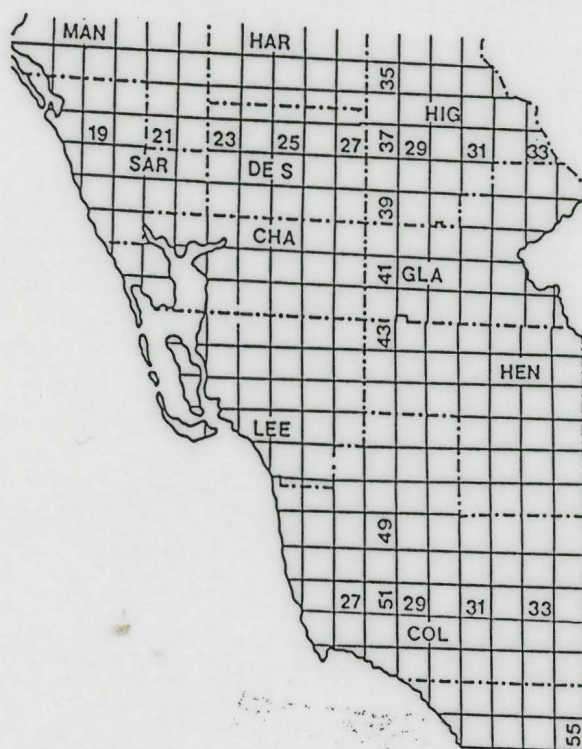


# THE BOULDER ZONE DOLOMITES OF FLORIDA

Volume 2

## PALEOGENE ZONES OF THE SOUTHWESTERN PENINSULA



George O. Winston

Miami Geological Society

1996

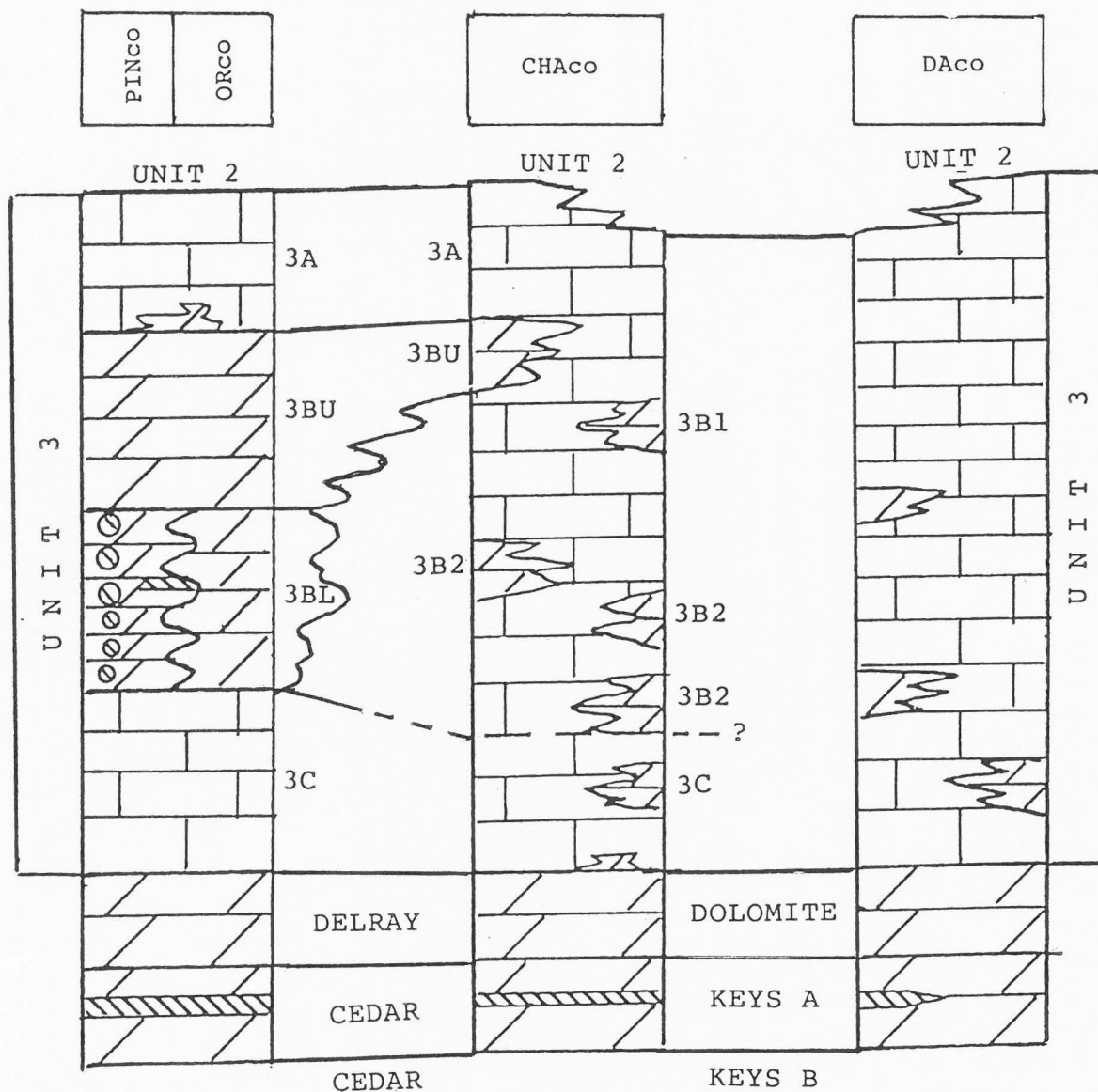
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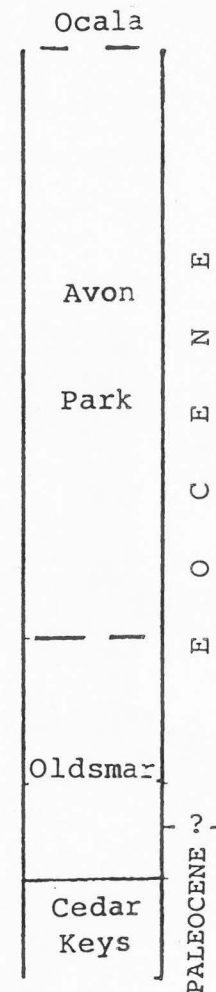
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The Suite (e.g. PINco) is defined in the Glossary.  
Individual Suites are defined in Appendices.

Generalized Geologic Columns  
Showing Boulder Zone Dolomite Units  
in the Suites of the Southwestern Peninsula



Conventional  
Nomenclature



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#### DEDICATION

This volume is dedicated to the late Harry Wassall (1921-1995). His original suggestion to me and subsequent financial backing turned into a 15-year program of examining drill cuttings in over 575 wells in onshore and offshore Florida and northern Cuba. The resulting five volumes on the geology and oil possibilities of the Florida section from the Eocene into metamorphic basement were published by his company (Petroconsultants).

Most of my subsequent Miami Geological Society subsurface publications were based on data accumulated during the above-mentioned project.

Harry Wassall was a friend. He will be missed.

*Miami Geological Society - Gift*

*5/06*



## ABSTRACT

In this study a three-part numerical subdivision of the interval between the base of the Hawthorn Group and the Delray Dolomite is used instead of the conventional nomenclature, which is unsatisfactory due to interfingering and transitional contacts. Boulder Zone phenomena occur only in Unit 3, which is essentially Avon Park plus the limestone of the unidentifiable Oldsmar Formation of conventional usage, the Delray Dolomite, and part of the Cedar Keys A. Complete lithologic data were available on most injection wells. For most oil tests, lithologic data were incomplete, requiring interpretation of lithology from resistivity curves on old ES or induction logs. The limestones of Unit 3 consist of wackestones, packstones, chalky micrites and grainstones. The thickness of Unit 3 ranges from 1100 to 2000 feet.

Unit 3A is entirely limestone except for a local 100-foot thick dolomite. The lithology of this dolomite suggests that it is favorable for injection, however, no video tapes are available to confirm this hypothesis. Downhole video surveys of injection wells were available for subdivisions 3BU, 3BL, 3B-1, 3B-2, 3C, as well as the Delray Dolomite and Cedar Keys A. Unit 3 dolomites commonly have a euhedral texture accompanied by subordinate anhedral texture. Cryptocrystalline texture was usually a minor constituent.

Units 3BU and 3BL consist of dolomite and only occur in the northern part of the southwestern Peninsula area. The presence of anhydrite in 3BL distinguishes it from 3BU. In 3BU, video tape surveys show that megaporosity features are common, indicating that this is a good unit for injection. Porosity in 3BL is usually plugged with anhydrite and few megaporosity features are present. In the central and southern parts of the study area, dolomite Unit 3B-1 is limited to Collier County and environs. Locally, 3B-1 is used for injection of oil field brine. Unit 3B-2 is more widespread, with a thick area in Charlotte and Glades Counties, and another in Collier and Lee Counties. Rare video tapes show good megaporosity features. Oil field brine is also injected into this Unit. Thick Unit 3C dolomites occur in Charlotte and Glades Counties, and also in western Collier County. Video tapes show abundant megaporosity features.

The Delray Dolomite, although present throughout the study area, is only favorable for injection in the central and southern part, where video tapes show the presence of megaporosity, and the unit is sufficiently thick for use as an injection zone. The upper half of Cedar Keys A is composed of dolomite, and in some areas contains favorable megaporosity. The lower half contains considerable anhydrite and rare video tapes indicate little or no megaporosity.

In part of Collier County, lenticular occurrences of bedded anhydrite decrease the favorability of Units 3B-1 and 3B-2 for injection. These anhydrites may have been precipitated from sulfate-bearing waters rising along faults extending downward into the thick anhydrites of the Cedar Keys Formation. Six cross-sections show lateral changes in facies and thicknesses of units throughout the study area.

The structure of the Southwestern Peninsula is dominated by a large flat area in Collier, Hendry and Lee Counties. A west-plunging nose extends from Highland through Sarasota Counties. Along the eastern boundary of the study area there is a broad

north-south swell. Local, broad highs were mapped in areas of dense well control. Only in the Sunniland oil field is close well spacing available. Here, structure on the base of Cedar Keys A shows a northeastly plunging nose, while on the Lake Trafford Formation at 11,000 feet, an anticline is present. Four faults are established either by missing section or bed displacements of up to 200 feet. Geological data suggest six more may exist. In Volume 1 of this study (Winston 1995a), thick wall collapse zones were shown to be present near known faults; therefore, thick wall collapse zones in the study area are suggestive of nearby faults.

Examination of downhole videos establishes that most megaporosity wall features consist of vugs, megavugs, channels, cavities, and wall collapse zones (each defined in this study). The reservoir quality for injection is determined primarily by the quantity of these porosity types. Units 3BU, 3B-2, 3C, and the Delray Dolomite in certain areas have the best wall feature porosities. Several caverns have been reported by drillers. Many appear to be in limestone as well as dolomite. Various speculations on the origin of wall features shown by downhole videos include solution, solution enlargement, and massive fracturing.

Boulders in the various Boulder Zones are man-made. They are produced by drilling into highly fractured rock, which then collapses, or by the collapse of a cavity roof when breached by the drill bit. Boulder recovery in oil tests and drilling techniques is discussed.

## ACKNOWLEDGEMENTS

First, I would like to express my appreciation to the Miami Geological Society for funding visits to the Florida Geological Survey Sample Library in Tallahassee to examine drill cuttings.

Next, I wish to thank my wife Mary for persisting at the word processor for revisions of this publication.

Bob Caughey deserves special mention for providing me with over 40 sets of drill cuttings as well as numerous sample logs, GR-DIL logs, caliper logs, graphic drilling-time logs, and well history plots (time vs depth) with driller's comments on drilling problems for numerous oil tests.

In addition, I am grateful to the following companies, government offices, and individuals who enthusiastically gave me access to their data for the preparation of Volume 2 of this study.

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Lastly, I appreciate the helpful comments and suggestions provided by Kevin Cunningham and Ron Reese.

## INTRODUCTION

### Background

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 bit. If not drilled up, they must be fished out. Boulder Zone dolomites were first encountered in the middle of Unit 3 (inside text cover) at the Sunniland oil field in northwestern Collier County in 1943. They were so named by the drillers, who having had experience drilling actual boulders elsewhere, assumed the jerky drilling and chattering action of the bit was caused by similar conditions.

Boulder-producing dolomites are those which contain cavities or wall-collapse zones. In the study area they are present in several intervals of Unit 3, occasionally in the Delray Dolomite, and uncommonly in the upper part of the Cedar Keys A. Down-hole video tapes of injection wells in the western part of the study area show the nature of other Boulder Zone dolomite wall features, all of which are defined in the section on Boulder Zone Phenomena.

The study area is shown in Figure 1. So that this volume may be used independently of Volume 1 (Winston 1995a), I have included information from that study defining Boulder Zone wall features. Volume 1 includes the southeastern Peninsula counties from Broward through Monroe. It presents data on the Boulder Zone in the Delray Dolomite, Cedar Keys A, and Rebecca dolomites. Only one localized thick dolomite with Boulder Zone features is present in the Avon Park (Unit 3) in the southeastern Peninsula (Winston 1995a). The principal difference between the southwestern and southeastern Boulder Zone provinces is the presence in the southwestern Peninsula of thick boulder-producing

dolomites in the Unit 3 (Avon Park) section.

In contrast, the Boulder Zone dolomites in southeastern Florida are confined entirely to the Delray Dolomite and the Cedar Keys A section (inside text cover) except in part of Palm Beach County where a thick Unit 3 (Avon Park) dolomite has Boulder Zone wall characteristics.

Injection well numbers on the various maps are those used by the Florida Department of Environmental Protection. Oil tests are identified by Permit Number. To facilitate locating wells, in the text their numbers are occasionally followed by the three-letter county designations used on the maps.

Dolomite boulders in oil tests have been reported in zones which are known to be limestone. These boulders may originate from higher dolomite beds that slough off and fall into the borehole during drilling, or they may be from highly fractured limestone.

#### Purpose

The purpose of this study is to map the areal distribution of dolomite beds capable of developing Boulder Zone wall features in Unit 3, the Delray Dolomite and Cedar Keys A.

#### Methods

To acquire lithologic data, drill cuttings from injection wells and oil tests (inside figure cover), were examined wet with a ten-power stereoscopic microscope. Injection well GR-DIL logs and ES logs of oil tests were used to correlate Unit 3 dolomites, the Delray Dolomite, and Cedar Keys A.

All lithologic and down-hole video descriptions used to prepare this report are original. All available down-hole video surveys of injection wells were examined and the wall features plotted on a scale of one inch equals ten feet. Graphic logs and



videos of three injection wells are included in this report. Wells outside the study area were used to reduce error at the boundaries of contour maps.

For oil tests, complete sets of cuttings from Unit 3 were virtually non-existent. Oil tests are drilled by the conventional rotary method (page 44), which usually results in loss of circulation and cuttings in highly porous zones of mid-Unit 3. In injection wells, because of the use of reverse-air circulation drilling (page 44), a complete set of cuttings are recovered.

Where cuttings were not available, dolomite beds in Unit 3 were interpreted from high resistivity readings on short or long resistivity curves on ES logs. As the SP curve on these logs is usually a straight line, it could not be used as a back-up. In some wells where cuttings were available, low resistivity readings were present where cuttings were composed of dolomite, possibly because of extreme hole enlargement. For this reason, more dolomite may be present in the lost circulation zones than is shown on the cross-sections and maps.

Visual porosity as used in this publication refers to highly permeable porosity as that found in lime grainstone or in fine to medium crystalline euhedral dolomite. My visual estimates are based on a comparison of these estimates with geophysical logs many years ago.

## PREVIOUS INVESTIGATIONS

The papers cited below are the only ones which discuss either Boulder Zone lithostratigraphic data or Boulder Zone drilling problems. 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 lithologic or other geologic data. In use since 1943, the term Boulder Zone was introduced into the literature by Kohout (1965).

Burke (1967) detailed Boulder Zone drilling problems and their solutions in the West Felda oil field.

Chen (1964) presented triangle facies maps and isopachs of the Ocala, Avon Park-Lake City, Oldsmar and Cedar Keys formations, as well as generalized rock descriptions for these units over the entire Florida Peninsula.

Miller (1988) presented generalized lithologic descriptions and isopach maps of the same units.

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 Eocene beds and the Rebecca Shoal Dolomite reef. In light of current data, it is obsolete and of historical interest only. I have since described this investigation as "a study of nothing (cavities) with no data (lack of cuttings)".

## STRATIGRAPHY

### Correlations

The conventional nomenclature between the base of the Hawthorn Group and the Cedar Keys was defined in the northern and central Florida Peninsula. In the southern Peninsula none of the conventional stratigraphic units have horizontally consistent lithologic boundaries. The boundaries are frequently transitional, interfingering, or even nonexistent (Fig. 2).

To avoid entanglement with the established, regionally unsatisfactory nomenclature, I have employed a system of numbers and letters to define various units based on their typical lithologies in the study area.

This publication is part of a regional study involving the entire section between the base of the Hawthorn Group and the base of Cedar Keys A. As no Boulder Zones occur in Unit 1 (essentially Suwannee) or Unit 2 (essentially Ocala), this report will deal only with Unit 3, the Delray Dolomite, and Cedar Keys A, all of which may exhibit Boulder Zone phenomena.

Unit 3 is essentially Avon Park plus the limestone member of what has been conventionally called the Oldsmar (front cover). The basal dolomite of the Oldsmar was separated and named the Delray Dolomite (Winston 1995a).

Identification of consistent marker beds was necessary to determine which dolomites in Unit 3 were equivalent. The only horizons satisfying this requirement were the base of the Hawthorn Group and the base of Cedar Keys Unit A (top Cedar Keys B). The base of the Hawthorn Group was almost always identifiable in cuttings, and the top of Cedar Keys B was always

identifiable on geophysical logs.

As cuttings were seldom available in oil tests in the section below mid-Unit 3, lithologies were interpreted from geophysical resistivity curves. Although this type of data, particularly from the old ES logs, is less than reliable, it is the only way to identify dolomite beds regionally in the lower Unit 3 section.

Micro fossils were occasionally useful in establishing the presence of various Units; they were not used to establish Unit tops.

### UNIT 3

In the study area, Unit 3 includes the section between the base of Unit 2 (essentially Ocala) and the top of the Delray Dolomite. Persistent dolomite beds or groups of dolomite sequences were used to subdivide Unit 3 into several local units for mapping dolomite beds in thicknesses useful to the injection well industry. In the southern part of the study area, mapping of Unit 3B-1 and 3B-2 dolomite packages included only those with beds over 50 feet thick. This is considered to be the minimum thickness for injection purposes; therefore, the isolith Figures represent injectable dolomite thicknesses. Combined thicknesses of multiple beds where no bed reached 50 feet, is followed by the letter "K" in the isolith numerals, symbolizing that the dolomites in the interval are broken into thin beds.

### Lithology

Unit 3 consists of limestones and dolomites in varying percentages. Beds of incompletely dolomitized limestone, ranging from slightly to almost complete, are common.

The limestones described below are distributed throughout Unit 3.

Wakestones and chalky micrites are common. Grainstones and packstones are much less abundant. Grains are rounded, and usually range in size from very fine to fine. Beds containing medium-sized grains are occasionally present. Chalky porosity is common in wakestones, micrites, and occasionally in packstones. Visible porosity in grainstones and packstones usually ranges from 5% to 10% with a few beds of 15% or more. Colors are commonly cream and tan with occasional orange/tans.

#### Thickness

Unit 3 ranges from 1100 feet in Well 68COL to 2000 feet in Well 1086COL (Fig. 3). This map shows the reverse of what one would expect, with the thinnest section in the basin and the thickest section around the rim (see below).

#### Age and Correlation

In Collier, Lee, and Hendry counties the fauna of Units 2 and 3 occasionally overlap. In Well L-2 in northeast Hendry County, Unit 1 interfingers with Unit 2, which in turn interfingers with Unit 3 (Winston 1995e & Fig. 2).

The age of Unit 3 over most of the study area (where it is not interfingering with Unit 2) is early and middle Eocene in age according to paleontological evidence (Applin & Applin 1944). In the eastern part of the study area where the above-mentioned interfingering occurs, Unit 3 would appear to also be Late Eocene and even early Oligocene in age as the interfingering with Units 1 and 2 becomes complete eastward in Well 59 (Fig. 2).

From this evidence it appears that the age of the entire "Avon Park" of Volume 1 (Winston 1995a), which in most of the southeastern Peninsula consists entirely of Unit 3 lithology, is early Eocene through early Oligocene in age. Further evidence that these units are all interfingering eastward is supported by

the isopach of Unit 3 (Fig. 3), which shows a thickening eastward from 1100 feet in basin well 68COL to 2000 feet in Well 1086COL out of the basin to the east.

### Unit 3A

#### Occurrence

Unit 3A can only be identified where dolomites of Unit 3BU delineates its base (inside text cover). Elsewhere, equivalent limestones are present but the base cannot be identified.

#### Lithology

This unit is a limestone except in the northwestern part of the study area. Here, Wells 236MAN and 55CHA (Fig. 4), the basal part of 3A is dolomitized (cross-section A-B). This lower dolomited portion of Unit 3A is distinguished from the upper dolomites of Unit 3BU by the character of the 3A dolomite resistivity curves. In Well 20SAR, the 120-foot interval of dolomite (Fig. 4) is not included within the contours because it is broken up into six beds, none of which are over 35 feet thick.

In Well 55CHA, the dolomite of Unit 3A consists of interbedded euhedral and anhedral textures. Euhedral dolomite is fine to medium crystalline with 5% to 15% intercrystalline porosity. Colors range from tan to brown and orange/brown. In Well 236MAN, dolomite texture consists of brown, very fine crystalline euhedral texture. A twenty-foot interval of cryptocrystalline dolomite was present in this well. Visual porosity in euhedral dolomite consists of intercrystalline and pinpoint with values ranging from 5% to 10%. No videotapes are available in 3A dolomite intervals.

#### Thickness

The dolomite of 3A reaches 110 feet in Well 55CHA (Fig. 4).



### Boundaries

The top of Unit 3A (as well as Unit 3) is defined by the change from tan, chalky or microgranular limestone, or microcrystalline dolomite of Unit 2 above, to a cream or orange/tan packstone, grainstone, or wackestone containing rounded, very fine to medium skeletal grains below. The base (except in Wells 236MAN & 55CHA) is defined by the change from the limestone of Unit 3A above to dolomite of Unit 3BU below.

### Age and Correlation

Unit 3A correlates more or less with the upper limestone section of the revised Avon Park of Miller (1988). Its age as determined by paleontology is middle Eocene (Applin & Applin 1944).

### UNIT 3B

This unit is subdivided into several local dolomite members which are either entirely dolomite, or sequences which include dolomite beds within a generally limestone section. The age of 3B is middle Eocene by paleontology (Applin & Applin 1944). It correlates with the dolomite member of the revised Avon Park of Miller (1988) in which he includes the now-abandoned Lake City limestone of Applin & Applin (1944).

The following artificially-named Suites are defined in the appendix. The term "Suite" is defined in the glossary. In the PINco and ORco Suites (Fig. 5), Unit 3B is subdivided into 3BU and 3BL. To the south beyond the pinchouts of 3BU and 3BL, thick dolomite beds are combined and mapped as Units 3B-1 and 3B-2. The lithology of Unit 3B defines the character of the PINco, ORco, CHAc, and DAc Suites of Winston 1993 (Fig. 5 & Appendices 4, 5, 6 & 7).

## Unit 3BU

### Occurrence

Unit 3BU is limited to the northern half of the study area (Fig. 6). It is present in the ORco and PINco Suites and the northern portion of the CHAc Suite. It changes facies rapidly from dolomite to limestone in a 6-mile-wide area in central Charlotte and Glades Counties.

### Lithology

Unit 3BU is entirely dolomite, but toward the southern pinchout, it may contain a thin limestone or calcareous dolomite.

The dolomite of 3BU consists almost entirely of euhedral and anhedral textures in varying proportions. Cryptocrystalline dolomite occurs only in minor amounts in the lower part of the section.

Euhedral texture is usually fine microcrystalline to very fine crystalline. In Wells 16SAR and 19LEE, fine to medium crystalline euhedral dolomites are present. Rarely, relic texture is present in the form of very fine to fine rounded skeletal grains.

Visible porosity, which occurs in all wells except 178CHA is confined to euhedral dolomite, and consists of intercrystalline, pinpoint and, occasionally moldic types and ranges from 5% to 10%. In many wells, porosity estimated at 15% occurs in thin beds. In Wells 16 and 20SAR, thin zones of 20% porosity were observed.

The most common colors are orange/brown, orange/tan and tan. In some wells thin beds of brown and cream are present.

### Thickness

Unit 3BU ranges from 650 feet in Well 236MAN to zero in Wells 70 and 683CHA.

### Boundaries

The upper contact is usually defined by the change from the limestones of Unit 3A above to the dolomite of 3BU below. (The exception to this is in the previously noted 3A dolomite in Wells 236MAN and 55CHA.) In the PINco Suite area (Fig. 5), the lower boundary is defined by the change from pure dolomite of 3BU above to anhydritic dolomite of Unit 3BL below. In Well 679DES in the DRco Suite (Fig. 5), a thin limestone separates 3BU dolomite from a non-anhydritic 3BL dolomite. In the CHAco Suite area, the thinning dolomite of 3BU overlies a section of interbedded limestones and dolomites.

### Age and Correlation

Unit 3BU correlates with the upper Avon Park dolomite of Miller (1988) and probably with the original Avon Park of Applin & Applin (1944). Its age, based on fauna present in its limestone equivalents, is middle Eocene (Applin & Applin 1944).

## Unit 3BL

### Occurrence

This unit is restricted to the northernmost two-to-four tiers of townships in the study area (Fig. 7). A thin remnant extends southward to include Well 19 in northwest Lee County.

### Lithology

Within the study area, this Unit occurs only in a few wells in the PINco and DRco Suites (Fig. 5) in Manatee and northern Sarasota counties. In the PINco Suite, the dolomite of 3BL is characterized by the presence of various forms of anhydrite; in the DRco Suite (Well 679DES), anhydrite is absent.

Unit 3BL is predominately euhedral dolomite with minor amounts of anhedral and cryptocrystalline texture. In Wells

236MAN and 679DES, crystal size is very fine to fine. To the south of these wells, the unit thins rapidly, and crystal size decreases to very fine microcrystalline and microcrystalline.

In the PINco Suite, anhydrite in Unit 3BL commonly occurs as beds, nodules, and selenite porosity plugging. In the cuttings from several injection wells, no anhydrite was observed, but on the downhole video tapes anhydrite was visible as an occasional white mottling on the wall of the hole.

When not plugged by selenite, porosity is visually estimated at values of 5% to 15%. Intercrystalline, pinpoint and moldic porosity were observed in Wells 236MAN and 679DES; in the other wells with thin or incompletely penetrated sections, porosity was ineffective or absent.

#### Thickness

Figure 7 shows Unit 3BL thinning rapidly southward from 740 feet in Well 236MAN to zero, except in Sarasota and northwestern Lee Counties, where a broad thin area survives.

#### Age and Correlation

Unit 3BL correlates with the lower dolomite section of the revised Avon Park of Miller (1988), and more or less with the abandoned Lake City limestone. The age is middle Eocene based on paleontology from its limestone equivalents (Applin & Applin 1944).

### 3B-1 Dolomites

#### Occurrence

Locally thick occurrence of this dolomite in assemblage are present in Collier County and in adjacent Lee and Hendry Counties (Fig 8). Thin dolomite beds are common elsewhere in the southern part of the study area.

## Lithology

Lithologic data on dolomites in this zone were available from only 6 wells, all in Collier County.

In Wells 291 and 103, only euhedral texture was present. The other wells encountered a mixture of euhedral and anhedral textures. No cryptocrystalline dolomite was present. Euhedral crystal size ranged from microcrystalline to fine crystalline. In Well 291, twenty feet of rock with 10% porosity as visually estimated was observed; elsewhere 5% was common.

The 3B-1 dolomites are orange/brown or brown.

## Thickness

A maximum thickness of 120 feet occurs in Well 170LEE. Areas with thicknesses of over 100 feet occur locally within the 50-foot contour (Fig. 8). Unless at least one bed over 50 feet thick was present, the dolomite assemblage in a well was not included within the contours on the isopach map (Fig. 8).

## Boundaries

There are no finite boundaries to this zone. Dolomites of Unit 3B-1 are lateral equivalents of Unit 3BU in the CHAcO and ORCO Suites.

## 3B-2 Dolomites

## Occurrence

Three areas of thick dolomite are present (Fig. 9). A linear east-west trend is present in Charlotte and Glades Counties. Another is present east of the study area in a north-south orientation. Between the two, and probably connecting them, is a third central area with several locally thick dolomite assemblages.

3B-2 dolomites are much more widespread than are those in the 3B-1 zone.

### Lithology

Within the northern thick area, only wells 70SAR and 21CHA had lithologic data. There, euhebral and anhebral textures predominated, with cryptocrystalline a minor constituent. Euhebral texture varied from fine microcrystalline to fine crystalline. Visually estimated porosity was generally 5% pinpoint and intercrystalline in euhebral dolomite. An interval of 20% porosity was present in Well 70CHA.

In the central connecting area in Collier County, sixteen wells had drill cuttings available. Euhebral texture predominated in most wells, with anhebral dominating in a few. Cryptocrystalline texture was of minor importance. Visually estimated intercrystalline and pinpoint porosity was confined to euhebral dolomite. Generally, it ranged from 5% to 10%, but in Well 121COL (and the ALLEY well outside the study area to the east), porous zones as high as 20% were observed.

Colors were usually orange/brown, orange/tan and tan, with brown, dark brown, and cream occasionally present.

### Thickness

Maximum observed thickness within the northern dolomite trend was 445 feet in Well 375CHA (Fig. 9). Within the central connecting area, maximum observed thickness was 370 feet in Well 250LEE.

In Well 69COL and I-75COL, 3B-2 dolomite is continuous with underlying 3C dolomite.

## UNIT 3C

Unit 3C can be positively identified only in the PINco and ORco Suite areas as the limestone member of the conventional Oldsmar Formation. Elsewhere, without the presence of an overlying 3BL dolomite, this equivalence becomes more problematical southward until there is no longer any basis for identification. For some of the study area, the top of 3C is picked at the base of 3B-2 dolomite. Elsewhere it is based on geophysical log correlations. The age of the limestone member of the Oldsmar, and hence Unit C, was determined as lower Eocene based on paleontology (Applin & Applin 1944). This age would apply to most of Unit C even when its correlation is doubtful.

## 3C Dolomites

### Occurrence

Significant quantities of 3C dolomites occur in two east-west trends; one in Charlotte and Glades Counties and the other in southwestern Collier County (Fig. 10). Elsewhere minor amounts of no industrial significance are present.

### Lithology

Cuttings in Unit C dolomites were available for only nine wells. In Well 70CHA and Wells 121, 382, 69, 134, and 68 in Collier County, 3C dolomite was entirely of the euhedral variety. In Wells 1201 and 1208COL the section consisted entirely of anhedral dolomite. These anhedral sections were without visible porosity in cuttings.

Euhedral dolomite ranged from fine microcrystalline to very fine crystalline in most wells, but in Wells 68, 69, and 121COL, medium to coarse crystal texture was common. These three wells plus Well 70CHA contain zones of visually estimated



intercrystalline and vug porosity which ranged up to 20%. In the other wells, 5% to 10% porosity was the rule. The most common colors are orange/brown, orange/tan and tan. Frequently present were brown and dark brown. Light gray and cream colors are rare.

#### Thickness

Thin dolomites are present virtually everywhere in the study area (Fig. 10). The small thick area in Manatee County is represented only by Well 236 where 3C dolomite is 110 feet thick. In the Charlotte-Glades trend, a maximum thickness of 240 feet is present in Well 310. In this well, 3C dolomite is continuous with overlying 3B-2 dolomite.

The best development of 3C dolomite is in western Collier County. In Well 69 in the northern thick area, the entire 3C interval is dolomite and is continuous with both the overlying 3B-2 dolomite and the underlying Delray Dolomite. Here, 3C dolomite thickness is 530 feet. It was separated with difficulty by regional geophysical log correlation.

To the south, a lesser tongue involving Well 68 contains a 280-foot 3C dolomite bed is separated from the Delray Dolomite by a thin limestone.

#### Boundaries

Usually a limestone occurs between the Delray and 3C dolomites, and between 3B-2 and 3C dolomites. However, in several wells, 3C dolomite is continuous with either overlying 3B-2 dolomite or the underlying Delray Dolomite or both, requiring geophysical interpretation to separate them.

### DELRAY DOLOMITE

#### Occurrence

The Delray Dolomite occurs throughout the study area.

## Lithology

Only three injection wells, 55CHA, 68COL, and 69COL, four oil tests, 236MAN, 178CHA, 282COL, and 679DES have complete or nearly complete sets of cuttings.

In Well 20SAR, the lower half of the Delray Dolomite is faulted out. In injection wells 68COL, 69COL, and 20SAR, the Delray Dolomite is almost entirely euhedral with occasional thin beds of anhedral texture. In oil tests 178CHA and 236MAN, only the upper section is euhedral dolomite; the lower section consists of anhedral and cryptocrystalline textures. In Well 679, the Delray Dolomite is almost entirely cryptocrystalline.

Euhedral dolomite varies from very fine to coarse crystalline, but is mostly fine crystalline. Visually estimated intercrystalline porosity ranges from 5% to 10%. On downhole video surveys of Wells 68COL, 55CHA, and 20SAR, vugs, megavugs, and cavities are present. Wall collapse, when present, considerably enhances permeability.

## Thickness

Maximum thickness is 380 feet in Well 160COL. The average thickness is 200 feet.

## Age and Correlation

No faunal data are available. Lithologic data presented in Volume 1 (Winston 1995a) indicate that the basal half of the Delray Dolomite is equivalent to the uppermost Rebecca Shoal dolomite reef. If the upper Rebecca Shoal reef is entirely Paleocene, then the lower Delray Dolomite is also Paleocene. The nearest paleo data by Applin & Applin (1944) indicates a lower Eocene age in the top of Unit 3C limestone, some 500 feet above the Delray Dolomite. The nearest paleo data in the underlying Cedar Keys is in northern Florida and occurs some 500 feet below

the Delray Dolomite. Paleontologic data by Cole (1944) establishes a Paleocene age for the lower part of Cedar Keys Unit B.

#### CEDAR KEYS A

##### Occurrence

Cedar Keys A is present throughout the study area (Fig. 12). It is the uppermost of six members introduced by Winston (1994) in a subsurface study of the formation.

##### Lithology

Complete lithologic data were available on only five wells: 236MAN, 679DES, 282COL, Wells 178CHA, and 55CHA. In some wells, the Cedar Keys A appears to be transitional between underlying Cedar Keys B and the overlying Delray Dolomite. Cryptocrystalline dolomite occurs in quantity in Wells 679DES and 236MAN. Anhydral dolomite occurs only in Well 55CHA, and Well 59 to the east outside the study area where it amounts to some 30% of the unit.

Euhedral dolomite occurs in all wells except 679. This texture is thickest in Well 178CHA, amounting to some 80% of the section. In the basal portion of Cedar Keys A, relic pellet textures in dolomite are common in all wells but 679. This texture reaches a maximum of 70% of the section in Well 282COL.

Anhydrite beds and nodules are common (Fig. 13) in the middle and lower sections.

Visually estimated porosity was confined to the relic pellet facies where it consisted of intergranular and pinpoint ranging from 5% to 10%. Chalky porosity was also prevalent. In Well 55CHA, a downhole video survey showed the upper 40 feet of Cedar Keys A had abundant vugs and megavugs. Well 68COL had zones of

vugs, megavugs and cavities in the upper 90 feet. In Well 20SAR the upper section is faulted out. The remaining remnant of Cedar Keys A exhibited only scattered vugs and megavugs.

#### Thickness

The thickest section of Cedar Keys A in the study area is 240 feet in Well 236MAN (Fig. 12). The average thickness is 200 feet.

#### Boundaries

Typically, the top of Cedar Keys A is a gray to dark gray dolomite which is usually anhedral or cryptocrystalline in texture. Occasionally this color is not present, in which case correlation of geophysical logs is necessary to determine the top. The base, being lithologically transitional with Cedar Keys B can best be established by a sudden decrease of resistivity on geophysical logs, typical of the contact.

#### Age and Correlation

No paleontological data are available for establishing an age. It correlates with a part of the upper Rebecca Shoal dolomite reef. As its color and texture appear to be a continuation of the lithology of the underlying Cedar Keys B, it is possibly also Paleocene in age.

### CEDAR KEYS B

Cedar Keys B occurs throughout the study area. It is composed principally of chalky to microcrystalline porous tan and cream dolomite. Relic pellet texture is common. Anhydrite is uncommon except in Highland and Glades Counties, where over 200 feet are present.

The top of Cedar Keys Unit B is easily identified on

resistivity logs by a sharp decrease in resistivity. On Figure 20, the ES log on Well 178 shows this sharp resistivity decrease.

#### ANOMALOUS STRATIGRAPHIC AREAS

Three areas within the CHAcO Suite contain unusual lithologic assemblages. Area A in western Collier County (Figs. 5 & 10) is anomalous in that Unit 3C, normally mostly limestone, is here completely occupied by dolomite. Well I-75 six miles distant did not completely penetrate Unit 3C, but as dolomite was encountered at the same depth as in Well 69, the 3C section in Well I-75 is probably also all dolomite. Contouring suggests that 3C dolomite extends into southern Lee County.

In Well 68 to the south, the lower two-thirds of Unit C is dolomite, which is separated from the underlying Delray Dolomite by a thin limestone.

In Area B in western Sarasota County (Fig. 5) within CHAcO Suite limestone, the section underlying 3BL dolomite consists of interbedded limestones and dolomites which contain beds and nodules of anhydrite. This section is the southward equivalent of Unit 3BL.

Area C in northern Collier County (Figs. 5 & 14) contains several wells which encountered anhydrite beds and nodules in Unit 3B. In this area, unlike other areas of anhydrite occurrence, its presence is confined to isolated wells. These form narrow, lenticular northwest-southeast trends (Fig. 14). The presence of nodular anhydrite in some wells on this Figure appears to indicate proximity to a bedded anhydrite section. Adjacent or nearby wells may have only anhydrite nodules, or no anhydrite whatsoever. For instance, Well 103 has 115 feet of

bedded anhydrite, while Well 86 a mile away has none. Anhydrite beds also do not correlate between wells.

The linearity of these anhydrite trends and their isolation from each other suggest that these deposits are not primary, but are more likely to be local alterations of limestone or dolomite. The most reasonable hypothesis for this would seem to be alteration of carbonate rocks by sulfate-bearing waters rising along fault planes from the deeper anhydrite-rich Cedar Keys below. That this can happen was shown by the presence in anhydrite thin sections from an eastern North Dakota Mississippian anhydrite of obvious crinoid stems. A projection of the North Port fault to the southeast (Fig. 5) passes through Area C and through Well 121, which contains one of the thickest accumulations of anhydrite beds in Area 3C. The other linear anhydrite accumulations are parallel to this fault projection. Only at Well 86COL is there direct evidence for faulting (see page ) both by missing section in the Delray Dolomite (Fig. 11) and structural displacement on the Lake Trafford Formation at 11,000 feet (not illustrated). There is no other deep subsurface evidence for faulting in the area. If other faults are present, they are probably of small displacement and were possibly absorbed within the thick, soft sediments of the sub-Cedar Keys chalky limestones of the Pine Key Formation.

The presence of nodular anhydrites in some wells on Figure 14 appears to indicate proximity to a bedded anhydrite section.

## STRATIGRAPHIC CROSS-SECTION HIGHLIGHTS

Six cross-sections are included in an accompanying ring binder. This form of binding allows the reader to combine them to form a variety of cross-sections by folding over the end of one, superimposing it on the beginning well of another.

Unfortunately, on several key wells no cuttings were available, necessitating the interpretation of ES logs to identify dolomite beds.

A-B This cross-section shows the pinchout southward of units 3BU and 3BL. It also demonstrates that these two units are not continuous with units 3B-1 and 3B-2. In Well 70/310 the thickening upward of the Delray Dolomite at the expense of the overlying 3C limestone is apparent. In Well 20, the anhydrites of 3BL occur southward in its limestone equivalent.

B-G This cross-section extends A-B to the south. It illustrates the disappearance of Unit 3B-2 and the appearance of thick 3C dolomite in Well 69. In Well 68, the extreme thinning of Unit 3 could be due to a fault cutting out part of the section, but data are insufficient to show this to be the case.

B-H This cross-section is the only one on which Unit 3B-1 appears. It also shows the anhydrites of Anomalous Area C (see p. 23 & Fig. 14) in Wells 271 and 222. Also shown is the eastward thinning of 3B-2 dolomites.

C-D Here, 3BU thins southward to Well 59. This section shows that 3BL and 3B-2 are separated by a limestone facies. It also illustrates the gradual thickening of the Delray Dolomite.

E-F This cross-section shows the 3B-2 thick in the Charlotte-Glades area. In Wells 289 and 178, the Delray Dolomite is thinning westward onto the Sarasota Arch. Compare the actual

thickness of the Delray Dolomite in Well 373 with Wells 310 and 269 to support the presence of a fault in Well 373.

J-K This cross-section shows an apparent fault in the 3C interval of Well 291. The 3B-2 section in this well is thicker than in Well 222 to the northwest. In Well 222 anhydrite occupies the section equivalent to 3B-1 in Well 291. This interval pinches out to the east. In the eastern part of the cross-section, 3B-2 dolomite has thinned considerably. The 3C interval in Well 167 at the eastern end of the cross-section is half the thickness in Well 222 in the western end.



## STRUCTURE

### Regional Structure

Regional structural features of the Florida Peninsula are shown on Figure 1. The study area lies on the landward extension of the offshore Cenozoic South Florida Basin.

As can be seen on Figures 15 & 16, a southwest-plunging nose forms the onshore extension of the offshore northeast-plunging Sarasota Arch. South of this feature, the onshore portion of the South Florida Basin consists of a large, essentially flat area, bounded on the east by a broad low swell.

### Local Structure

Where control is plentiful in Lee, western Hendry, and western Collier Counties, broad local highs can be mapped. In the large areas where control is lacking, these same types of local highs are probably present.

The only close local control available in the study area is in the Sunniland oil field where there are shallow geophysical logs and drill-cutting data with which to map this structure. Structure on top of Cedar Keys B (Fig. 17) consists of gentle northeast dip with a slight nosing. In contrast, structure on the top of the Lake Trafford Formation at a depth of 11,000 feet (Fig. 18) shows an anticline with some 75 feet of closure.

### Faulting

Three of the known faults (A, B, & F) shown on Figure 19 are established by missing section. The North Port fault (Winston 1995b) has cut out the basal Delray Dolomite and the upper Cedar Keys A (Fig. 20). The trace of this fault (Fig. 22) was established by connecting it to Well 70CHA to the southeast,

where a thick section of wall collapse is present. Evidence that thick wall collapse suggests the nearby presence of a fault system was presented in Volume 1. Figure 19 shows a southeastward projection of the North Port Fault extending from Charlotte into Collier County. After reviewing this publication, Ron Reese (personal communication) pointed out that this projection coincided with the northeast flank of a southeast-plunging nose which he had mapped on a lower Hawthorn marker. This nose has 50 feet of relief on its northeast side in northern Collier County and 100 feet in Lee County. If this relief is the result of faulting, the fault would have a comparable displacement.

The Venice fault system (Winston 1995b) has cut out two intervals: one in Unit 2 and the other in Unit 3 (Fig. 21). The trace of this fault was hypothesized to parallel the North Port Fault (Fig. 22). The Northeast McGregor fault is established by missing section in Unit 3 and a commensurate thickening of Unit 1 in Well 208LEE, as compared to Well 161 one mile south (Fault F, Figs. 19 & 23). These data suggest that movement probably took place during the deposition of Unit 1. The McGregor fault system (Fig. 23 & G on Fig. 19) was established by Sproul et al (1972) by structural offsets in Neogene beds in closely-spaced shallow wells. As much as 150 feet of displacement is present.

The Estero Fault System (Fig. 24) was derived by Burns (1983) using "...correlation of marker beds in the lower Tampa-Hawthorn....apparent dips exceeding 4 degrees in less than 500 feet strongly suggest faulting." No cross-section was included.

At locations E & H (Fig. 19) an excessively thin Delray Dolomite section suggests the possibility of faulting. At locations D & J, thick wall collapse suggests the presence of

nearby faulting.

On Figure 22, the North Port fault is shown practically intersecting Warm Spring (Winston 1995d). A further extension of this fault to the northwest puts it close to Pinehurst Spring; both of these springs contain warm sulphur water. On Figure 19 the inferred faults C (Little Salt Spring) and K (Mud Hole Spring) are based on the association of the North Port fault with the aforementioned sulfur springs.

The presence of the Pepper Hammock fault is indicated by 250 feet of missing section in Unit 3C (cross-section J-K) compared with Well 380 four miles northwest. Well 380 is the nearest well with an up-hole E-log. The entire Unit 3 interval is 250 feet too thin.

The twelve known and suspected faults shown by the sparse control in the study area suggest that many more may be present in the large areas of no control.

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## Appendix 1

### GLOSSARY

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

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

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

Boulder Zone - 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.

Dredging - 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.

Floridan Aquifer System - In the southwestern Peninsula the aquifer includes rocks from the base of the Hawthorn Group into Cedar Keys A.

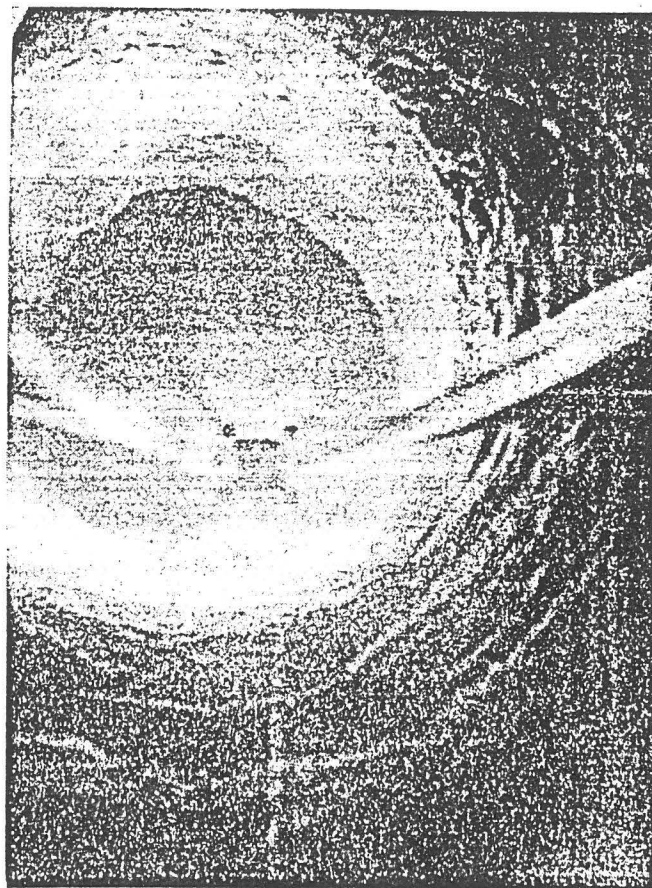
Suite - A vertical grouping of lithologies distinguished from adjoining vertical groups by a distinctive lithologic assemblage (see Winston 1993). The four Suites used in this study are defined in the Appendix.

Cone Fauna - A term used by Vernon (1951) combining *Dictyoconus cooki* and *Coskinolina floridana*.





**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.

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.

Robert G. Burke  
Southwest Editor

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 coun-



try 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 9½-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 13¾-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 down-hole camera and employing proper tools and drilling techniques for the conditions encountered.

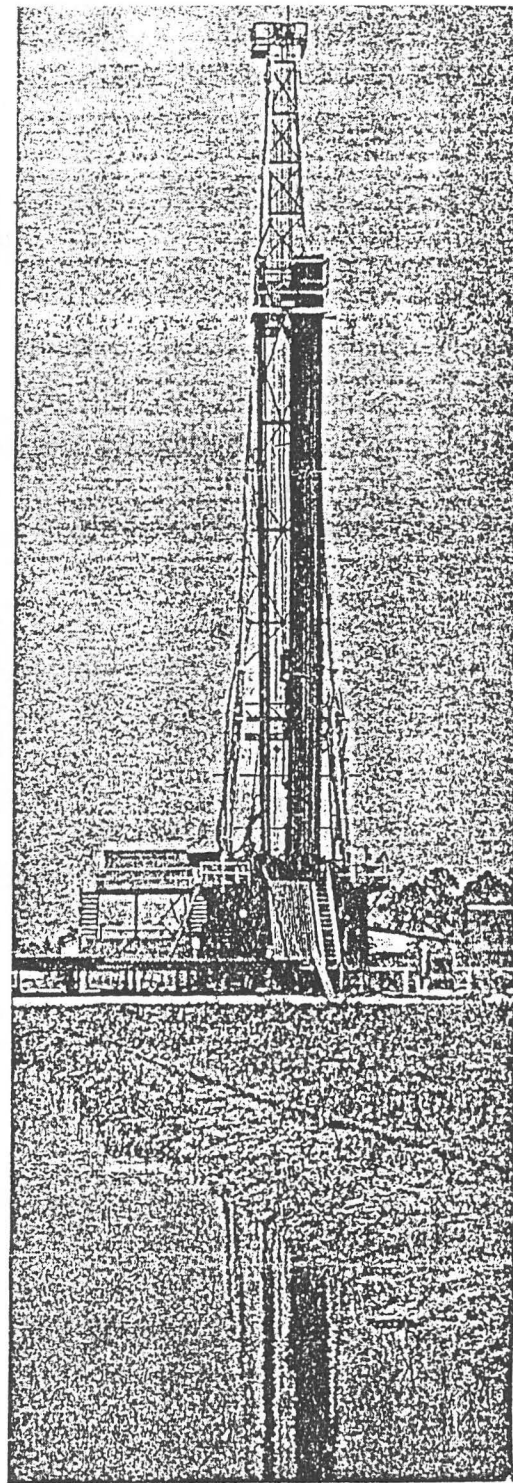
Stereoscopic photographs, which are much in demand for geology classes and other drillers, are of excellent quality. They were taken by Lane Texas Co., a water driller who developed the camera.

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 8½-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



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.

from boulders in that hole.

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 3

## WELL LISTS

### Oil Tests

| Well | Oper       | #    | Lease               |
|------|------------|------|---------------------|
| 46   | Humble     | 3    | Lee Cypress         |
| 62   | Humble     | 1    | Keene               |
| 86   | Humble     | C-1  | GCRC                |
| 92   | Humble     | 1    | Lee Cypress         |
| 98   | Humble     | D-1  | GCRC                |
| 103  | Humble     | E-1  | GCRC                |
| 121  | Humble     | 16   | GCRC                |
| 133  | Humble     | B-1  | Collier             |
| 134  | Humble     | 2    | Collier Corp.       |
| 152  | Coastal    | 1    | Tiedke              |
| 160  | Gulf       | 1    | CNS                 |
| 161  | Humble     | 1    | Kirchoff            |
| 162  | Comm.Oil   | 1    | Red Cattle          |
| 167  | Comm.Oil   | 1    | Wisehart            |
| 178  | Gulf       | 1    | Vanderbilt          |
| 207  | Humble     | 1    | CNS (hole 2)        |
| 208  | Sunnyland  | 1    | Walton              |
| 222  | Humble     | 1    | Currey              |
| 225  | CONOCO     | 1    | Carlton             |
| 236  | Magnolia   | 1    | Schroeder           |
| 237  | Amerada    | 1    | Swenson             |
| 250  | Gulf       | 2    | CNS                 |
| 265  | Humble     | 1    | State 1004          |
| 269  | Amerada    | 1    | Lykes               |
| 271  | Humble     | 1    | CNS                 |
| 279  | Comm.-Gulf | 1    | Red Cattle          |
| 282  | Humble     | B-2  | GCRC                |
| 289  | Calco      | 1    | State 224-B         |
| 291  | Humble     | 2    | Miles Collier       |
| 310  | Gulf       | 1    | Stevens             |
| 371  | Sun        | B-1  | Red Cattle          |
| 373  | Mobil      | 1    | Babcock             |
| 375  | Mobil      | 1    | State 224-B         |
| 380  | Humble     | 1    | Price Imp.          |
| 609  | Shell      | 1    | Punta Gorda         |
| 679  | Amoco      | 19-2 | Knight              |
| 683  | Kirby      | 1    | State               |
| 740  | Shell      | 7-4  | Gulf & Western      |
| 859  | Humble     | 26-2 | Lehigh Cons. Tomoka |
| 862  | Amoco      | 6-2  | Jackson             |
| 1037 | H&H        | 27-4 | Gerry Bros.         |
| 1060 | Exxon      | 2-8  | Collier             |
| 1063 | H&H        | 20-3 | Oleum               |
| 1086 | H&H        | 10-2 | Oleum               |
| 1121 | Exxon      | 1    | Raccoon Pt. SWDS    |
| 1127 | Davis      | 28-4 | Barrielo            |
| 1193 | Huber      | 26-2 | Lykes               |
| 1201 | RK Pet     | 28-3 | Pepper              |
| 1208 | Sabine     | 4-2  | Collier             |
| 1238 | Sabine     | 3-1  | Alico               |
| 1264 | Triton     | 13-2 | Larson              |

# Injection Wells

| Map No. | Well Name          |
|---------|--------------------|
| 13      | Atlantic Utilities |
| 15      | Knight's Trail RO  |
| 16      | Venice Gardens RO  |
| 17      | Englewood RO       |
| 18      | Plantation RO      |
| 19      | Gasparilla         |
| 20      | North Port         |
| 21      | North Ft. Myers    |
| 55      | Eastport           |
| 57      | Sarasota           |
| 59      | Belle Glade        |
| 68      | Marco Island       |
| 69      | North Collier      |
| 70      | Zemel Road         |

# Research Wells

|       |                                |
|-------|--------------------------------|
| Alley | Alligator Alley-USGS           |
| I-75  | South Florida Water Management |
| L-2   | South Florida Water Management |

## Appendix 4

### PINco Suite (Fig. 3)

Type Well: Coastal 1 Wright (P 75) 7-30S-17E, Pinellas County (Fig. 5)

Type Interval: Top 195 feet samples (no E-log for top); base 3100 feet E-log, 3115 feet samples.

Name Derivation: Pinellas County

Thickness Range: 1800-2950 feet

#### Description of contained lithologies:

The upper several hundred feet are limestone, composed of light-colored skeletal grainstones Units 1, 2, and 3. Beneath is a thick section of tan, cream and orange-brown dolomite of euhedral, anhedral or occasionally cryptocrystalline texture. The euhedral variety is microcrystalline to fine crystalline or chalky. Occasional very fine to fine grain relic skeletal dolomites occur.

In the lower section (3BL), thin beds and nodules of anhydrite appear in the dolomite, with selenite and gypsum filling dolomite porosity. Peat and lignite beds are present, as well as occasional peaty partings and cherty beds.

The lower one-fourth of the Suite in the type well is the co-type interval for the Oldsmar formation (Winston 1977). The limestone fraction of this formation consists of cream, tan and white very fine to fine grain skeletal wackestone with occasional dolomite crystal inclusions. White, tan and gray-brown chalky micrite is common. Basal Oldsmar dolomite, now designated the Delray Dolomite, is euhedral, anhedral and occasionally cryptocrystalline. The euhedral variety is chalky to medium crystalline. Colors are tan and orange-brown.

#### Comments:

The Oldsmar formation is only recognizable when sandwiched between the thick Unit 3B dolomite and the Delray Dolomite. Rock equivalents to the Oldsmar occur in all Suites.

#### Distribution:

West-central Peninsula and offshore to the west (Fig. 5).

#### Upper Boundary:

Defined, when not outcropping, by the change from phosphatic sandy chalky micrite and light-colored skeletal wackestone of the Hawthorne above, to white to cream skeletal grainstone and packstone of Units 1 or 2.

#### Lower Boundary:

Defined by the change from brown and orange-brown or tan anhedral dolomite of the basal PINco Suite Delray Dolomite above to gray cryptocrystalline or anhedral dolomite of the Cedar Keys Unit A below.

Age: Eocene and Oligocene.

## Appendix 5

### ORco Suite (Fig. 5)

Type Well: Sand Lake 1 Injection (W-13287), 32-33S-29E,  
Orange County (not in study area)

Type Interval: Top 190 feet samples, 180 feet GR log; base 1983  
feet samples, 1975 feet GR log; no E-log  
available

Name Derivation: Orange County

Thickness Range: 1300-2200 feet

#### Description of contained lithologies:

The ORco Suite is 80-90% dolomite which is mostly euhedral with anhedral and cryptocrystalline textures occasionally present. Euhedral dolomite is very fine microcrystalline to fine crystalline with abundant relic skeletal packstone lithologies. Colors are brown, tan and orange-tan.

Subordinate limestone consists of very fine to fine grain skeletal packstone, grainstone and chalky micrite. Colors are cream, tan and brown. Limestone occurs in the upper section Unit 1 and in the lower Unit 2 section.

Boulder Zone cavities can occur anywhere in this thick dolomite Suite, but are not common.

Distribution: The ORco Suite is located in the central Peninsula area (Fig. 5).

Upper Boundary: Defined by the change from phosphatic dolomite, sand or clay of the Hawthorne above, to non-phosphatic white to cream limestone packstone of Unit 1 or 2 below.

Lower Boundary: Defined by the change from brown anhedral dolomite of the Delray Dolomite above, to gray cryptocrystalline or anhedral dolomite of the Cedar Keys Unit A below.

Age: Eocene and Oligocene.

## Appendix 6

### CHAcO Suite (Fig. 5)

Type Well: Gulf 1 Vanderbilt (P 178), 35-41S-21E,  
Charlotte County (Fig. 5)

Type Interval: 705 feet samples (no E-log of top); base 3180  
feet samples and E-log

Name Derivation: Charlotte County

Thickness Range: 2200-2400 feet

Description of contained lithologies: The CHAcO Suite is 60-70% limestone. The limestone is usually a very fine grain skeletal wackestone or packstone with a chalky matrix. Occasional zones of grainstone with fine to medium grains are present. Colors are tan or cream. Chalky cream-colored micrite is common. Dolomite crystal inclusions are frequently present in limestones.

Dolomite is anhedral, euhedral or cryptocrystalline. The euhedral variety is usually microcrystalline to fine crystalline, but when lining Boulder Zone channels in anhedral dolomite, the crystal size can be medium to coarse. Colors are tan, orange-brown and dark brown.

Comments: CHAcO differs from DAcO in having more dolomite, and in particular, containing a 100-200 foot thick regionally persistent Boulder Zone dolomites.

Distribution: The CHAcO Suite occurs as a 100-mile wide band extending east-west across the southern Peninsula (Fig. 5).

Upper Boundary: Defined by the change from phosphatic limestone, dolomite or sandy limestone of the Hawthorne Arcadia above, to white, tan or cream skeletal packstone or grainstone of Units 1 or 2 below.

Lower Boundary: Defined by the change from basal CHAcO brown anhedral or coarse crystalline euhedral Delray Dolomite above, to gray cryptocrystalline or anhedral dolomite of the Cedar Keys Unit A below.

Age: Eocene and Oligocene.

## Appendix 7

### DACO Suite (Fig. 5)

Type Well: MDWS 5 Injection (50, W-13768), 21-56S-40E,  
Dade County (Fig. 5)

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

Name Derivation: Dade County

Thickness Range: 1900-3000 feet

Description of contained lithologies:

The DACO Suite is 90-95% limestone. The limestone is tan and cream (white in the upper Suwannee) grainstone and packstone. There is little wackestone or micrite. Foraminifera are common, with the "cone" fauna (see Glossary) extending downward to within 100 feet of the base of the Suite in the southeastern Peninsula. Grain size is fine to medium and occasionally coarse.

Zones of dolomite crystal inclusions occur locally. At the base is the Delray Dolomite consisting of anhedral dolomite with pockets of euhedral. The euhedral variety is fine to medium crystalline, and occasionally coarse crystalline. Cryptocrystalline lithographic dolomite is frequently present in the southeastern Peninsula in the Delray Dolomite.

Distribution: Southern Peninsula.

Upper Boundary: Defined by the change from white fossiliferous limestone of the Hawthorne Arcadia above to the white or tan skeletal limestone of the Suwannee below. Where the Hawthorne lacks phosphate, it is indistinguishable from the Suwannee in cuttings. In northern Collier County, phosphatic sandy Arcadia limestone overlies phosphatic sandy Unit 1 limestone making it difficult to separate them.

Lower Boundary: Except in injection wells, the samples covering the lower boundary are everywhere missing due to lost circulation. In the injection wells the boundary is defined by the change from brown and tan anhedral Delray Dolomite above to gray anhedral or cryptocrystalline lithographic dolomite of the Cedar Keys Unit A below. Picking this boundary is aided by regional correlation using gamma ray logs.

Age: Eocene and Oligocene.



## 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 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.

The three included borehole video surveys were selected for image quality plus maximum penetration of Unit 3B, Delray Dolomite and Cedar Keys A sections. Their graphic logs are shown on Figures 28, 29 & 30.



## WALL FEATURE DEFINITIONS & DESCRIPTIONS

### a. VUGS

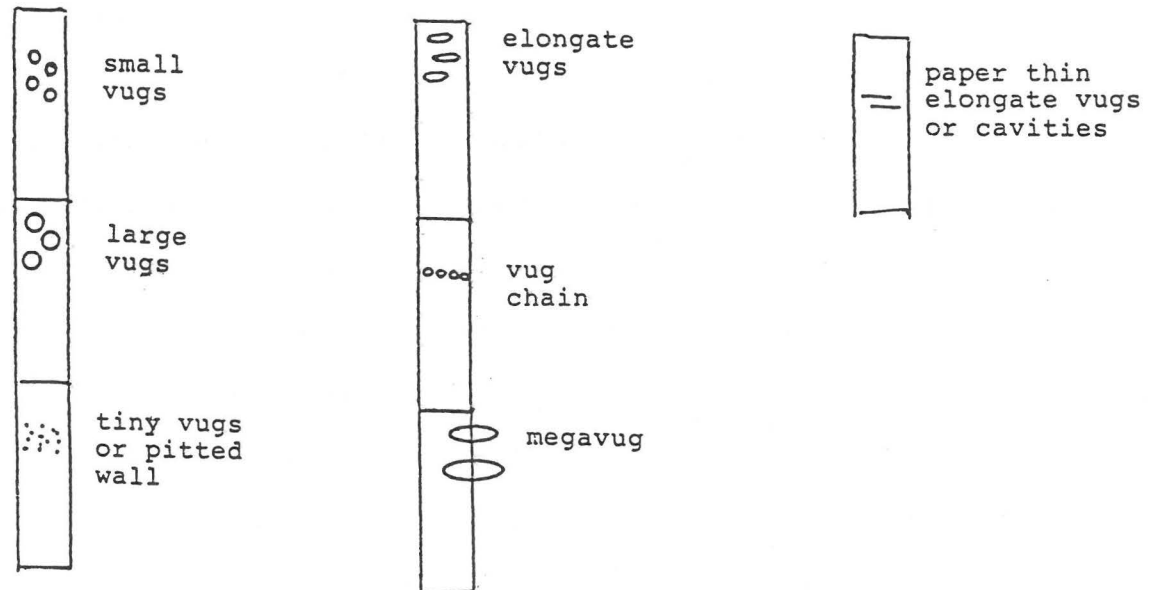
The lower limit of vug visibility on the tapes is probably on the order of one-half inch. Vugs are either round in shape, or elongate in a horizontal direction. Occasionally elongate vugs occur at various vertical angles. Elongate vugs are usually some one inch high and may be up to six inches in length.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

A chain of "bleeding vugs" consists of tiny vugs with short black marks several inches long running down the wellbore wall. This same cluster of vugs is 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".



## 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.

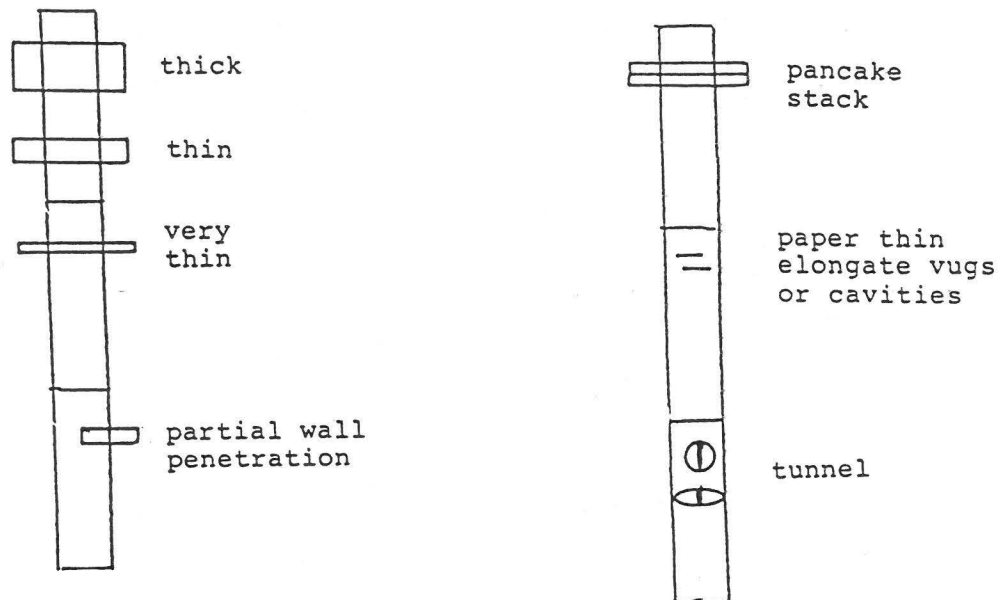
In diameter cavities are probably three to six feet and from a few inches to several feet in thickness. In three out of four instances, the borehole cuts only part of a cavity. In the other case, the cavity completely encircles the wellbore.

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 phenomenon 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.



### c. CAVERNS

In the Southwestern Peninsula, major caverns are present (see below). The cavern in Well 323 was documented by downhole stereo photographs and a 96-foot bit drop, followed by a twist-off. The photographs show nothing but white except for one, where the twisted off drill pipe can be seen leaning against the wall of the cavern. Most, if not all so-called "caverns" on video tape, are large wall collapse zones, where the wall has moved back beyond the range of the camera. Although "caverns" are seen usually as black pictures, occasionally a white picture without visible wall is present. Many apparent "caverns" (black or white) have a ledge protruding into the range of the camera, indicating that they are actually wall collapse zones. When a "cavern" appears above or below a wall collapse zone, that is probably what it is.

(No true "bit-drop" caverns in videotaped wells)

#### d. WALL-COLLAPSE ZONES

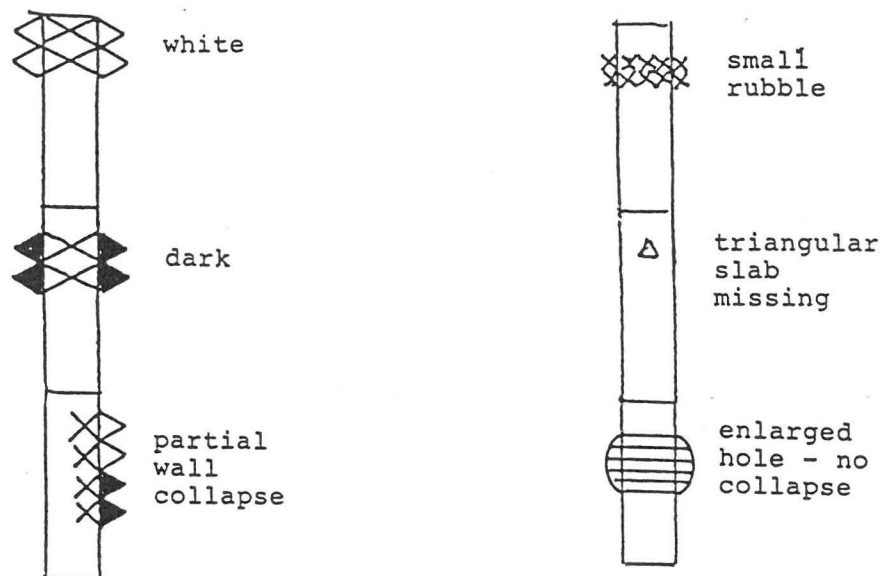
Wall-collapse is identified by a blocky appearance and enlargement of the borehole wall. The presence of numerous open, intersecting fractures, when penetrated by the bit, cause large blocks of rock to lose support and fall into the hole. This feature is the source of most of the "boulders" in the southwestern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

Thick hole enlargements on caliper logs seem to be 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.

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).

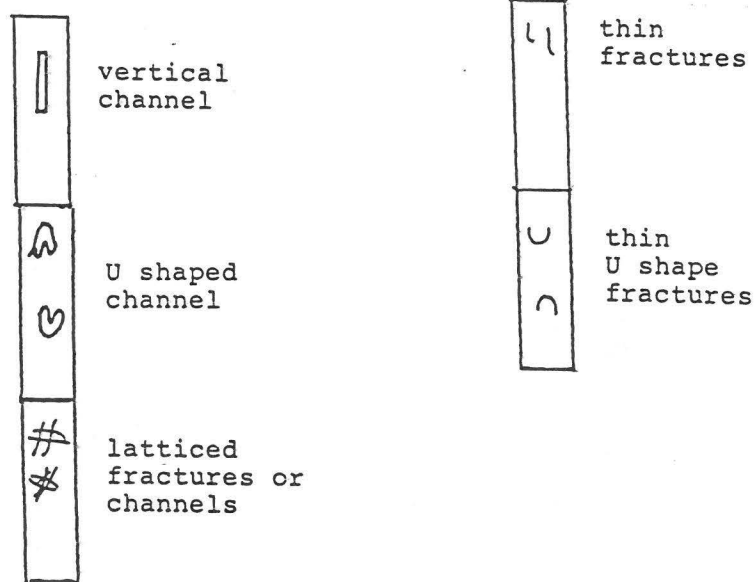


e. LINEAR OPENINGS

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-enlarged 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 may be caused by color differentiation, linear chains of tiny vugs, or bands of softer and harder rock. Most likely, differing hardness in response to the drill is the main cause, with color differences responsible for the wider bands.

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

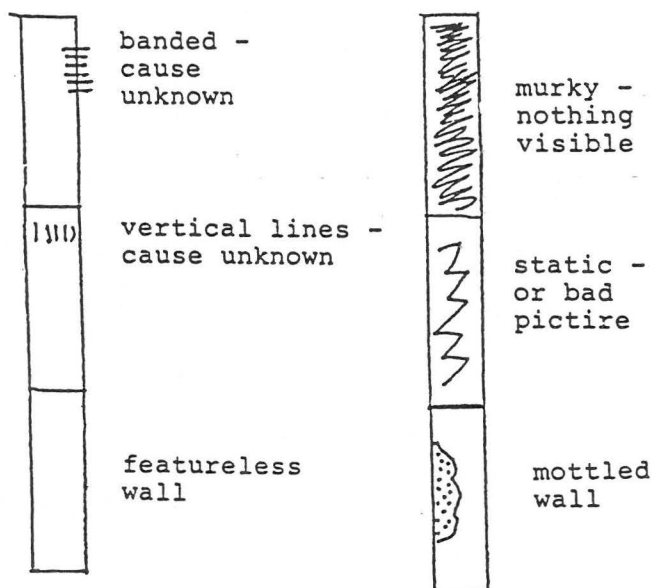
Vertical parallel lines are rare. They are usually a few inches long and are closely packed, encircling the entire hole. As these lines are vertical, it is hard to see how they would be caused by the drill bit, which should produce spiral marks. Rare vertically oriented lines which do occur with a right-hand 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.

Dark areas on the bore hole wall have shapes and dimensions of megavugs, cavities or vertical channels. Indeed, they could be features filled in with secondary dolomite, 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 is 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.

If present, extended cavern systems would contribute considerably to reservoir capacity and permeability. Small local caverns obviously would have limited capacity.

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

In southeastern Florida at multiple well sites, zones of well-developed wall-collapse occasionally extend to adjacent wells (Winston 1995a).

## QUALITY OF POTENTIAL INJECTION ZONES

Injection quality of a dolomite is dependent on three factors: (1) bed thickness, (2) abundance of vugs, megavugs, channels or wall collapse, (3) how well they are connected. The latter can only be determined by injection or withdrawal tests. The second can be determined by inspection of downhole video tapes, and the first by sample and/or geophysical log correlations.

To determine quality no. 2 of a dolomite, graphic representations of the wall features on all available downhole video tapes of injection wells were examined to determine the potential injection quality of a dolomite. The overall quality of potential injection zones (items 1 & 2 above) is summarized in Table 1.

No video survey was made on Well 57SAR.

### 3A Dolomite

One survey of 3A limestone in Well 17 showed thick wall collapse. No surveys of 3A dolomite are available.

### 3BU

Well 13 contains numerous intervals of vug porosity in various sizes but they are mainly small and scattered. Thin intervals containing megavugs, cavities and thin wall collapse zones are also present. Well 15 has excellent development of vug, megavug, and cavity porosity and a few thin wall collapse zones. Well 16 is about the same, but has many more cavities. In Well 17, the upper sixty-foot section has numerous channels, cavities, and thin wall collapse zones. In the lower section, only scattered vugs, megavugs, and cavities are present. In Well 18, one mile away, most of the interval is composed of wall collapse, with the camera stopped by a bridge after 100 feet 3BU



were surveyed.

Well 20 has a 15-foot zone of wall collapse at the top, with vugs of various sizes prevalent throughout. Cavities and megavugs are only occasionally present. In Well 19, 3BU is only 190 feet thick. Several minor wall collapse zones are present along with occasional cavities and megavugs. Zones of vugs of various sizes are common. A total of some 50 feet of 3BU has only scattered vugs.

### 3BL

Six wells were surveyed in this section. Well 13 has scattered vugs with rare megavugs and cavities. Beds and nodules of anhydrite are common. Well 15 is the same. In Well 16, the ten feet surveyed contain numerous vugs of varying sizes along with anhydrite nodules. Well 19 had a 30-foot surveyed interval which contained thin zones of large vugs and nodules of anhydrite. Well 20 had 80 feet of 3BL dolomite in which several intervals contained a fair number of vugs of various sizes along with several anhydrite beds.

### 3B-1

The boundaries of 3B-1 are indeterminate. The dolomites assigned to this unit are equivalent to 3BU, but these dolomites are not connected.

The only video survey to encounter this unit was Well 70. Several thin dolomites have dense vug fields with a few cavities and channels. None of these beds were thick enough to qualify as an injection zone. Data on this well can be extrapolated to infer similar reservoir conditions elsewhere in 3B-1.

### 3B-2

The boundaries of 3B-2 are indeterminate. The dolomites assigned to this unit are equivalent to 3BL, but these dolomites

are not connected.

Only four wells have video surveys in this section. In Well 70, 3B-2 is broken into several thick beds which contain intervals of abundant channels, vugs, megavugs, cavities, and thick wall collapse. Several intervals contain only a few vugs. Well 21, only a few miles distant, is quite different. Here, small vugs dominate the 200-foot section with occasional channels, cavities, and wall collapse zones. Scattered zones totalling 45 feet of the interval contain few wall features. In Well 69, wall collapse and channels dominate a basal 140-foot interval with only occasional cavities and vugs. A West Felda brine injection well (P371) has several thick pancake stacks of cavities.

### 3C Dolomites

In Well 69 (no video survey), the caliper log indicates the presence of thick zones of wall collapse. In Well 68, 3C dolomite contains numerous vug fields and channels with cavities and megavugs occasionally present. In Well 70, the penetrated section of 70 feet is occupied entirely by wall collapse.

### Delray Dolomite

Only five injection wells penetrated this unit and only three have video surveys. In Well 20, the lower part of the section was faulted out; most of the remaining 70-foot interval has good vug, megavug, and cavity development. Several thin intervals contain only scattered megavugs and cavities. In Well 55, half of the section is dominated by wall collapse. In the non-collapsed section, there are abundant cavities, vugs, and megavugs. In Well 68, vugs and megavugs are common to abundant; cavities are uncommon. In Well 69, this section was not surveyed

due to a bridge up hole. The caliper log indicates the presence of several thin wall collapse zones.

#### Cedar Keys A

Four injection wells penetrated this unit. Unlike in the Southeastern Peninsula, this unit contains anhydrite (Fig. 13). Development of wall features is usually poor and confined to the upper, generally non-anhydritic section. Well 55 has good development of vugs and megavugs accompanied by a few cavities. Well 68 has numerous cavities; vug and megavug development is poor. Well 69 was not surveyed due to a bridge in the hole. In Well 20, the upper half of the unit has been faulted out. The remaining section contains poorly developed wall features, mainly small vugs. Several anhydrite beds are present.

## 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 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.

In Well 59 east of the study area, 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, or they 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. In the Delray Dolomite, solution of originally deposited anhydrite lenses or nodules is very unlikely, as I have never seen even a trace of anhydrite in this unit in the more than seventy Delray Dolomite sections I have examined.

5. 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.

#### 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

Several caverns have been reported in the study area (Table 2), but logs are not available to cover these cavernous intervals. In Well 323, a 96-foot bit-drop was experienced, resulting in a twist off of the drill pipe. Subsequent stereo photographs of the interval showed nothing but reflected white light with no picture of a wall. One frame showed the twisted off drill pipe leaning over and disappearing into the haze. Obviously this cavern is of considerable horizontal size. Neither log nor sample data are available in an adjacent well. Data from a well approximately one mile away suggest that this cavern is in 3C limestone beneath a 3B-2 dolomite. One reported cavern occurs in Unit 2 limestone and two others in the equivalent of Unit 3A. There is no way that evidence from drill cuttings could substantiate a subaerial origin for these caverns.

## DRILLING TECHNIQUES

Burke (1967) (See Appendix 2) and Banks (1950) present details on Boulder Zone drilling problems and remedial techniques.

### 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 Zones, 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. 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 results in stuck pipe and "twist-offs".

## HOW BOULDERS ARE FORMED AND RECOVERED

### Boulder Formation

Prior to 1967, conventional drilling techniques in the southwestern Peninsula 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 then fall to the bottom of the cavity where it was rolled around in the small hole, 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 26 from an oil test, show that it changed position several times before being fished out. The fourteen boulders also shown on Figure 26 were 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 a small hole the curve of the wall would provide 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 also may 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 using one of the devices shown on Figure 27.

The boulder recovery junk basket consists of a piece of drill pipe with a cylinder of casing six to eight feet long welded at the top and base to the drill pipe. 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 would fall into the slots.

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.

Details on reported drilling problems (other than caverns) are shown on Table 3.

| Well | 3BU       | 3BL           | 3B-1      | 3B-2      | 3C dol        | DD            | CK A          |
|------|-----------|---------------|-----------|-----------|---------------|---------------|---------------|
| 13   | fair      | no good       | absent    | absent    | did not reach | did not reach | did not reach |
| 15   | good      | no good       | absent    | absent    | did not reach | did not reach | did not reach |
| 16   | good      | did not reach | absent    | absent    | did not reach | did not reach | did not reach |
| 17   | poor      | did not reach | absent    | absent    | did not reach | did not reach | did not reach |
| 18   | good      | did not reach | absent    | absent    | did not reach | did not reach | did not reach |
| 19   | fair      | no good       | absent    | absent    | did not reach | did not reach | did not reach |
| 20   | good      | poor          | absent    | no good   | poor          | poor          | poor          |
| 21   | absent    | absent        | absent    | fair      | no good       | did not reach | did not reach |
| 57   | no survey |               |           |           |               |               |               |
| 55   | no survey | no survey     | absent    | absent    | absent        | good          | good          |
| 68   | absent    | absent        | no survey | no survey | good          | good          | fair          |
| 69   | absent    | absent        | absent    | fair      | (good*)       | (fair*)       | no survey     |
| 70   | absent    | absent        | fair      | fair      | good          | did not reach | did not reach |

Table 1

\* video survey did not reach but caliper log indicates wall collapse

TABLE 2

## Reported Cavern Occurances

| Well  | Loc      | tk<br>feet | Depth     | Unit | Wildcat/<br>Oil Field |
|-------|----------|------------|-----------|------|-----------------------|
| W-966 | 34-38-29 | 8          | 956-64    | 2    | HIGHLAND              |
| 152   | 25-42 23 | 65         | 1233-99   | 3A(L | HIGHLAND              |
| 207   | 5-45-29  | 20         | 1825-48   | 3A(L | HENDRY                |
| 406   | 24-48-29 | 14         | 1790-1804 | 3A(L | Sunniland             |
| 329   | 19-45-29 | 10         | 2475-85   | 2B-2 | Felda                 |
| 416   | 32-45-28 | 5          | ?         | 2B-2 | West Felds            |
| 813   | 27-44-26 | 14         | 2054-68   | 2B-2 | Lehigh Park           |
| 859   | 26-44-26 | 5          | 2353-58   | 2B-2 | Lehigh Park           |
| 86    | 21-47-28 | 16         | 2810-36   | 3C(L | COLIER                |
| 323   | 32-45-29 | 96         | 2526-2612 | 3C(L | Felda                 |
| 425   | 8-45-27  | 15         | 2715-30   | 3C(L | HENDRY                |
| 426   | 5-46-28  | 25         | 2835-60   | 3C(L | West Felda            |
| 1064  | 3-49-30  | 62         | 2646-2708 | 3C(d | Bear Island           |

Wildcats' county in capital letters

Oil oil field in lower case letters

TABLE 3

## Key to Abbreviations

Well - Oil Test Permit Number

Locations: Sec - Twp - Rge

WC = wildcat

HEN = county abbreviations on maps

Oil Fields: F = Felda

WF = West Felda

LP = Lehigh Park

TC = Townsend Canal

SUN = Sunniland

BI = Bear Island

MidF = Mid-Felda

RP = Raccoon Point

Unit: 3B-1, 3B-2, Delray Dolomite & Cedar Keys A are always dolomite  
 3A & 3C may be either limestone (L) or dolomite (d)

## MISCELLANEOUS

| Well | Location |        | Depth     | Unit  | Feature             |
|------|----------|--------|-----------|-------|---------------------|
| 207  | 5-45-29  | WC HEN | 1825      | 3A(L) | lost fish in cavern |
| 208  | 13-45-24 | WC LEE | 2345      | 3B-2  | stuck pipe          |
| 250  | 22-45-26 | WC LEE | 2310      | 3B-2  | water flow          |
|      |          |        | 2845      | 3B-2  | water flow          |
| 271  | 16-46-27 | WC LEE | 1690-1805 | 3A(L) | zero resistivity    |
| 322  | 33-45-29 | F      | 1710-20   | 3B(L) | wall collapse       |
| 329  | 19-45-29 | F      | 2130      | DD    | bridge              |
| 334  | 29-45-29 | WC HEN | 2057-61   | 3B-1  | wall collapse       |
|      |          |        | 2177-88   | 3B-2  | wall collapse       |
| 336  | 33-45-29 | F      | 2100-30   | 3B-2  | wall collapse       |
| 419  | 32-45-28 | WF     | 1270      | 2     | bridge              |
| 455  | 31-45-28 | WF     | 1955-65   | 3B-2  | wall collapse       |
| 594  | 30-45-28 | WF     | 2067-2156 | 3B-2  | bridge              |
| 714  | 13-45-27 | WF     | 3264      | DD    | last boulders       |
| 902  | 34-48-30 | BI     | 2035-2240 | 3B-1  | wall collapse       |
| 1151 | 3-45-28  | TC     | 2503      | 3B-2  | bridge              |
| 1193 | 26-39-31 | WC HIG | 2990      | DD    | bridge              |
| 1224 | 29-46-28 | WC COL | 1270      | 2     | bridge              |
|      |          |        | 2803      | 3C    | stuck pipe          |
|      |          |        | 2983      | 3C(d) | bridge              |
|      |          |        | 2940-3000 | 3C(d) | stuck pipe          |

(TABLE 3 continued)

## CAVITIES

| Well | Location |        | Depth   | Unit  |
|------|----------|--------|---------|-------|
| 152  | 25-42-33 | WC HEN | 1302-09 | 3A(L) |
| 406  | 24-48-29 | SUN    | 1900±   | 3B-1  |
| 407  | 14-45-27 | WF     | 2816-20 | 3C(d) |
| 425  | 8-45-27  | WC LEE | 2313-15 | 3B-2  |
|      |          |        | 2733-34 | 3C(L) |
|      |          |        | 2750-51 | 3C(L) |
| 524  | 14-46-28 | WC COL | 3062-65 | DD    |
| 655  | 19-45-28 | WF     | 2138    | 3B-2  |
| 1134 | 20-47-29 | WC COL | 1970-74 | 3A(L) |
| 1190 | 2-52-34  | RP     | 3070-71 | DD    |
|      |          |        | 3088-89 | DD    |

## REAMING

| Well | Location |        | Depth     | Unit  |
|------|----------|--------|-----------|-------|
| 284  | 14-45-26 | WC LEE | 3000-3500 | DD    |
| 425  | 8-45-27  | WC LEE | 2785      | 3C(L) |
|      |          |        | 2820      | 3C(L) |
|      |          |        | 2842      | 3C(L) |
|      |          |        | 2892      | 3C(L) |
|      |          |        | 2925-35   | DD    |
|      |          |        | 3000      | DD    |
| 594  | 30-45-28 | WF     | 2067-2156 | 3B-2  |
| 712  | 22-44-26 | LP     | 2550      | 3B-2  |
| 714  | 13-45-27 | WF     | 2227-440  | 3B-2  |
| 735  | 13-45-27 | WF     | 2900-3000 | DD    |
| 812  | 27-44-26 | LT     | 2790      | 3C(d) |
| 829  | 26-44-26 | LP     | 2246-2353 | 3B-2  |
| 831  | 31-49-31 | WC COL | 2906      | 3C(d) |
|      |          |        | 2397      | 3B-1  |
|      |          |        | 2523      | 3B-2  |
|      |          |        | 3629      | CK C  |
| 996  | 29-45-28 | WF     | 2894-3365 | DD    |
| 1064 | 3-49-30  | BI     | 2805-2950 | 3C(d) |
|      |          |        | 3064-3195 | DD    |
| 1131 | 13-45-27 | WF     | 1627-1739 | 3A(L) |
|      |          |        | 2072-2420 | 3B-2  |
|      |          |        | 2531-2695 | 3B-2  |
|      |          |        | 2947-3082 | DD    |
| 1151 | 3-45-28  | TC     | 2383-2929 | 3B-2  |
|      |          |        | 2929-3840 | DD    |
|      |          |        | 2850      | DD    |
| 1193 | 26-39-31 | WC HIG | 2990-3100 | DD    |

(TABLE 3 continued)

## Reported Boulders

|      |          |        |                                                                       |                                                                      |
|------|----------|--------|-----------------------------------------------------------------------|----------------------------------------------------------------------|
| 35   | 20-48-30 | SUN    | 2587-617<br>2617-2700<br>2700-811                                     | 3C (d)<br>3C (d)<br>3C (d)                                           |
| 62   | 23-35-23 | WC HAR | 1256-85<br>1311-83<br>1442-1569                                       | 3BU<br>3BU<br>3BU                                                    |
| 63   | 20-48-30 | SUN    | 3016-257                                                              | DD                                                                   |
| 64   | 23-48-28 | WC COL | 2900-3600                                                             | DD                                                                   |
| 86   | 21-47-28 | WC COL | 2066                                                                  | 3B-1                                                                 |
| 103  | 19-47-28 | WC COL | 2780-3047<br>3179-3289                                                | 3C (L)<br>DD                                                         |
| 191  | 25-45-28 | F      | 2280-480<br>2735-56                                                   | 3B-2<br>3C (L)                                                       |
| 204  | HEN      | WC HEN | 2000<br>2090<br>2210<br>2260<br>2310<br>2410<br>2650<br>3020          | 3B (L)<br>3B (L)<br>3B-2<br>3B-2<br>3C (d)<br>3C (L)<br>3C (d)<br>DD |
| 250  | 22-45-24 | WC LEE | 1992-2326<br>2385-3729                                                | 3B-1\$2<br>3B-2&DD                                                   |
| 271  | 16-46-27 | WC LEE | 2940-3077                                                             | DD                                                                   |
| 425  | 8-45-27  | WC LEE | 2180                                                                  | 3B-2                                                                 |
| 462  | 5-46-28  | WF     | 3011-3350                                                             | DD                                                                   |
| 524  | 14-46-28 | WC COL | 2940-3235                                                             | 3C (L&DD)                                                            |
| 645  | 24-45-28 | WF     | 2600-2800                                                             | 3C (d)                                                               |
| 714  | 13-45-27 | WF     | 2317                                                                  | 3B-2                                                                 |
| 735  | 13-45-27 | WF     | 2266                                                                  | 3B-2                                                                 |
| 794  | 33-45-29 | F      | 2215-3540                                                             | 3B-2&DD                                                              |
| 919  | 11-46-26 | WC LEE | 2786-3351                                                             | 3C (d) & DD                                                          |
| 949  | 26-45-28 | Mid F  | 3400                                                                  | CK A                                                                 |
| 950  | 7-44-26  | WC LEE | 2100                                                                  | 3B-2                                                                 |
| 982  | 14-49-30 | B!     | 2208<br>3134-80                                                       | 3B-2<br>DD                                                           |
| 1014 | 29-44-27 | WC LEE | 1730<br>1797<br>2700-2810<br>2852-915<br>3150<br>3165<br>3225<br>3234 | 3A (L)<br>3A (L)<br>3C (d)<br>DD<br>DD<br>DD<br>DD<br>DD             |
| 1131 | 13-45-27 | WF     | 1470-1740                                                             | 3A (L)                                                               |
| 1151 | 3-45-28  | TC     | 2883-2929<br>2850<br>2929-3840                                        | 3B-2<br>DD<br>DD                                                     |
| 1153 | 20-45-28 | WF     | 2180<br>2280<br>2848-991<br>2960-3084<br>3120<br>3550                 | 3B (L)<br>3B-2<br>3C (L)<br>DD<br>DD<br>CK A                         |

## FIGURES

Inside Text Cover - Generalized Geologic Columns

Inside Figures Cover - Well Locations

1. Regional Structure and Study Area Location
2. Interfingering of Units 1, 2 & 3 in Well L-2
3. Isopach Unit 3
4. Isolith 3A Dolomite
5. Distribution of Unit 3 Suites & Anomalous Stratigraphic Areas
6. Isopach 3BU Dolomite
7. Isopach 3BL Dolomite
8. Isolith 3B-1 Dolomites
9. Isolith 3B-2 Dolomites
10. Isolith 3C Dolomites
11. Isopach Delray Dolomite
12. Isopach Cedar Keys A
13. Regional Isopach Cedar Keys A & Anhydrite Isolith
14. Isolith Unit 3B Anhydrites - Northern Collier County
15. Structure Top Cedar Keys A
16. Structure Top Cedar Keys B
17. Sunniland Oil Field Structure Top Cedar Keys B
18. Sunniland Oil Field Structure Top Lake Trafford
19. Fault Locations
20. North Port Fault
21. Venice Fault
22. Traces of North Port and Parallel Venice Fault
23. McGregor Fault System
24. Estero Fault System
25. Cross-Section Index
26. Boulder Photographs
27. Devices used in Boulder Recovery
28. Videolog Symbol Key
29. Videolog Well 13
30. Videolog Well 68
31. Videolog Well 70
32. Thicknesses & Locations of Caverns in Oil Fields

Cross-Sections (in ring binder)

Cross-Section Index

A-B  
C-D  
E-F  
B-G  
B-H  
J-K

Videotape with Three Down Hole Surveys (in box)





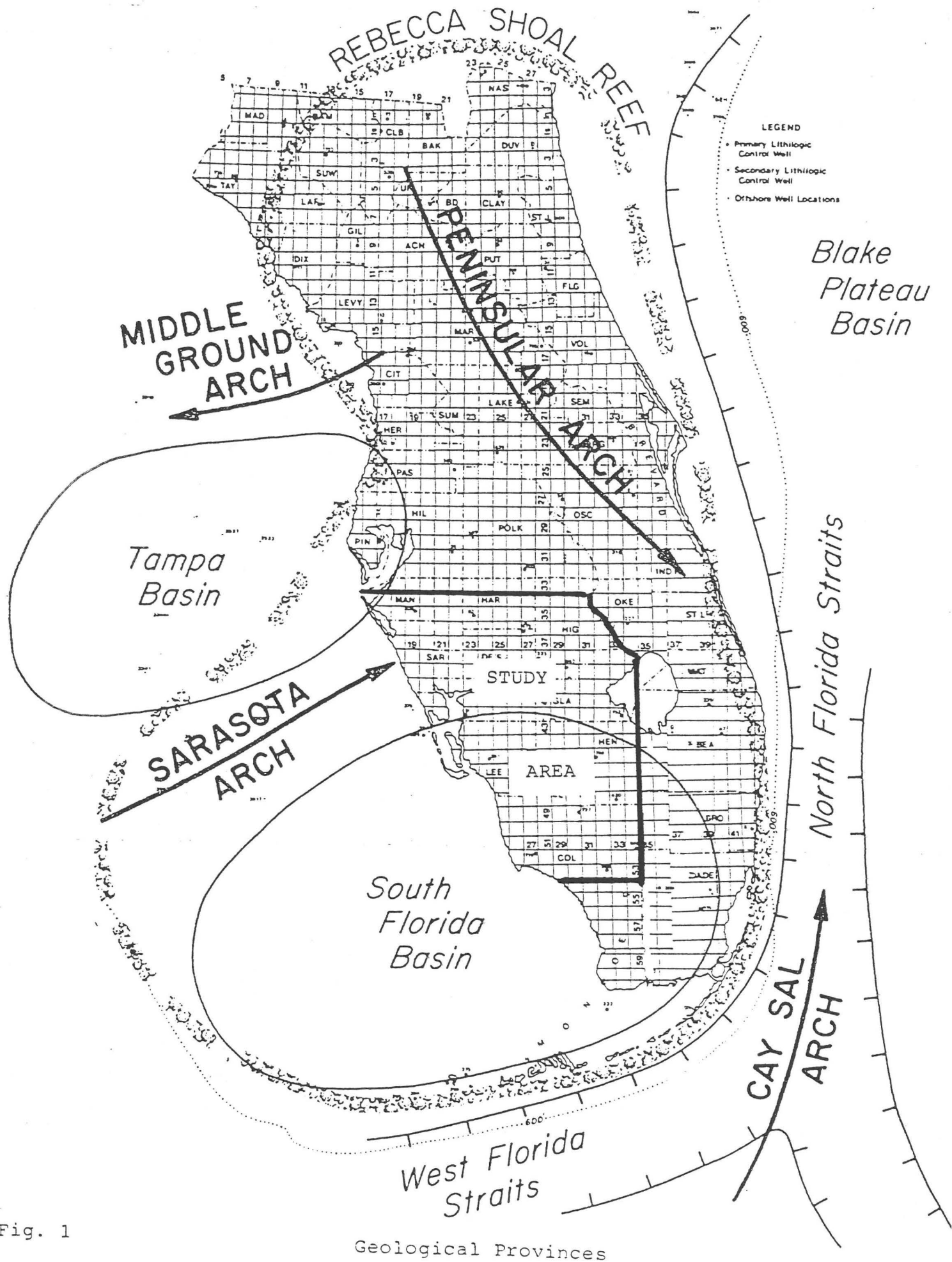
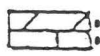
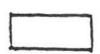
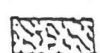


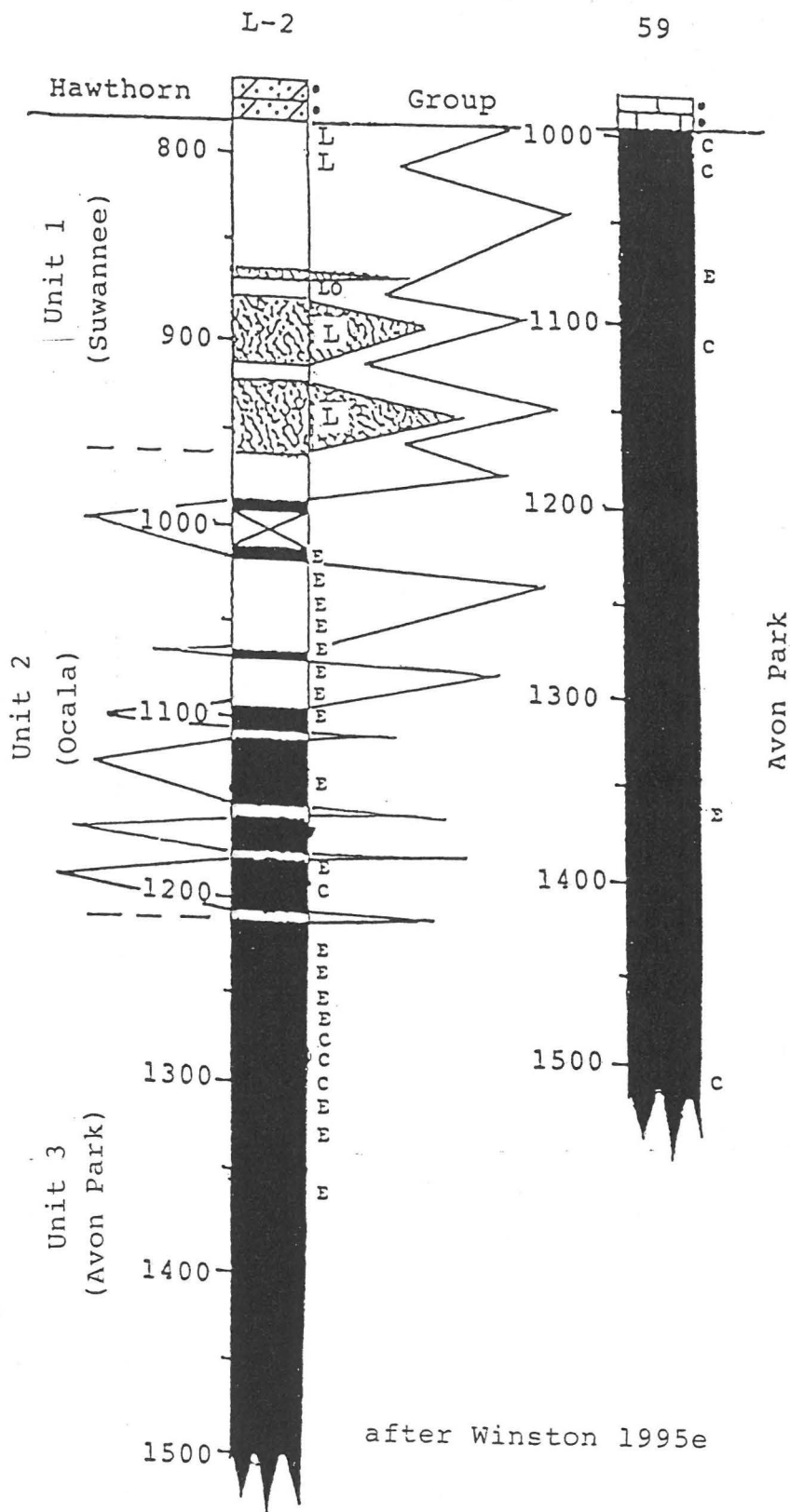
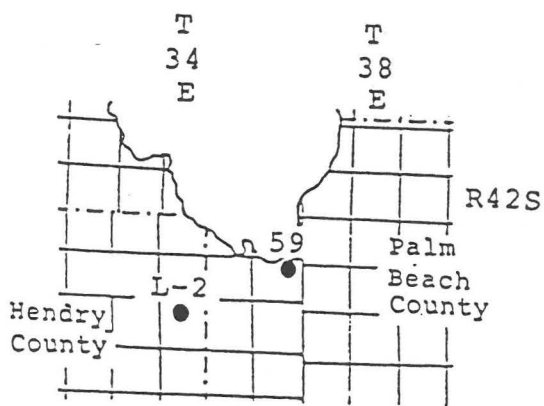
Fig. 1

# FAUNA

L large *Lepidocyclina*  
 L small *Lepidocyclina*  
 O *Operculinoides*  
 E echinoderm  
 C "cones"

# LITHOLOGIES

 phosphatic dolomite/limestone  
 Ocala-like limestone  
 Suwannee-like limestone  
 Avon Park-like limestone  
 missing samples



Interfingering of Units 1, 2 & 3 in Well L-2

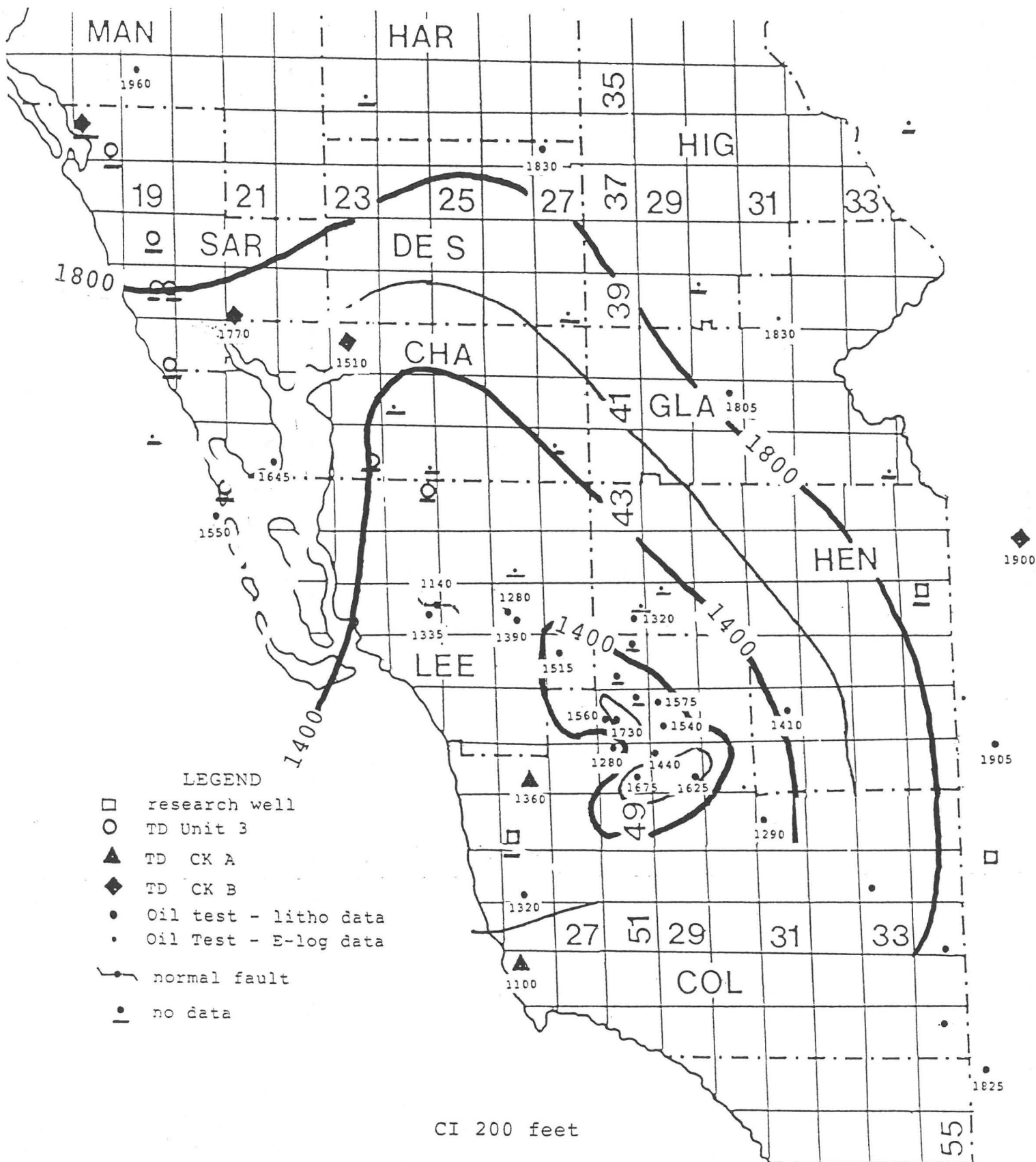


Fig. 3

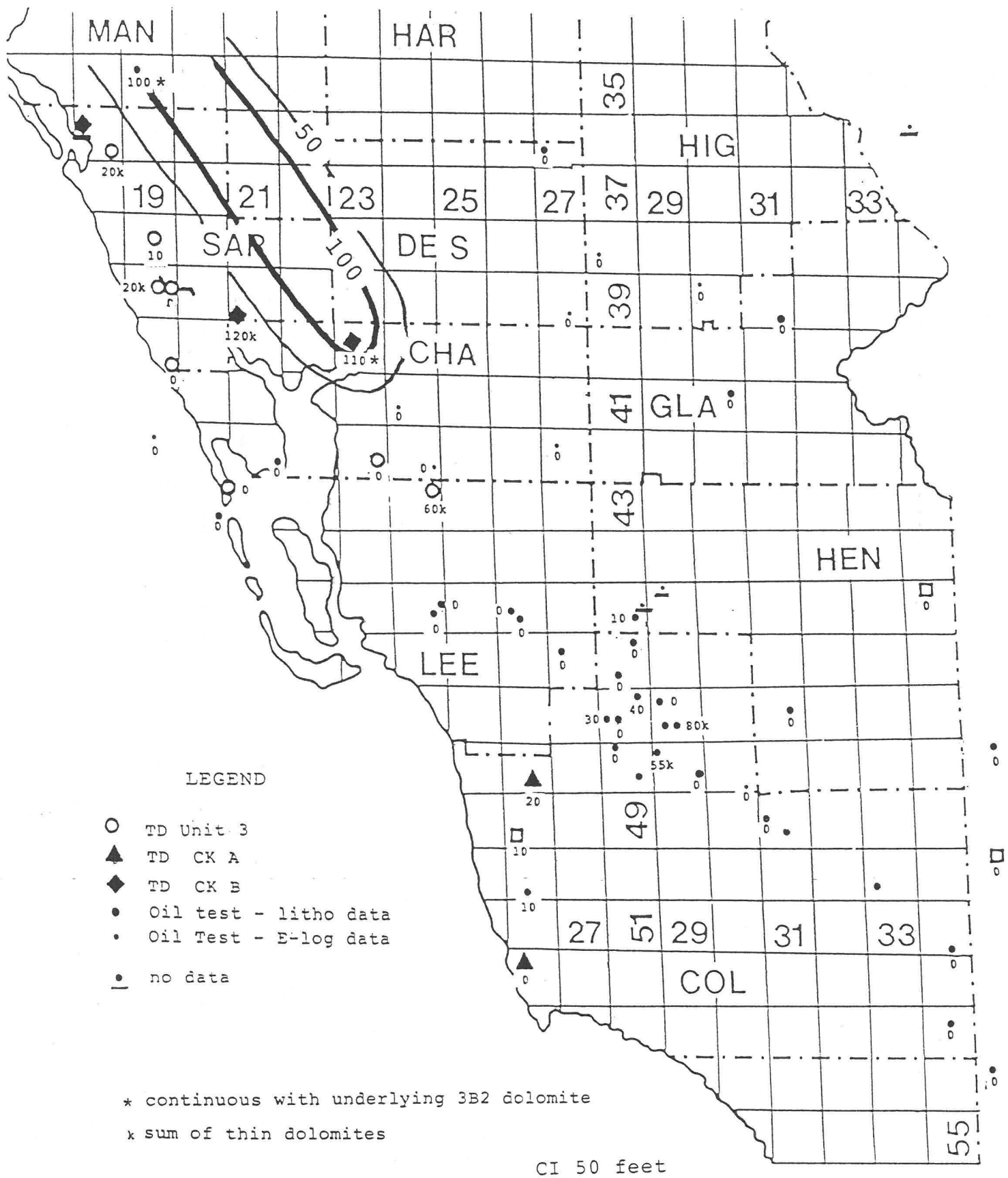
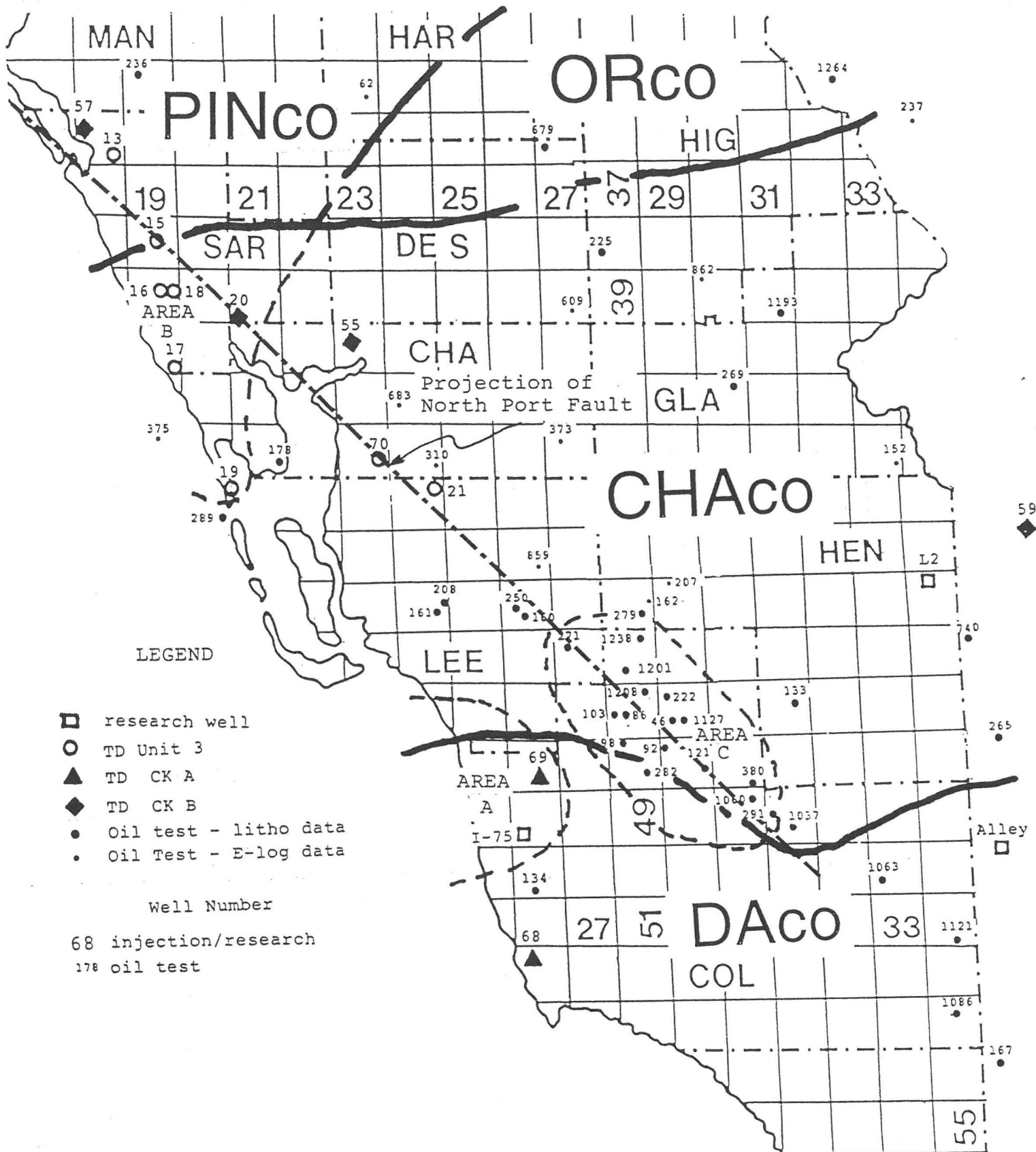


Fig. 4



Distribution of Suites  
&  
Anomalous Stratigraphic Areas A, B & C

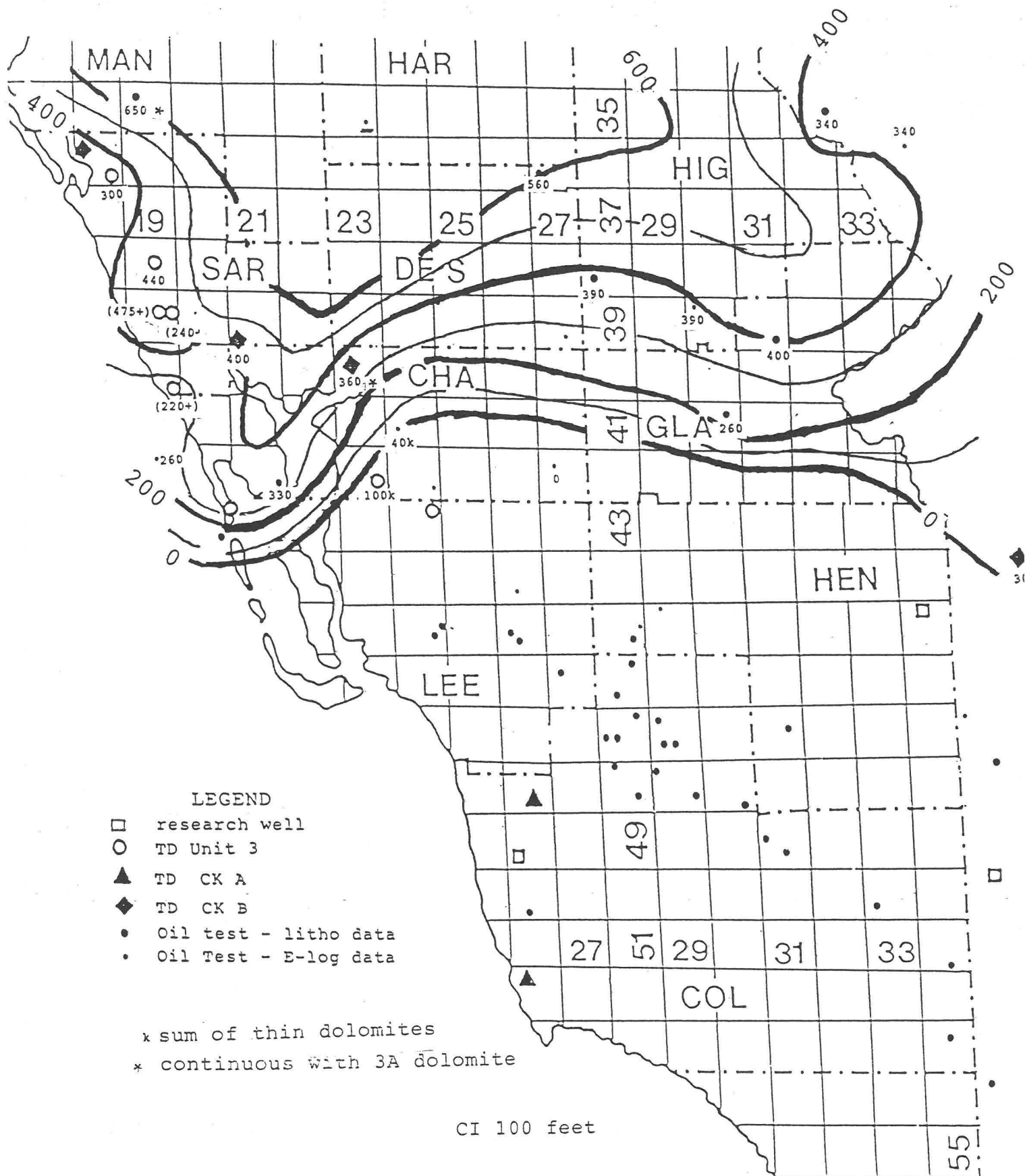


Fig. 6

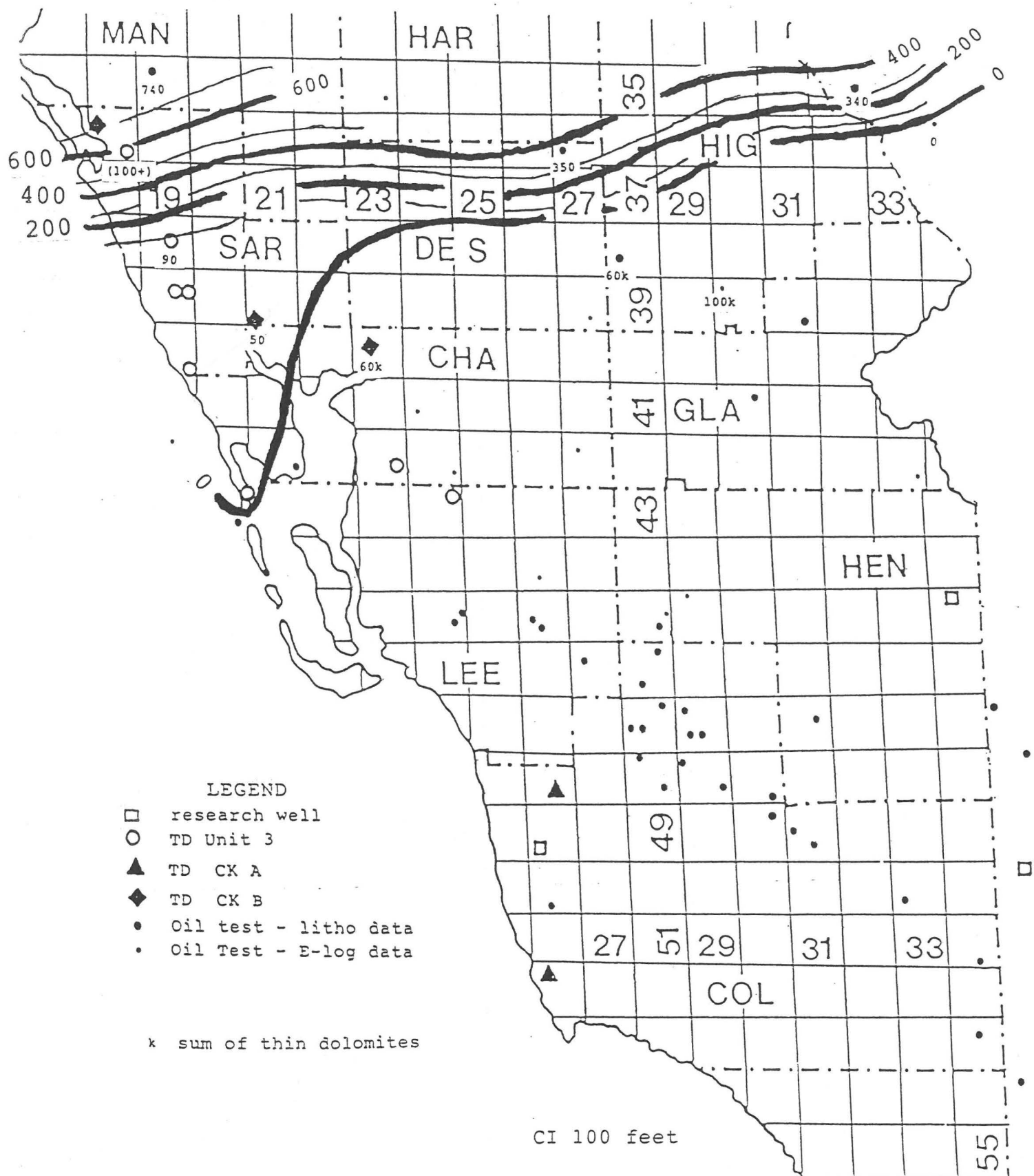


Fig. 7



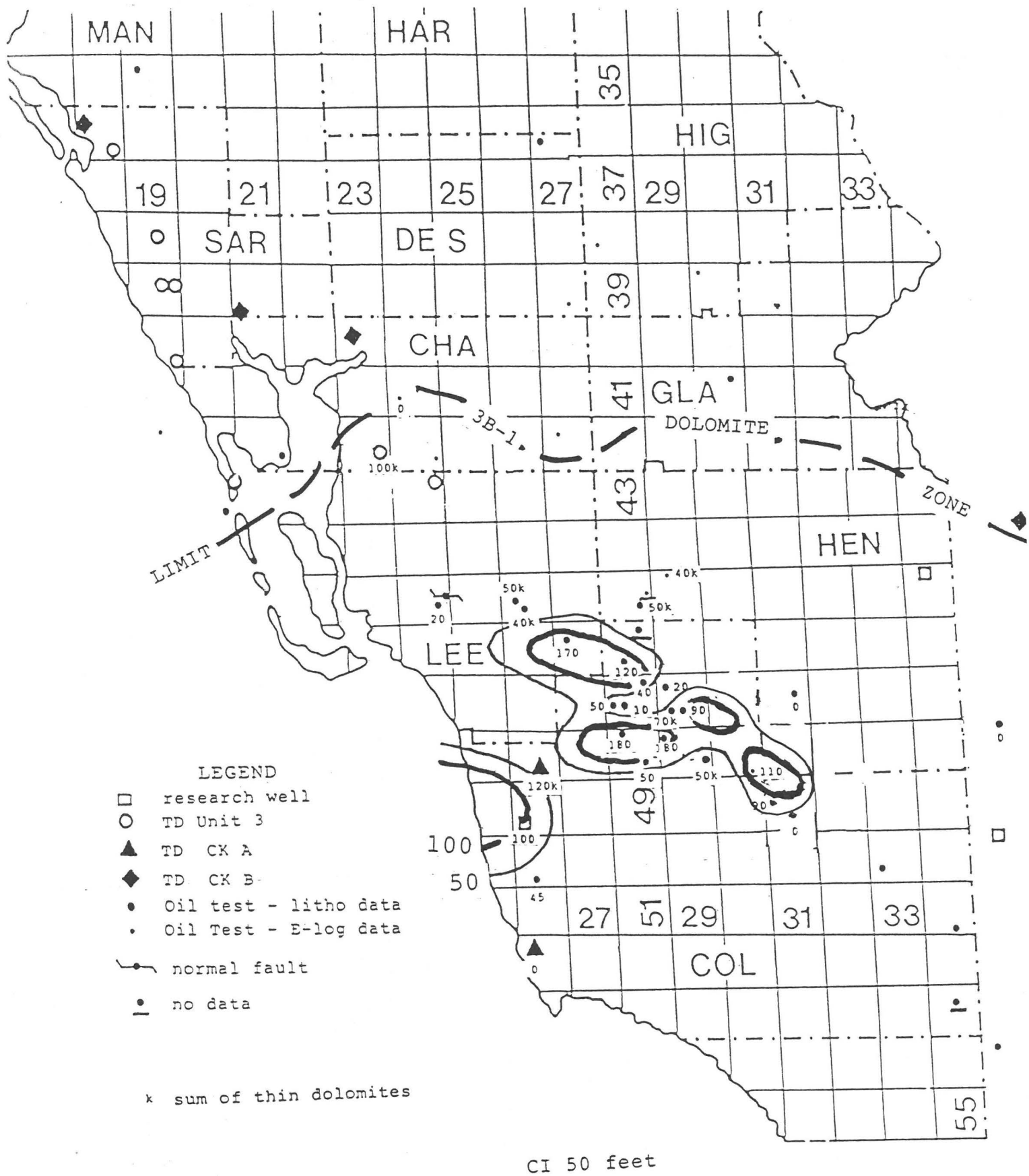


Fig. 8

Isolith Unit 3B1 Dolomite



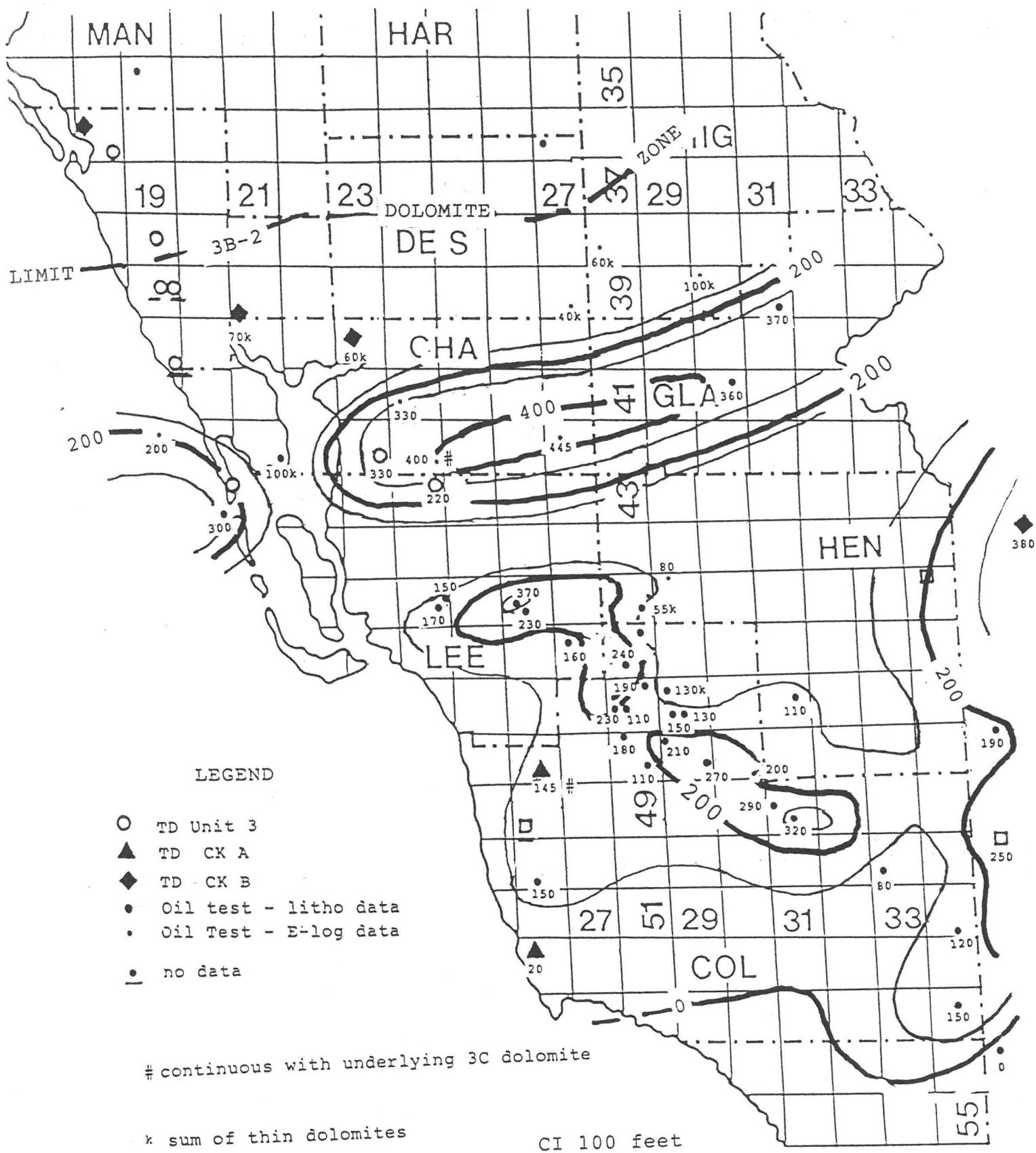


Fig. 9

Isolith Unit 3B2 Dolomite

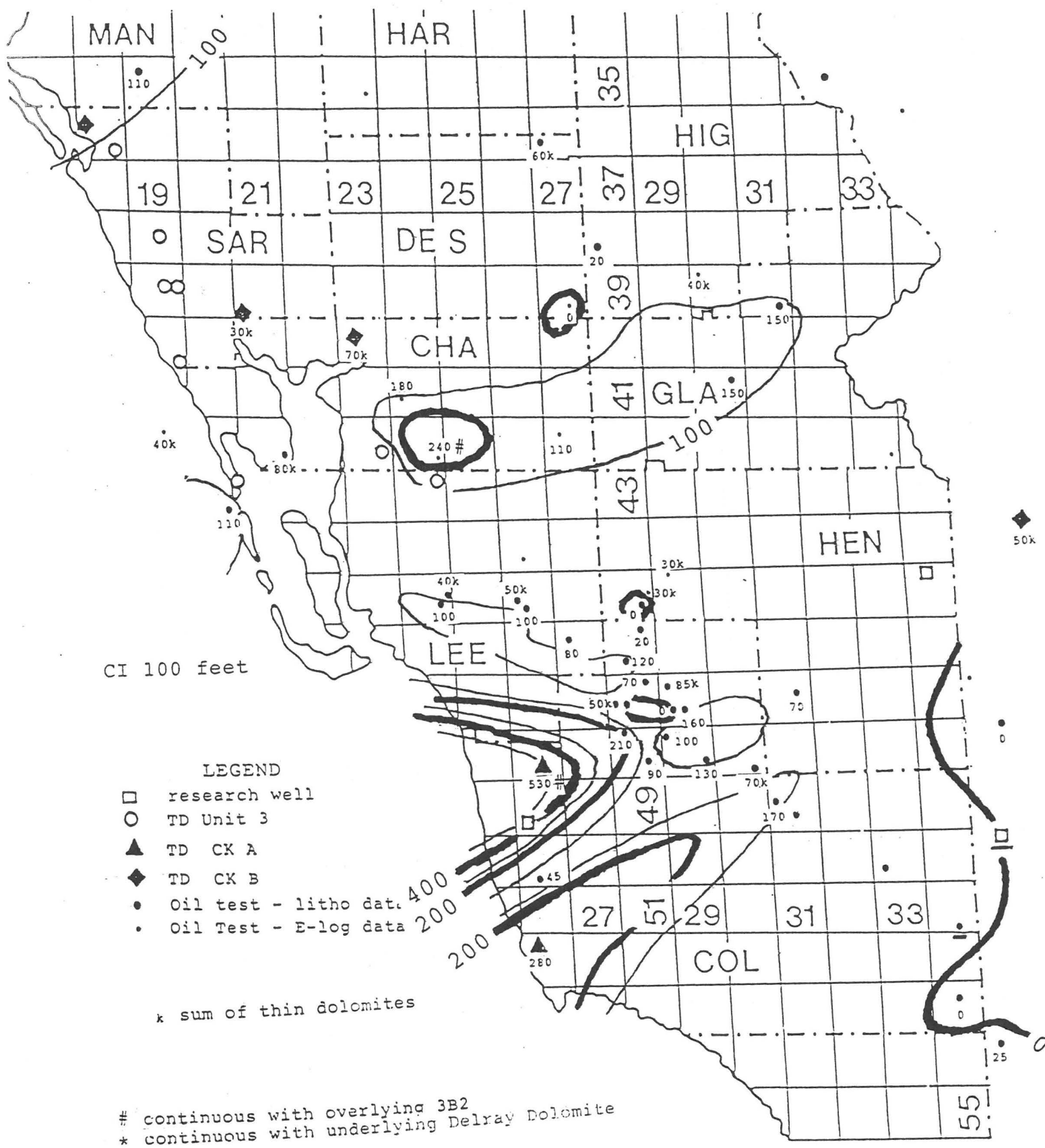
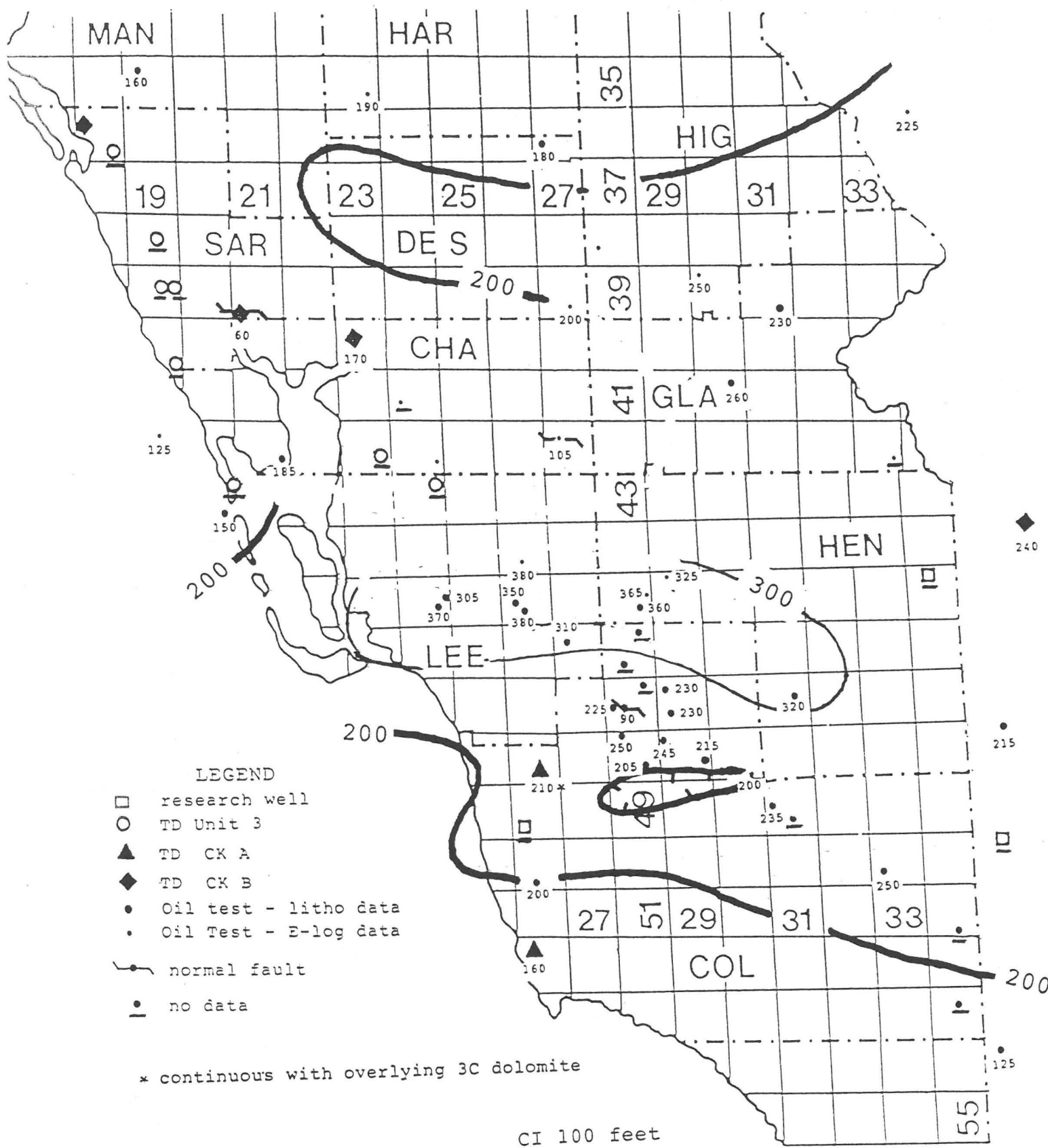


Fig. 10





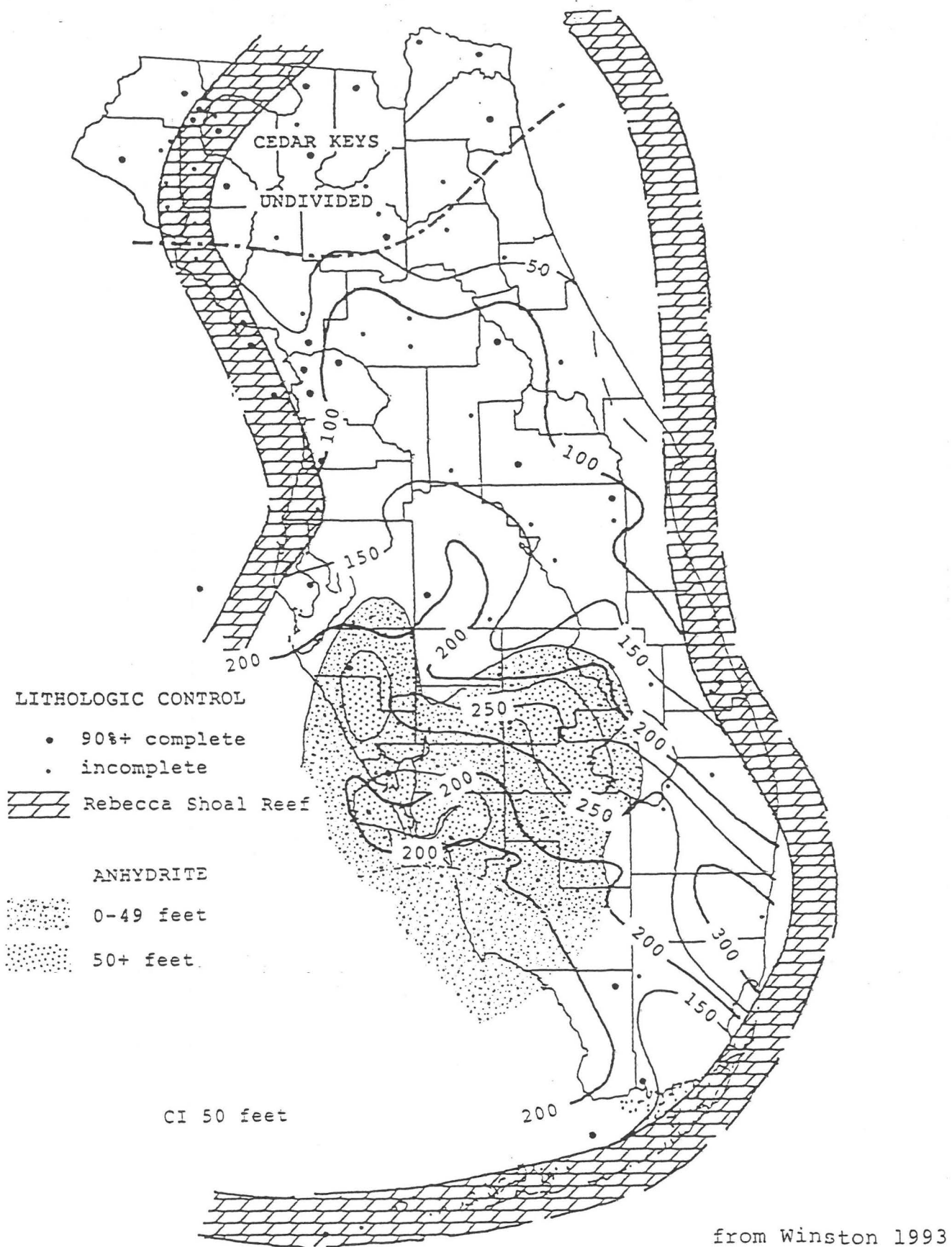
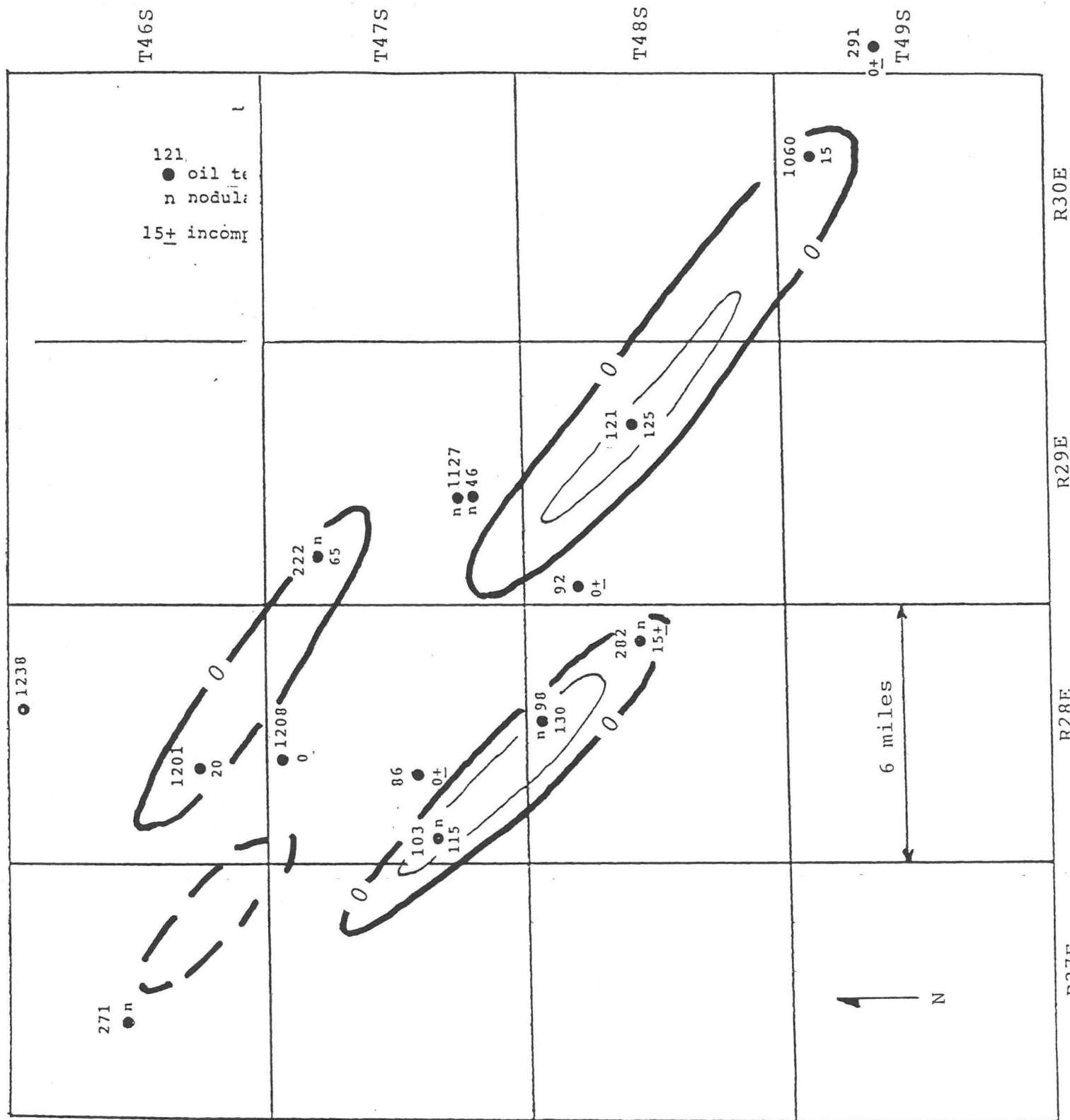


Fig. 13

CEDAR KEYS A - Isopach and Anhydrite Isolith



Anomalous Area C  
Isolith Unit 3B Anhydrite  
Northern Collier County





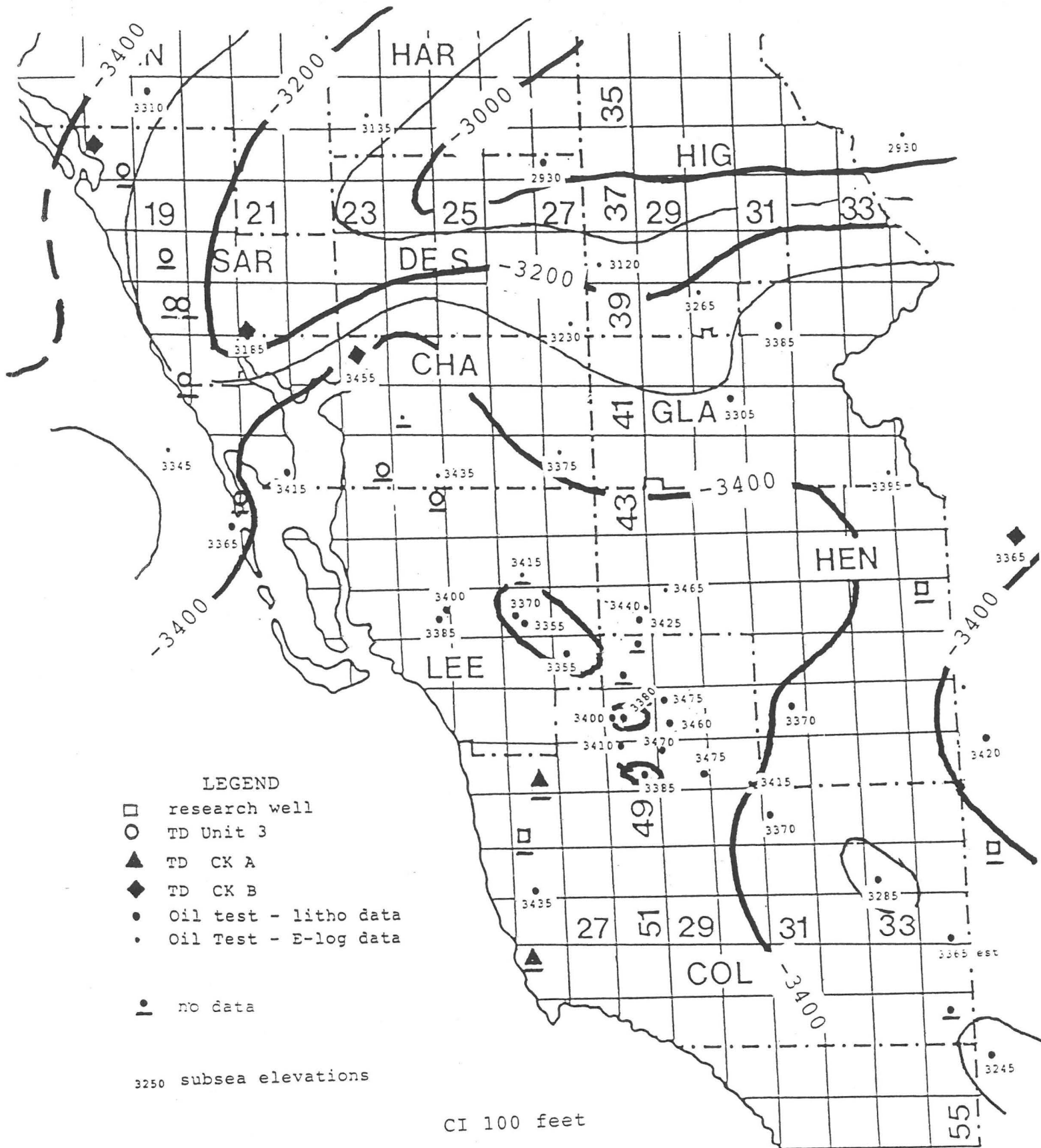


Fig. 16



Fig. 17

Structure Top Cedar Keys B

Suniland Oil Field

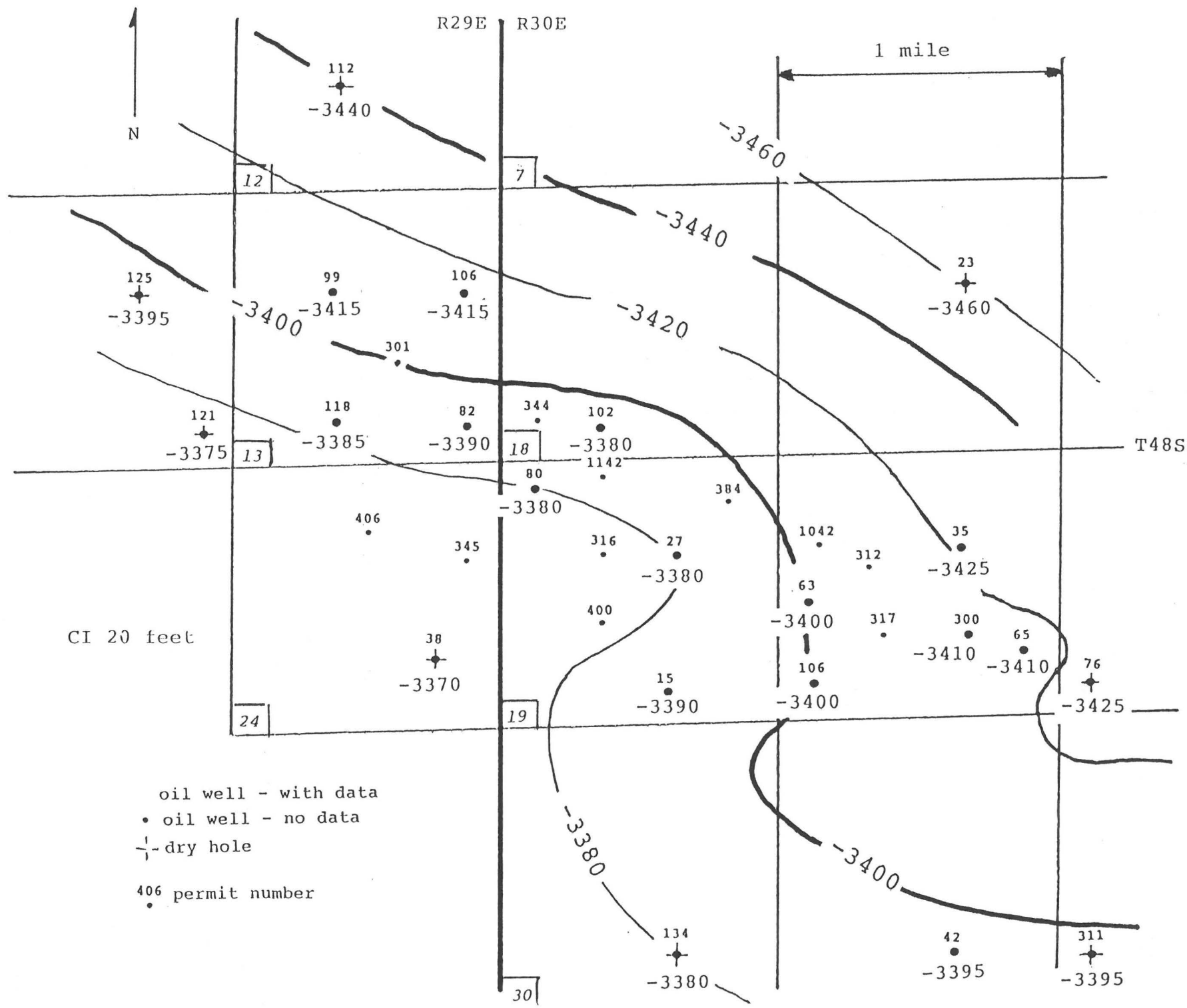
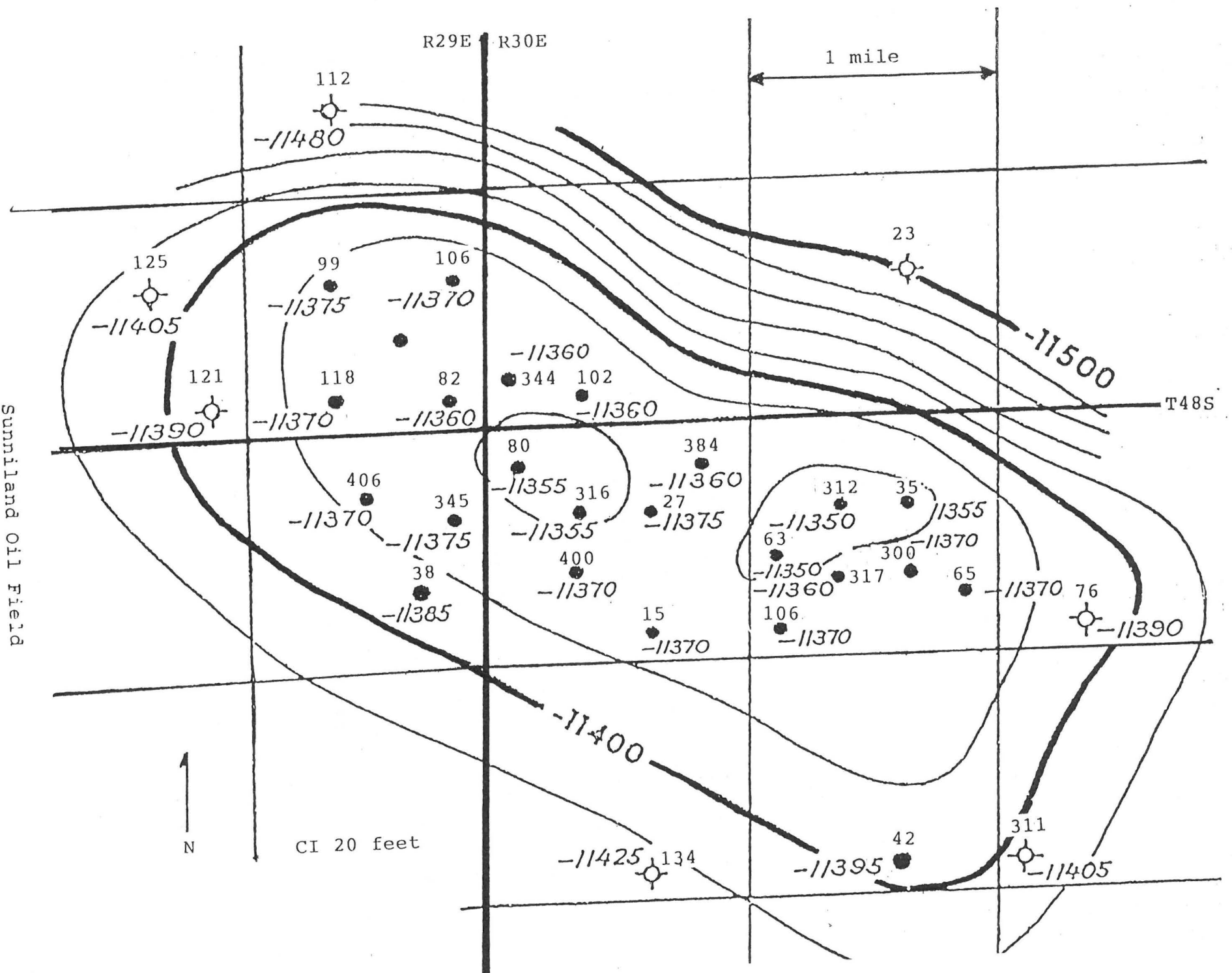
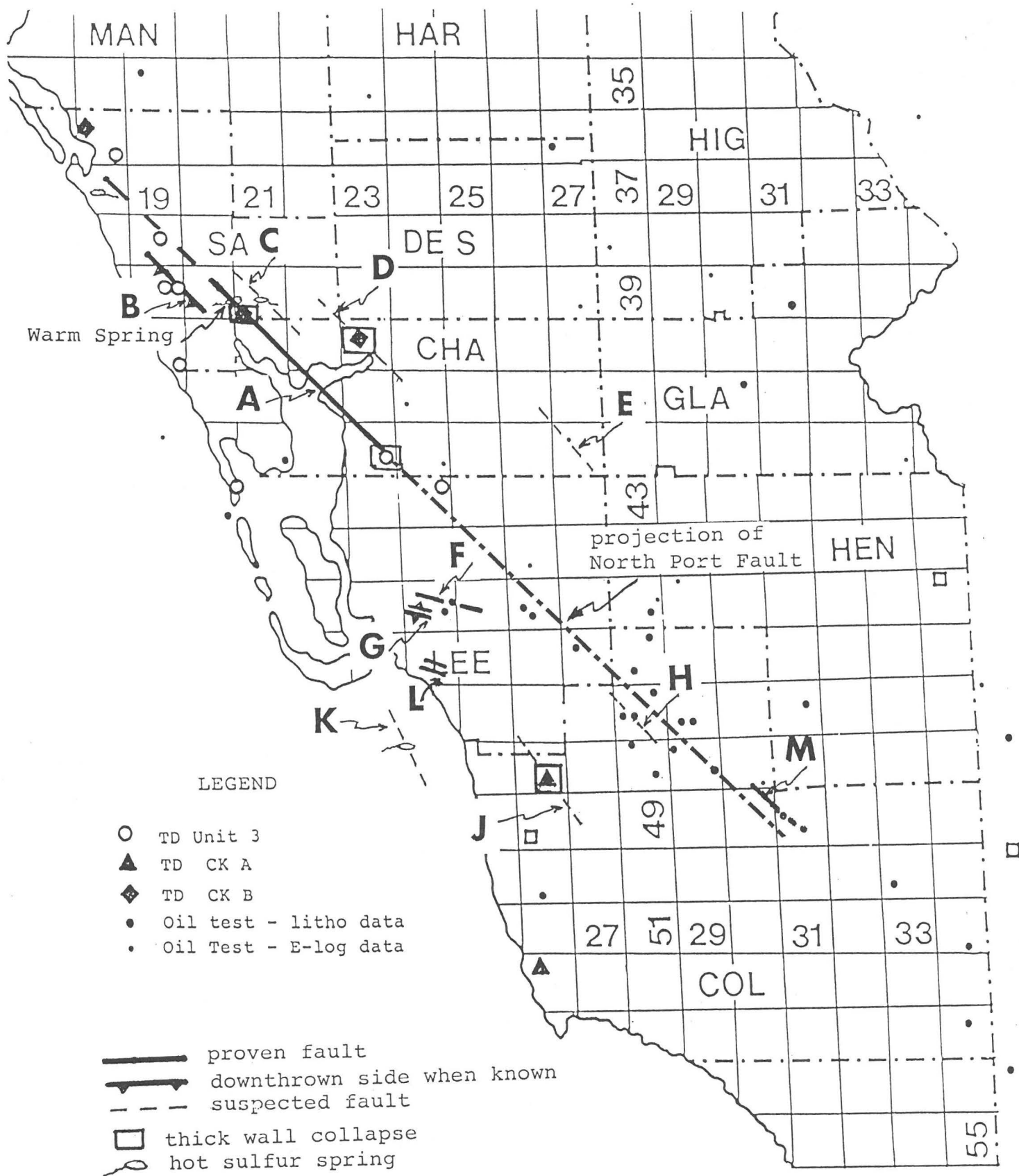


Fig. 18

Suniland Oil Field  
Structure Top Lake Trafford



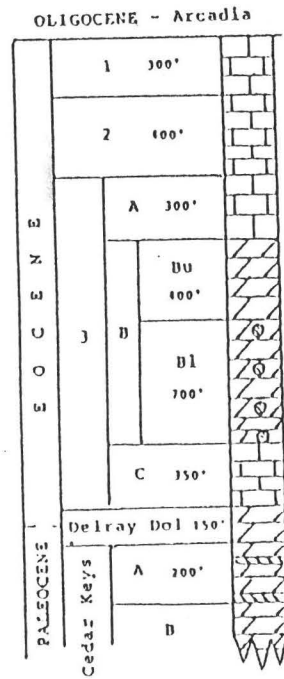
- A North Port fault
- B Venice fault
- C suggested fault at Little Salt Spring
- D suggested by thick wall collapse
- E very thin Delray Dolomite section
- F Northeast McGregor fault
- G McGregor fault system
- H very thin Delray Dolomite section
- J thick wall collapse
- K fault suggested by the presence of Mud Hole warm spring
- L Estero fault system
- M Pepper Hammock fault



Fault Locations

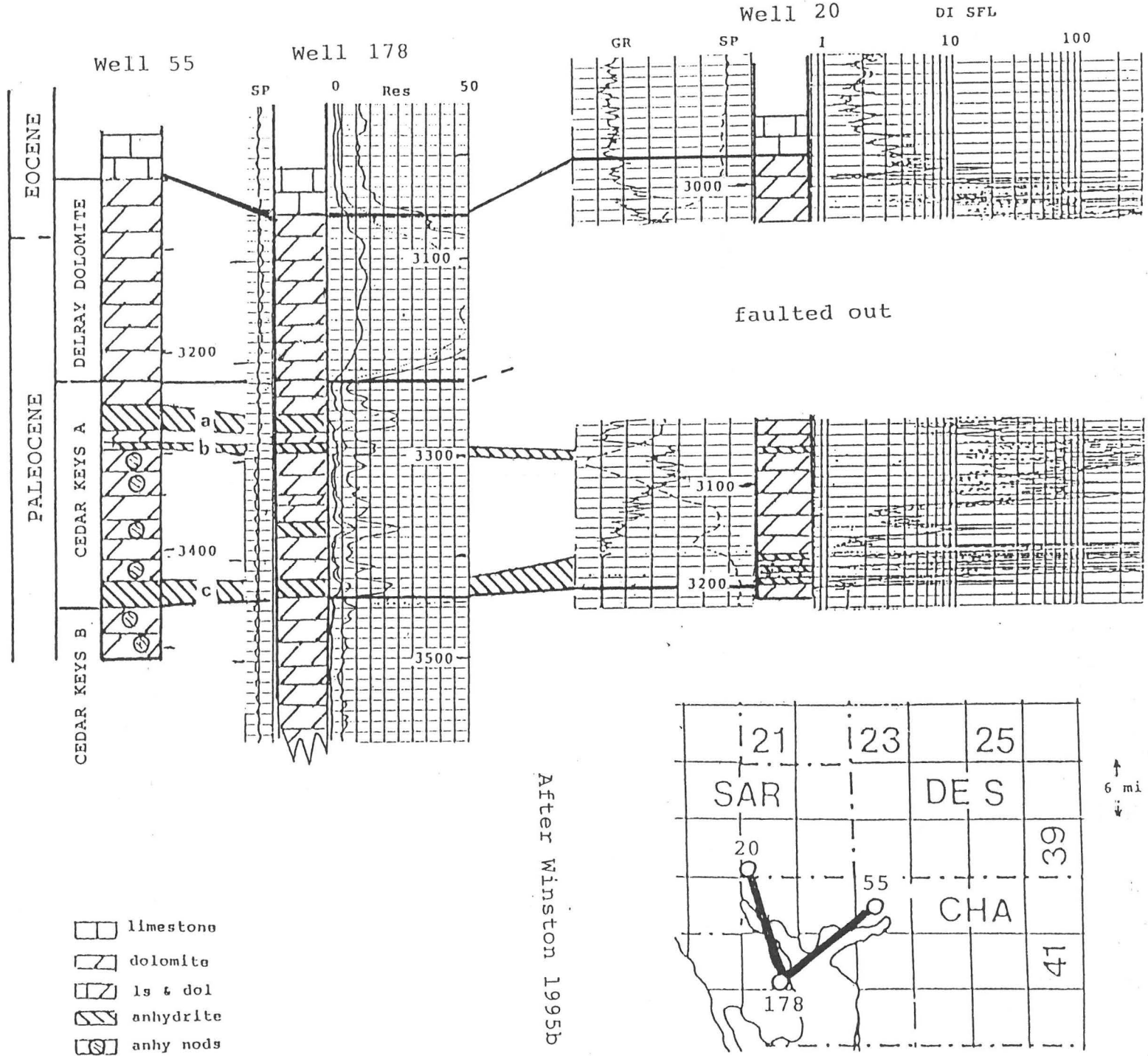
Fig. 20

North Port Fault



Generalized Geologic Column

Sarasota County



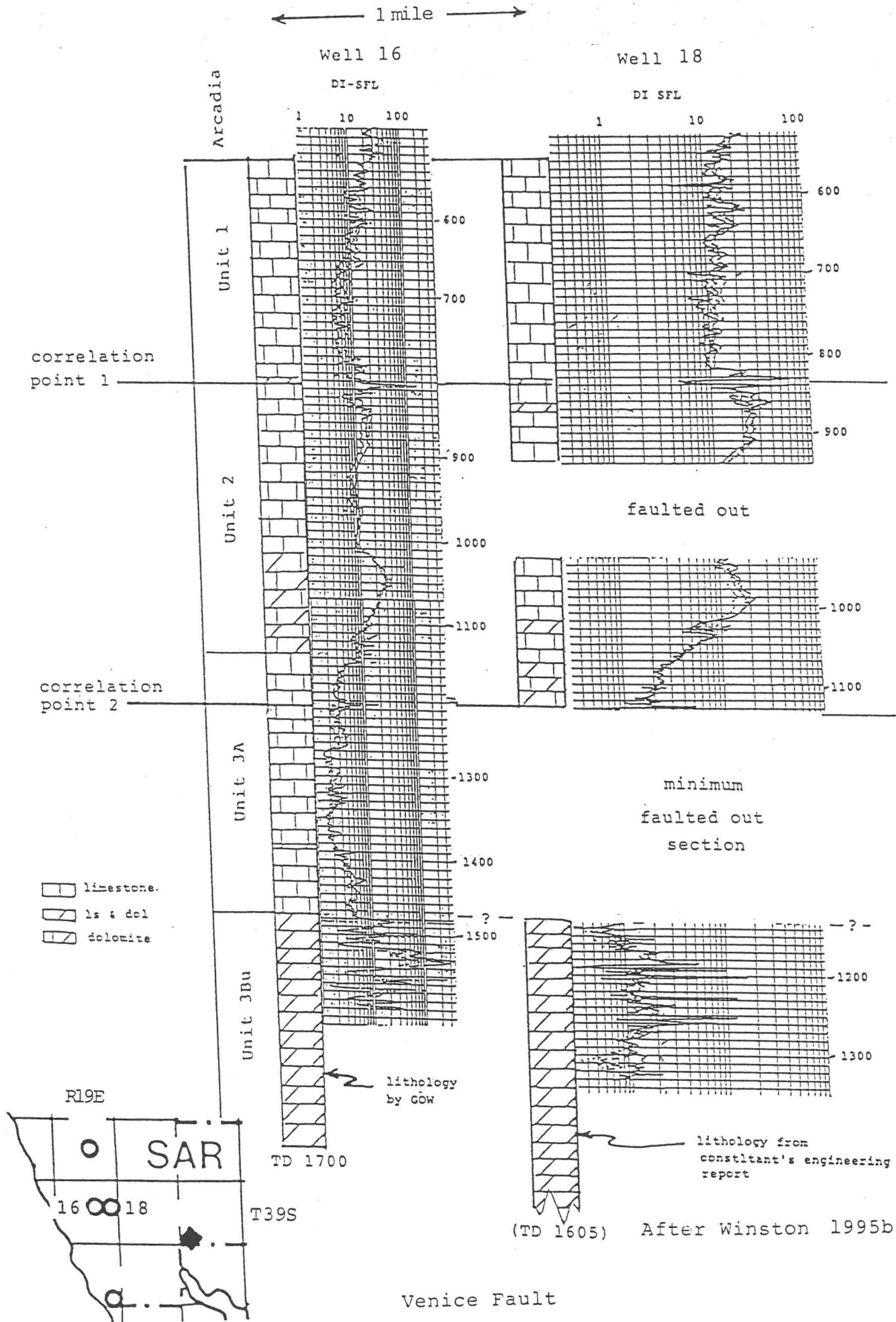
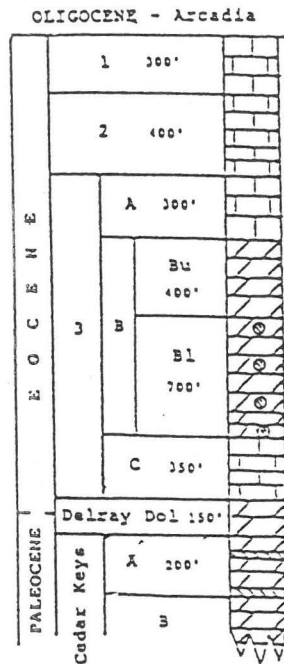


Fig. 21



Generalized Geologic Column

Sarasota County

After Winston 1995d

Wells

 TD  
Temp  
F

|    |                   |              |
|----|-------------------|--------------|
| 70 | Zemel Road IW     | NA           |
| 20 | North Port IW     | 89° at 3000' |
| 15 | Knight's Trail IW | NA           |
| 18 | Venice RO IW      | NA           |
| 16 | Venice Gardens IW | NA           |

Springs

 SO4  
(mg/L)

 Temp  
F

|   |              |      |       |
|---|--------------|------|-------|
| W | Warm Mineral | 1700 | 73-99 |
| L | Little Salt  | 530  | 87-95 |
| P | Pinehurst    | 9.4  | 105   |
| M | Mud Hole     | 4000 | 96    |

Traces of North Port &amp; Venice Faults

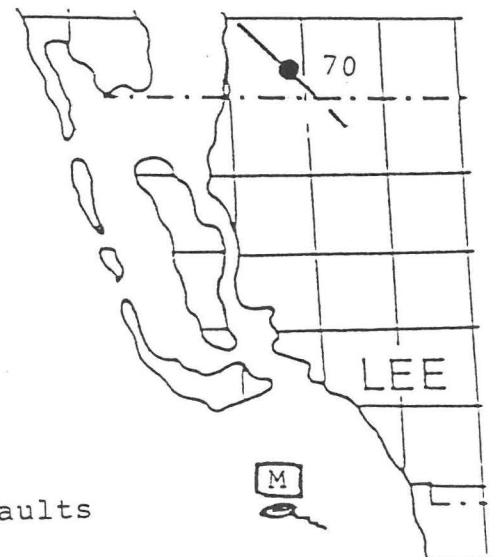
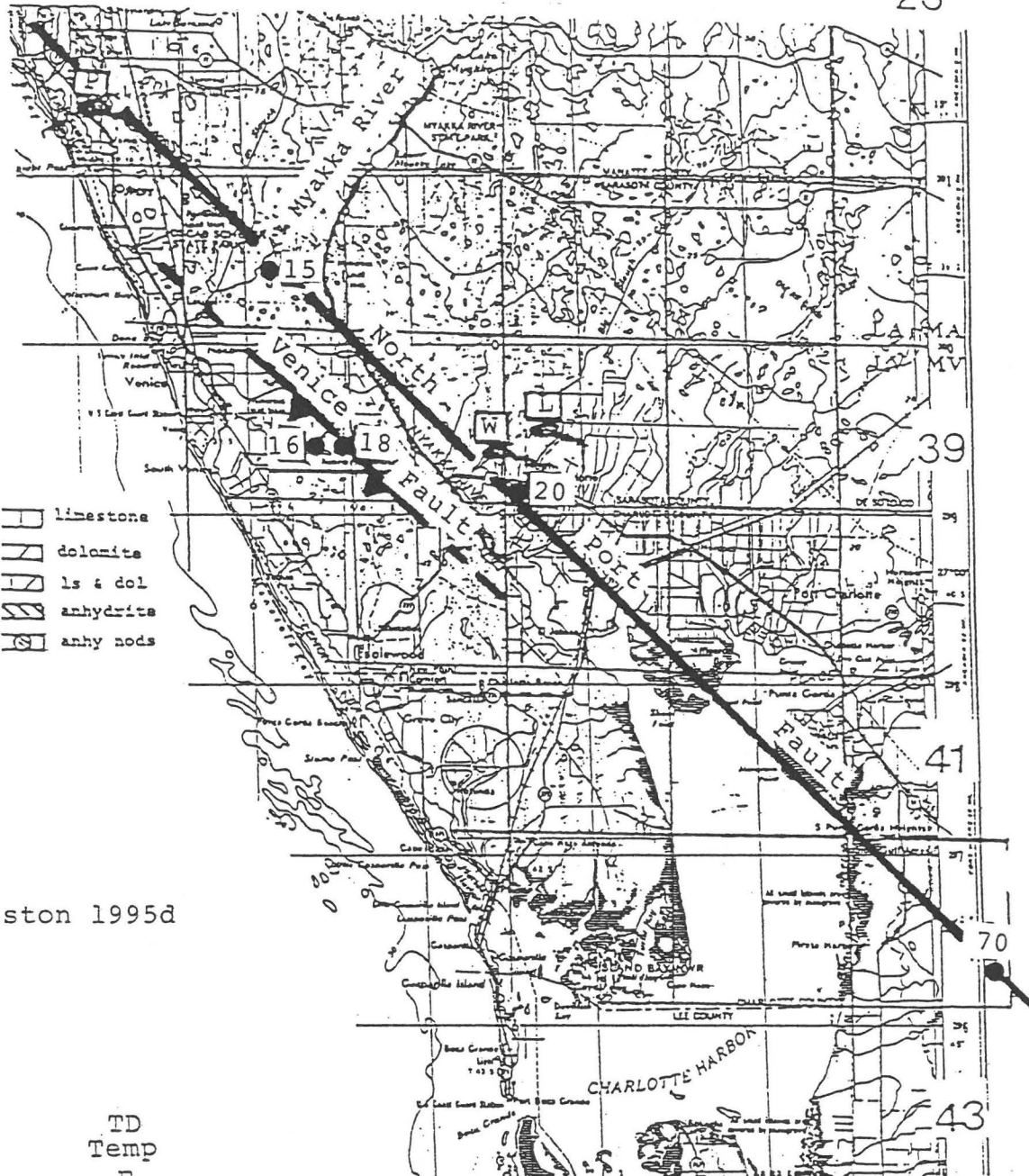


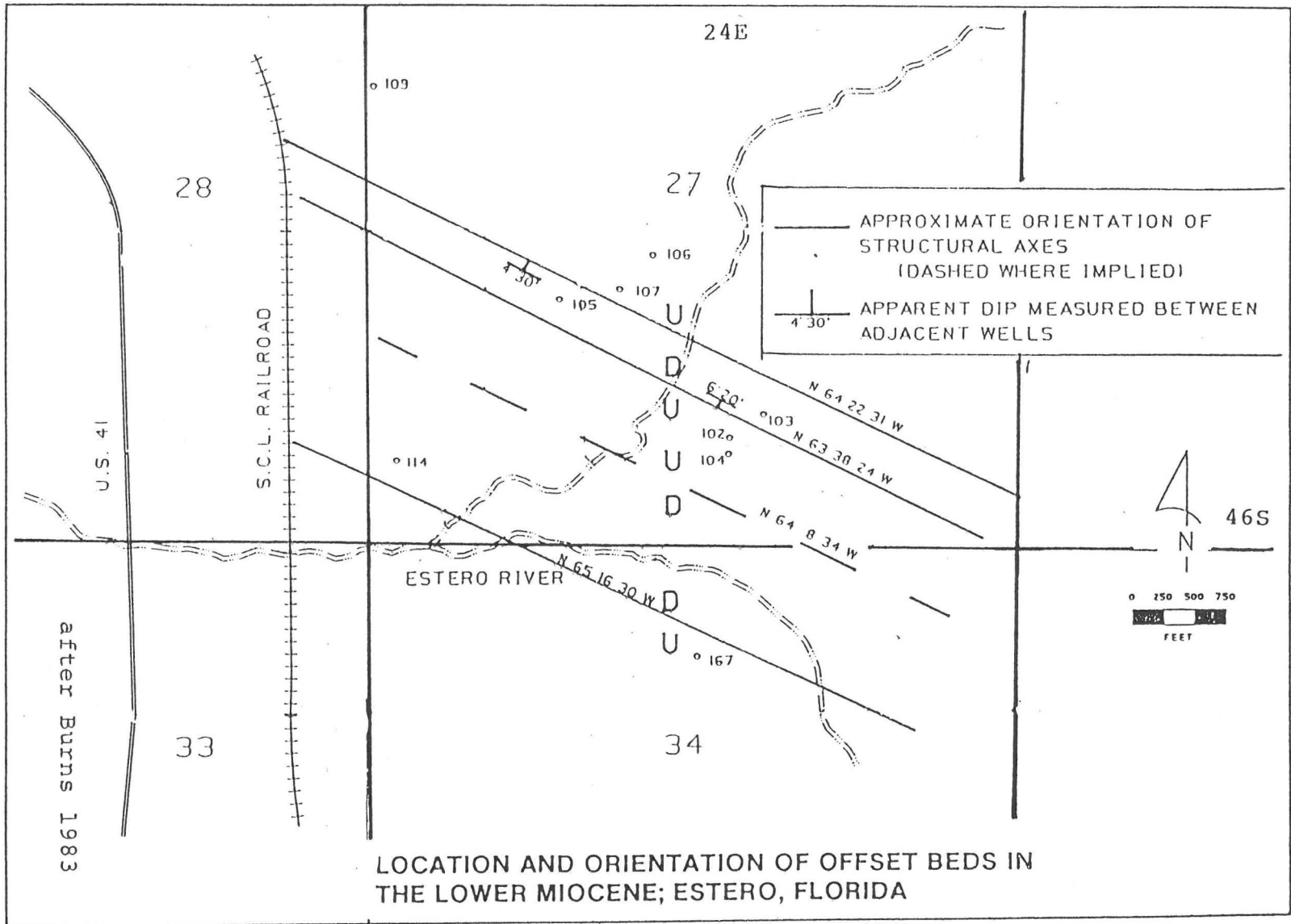
Fig. 22

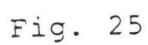


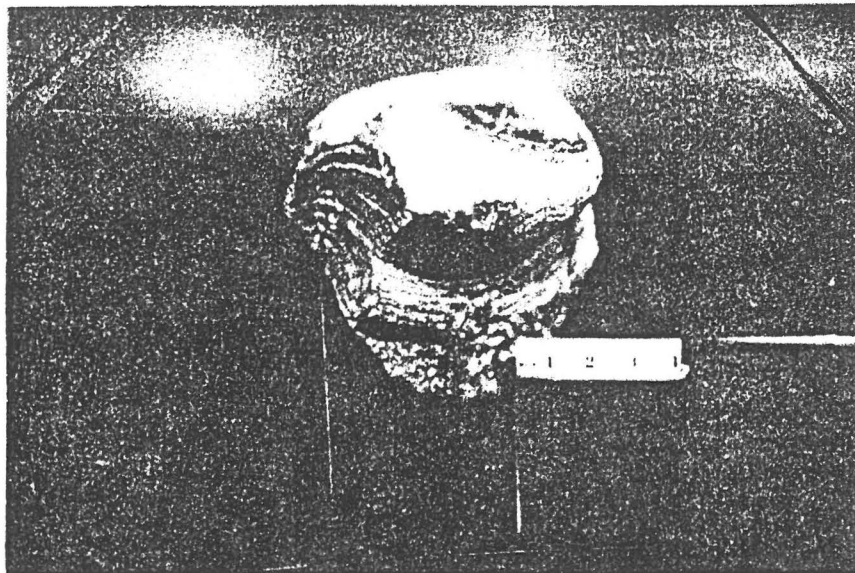




# Estero Fault System







"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.

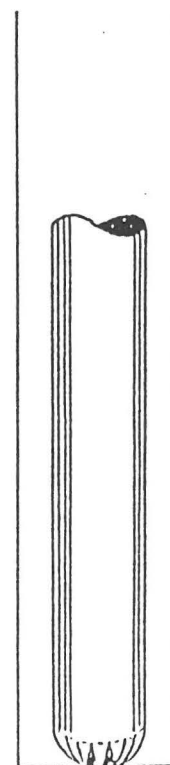
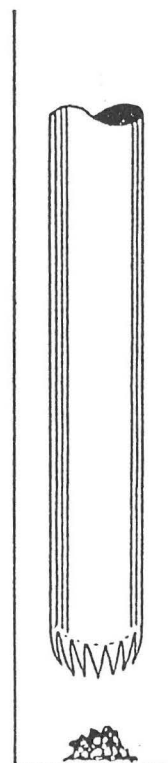
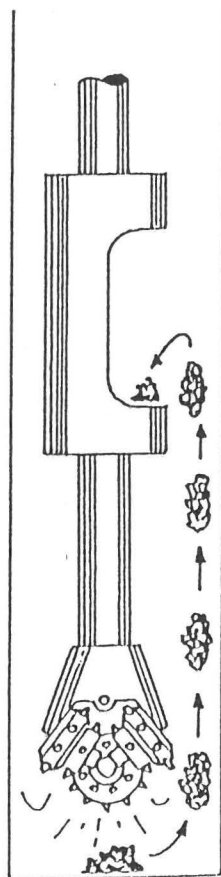


Hamilton 1 Keen  
Lake County  
(outside study area)

(no depth given)

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

# Boulder Photographs



Devices used in Boulder Recovery

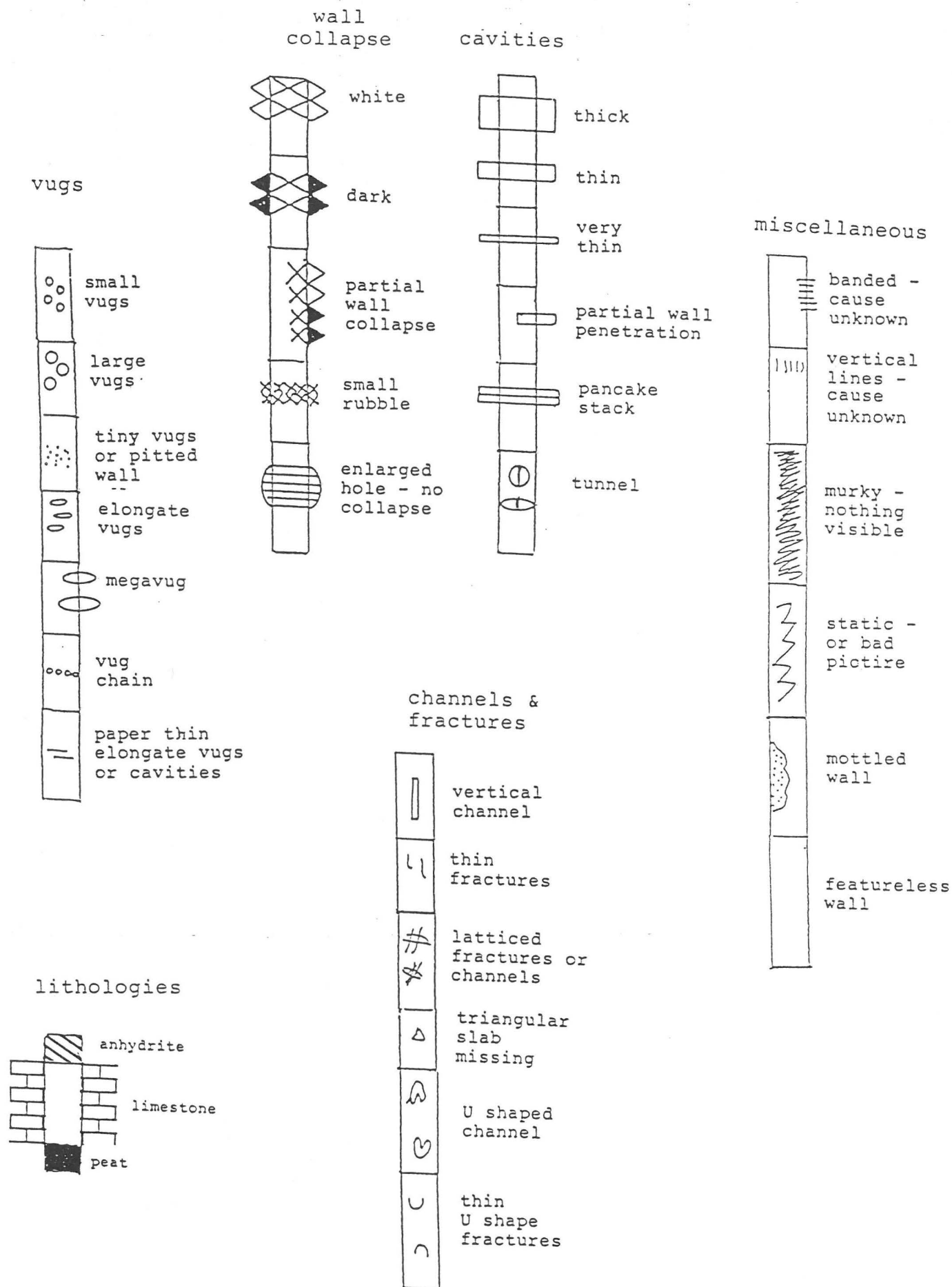


Fig. 28

Symbol Key

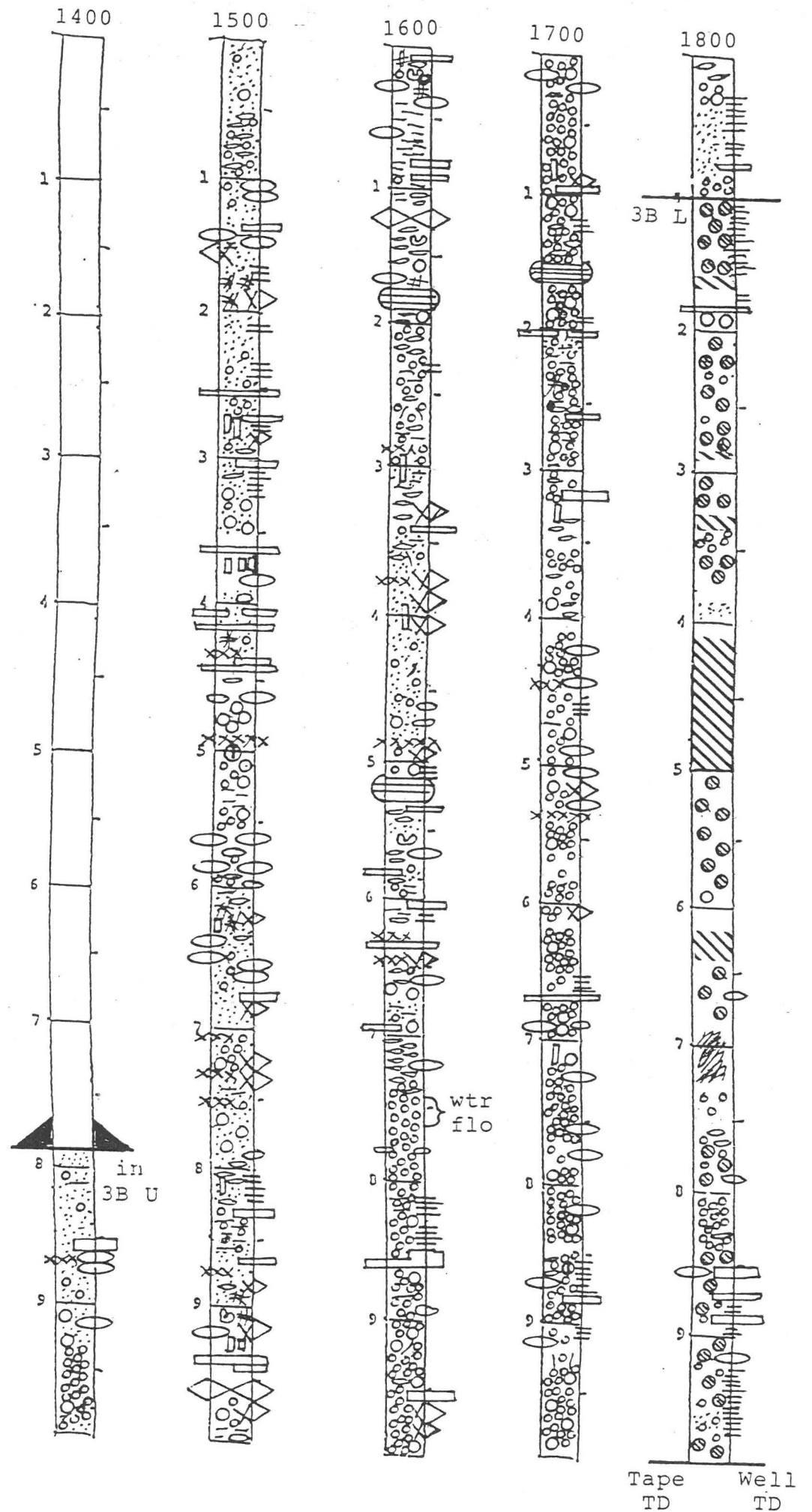


Fig. 29

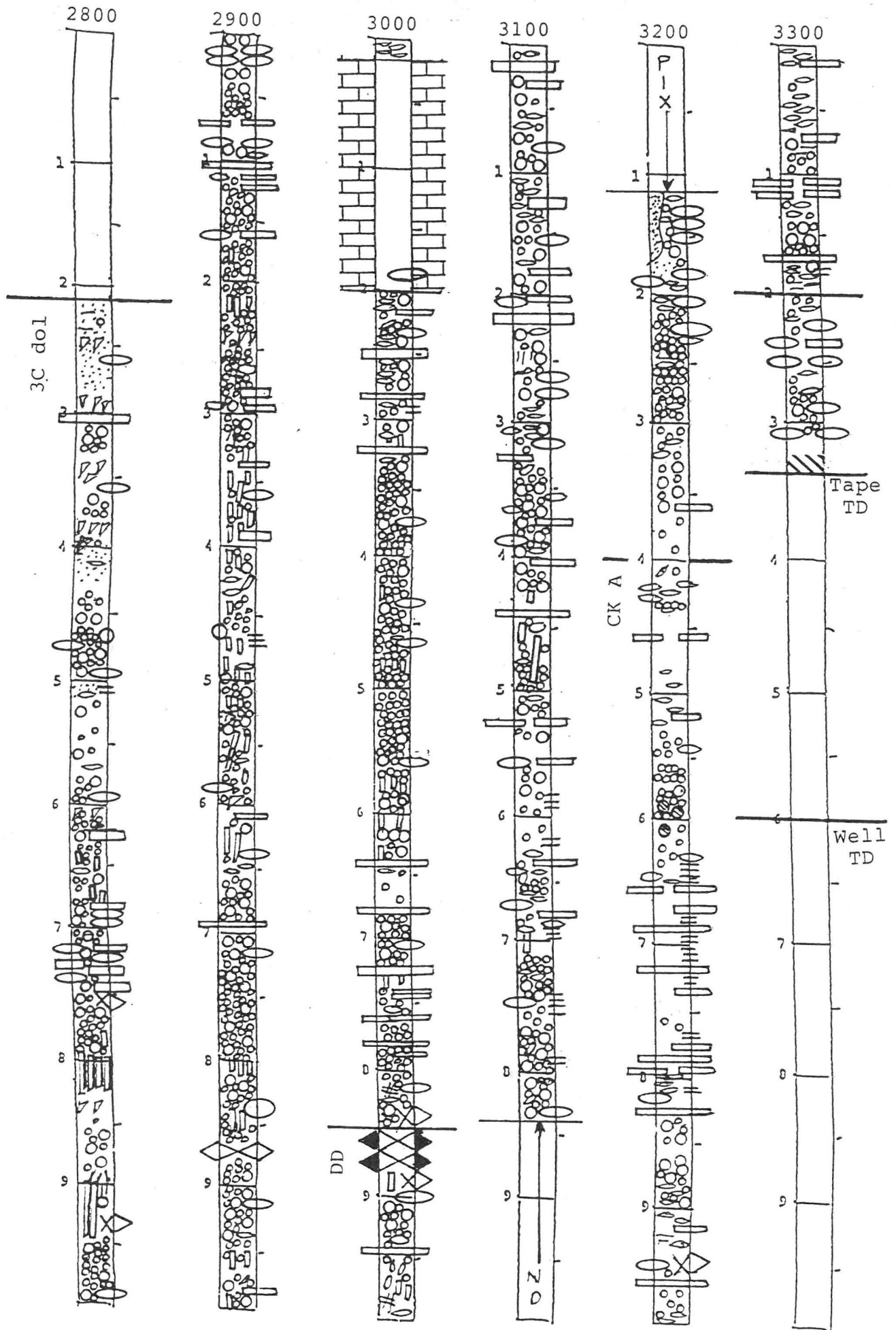


Fig. 30

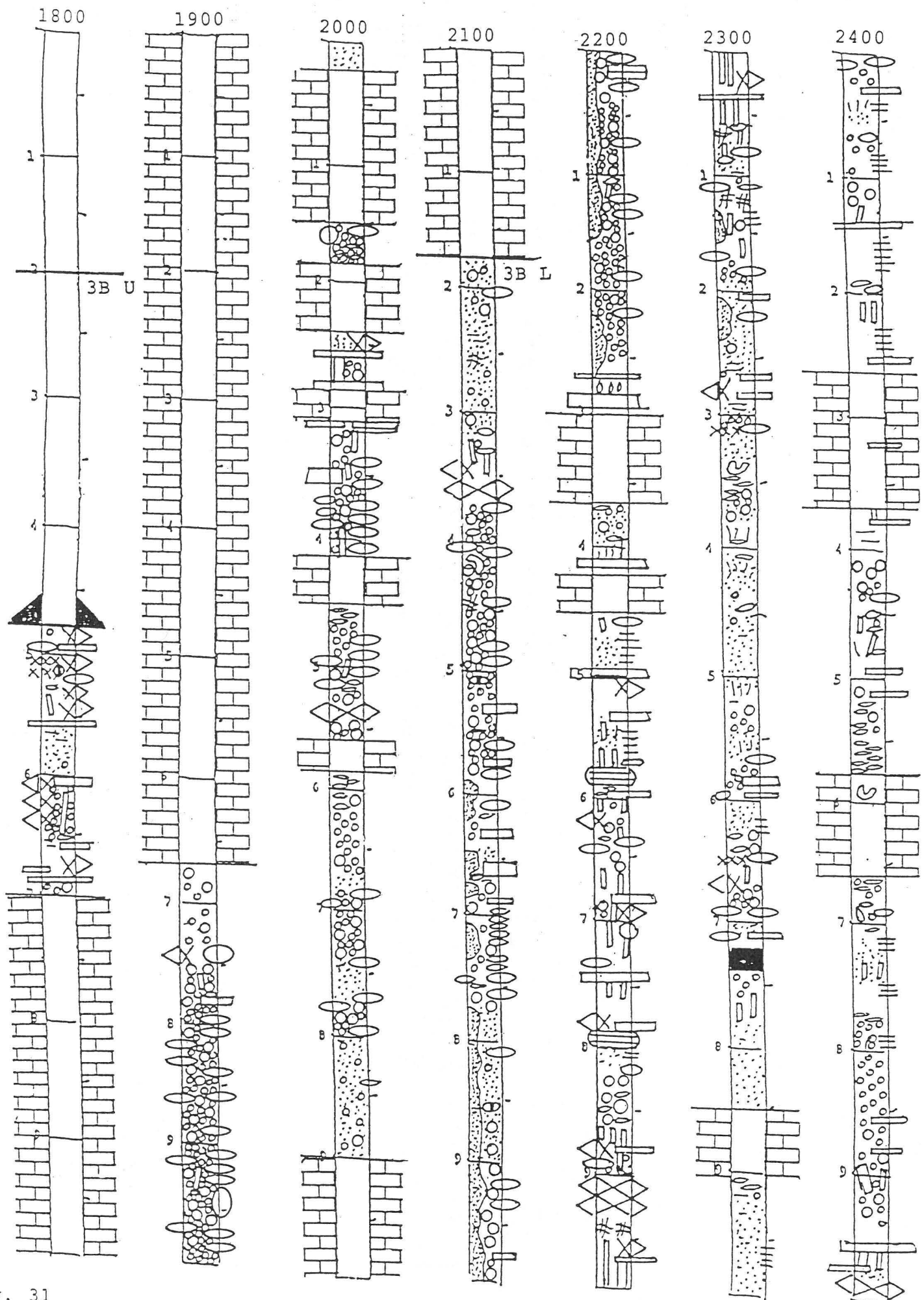
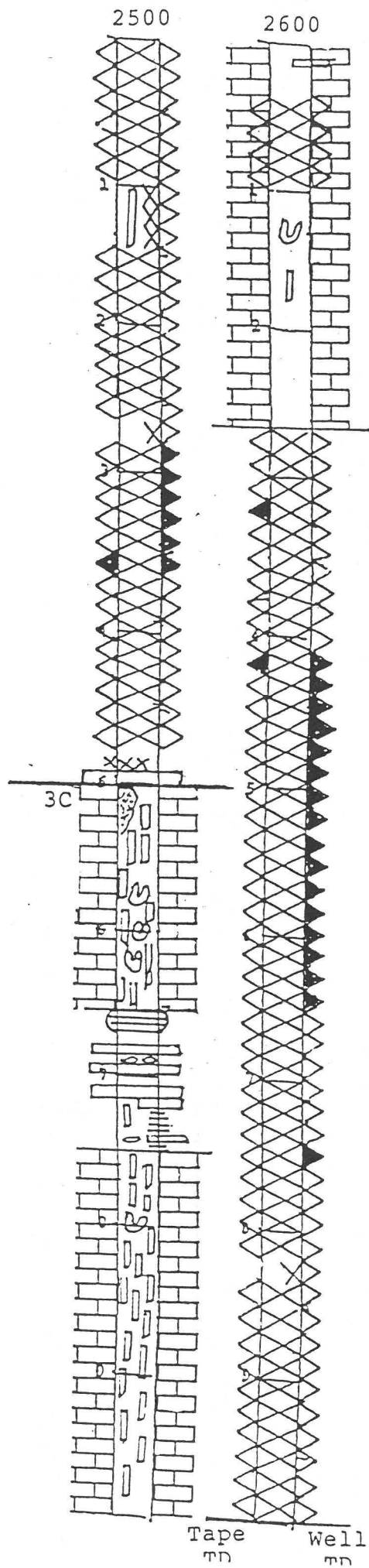
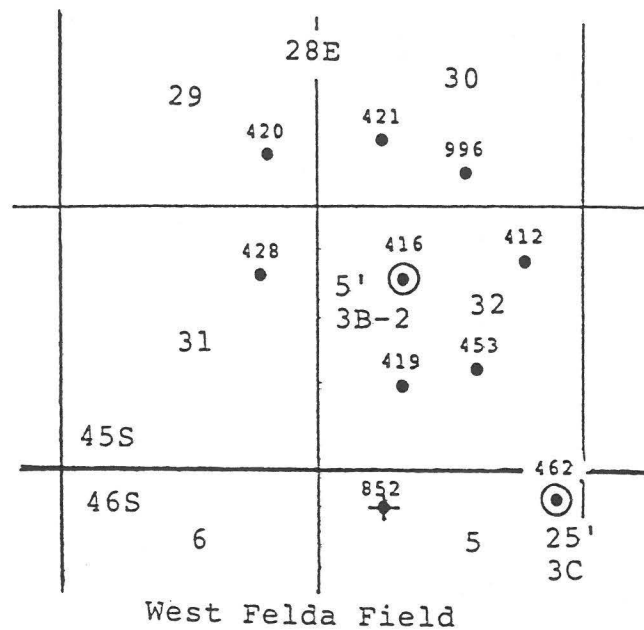
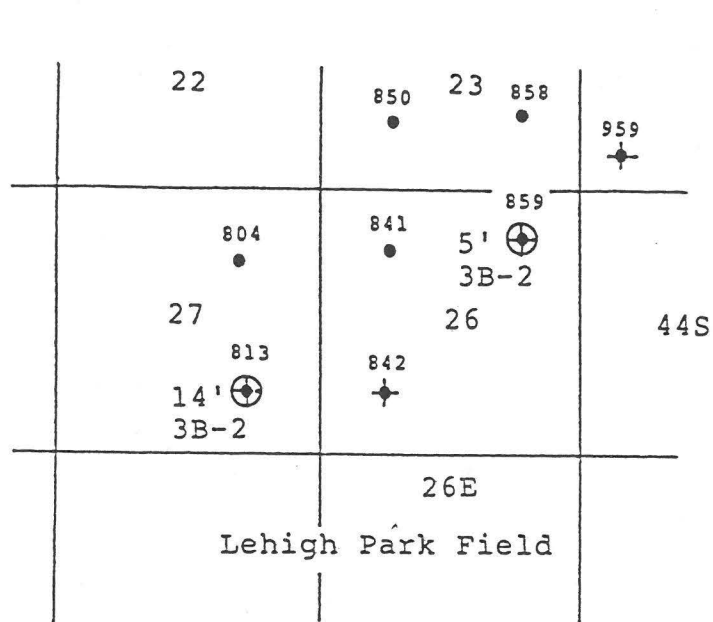


Fig. 31

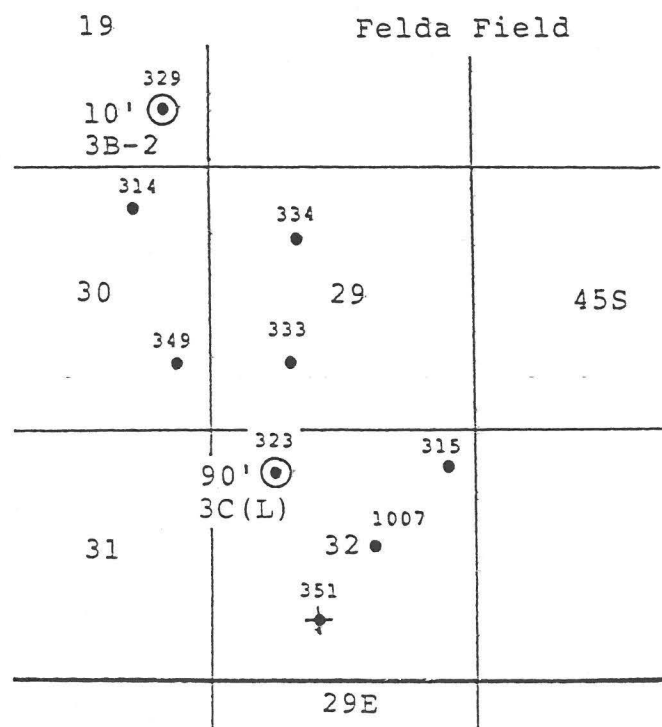
(over)







• oil well  
 + dry hole  
 ⊙ data point  
 3B-2 Unit in which  
 cavern is located



Thicknesses and Locations of Caverns in Oil Fields