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DEPOSITIONAL FACIES ANALYSIS AND SEA LEVEL CURVE DETERMINATION FROM THE SOUTHWESTERN ST. FRANCOIS MTS. TO THE WESTERN MARGIN OF THE REELFOOT RIFT, MISSOURI

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ABSTRACT

Knowledge of the relative influence of eustatic and tectonic controls on sedimentation in basins is important to developing a regional facies model. The Reelfoot Rift basin is located on the southern margin of the North American Craton. The tectonic and sedimentary history of the rift began during Middle Cambrian time and extended through the Early Ordovician. Oil test well cuttings and cores were used to construct a stratigraphic fence extending from the Cambro-Ordovician platform west of the St. Francois Mts. southeastward into the rifted basin. Three major transgressive-regressive sequences and numerous minor transgressive-regressive sequences were observed in Cambro-Ordovician rocks in and adjacent to the Reelfoot Rift. The major sequences are likely to have been controlled by eustatic sea level events and the minor sequences are likely to have been influenced by both eustatic and local tectonic controls.

INTRODUCTION

In recent years, development of sequence stratigraphy has played an important role in unraveling the depositional history of basins. To understand the sequence stratigraphy of a basin it is critical to know the relationship between eustatic and local tectonic controls on the facies distribution and stratigraphic sequences. The purpose of this study is to determine the depositional environments in and adjacent to the Reelfoot Rift Basin and the influence, if any, of eustatic and tectonic controls on these environments.

Tectonic Background

The Reelfoot Rift is located along the southern margin of the North American Craton and is positioned southeast of the Ozark Uplift (Fig. 1). The Reelfoot Rift has been identified as the failed arm of the Early Paleozoic triple junction that was associated with the opening of the Proto-Atlantic Ocean.

Ervin and McGinnis (1975) state that in late Precambrian time, the area comprising the Mississippi embayment and the Illinois Basin underwent epeirogenic uplift due to emplacement of low-density mantle material at the base of the crust, accompanied by local intrusions into the crust. This uplift marked the beginning of the development of the Reelfoot Rift and was part of the widespread rifting activity that affected the North American continental masses between 1.3 and 1.1 b.y. ago. The end of the period of active uplift probably is marked by igneous activity in the flanking St. Francois Mountains, following intrusion of basic dikes and sills into the older granite and felsite about 1.1 b.y. ago.

Stratigraphic Background

The Cambrian System in Missouri unconformably overlies Precambrian igneous basement and consists of six formations shown in Figure 2. These units are exposed in and around the St. Francois Mountains portion of the Ozark Uplift (Palmer, 1989). Lower Ordovician rocks rest unconformably on the Cambrian age Eminence Dolomite. The Ordovician System in Missouri consists of three Series: the Cincinnatian, Mohawkian, and Canadian Series. Of these, only formations from the Canadian Series are included in this study (Fig. 2).

The base of the Cambrian Section is represented by the Lamotte Sandstone. Thacker and Anderson (1977) describe the bulk of the Lamotte as being made up of well-sorted, fine- to

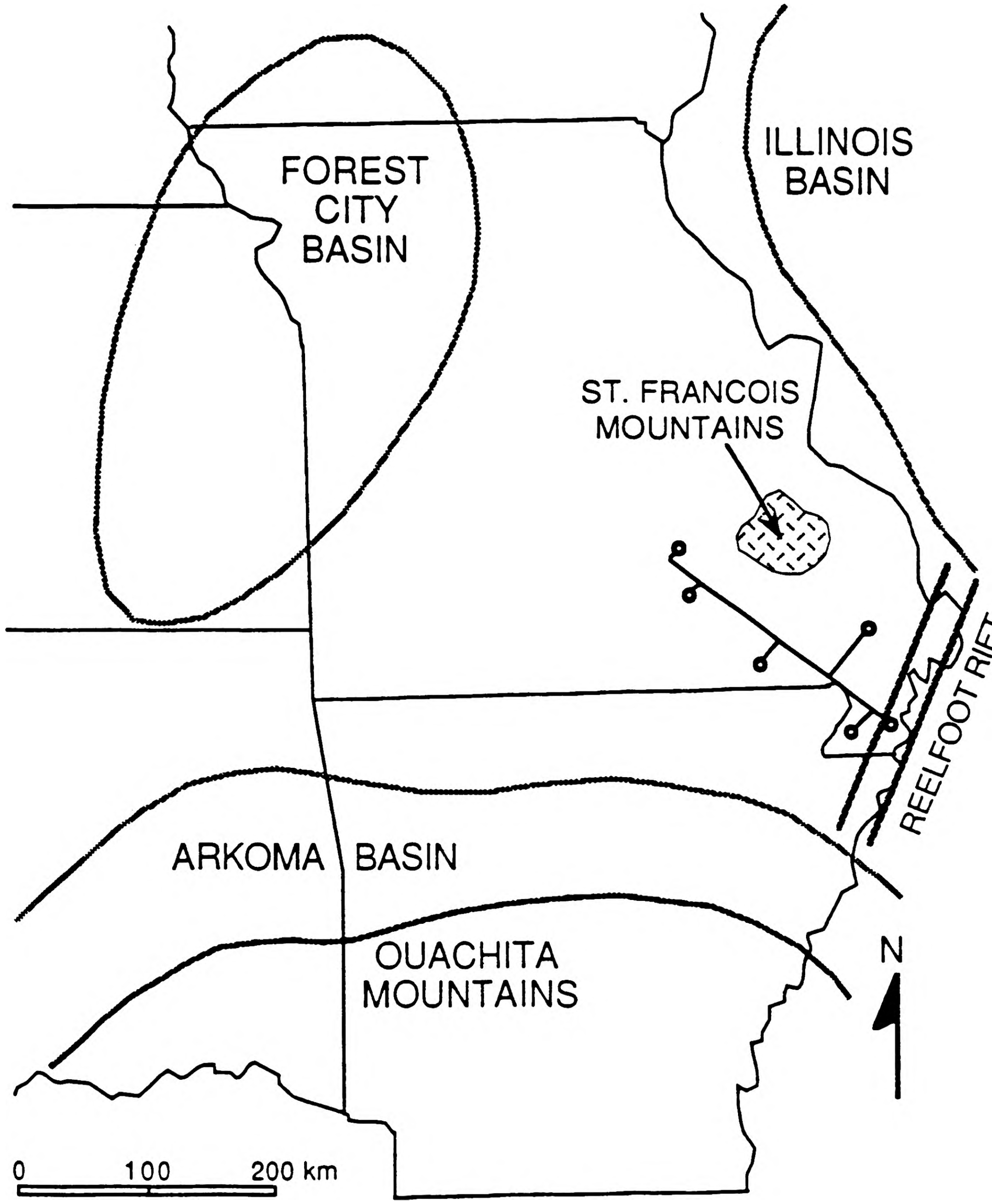

Fig. 1.- Regional tectonic map showing major sedimentary basins and orogenic belts. Line of stratigraphic fence and locations of test wells studied are shown.

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medium-grained, rounded and frosted quartz sand grains with a basal conglomerate. The overlying Bonneterre Dolomite, including the Sullivan Siltstone and Whetstone Creek Members (a coarse grained calcarenite) forms a conformable gradational transition from quartz sand to dolomite (Palmer, 1989). The Davis Formation is thought to represent an intrashelf basin facies with a series of shales interbedded with shaly limestones, clean limestones and local dolomites (Palmer, 1989). According to Palmer (1989) the overlying Derby Doerun Dolomite is primarily thin and irregularly bedded, fine-to medium-crystalline, argillaceous dolomite. Thacker and Anderson (1977) have describe the overlying Potosi and Eminence Dolomites as a massively bedded, fine- to medium-crystalline, highly burrowed dolomite.

The Gasconade Dolomite is the lower most Ordovician unit encountered within the study area. The Gasconade consists predominantly of light-brownish-gray to brown, medium-to coarsely-crystalline dolomite, finely crystalline dolomite, and cherty dolomite. The base is marked in many

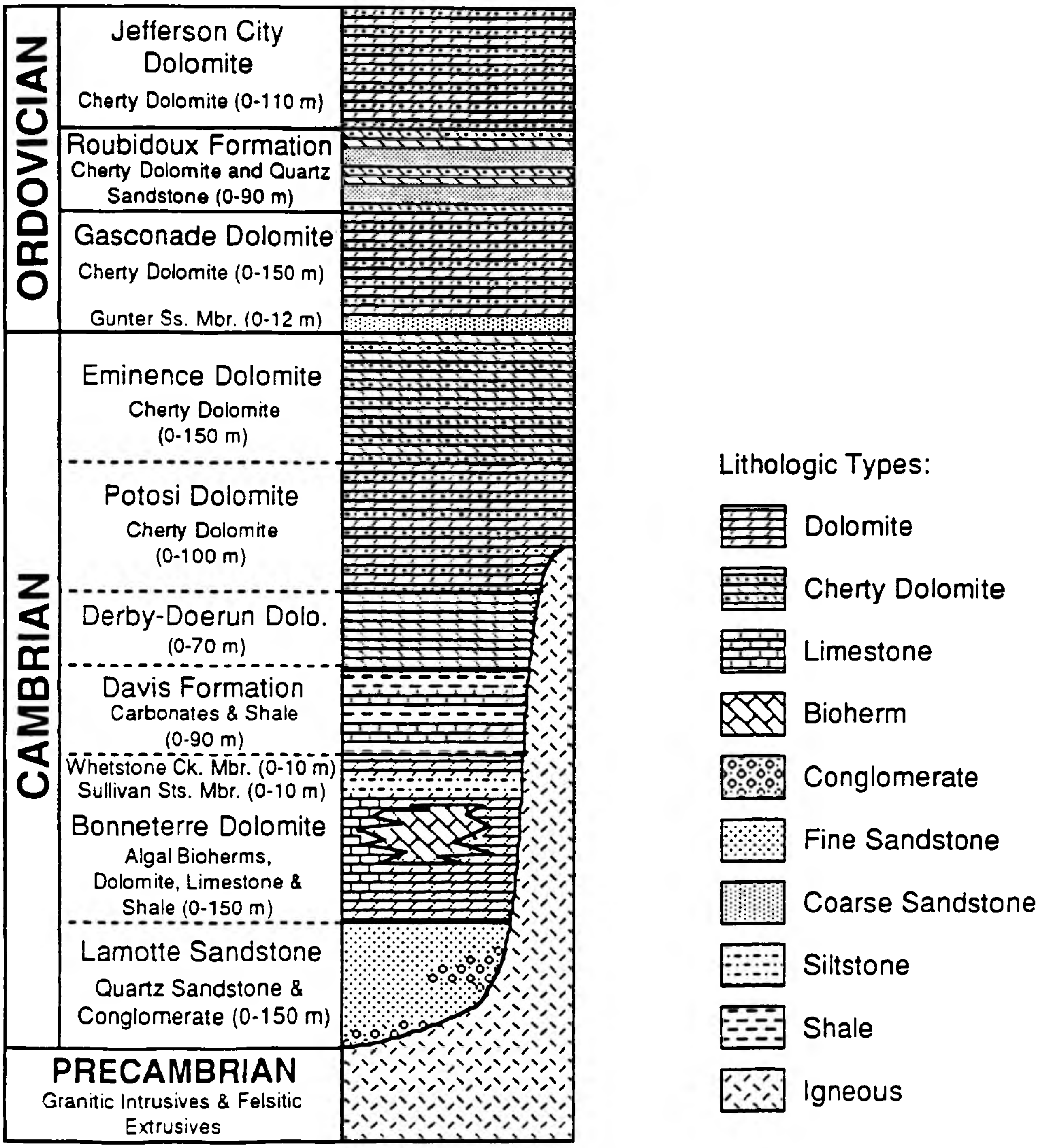

Fig. 2.- Stratigraphic column showing Cambro-Ordovician units encountered in the study area.

In the Mississippi Embayment or "boot heel" area of southeastern Missouri, the Cretaceous System includes both marine and nonmarine strata resting unconformably on underlying Lower Ordovician rocks. The thickness of the Cretaceous System in southeastern Missouri exceeds 152 meters (Howe, 1961).

This study determines depositional facies and relationships of Cambro-Ordovician rocks in Southeastern Missouri in order to calculate the relative Lower Paleozoic sea level curve for this region. Further study will involve the use of Phil™ 1.0 (Marco Polo Software, Inc., Houston, TX), a basin modeling program, to model the subsidence and deposition within the Reelfoot Rift and to separate the influences of eustatic sea level variations from the effects of tectonic subsidence of the rift.

METHODS

The study was conducted using well logs scaled to a 1in = 45.75m scale and redrawn on 24in x 36in paper for interpretation and correlation. Because detailed and laborious analysis of insoluble residues and observation of well cores is necessary to determine formation boundaries, all formation divisions were left as interpreted on all logs. Well logs found at the Missouri Geological Survey (MOGS) were interpreted and marked for maximum transgressive sequences (MTS) and maximum regressive sequences (MRS). The well logs used from the MOGS were: Amoco's Spence Trust No. 1; M. H. Marr et al. (MOGS Log No. 8742); and the Strake Petroleum, Inc. (MOGS Log No. 7222). Also used, were logs of cores interpreted by Zhenhao He of the University of Missouri at Rolla and James Palmer of the Missouri Geological Survey. These logs include: SV-3; MSH-1; and 319-11-A.

RESULTS

The logs used for this study have been categorized by their relative paleogeographic locations (Fig. 3). Logs produced by Z. He and J. Palmer include SV-3, MSH-1 and 319-11-A and were categorized as representing a carbonate platform (He, 1993). Logs from the MOGS included the M. H. Marr et at. and Amoco's Spence Trust No. 1, both categorized as basin margin, and the Strake Petroleum, Inc. test well, categorized as deep basin (Shelton et al., 1992; 1993).

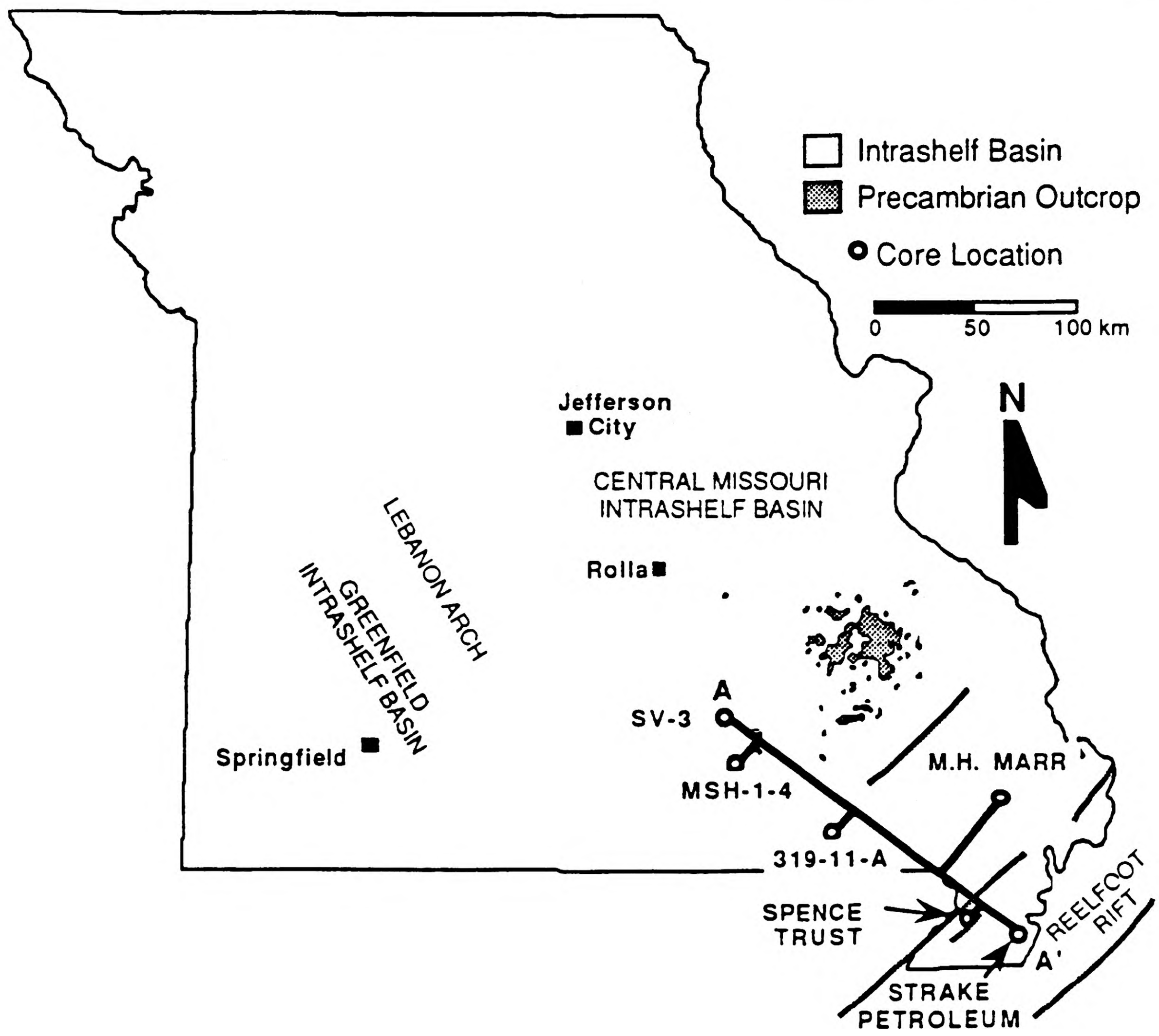

Fig. 3.- Map of Missouri showing Cambro-Ordovician paleogeography, stratigraphic fence A-A' and locations of test wells used in the study.

Carbonate Platform

Both SW-3 and MSH-1-4 (Fig. 3) penetrated Precambrian rocks at 503m and 675m, respectively. These rocks consists of highly fractured, coarse crystalline granite with some evidence of metamorphism. All three wells penetrate the Lamotte Sandstone. A conglomerate, consisting of sand to boulder sized grains and rock fragments, forms the base of the Lamotte. Cross-bedding is occasionally discernible in wells penetrating the formation. Alternating layers of quartz sandstone and shale occur near the top of the Lamotte, as are instances of quartz sandstone grading upward into calcareous siltstone.

The base of the Bonneterre Dolomite (71-76m thick) in wells SV-3 and 319-11-A exhibited alternating layers of black shale and mudstone grading upward into alternating layers of black shale and ribbon rock (thin bedded wackestones, packstones and grainstones). In MSH-1-4, the shale layers are absent, replaced by ribbon rocks and oolites which grade upward into crystalline carbonates and thrombolites with occasional interbedded ribbon rocks. Above the base of the Bonneterre in well 319-11-A is a 12m thick laminated cyclic thrombolite capped by "white rock." White rocks are sections of bleached dolomite; bleaching is believed to result from subaerial exposure (Gregg and Gerdemann, 1989). The base of the Sullivan Siltstone Member is primarily siltstone grading upward to alternating layers of shale and siltstone. At the top of the Bonneterre, the Whetstone Creek Member consists of dolomitic oolite and shale grading upward into ribbon rock. These two members are found in all three logs and have a combined thickness ranging from 7-29m.

The overlying Davis Formation consists of alternating layers of black shale and ribbon rock which constitutes most of the formation in SV-3 and MSH-1-4. For 319-11-A, the whole of the Davis Formation consists of ribbon rock mudstone, grainstone and crystalline carbonate layers capped at the top of the formation by a thin layer of shale. MSH-1-4 exhibits limy siltstone grading upward into alternating layers of shale and mudstone within the top 30m of the formation.

At the base of the Derby Doerun Dolomite, alternating layers of dolomitic siltstone and ribbon rock are capped by crystalline carbonates in SV-3 (26m thick) and massive thrombolites in MSH-1-4 and 319-11-A (18-24m thick). Cyclic thrombolites with interbedded laminae are found at the top of the Derby Doerun in all the wells.

The Potosi Dolomite is the youngest formation represented in the carbonate platform cores. Like the top of the Derby Doerun, laminated thrombolite sequences are present throughout. Cyclic thrombolites grading upward into stromatolite boundstones are inter layered with thin, laminated, mudstones.

Basin Margin

M. H. Marr et al.

The Bonneterre Dolomite (1125-1394m) is the lower most formation penetrated by the well. It consists of shale and dark limestones and dolomites. Shaly limestone to silty limestone dominate the bottom 106m of the formation. Above 1250m dolomite predominates with interbedded oolite, glauconitic limestone, sand and silt layers overlying one another, respectively. The top of the formation is capped by 12m of oolitic dolomite. An abrupt change in grain size was observed on the insoluble residue log at 1173m.

The Davis Formation (1054-1125m) in this well lacks significant amounts of shale except for the 11m thick bed at the top of the formation. The formation is primarily crystalline carbonate with a sand oolitic dolomite layer between 1065m and 1084m.

Between 960m and 1055m is the Derby Doerun Dolomite. The base of the formation is represented by fine to medium grained shaly dolomite with thin oolite beds at 1005m and 1021m. Above 1006m the dolomite became sandy and graded into a shaly dolomite up to 975m.

Overlying the Derby Doerun Dolomite is the Potosi Formation (753-960m). The base of the Potosi consists of fine to medium grained dolomite fining upward to a silty and shaly dolomite by 911m. This is then overlain by cycles of dolomite overlain by sandy dolomite and capped by sandy oolite layers.

The Eminence Formation overlies the Potosi. Like the Potosi, the Eminence contains cycles similar to those observed at the top of the Potosi. Above 725m a fining upwards from sandy to

shaly dolomite which then grads up to pure dolomite to sandy dolomite and capped by a sandy oolite layer at 677m is present. This cycle is repeated twice to the top of the formation.

The Gunter Sandstone Member (614-623m) overlies the Eminence Dolomite. The Gunter Sandstone consists of sandy, oolitic dolomite. Above the Gunter Sandstone is the Gasconade Dolomite followed by the Roubidoux Formation and finally the Jefferson City Dolomite, all of which consist of massive dolomite with interbedded oolites.

Amoco Spence Trust No. 1

The Lamotte Sandstone (3027-3075m) is the lower most unit encountered in this core. The sandstone consists of very fine subangular sand with calcite and silica cements. The Lamotte is overlain by the Bonneterre Dolomite (2341-3027m). Between 2932m and 3027m are light to dark gray dolomites alternating with white to light gray limestones. The sequence is capped by a 6m thick layer of oolitic limestone overlain by white rock. White to medium dark gray limestone capped by 9m of oolitic limestone is present between 2893m and 2932m. The interval 2835m to 2893m is primarily light to medium gray limestone with alternating layers of dolomite and limestone in the top15m. From 2804m to 2835m alternating layers of light gray limestones and dolomites dominate. The top of this interval is capped by a 3m thick layer of oolitic limestone. The next 58m (2746-2804m) has 9m of light gray limestone at its base and the remainder being oolitic limestone.

Above 2746m to 2676m is a 6m thick layer of medium gray limestone followed by 64m of white and light gray dolomite with interbedded red clays and sand at the top. From 2676m up to 2633m there are alternating layers of light to medium gray limestone, oolitic limestones and dolomites and dark gray dolomite. Between 2554m and 2633m there is 43m of light to medium gray limestone at its base. This limestone is overlain by a 3m thick subrounded, unconsolidated sand followed by 34m of dark gray oolitic limestone.

The base of the Elvins Group (Davis and Derby Doerun Formations) is at 2341m. The base begins with 49m of white and light gray limestone followed by 55m of white to medium gray dolomite. This is again repeated with 21m of limestone overlain with 18m of dolomite up to 2198m. The bottom of the Derby Doerun Dolomite (2198?m) is marked by alternating layers of black shale and dark gray silty limestones and dolomites.

The bottom of the Eminence Dolomite is at 2083 as recorded on the log. The base is characterized by 58m of oolitic dolomite followed by 21m of dark gray dolomite up to 2006m. Above 2006m, alternating layers of dolomite and oolite beds predominate. The Gunter Sandstone Member can be picked out between 1655m and 1661m. The top of the Lower Knox (Eminence Dolomite), Middle Knox (Roubidoux Formation) and Upper Knox (Jefferson City Dolomite) are marked on the log at 1661m, 942m and 579m, respectively.

<u>Deep Basin</u>

The interpretation of the Strake Petroleum, Inc. test well is based upon the log obtained from the Missouri Geological Survey, which contained information only on the bulk composition of the cuttings. The base of the log (1375-1445m) showed increasing dark gray to black limestone and decreasing dolomite. Sand also increases toward the bottom. The top 20m contains a significant amount of glauconite.

The bulk composition of the rock between 1237m and 1375m showed a distinct decrease in the amount of shale in the samples from approximately 60% to <10%. Dolomite and limestone are both present throughout with both increasing to >90% bulk composition in the top 26m. Fine silt is present from 1315-1326m and 1254-1285m, as well as mafic igneous material from 1295m to 1303m. There is a sudden increase of shale at 1050m with a corresponding decreases in dolomite and limestone to approximately 1135m where the sample is >90% shale. Limestone and dolomite bulk compositions increase up to 1237m becoming >90% of the bulk composition. Fine silt is present at 1103-1106m, 1076-1091m and 1058-1065m, as well as mafic igneous material between 1109m and 1125m.

Between 978m and 1050m is a significant amount of limestone and dolomite (>90%). Silt sized grains are located between 1033m and 1050m. A probable unconformity as shown on the log exists at the top of the next interval (899-978m) with the sudden appearance of oolitic chert in

the upper 15m. From bottom to top within the interval the dark black limestone decreases in bulk composition disappearing at 957m. Silt sized particles are again observed between 940m and 945m as well as mafic igneous material between 945m and 954m.

The top of the Derby Doerun Dolomite marks the top of the next interval (856-899m). The bottom 9m are pure, dark black dolomite which suddenly gives way to pure, dark black limestone to the top of the interval. Tripolitic chert is present within the top 3m of the formation. Red limestone was observed at 876-890m and 856-860m with green limestone also present in this latter interval. Mafic igneous material is located at 863-872m, 878-881m, and 893-899m.

Above 856m there are numerous 1-2m intervals containing tripolitic chert. Of note, is the red limestones found between 809m and 821m with dike material being found along side. The top of the Paleozoic is at 628m with the beginning of the Cretaceous sediments appearing above.

DISCUSSION

Criteria for Determining Sea Level Changes

In determining the possible tops and bottoms of transgressive and regressive sequences, it is important to recognize several types of indicators including: tripolitic chert; white rock; oolitic sections; ribbon rocks; and basinal shales. Care was taken to ensure that sequence boundaries were picked at intervals not only where the above criteria are met, but where boundaries are most likely to actually occur.

Tripolitic chert is commonly produced during erosion of carbonate rocks and therefore, is good indicator of an erosional unconformity. "White rock" is produced much the same way as tripolitic chert. White rock results from bleaching of carbonate rocks during subaerial exposure. Oolites typically are produced on carbonate platforms and may migrate as far as the deep basin. However, oolites produced on the platform may be tens of meters thick and the increase or decrease of their relative abundance may indicate that a sea level change has occurred. Ribbon rocks are composed of sub parallel layers of clay, silt or sand and carbonate oozes or build ups (Read, 1989). Ribbon rocks are found on the ramps adjacent to the carbonate platform and are an indicator of a deep water environment. Basinal shales represent the deepest water environment encountered in this study and indicates the maximum extent of a transgressive sequence.

Major Transgressive and Regressive Sequences

Three major transgressive sequences were determined and are shown on Figure 4. The first transgressive sequence (T_1) is marked at the top of the Lamotte sandstone. This first transgression began sometime in the early to Middle Cambrian and is first recognized by the deposition of an arkosic conglomerate onto the underlying igneous Precambrian basement. Following this are near-shore cross-bedded sands, such as those found in SV-3. Only SV-3 exhibited this cross-bedding because the other logs either did not list that information or did not penetrate the formation deep enough to record it.

The base of the second major transgression (T_2) is marked by a prominent white rock overlying either deep basin or deep ramp facies of the T_1 sequence. This unconformity is located approximately at the Bonneterre-Davis contact. The white rock is found in all the wells except SV-3 and the Strake Petroleum's test well. In these two latter wells, the unconformity is interpreted as being located between the Bonneterre-Davis contact.

The Gunter sandstone Member forms the base of the third major transgression (T_3), and is observed in the Marr and Spence wells which are located adjacent to and within the Reelfoot Rift. Thompson (1991) described a basal conglomerate in the Gunter Sandstone containing pebbles from the underlying Eminence dolomite which provides evidence for a disconformity between these two rock units.

Minor Transgressive and Regressive Sequences

Numerous small scale transgressive-regressive cycles, not shown on Figure 4, exist in the Cambro-Ordovician section. These sequences are represented by 1-10m scale facies changes. The carbonate platform wells (SV-3, MSH-1-4, and 319-11-A) contain these cycles within and above the Derby Doerun Formation. These cycles are characterized by alternating layers of thrombolites

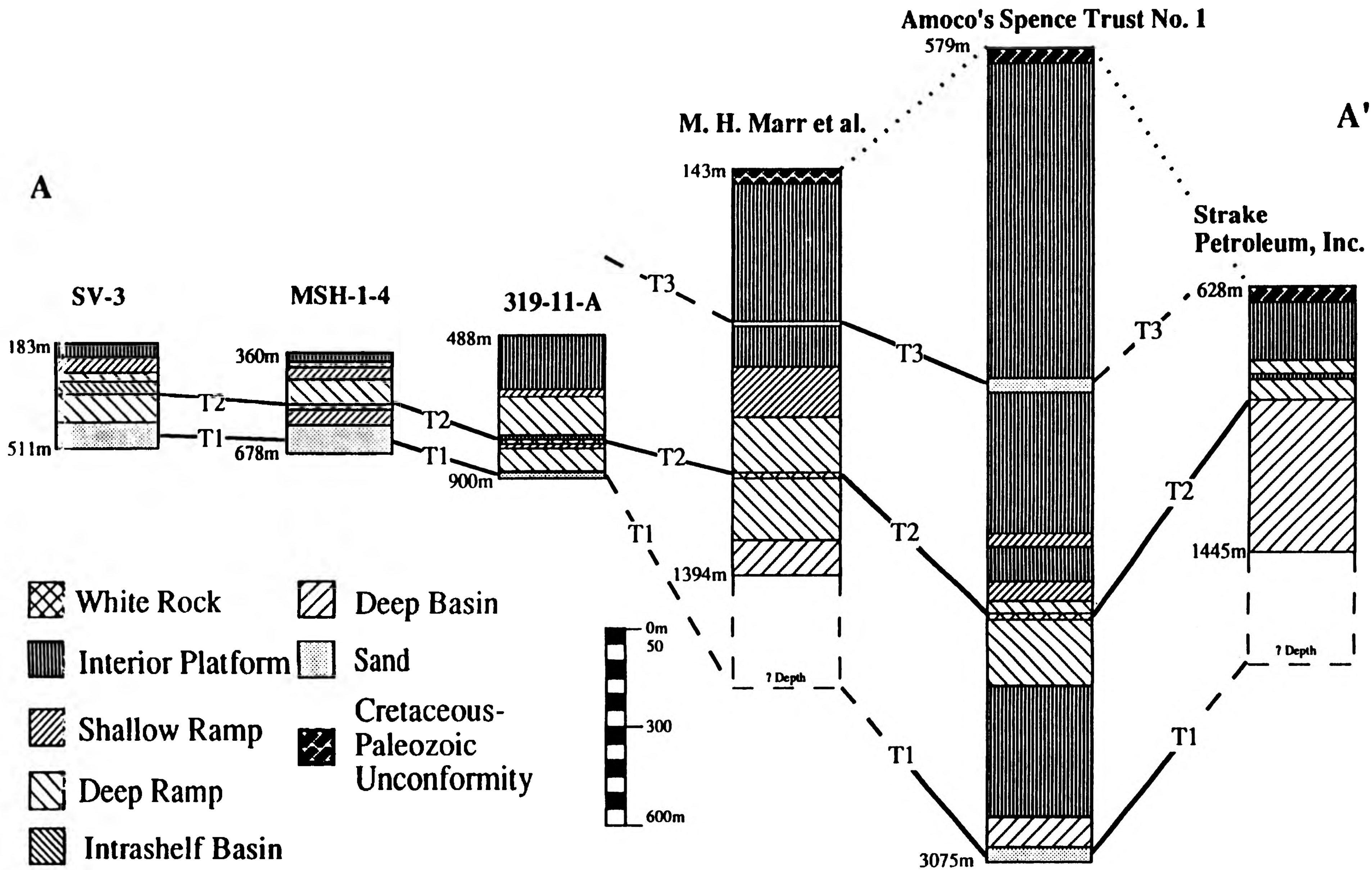

Figure 4. Stratigraphic Fence Across A-A'. T_1, T_2, and T_3 (solid lines; dashed where inferred) represent the bases of major transgressive cycles. Dotted lines indicate the Cetaceous-Paleozoic unconformity.

and supratidal, laminated mudstones. In the basin margin and deep basin wells (Marr, Spence Trusts, and Strake) such cycles occur throughout the section. These cycles are characterized by oolite units alternating with limestones and shaly limestone.

In the carbonate platform area, the small scale cycles likely are controlled by eustatic sea level change as tectonic controls exerted by subsidence of the rift are less likely to have a major effect on deposition here. Tectonic activity in the Reelfoot Rift region is likely to had a greater influence on development of the small scale cycles within the basin wells. These cycles occur in small clusters with noticeable undisturbed deposition between the clusters. This suggests periods of episodic or pulsating tectonic subsidence that may have resulted in repeated small scale relative sea level rises.

The Strake Petroleum test well is located within the deep basin. Here, as in the basin margin wells, cyclic sequences are present. However, these cycles do not appear in clusters, but occur in more regular patterns. This suggests that tectonic subsidence affecting the deep basin was more uniform as opposed to pulsating. Turbidite sequences were evident throughout the interval between 1315-944m and indicate continuing subsidence of the rifted fault blocks during deposition of these rocks.

Sequences T_1, T_2, and T_3 (Fig. 4) are all bounded by regional unconformities. These unconformities are correlatable throughout the wells, indicating that tectonic activity was not the cause of sea level changes and their associated unconformities. Instead, these unconformities are the result of eustatic sea level changes.

CONCLUSIONS

1. Cambro-Ordovician rocks in and adjacent to the Reelfoot Rift contain three major transgressive-regressive sequences that are controlled by eustatic sea level events.
2. These major transgressive-regressive sequences are bounded by unconformities or their correlative conformities that are defined by laterally continuous lithologic facies.
3. Minor transgressive-regressive cycles, which were observed, are likely influenced by both eustatic events and local tectonic controls.
4. Continuing research on this project will include application of a basin modeling program to further refine the influences of eustatic versus tectonic controls on rift sedimentation.

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