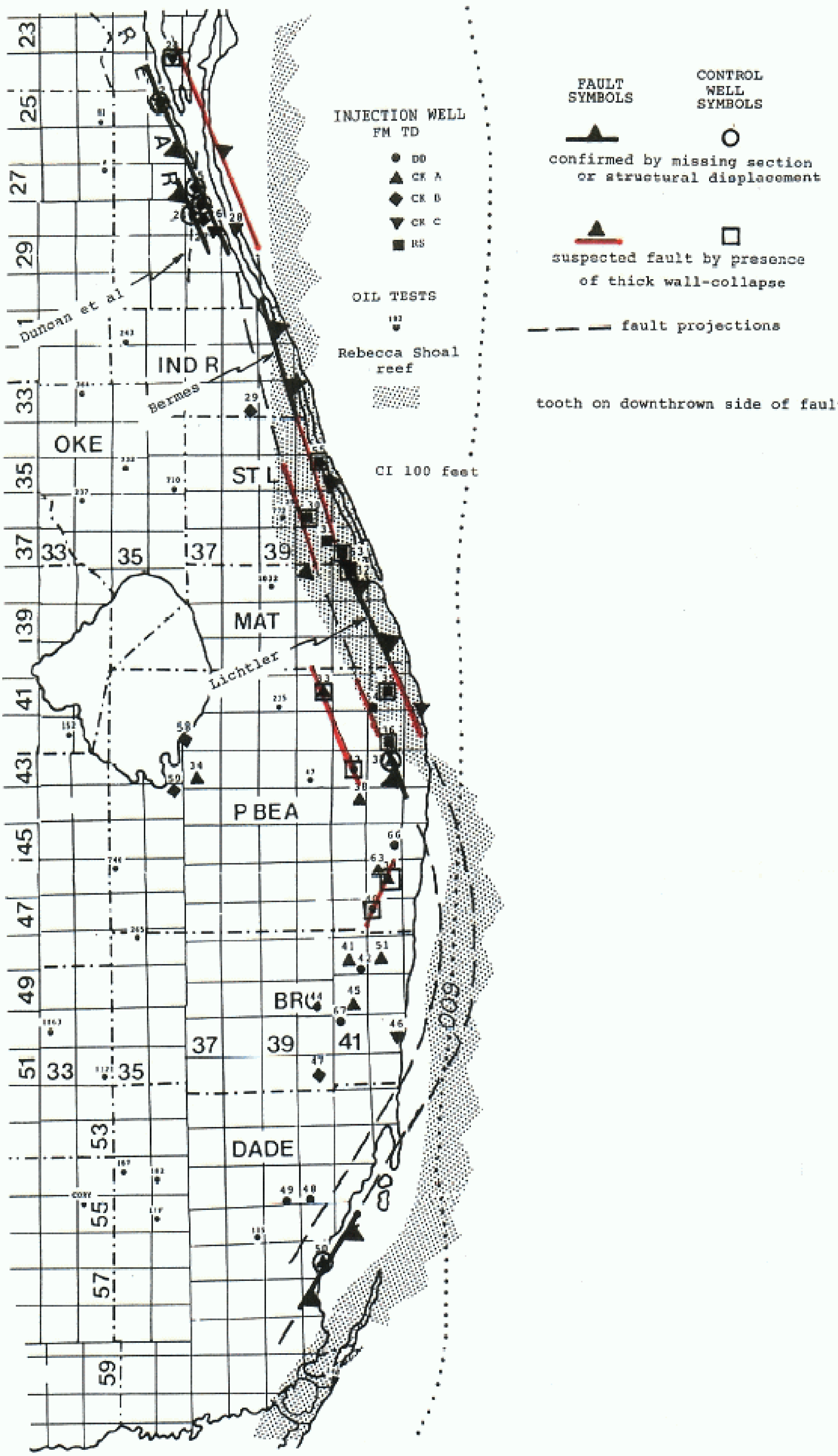
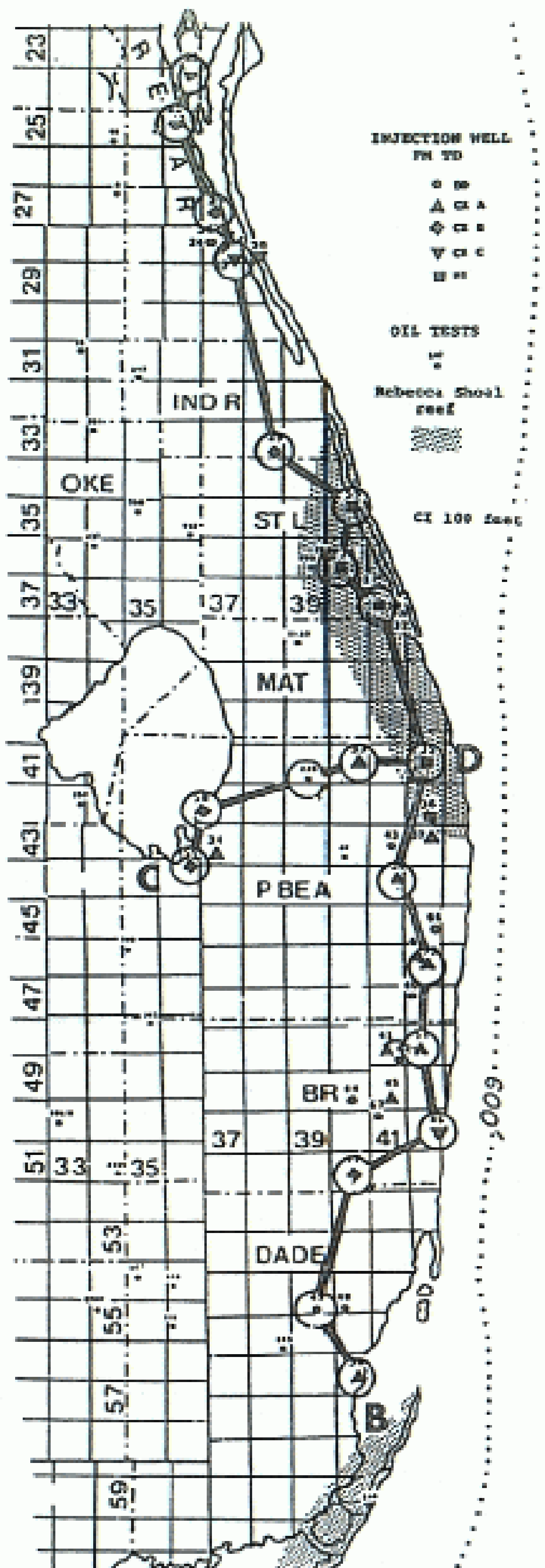
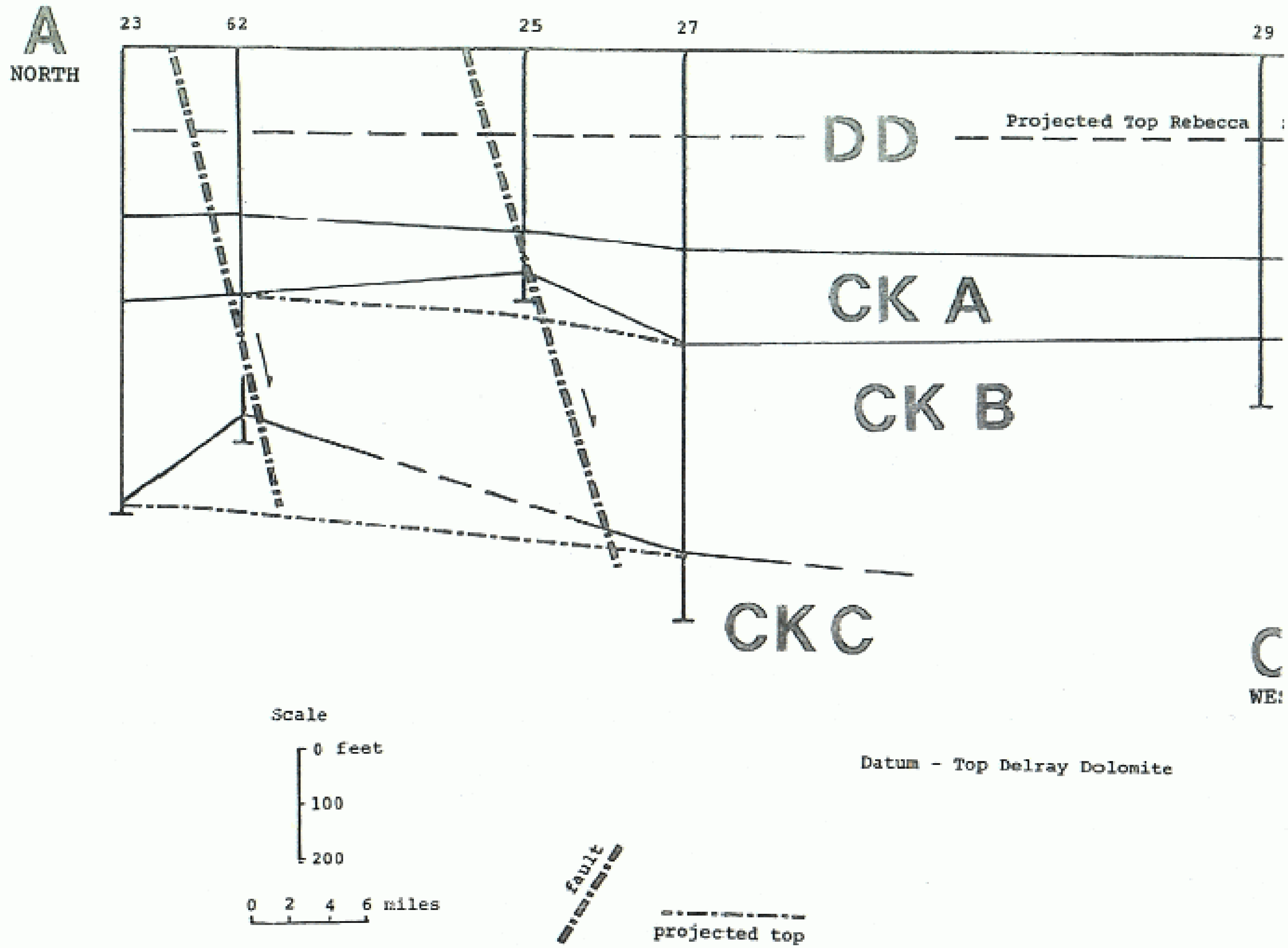
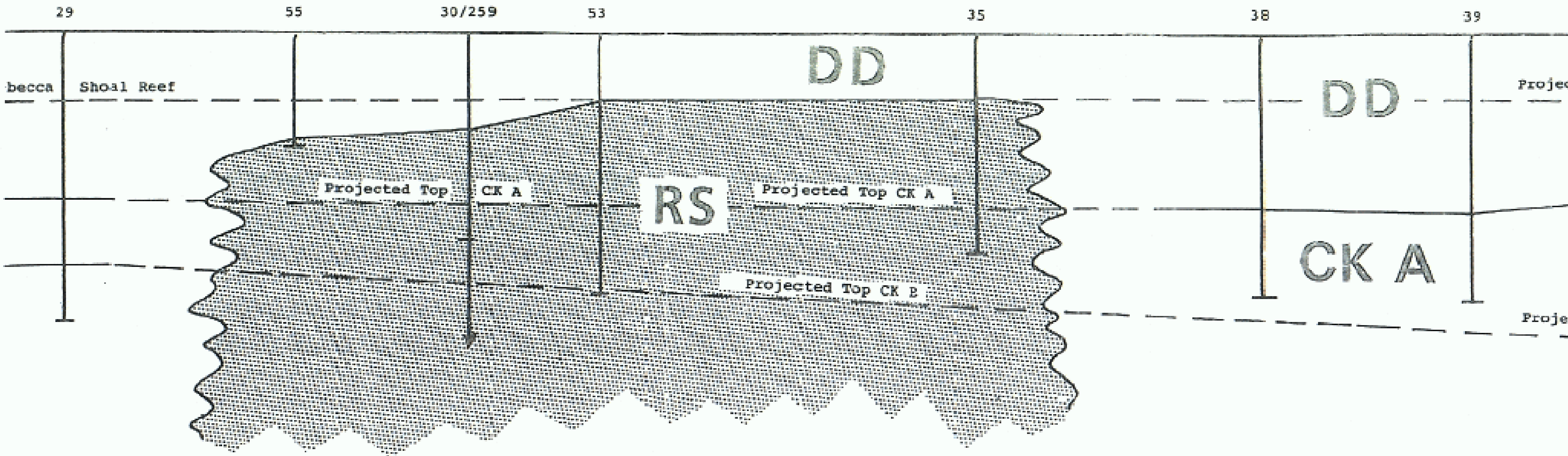
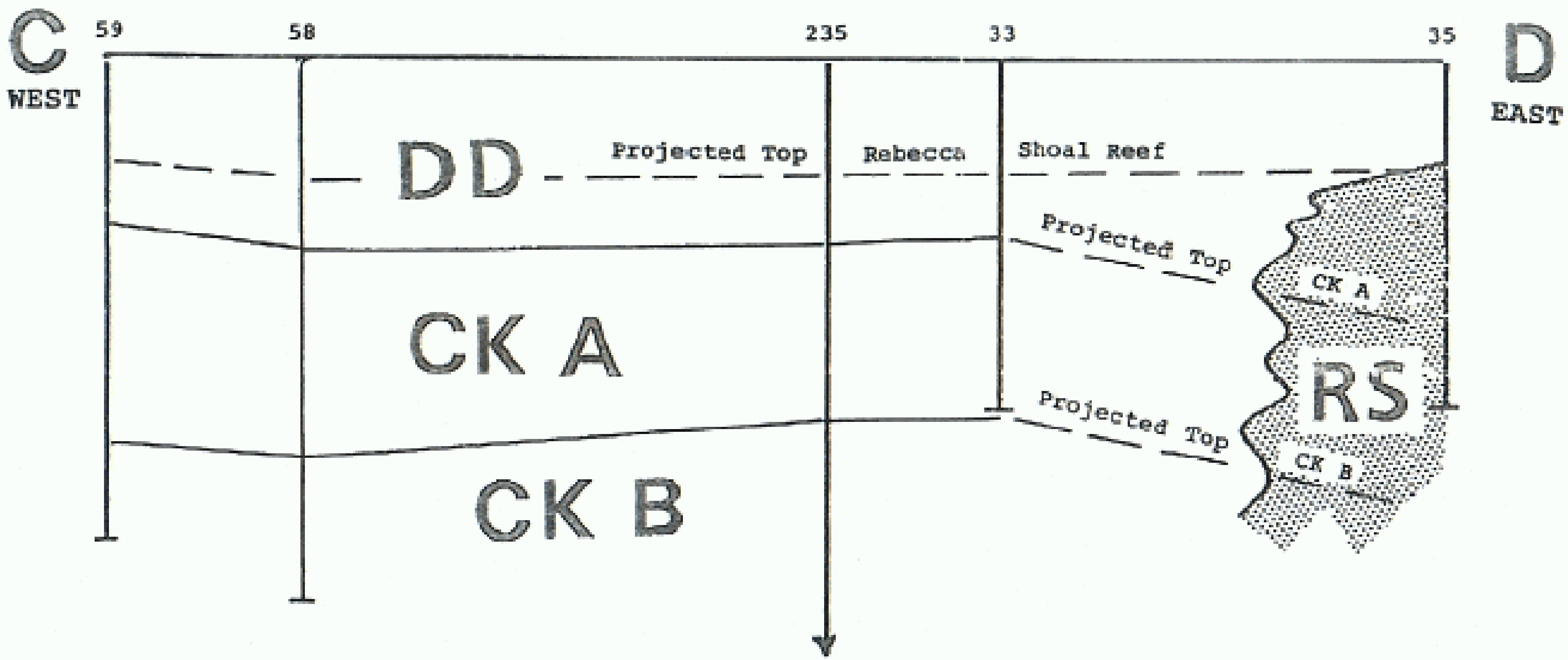


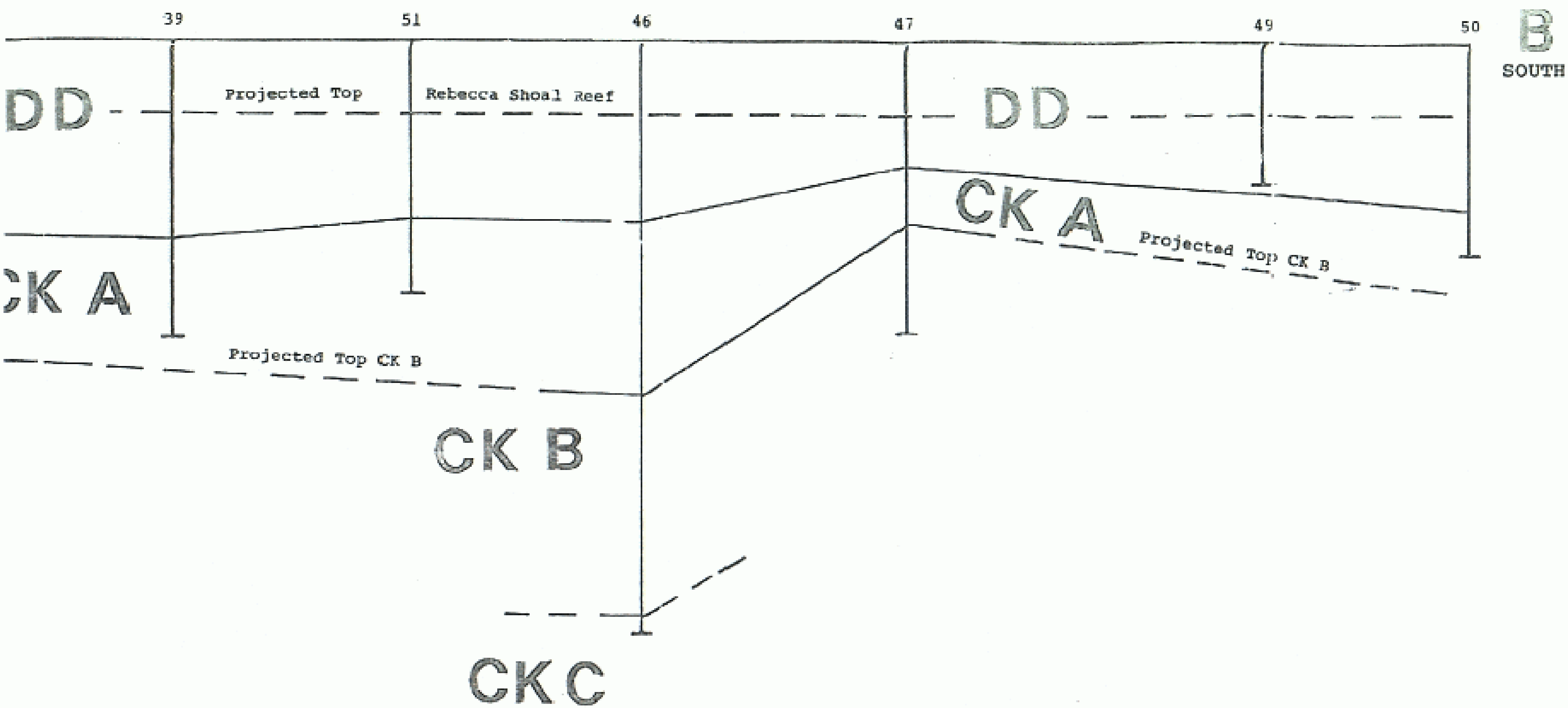
Fig. 31 Regional Distribution of Known or Suspected Faults


INJECTION WELL
FM TD
OIL TESTS
Rebecca Shoal reef
CI 100 feet
IND R
OKE
ST L
MAT
P BEA
BR
DADE
B
600


A
NORTH
23
62
25
27
29
DD
Projected Top Rebecca
CK A
CK B
CK C
C
Scale
0 feet
100
200
0 2 4 6 miles
fault
projected top
Datum - Top Delray Dolomite


29
55
30/259
53
35
38
39
becca
Shoal Reef
DD
DD
Project
Projected Top
CK A
RS
Projected Top CK A
CK A
Projected Top CK B
Projec


C
WEST
59
58
235
33
35
D
EAST
DD
Projected Top
Rebecca
Shoal Reef
Projected Top
CK A
CK A
RS
Projected Top
CK B
CK B



Stick Regional Stratigraphic Cross-sections