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Revision of the Stratigraphic Nomenclature of the Plio-Pleistocene Palm Spring Group (New Rank), Anza-Borrego Desert, Southern California

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ABSTRACT.—The paleontologic and geologic importance of the Plio-Pleistocene Palm Spring Formation (Salton Trough, southern California) demands an accurate and stable nomenclature. To resolve the semantic disagreements resulting from the differences between the *restricted* and *expanded* concepts of the Palm Spring Formation, this study elevates this unit to group rank and recognizes five lithostratigraphic units of formation rank within it: the Arroyo Diablo Formation (new), the Olla Formation (new), the Tapiado Claystone (new), the Hueso Formation (change in rank, emended name), and the Canebrake Conglomerate. This proposed revision affects mainly the rocks in the vicinity of Vallecito Creek, Fish Creek, and Carrizo Creek in the Salton Trough of southern California and unifies the tectonostratigraphic products of a major depositional system that filled small basins along the North American-Pacific transform boundary. This study presents the most recent revision of the stratigraphic nomenclature of the Palm Spring Formation. It continues a process that recognizes lithologically distinct facies of this unit as distinct lithostratigraphic units.

PURPOSE

The purpose of this paper is to elevate the Palm Spring Formation to group rank and to subdivide the Palm Spring Group into five formations in accordance with the provisions of the North American Stratigraphic Code (NASC) (1983). Raising the Palm Spring Formation to group rank helps eliminate semantic disagreements about which lithologies to include in the *Palm Spring.* These disagreements resulted from Woodring's (1932) ambiguous original definition of the unit. Designation of the Palm Spring Formation as a group preserves the general concept of this unit as it is recognized throughout the Salton Trough by most workers; recognition of five formations within the Palm Spring Group allows greater stratigraphic resolution in mapping and biostratigraphic studies.

In the Fish Creek-Vallecito Creek (FCVC) basin (1, 2, and 3 in figure 1), the Palm Spring Group includes five formations: the Arroyo Diablo Formation (new), the Olla Formation (new), the Tapiado Claystone (new), the Hueso Formation of Cassiliano (1998a) (change in rank, emended name), and the Canebrake Conglomerate of Dibblee (1954) (in part). The proposed new formations are lithologically distinct from each other and readily mapped at a scale of 1:24,000 (plate 1). The suggested change in nomenclature yields stability, facilitates communication, and renders invalid certain stratigraphic names that have not been proposed following the recommendations of the NASC (1983) because they have appeared in *gray literature* such as guidebooks and abstracts.

A second important purpose of this paper is to give wider recognition to the unpublished research of Woodard (1963) and Winker (1987) on the stratigraphic nomenclature of the post-Imperial Formation rock units in the Fish Creek-Vallecito Creek basin.

The Palm Spring Group is important because its vertebrate fossils provide critical information on the evolution and diversification of paleocommunities characteristic of the Blancan and Irvingtonian North American Land Mammal *Ages* (NALMA) (Pliocene and Pleistocene epochs, respectively) (Cassiliano 1994). These fossils occur in superposed faunas that have the potential to serve as a standard for Blancan and Irvingtonian biochronology and to define the Blancan-Irvingtonian boundary (Cassiliano 1999).

The Palm Spring Group represents the interplay of distinctive sediment sources and depositional processes within a series of small basins that developed along the transform boundary between the North American and Pacific plates. The resulting lithostratigraphic units are mappable, lithologically distinct from one another, and can be genetically related to specific depositional and tectonic environments (Winker 1987). The stratigraphic relationships among the formations within the Palm Spring Group are best seen in the FCVC basin (figures 1–3, plate 1). This basin reveals a progressive change in lithology from source areas in the surrounding mountains to progressively more distant areas of deposition that can be recognized as distinct formations. The intertonguing and gradational relationships among the subordinate rock units in the Palm Spring Group are the major criteria for including them in a single higher-ranking lithostratigraphic unit. A bajada is represented by the Canebrake Conglomerate. The alluvial plain proximal to the bajada is represented by the Hueso Formation; the more distal alluvial plain is represented by the Olla Formation and the lacustrine Tapiado Claystone or by the delta plain of the Arroyo Diablo Formation.

An analogous situation occurs in the Borrego-San Felipe basin (BSFB) north of FCVC (Winker 1987; Remeika and Jefferson 1993) (4 in figure 1). The BSFB includes the Borrego Badlands, the San Felipe Hills, and the southeast flank of the Santa Rosa Mountains. The Palm Spring Group in FCVC clearly demonstrates the mutually intertonguing contact relationships that occur among lithostratigraphic units deposited in environments ranging from proximal fluvial to lacustrine rocks to basin center. Because of these facies changes, the contacts between formations within the Palm Spring

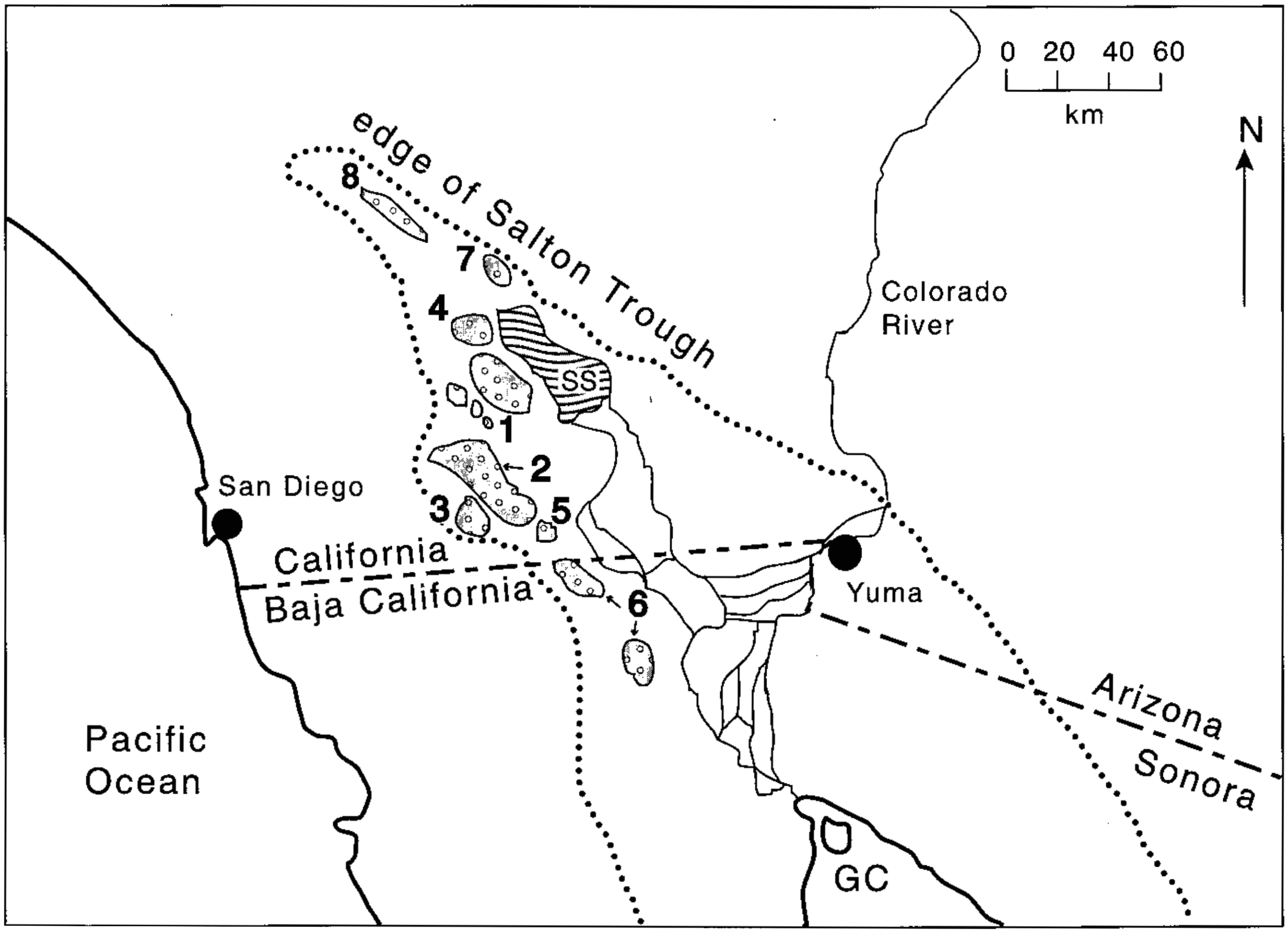

Figure 1. Location map of the Salton Trough showing outcrops of the Palm Spring Group. Based on figs. 1.1 and 7.1 of Winker (1987). 1 = Fish Creek-Vallecito Creek (FCVC), 2 = Carrizo Impact Area-Coyote Mountains, 3 = Sweeney Pass-Canyon Sin Nombre, 4 = Borrego-San Felipe Basin (BSFB), 5 = Yuha Buttes, 6 = Sierra de los Cucapas, 7 = Indio Hills, 8 = Mecca Hills, SS = Salton Sea, GC = Gulf of California.

Group are often gradational and arbitrarily placed (Woodard 1963; Winker 1987; Cassiliano 1998a), a situation recognized by the NASC (1983, Articles 10a, 23a, and 23b).

The Palm Spring Group also illustrates the fact that in well-exposed basins, lithostratigraphic units are all, ultimately, facies of an integrated depositional system. Dibblee (1954, 1984) recognized this when he referred to the Canebrake Conglomerate and Borrego Formation, which he mapped as individual lithostratigraphic units, as facies of the Palm Spring Formation as that unit was defined by Woodring (1932).

This paper presents the most recent revision of the stratigraphic nomenclature of rock units in the Salton Trough. Each revision resulted in the recognition of distinct lithofacies as smaller hierarchical units within larger lithostratigraphic units. The process began with Hanna's (1926) study that drew upon the earlier work of Kew (1914). Woodring's (1932) paper improved upon the work of Hanna; Dibblee (1954) refined the results of Woodring. Woodard (1963), in turn, augmented Dibblee's study. Winker (1987) corroborated and expanded the work of Woodard. This paper synthesizes the results of these studies in an effort to standardize the stratigraphic nomenclature in the FCVC area of the Salton Trough.

It is important to stress that the original research on the proposed new formations presented in this paper is based primarily on the informal member-level lithostratigraphic units Woodard (1963) and Winker (1987) designated, as well as on the published work of Dibblee (1954, 1984). The author is familiar with the lithologies and field relations of the Palm Spring Group by way of field study that complements and corroborates the results of Woodard and Winker. The revisions proposed here apply mainly to the FCVC basin because this is where the author studied the Palm Spring Group in the field. In other areas in the Salton Trough (figures 1 and 2), such as the BSFB, where the Palm Spring Group is exposed, Tarbet and Hollman (1944) and Dibblee (1954) formally named overlying and laterally equivalent rock units. Future study may determine that these rock units are part of the Palm Spring Group. In these additional areas the only rock units of the Palm Spring Group, as revised here, in the FCVC basin, that are currently recognizable are the Arroyo Diablo Formation, the Olla Formation, and the Canebrake Conglomerate. Recognition of the Palm Spring Group in other areas of the Salton Trough is based almost exclusively on lithologic similarities. From the work of Dibblee (1954, 1984), Proctor (1968), and Winker (1987), the Borrego Formation, named by Tarbet and Holman (1944), in the BSFB, should probably be included in the Palm Spring Group. These authors have shown that the Borrego Formation intertongues with and grades into rocks recognized as the Palm Spring Group in the BSFB. However, because the author has not field-checked the stratigraphy of the BSFB, it is not within the scope of this study to include the Borrego Formation in the Palm Spring Group.

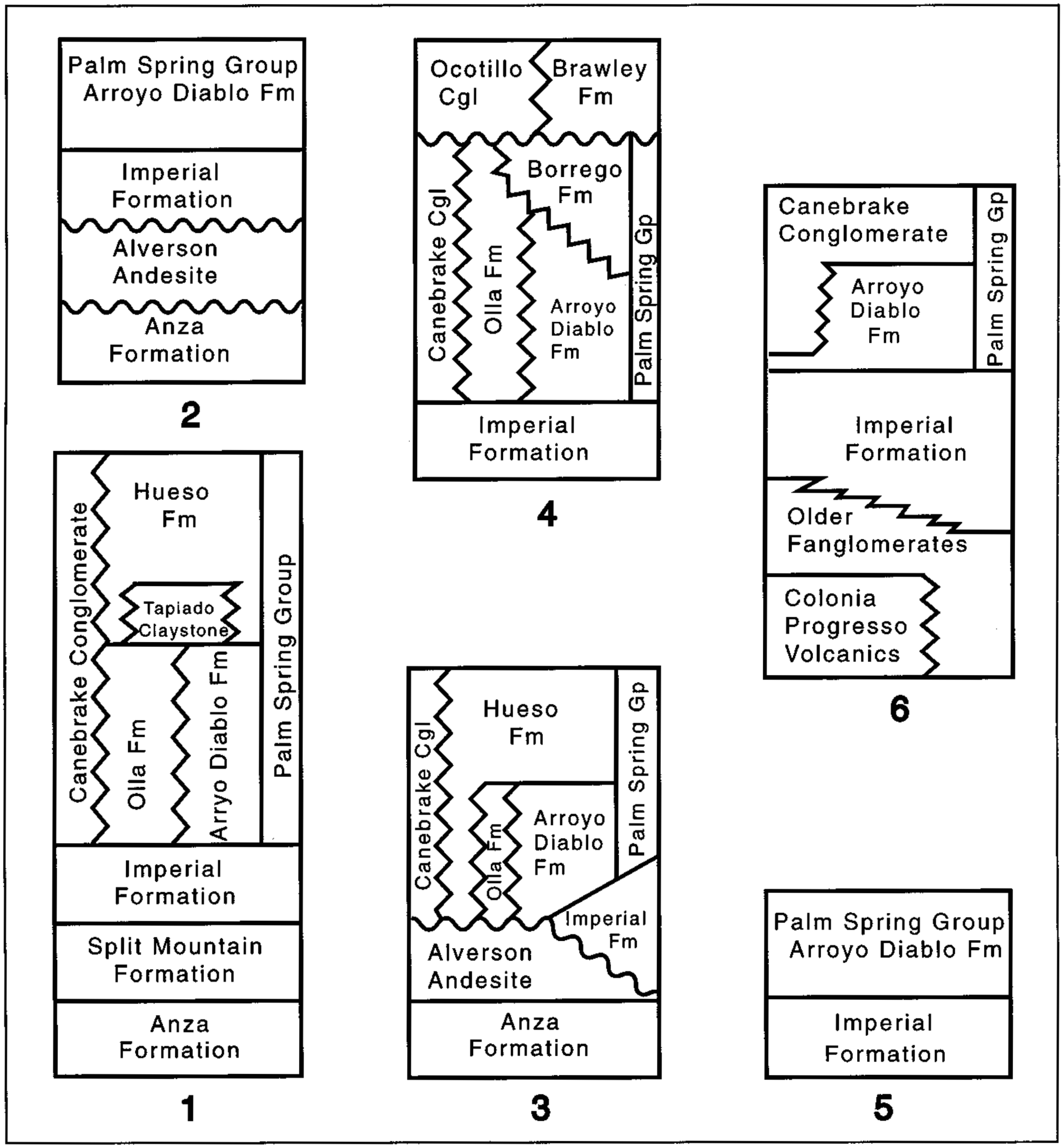

Figure 2. Revised lithostratigraphic nomenclature of the Palm Spring Group applied to different areas of the Salton Trough. Additional lithostratigraphic units shown to place the Palm Spring Group in stratigraphic context. Based on figs. 1.8, 1.9, 1.11, 7.1, and 7.3 of Winker (1987), with modifications. Used with permission of C. D. Winker.1 = Fish Creek-Vallecito Creek (FCVC) (Woodard 1963, 1974; Winker 1987; Cassiliano 1998a, this paper), 2 = Carrizo Impact Area-Coyote Mountains (Woodard 1974; Winker 1987), 3 = Sweeney Pass-Canyon Sin Nombre (Woodard 1963, 1974; Hoggat 1979; Winker 1987), 4 = Borrego Badlands-San Felipe Hills (Dibblee 1954, 1984; Winker 1987), 5 = Yuha Basin (Winker 1987), 6 = Sierra de los Cucapas (Winker 1987).

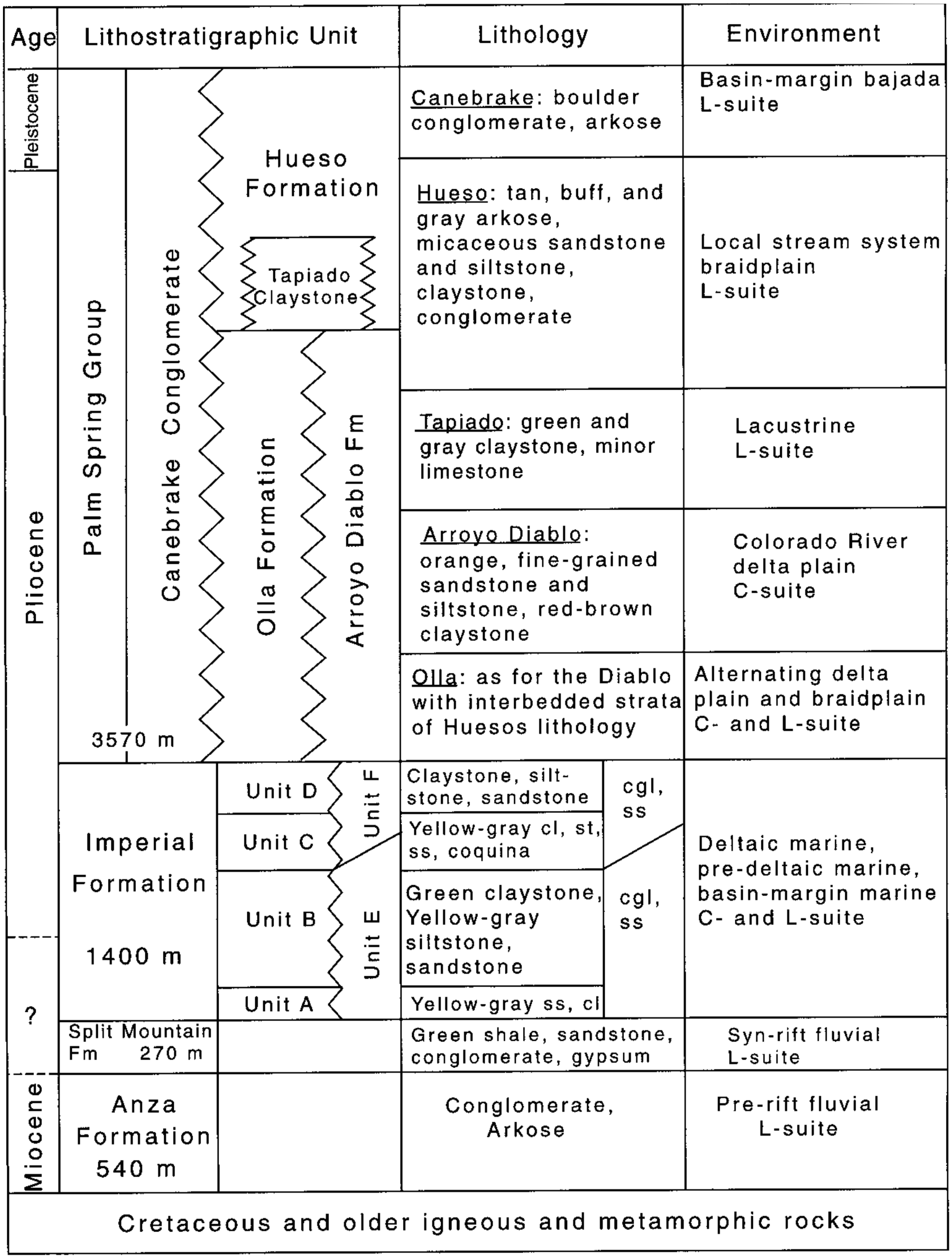

Figure 3. Summary of nomenclature, lithologies, provenance, and interpreted tectonostratigraphic environment of lithostratigraphic units in the Fish Creek-Vallecito Creek (FCVC) area. Subdivisions of the Imperial Formation are given letter designations rather than the informal names used by Woodard (1963) and Winker (1987). Modified from fig. 4 of Cassiliano (1998a).

INTRODUCTION

The Palm Spring Group in the FCVC basin of southern California preserves the Pliocene and Pleistocene history of the Salton Trough (northern Gulf of California) in approximately 3,750 m of continuously deposited rock. Deltaic, fluvial, lacustrine, and shallow-marine rocks record the dynamic interaction of tectonics, sediment sources, and depositional environments (Winker 1987). The opening of the Gulf of California and development of the transform boundary between the North American and Pacific plates controlled tectonic activity. The Colorado River and local stream systems that filled in the northern Gulf of California (Woodard 1963, 1974; Winker 1987) controlled sedimentation.

More than 15,000 fossils of Plio-Pleistocene terrestrial, lacustrine, and marine vertebrates have been collected from over 2,000 localities in the Palm Spring Group in FCVC (Cassiliano 1997, 1999). A continuous and complete magnetostratigraphic record calibrated by a fission-track date in FCVC (Opdyke *et al.* 1977; Johnson *et al.* 1983) contributes to geochronologic and biochronologic study of the Palm Spring Group.

The Palm Spring Group is exposed in several areas in the Salton Trough (Woodring 1932; Tarbet 1951; Dibblee 1954, 1984; Woodard 1963; Proctor 1968; Winker 1987) (figure 1). The best outcrops occur near Vallecito Creek, Fish Creek, Carrizo Creek, the Coyote Mountains, and Sweeney Pass (1, 2, and 3 in figure 1). Nomenclatural changes are most evident in these areas in the southern part of Anza-Borrego Desert State Park. Other areas where the Palm Spring Group lithology is exposed include the BSFB (4 in figure 1), Yuha Buttes (5 in figure 1), Sierra de los Cucapas (6 in figure 1), Indio Hills (7 in figure 1), and Mecca Hills (8 in figure 1).

Figure 2 shows, in a simplified way, the lateral and superpositional relationships of the Palm Spring Group to other lithostratigraphic units in the areas where the Palm Spring Group is exposed. Figure 3 places the Palm Spring Group in context with other lithostratigraphic units in FCVC. Detailed discussions of the numerous upper Cenozoic lithostratigraphic units in the Salton Trough include those of Kew (1914), Hanna (1926), Woodring (1932), Tarbet and Holman (1944), Tarbet (1951), Ver Planck (1952), Dibblee (1954, 1984), Woodard (1963, 1974), Proctor (1968), Winker (1987), and Cassiliano (1997, 1998a). Winker (1987), in a tectonostratigraphic study, provided genetic interpretations of lithostratigraphic units in the Salton Trough.

HISTORY OF THE NOMENCLATURE OF THE PALM SPRING GROUP

Figure 4 summarizes the history of the stratigraphic nomenclature of the Palm Spring Group in the FCVC basin.

The earliest formation named in FCVC was the Carrizo Formation of Kew (1914), a suite of marine and nonmarine rocks. Woodring (1932) noted that the name *Carrizo Formation* was preoccupied by an Eocene unit in Texas, expanded the concept of the Imperial Formation of Hanna (1926) to include all the marine rocks of Kew's Carrizo Formation, and named the remaining nonmarine rocks of the Carrizo Formation the *Palm Spring Formation.*

Woodring (1932, 9–10) wrote (figure references added):

> Conformably overlying the bluff siltstone with gradational contact are poorly consolidated or unconsolidated sands and silts of light shades of chocolate-brown and brick-red, which are well exposed in the vicinity of the ruins of the old stage station [CS on plate 1] on Carrizo Creek. For these beds, which have an estimated thickness of 1000 feet, the name Palm Spring formation is proposed. This name is derived from the name of a spring along the lower part of Vallecito Creek, which is designated as the type region. Vallecito Creek is a southeastward-flowing tributary entering Carrizo Creek about a mile above the old stage station. These beds have the appearance of nonmarine deposits, but the lower part may have been laid down in brackish water.

Woodring (1932) did not publish a geologic map of the lithostratigraphic units he described; whether he explored farther into the badlands north of Carrizo Creek and east of Vallecito Creek is not known. Therefore, his concept of the stratigraphic and areal extent of the Palm Spring Formation is indeterminate. He wrote that the Palm Spring Formation occurs mainly in the area around Carrizo Mountain (south side of Carrizo Creek) and on the west side of the Colorado Desert between Fish Creek Mountain and the Santa Rosa Mountains.

Other authors interpreted Woodring's (1932) original description of the Palm Spring Formation with either a restricted concept (e.g., Dibblee 1954, 1984; G. T. Jefferson 1998, personal correspondence) or an expanded concept (e.g., Woodard 1962, 1963; Winker 1987, Cassiliano 1998a) as to which rocks to include in the Palm Spring Formation. The concern over the lithologic content of the original Palm Spring Formation, and hence its stratigraphic extent, results from Woodring's (1932) describing rocks of a particular lithology near a specific geographic location (CS on plate 1) in one stream valley, but then designating the type region (MO on plate 1) in another stream valley in which the rocks have a very different lithology.

The restricted concept (Dibblee 1954, 1984; G. T. Jefferson 1998, personal correspondence) accepts only the lithology exposed near the old stage station in Carrizo Creek as a valid basis for the unit (CS on plate 1); that is, the restricted concept considers only the first two sentences of Woodring's description as the valid definition of the Palm Spring Formation. The rocks included in the restricted concept form most of the lower part of the Palm Spring Formation (Arroyo Diablo Formation of this paper) and often are the only rocks of the Palm Spring Formation exposed in areas of the Salton Trough outside FCVC.

The expanded interpretation of Woodring's Palm Spring Formation includes the Arroyo Diablo Formation of this paper, plus the rocks exposed in the vicinity of Palm Spring (MO on plate 1), and the rocks exposed in the valley of Vallecito Creek; that is, the expanded concept also considers the third and fourth sentences of Woodring's original description to be a part of the valid definition of the original Palm Spring Formation. The rocks near the spring and in Vallecito Creek (CS on plate 1) consist of arkosic, medium- to coarse-grained, tan and gray sandstone, and tan siltstone (the Hueso Formation of this paper) (Woodard 1962, 1963; Winker 1987; Cassiliano 1998a) and are therefore lithologically unlike those near the stage station. The expanded concept emphasizes that Woodring designated the rocks along the lower part of Vallecito Creek as the type region.

This debate over the restricted and expanded concepts of the Palm Spring Formation applies to FCVC. It is here that either informal names have been applied to the rocks overlying the brown and red sandstones and siltstones of the lower Palm Spring Formation (restricted concept) or published descriptions are vague and open to considerable interpretation. Also, the FCVC basin contains the stratotypes of the Palm Spring Formation and Canebrake Conglomerate (in both their original and revised definitions), as well as the stratotypes of the new formations this paper proposes. In other areas of the Salton Trough, the rocks overlying the lower Palm Spring Formation (Arroyo Diablo Formation of this paper) have been formally named (Dibblee 1954; Tarbet and Holman 1944) (figure 2).

Raising the Palm Spring Formation to group rank incorporates both the restricted and the expanded interpretation into a unified concept of these paleontologically and geologically important rocks. The following discussion continues tracing the history of the two interpretations.

Tarbet's (1951) lithologic description of the Palm Spring Formation is similar to Woodring's (1932). However, a generalized geo-

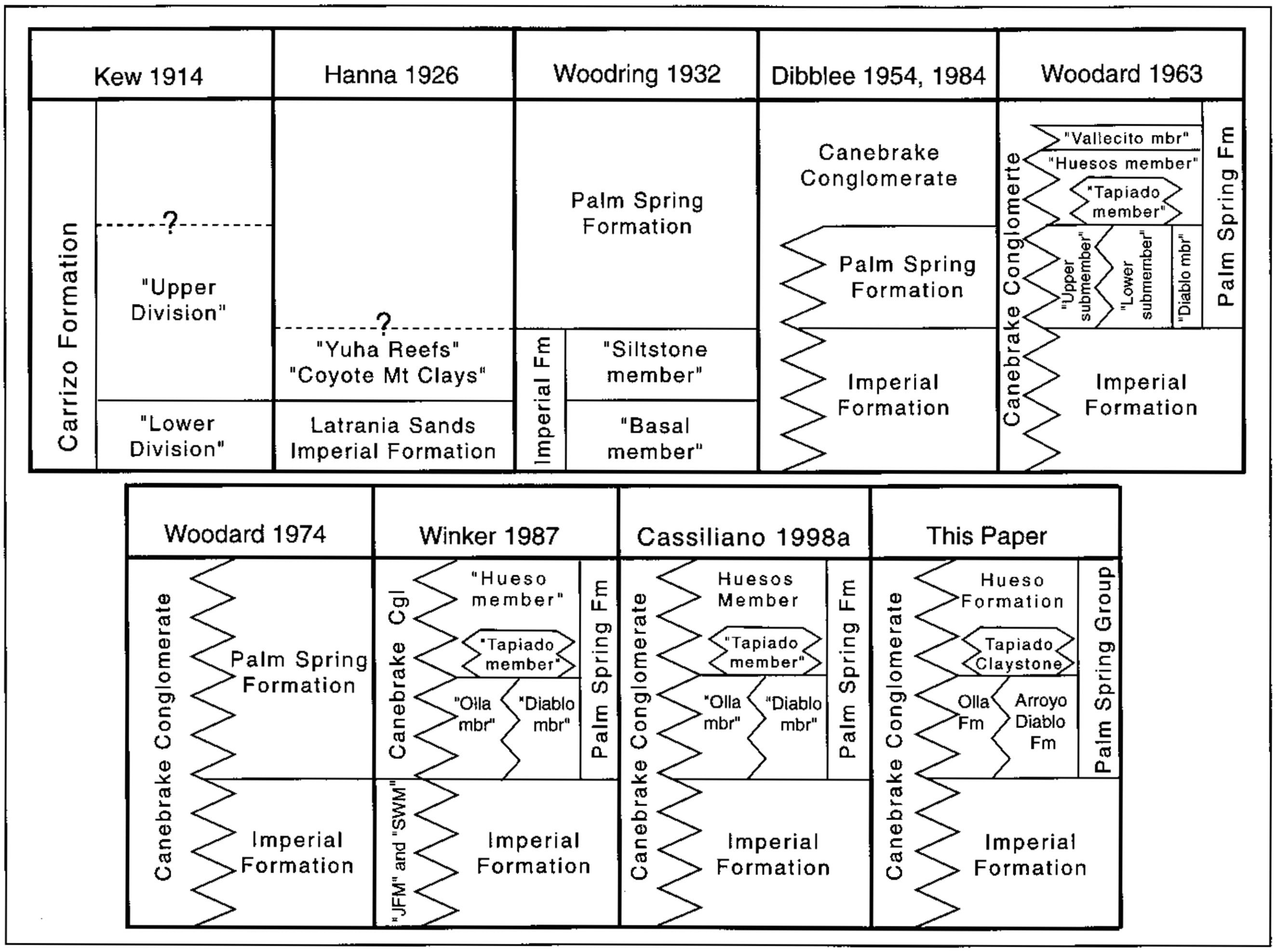

Figure 4. Synonymy chart for the Palm Spring Formation/Group in the Fish Creek-Vallecito Creek (FCVC) basin. Lithostratigraphic names in quotation marks are informal names. JFM is the informal Jackson Fork Member of Winker (1987). SWM is the informal Stone Wash Member of Winker (1987). The Imperial Formation is shown to place the Palm Spring Formation/Group in its proper superpositional context. Note the change in spelling from *Huesos* to *Hueso* to conform to the name on the Arroyo Tapiado Quadrangle. The upper limit of the Palm Spring Formation of Woodring (1932) is problematic, as discussed in the text.

logic map of the Imperial Valley by Tarbet (1951, fig. 40) shows the Palm Spring Formation extending to the Elsinore Fault zone in Vallecito Creek. Field observations show that the rocks mapped by Tarbet as Palm Spring Formation in Vallecito Creek are lithologically unlike those described in his text but like those of the proposed Hueso Formation.

The restricted concept of the Palm Spring Formation begins with Dibblee (1954), which is the first comprehensive study of the geology of the Salton Trough. The text description of the Palm Spring Formation leaves much to the interpretation of the reader because of its lack of detail. However, Dibblee's geologic map of the Salton Trough (1954, plate 2), including FCVC, at a scale of 1:375,000, shows that he restricted the Palm Spring Formation to the lithology exposed near the stage station in Carrizo Creek (CS on plate 1), as described by Woodring (1932). This restricted concept is clear, although the map scale is small in comparison with the large-scale, unpublished geologic maps of Woodard (1963, 1974) and Winker (1987).

Dibblee (1954) also named a new lithostratigraphic unit, the Canebrake Conglomerate, that is exposed throughout the Salton Trough. The type section of the Canebrake Conglomerate is along the south flank of the Vallecito Mountains that form the northern border of FCVC. Dibblee (1954, 23) proposed the Canebrake Conglomerate for all the rocks overlying and intertonguing with the restricted Palm Spring Formation:

> Southeastward along the strike, the lower 4,000 feet of the conglomerate grades into the Imperial and Palm Spring formations, and the upper 3,700 feet persists basinward into Carrizo Valley as a gray pebble and cobble conglomerate that rests on the Palm Spring formation.

This statement is significant because the restricted concept of the Palm Spring Formation includes in the Canebrake Conglomerate all the rocks in FCVC above and lateral to the chocolate-brown and brick-red sandstone and siltstone exposed at the Carrizo Stage Station (CS on plate 1). According to the restricted concept, the Canebrake Conglomerate includes, as a finer basinward facies, the arkosic sandstones and siltstones near Mesquite Oasis (MO on plate 1) and along the lower part of Vallecito Creek, the Hueso Formation of this revision, as well as the green claystones of the Tapiado Claystone, also of this revision. The Canebrake Conglomerate also includes, in this interpretation, the rocks laterally transitional between it and the restricted Palm Spring Formation, the Olla Formation of this revision.

Field observations show that the Canebrake Conglomerate does grade into and intertongue with the Imperial Formation and Palm Spring Formation southeast of the Vallecito Mountains. However, in FCVC, the lithology of the upper 1,128 m of the Canebrake Conglomerate, as published by Dibblee (1954), does not correspond exactly to that of the basinward rocks overlying the restricted Palm Spring Formation. Field observations show that the overlying part of the Canebrake Conglomerate grades basinward into arkosic, medium- to coarse-grained, tan and gray sandstone, and tan siltstone, i.e., the Hueso Formation and Olla Formation. Dibblee (1954) does not mention the very distinctive green claystone lens as part of the Palm Spring Formation or Canebrake Conglomerate, the Tapiado Claystone of this paper. However, his geologic map suggests that he did include these rocks in his concept of the Canebrake Conglomerate.

Significantly, in the legend for the geologic map, Dibblee (1954) writes that the Canebrake Conglomerate is the "torrential facies of Palm Spring and Imperial Formations." This implies that he recognized that the sedimentary units in FCVC are facies of a single depositional system and that those facies can be designated as formal lithostratigraphic units, a procedure allowed by the NASC (1983). By proposing that the Palm Spring Formation be raised to a group and its major facies designated as formations, this paper brings the process begun by Dibblee (1954) to its logical conclusion.

The expanded concept of the Palm Spring Formation begins with Woodard (1962), an abstract based on field work and extensive mapping in FCVC with the intent to revise the stratigraphic column of Dibblee (1954). This publication proposes no new names. It is the first publication to refer to the mammal fossils from FCVC as coming from the Palm Spring Formation, rather than from the Canebrake Conglomerate, as originally reported by Downs (1957). It is clear that Woodard considered the rocks overlying the restricted Palm Spring Formation as part of that unit, rather than as part of the Canebrake Conglomerate.

Downs and Woodard (1962, 21) described the vertebrate fauna of FCVC as follows: "The fauna occurs throughout approximately 2500 feet of medium- and coarse-grained arkosic arenites, siltstones, and silty sandstones of the upper Palm Spring formation."

Woodard further elaborated upon his expanded concept of the Palm Spring Formation in FCVC in his 1963 Ph.D. dissertation. This work is significant for several reasons. First, it provided the first detailed map of the geology of FCVC, mapped at a scale of 1:24,000. Second, Woodard provided detailed lithologic descriptions of all the rock units in FCVC. Third, he explained his reasoning for expanding the Palm Spring Formation to include the rocks above those near the stage station and the rocks transitional with the Canebrake Conglomerate. Fourth, this unpublished dissertation became the basis for the expanded concept of the Palm Spring Formation used by subsequent researchers.

Woodard (1963) proposed an informal subdivision of the Palm Spring Formation into four parts. The lower part of the formation he called the *Diablo Member,* which he further divided into upper and lower submembers. These submembers are not superposed but are lateral lithofacies reflecting different provenance suites (Winker 1987). The lower submember of the Diablo Member includes the rocks described by Woodring (1932) in Carrizo Creek, i.e., the rocks that form the basis for the restricted concept of the Palm Spring Formation. Woodard divided the upper part of the Palm Spring Formation into three members. The *Tapiado Member* refers to a green claystone lens above the Diablo Member and otherwise surrounded by the *Huesos Member.* The Huesos Member comprises the majority of the Palm Spring Formation above the Diablo Member. The *Vallecito Member* describes a coarse-grained, micaceous, arkosic sandstone facies found in a series of ten en echelon fault blocks in the FCVC area. Unfortunately, Woodard's (1963) nomenclature is invalid according to Article 4 of the NASC (1983), which does not recognize stratigraphic names proposed in dissertations and theses as formally published.

In 1974, Woodard redefined the stratigraphic nomenclature in the vicinity of Split Mountain Gorge on the east side of FCVC and, by extension, other areas in the Salton Trough. Unfortunately, Woodard (1974, fig. 2) did not formalize his 1963 member-level units in the Palm Spring Formation. However, his description of the Palm Spring Formation in the 1974 publication clearly indicates that his concept of this unit includes a greater stratigraphic extent than that mapped by Dibblee (1954).

Hoggatt (1979) mapped the rocks in the vicinity of Sweeney Pass, immediately south of FCVC. The accompanying report shows that she followed Woodard (1963) for the stratigraphic nomenclature of the post-Imperial Formation terrestrial rock units and the definition of those units. According to Hoggatt's report, only the lower part of the Diablo Member (Arroyo Diablo Formation) is exposed in the Sweeney Pass area. She also observed that where the Diablo Member approaches the mountain fronts, it intertongues with the Canebrake Conglomerate. Hoggatt did not recognize other subdivisions of the Palm Spring Formation, in the sense of Woodard (1963), in the Sweeney Pass area.

In 1984, Woodard revised the geologic map of the FCVC area made for his 1963 dissertation. This unpublished map clearly shows that he included in the Palm Spring Formation rocks above and lateral to the rocks exposed near the stage station. The map still shows the division of the Palm Spring Formation into members, but the accompanying columnar section does not. This map was included with the guidebook for the Society of Vertebrate Paleontology field trip to the Anza-Borrego Desert (White *et al.* 1991).

Winker (1987) revised, in part, the members of the Palm Spring Formation proposed by Woodard (1963). He retained the Hueso Member and expanded its concept to include the Vallecito Member as a local facies. He retained the Tapiado Member as originally proposed. He restricted the Diablo Member to Woodard's (1963) lower submember and proposed the upper submember as the *Olla Member.* There is a typographical error in Winker (1987, 201) with regard to the Diablo Member. On this page he calls the lower submember the *Olla Member* and the upper submember the *Diablo Member.* However, Winker's descriptions and genetic characterizations of the Olla and Diablo Members, his fig. 1.9, and text on page 221 clearly show that the statement on page 201 is erroneous. Winker's subdivisions of the Palm Spring Formation are informal, because like Woodard's (1963) they were proposed in an unpublished Ph.D. dissertation. Winker's detailed mapping extended many of the *members* of the Palm Spring Formation to areas adjacent to the FCVC basin, such as the Carrizo Badlands and Sweeney Pass, as well as to nearby basins, such as BSFB (Fig. 2).

Remeika (1991) elevated the Diablo Member of Winker (1987) to the rank of formation *(Diablo Formation)* and revised the Palm Spring Formation to include only rocks in FCVC that lie above Winker's Diablo Member. Remeika's proposals were made in an abstract, a medium that does not meet the requirements for valid publication of lithostratigraphic names (NASC, 1983, Article 4). Furthermore, Remeika's proposed changes do not take into account the rocks laterally equivalent to his Diablo Formation (Olla Formation). Remeika's justification for the nomenclatural changes was based on the distinction between the Colorado River provenance of the Diablo Formation and the local provenance of the rocks above the Diablo Formation in the FCVC area. However, naming of lithostratigraphic units is based not on their provenance (an inference) (NASC, 1983, Article 22d), but on their lithology (an observation).

Remeika's (1991) nomenclatural changes were subsequently used in several publications concerned with the paleontology and

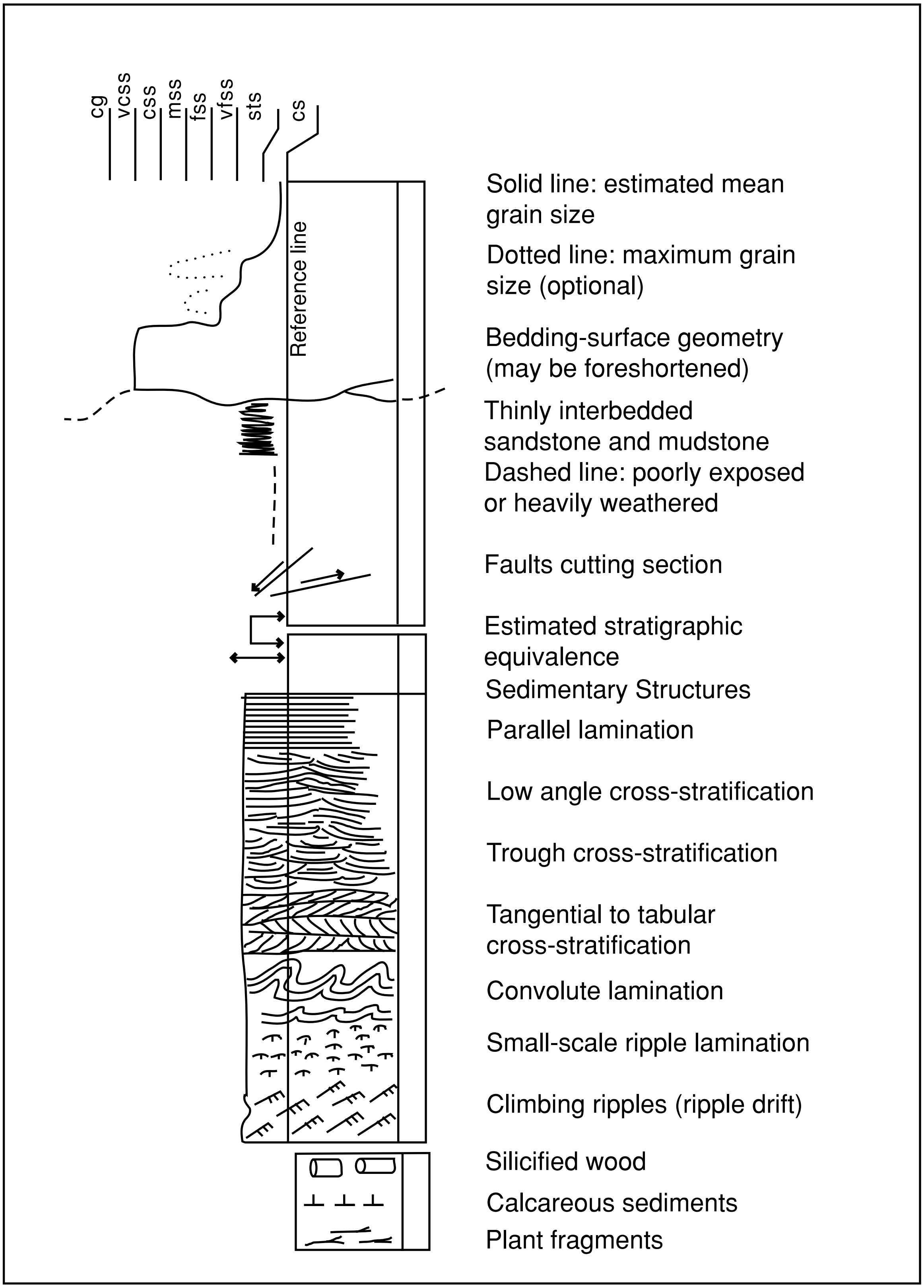

Figure 5. Key for figures 7–12. Based on fig. 1.13 of Winker (1987). Used with permission of C. D. Winker. cs = claystone, sts = siltstone, vfss = very fine-grained sandstone, fss = fine-grained sandstone, mss = medium-grained sandstone, css = coarse-grained sandstone, vcss = very coarse-grained sandstone, cg = conglomerate.

geology of the Salton Trough (Remeika and Jefferson 1993; Reynolds and Remeika 1993; Remeika 1994; Remeika *et al.* 1995). These publications gave Remeika's nomenclatural changes a legitimacy they did not warrant.

Cassiliano (1998a) proposed the *Hueso Member* as a formal lithostratigraphic unit within the Palm Spring Formation. Thus, this paper does not address the Hueso Member, except as a summary and as a proposal to change its rank to that of a formation. Two reviewers of this paper noted a discrepancy in the spelling of the unit name. Woodard (1963), who first used the name, and Cassiliano (1994, 1997, 1998a, 1999) spelled the name of the unit *Huesos*; Winker (1987) and the U. S. Geological Survey spelled the name *Hueso.* The author agrees with the reviewers that the spelling of the name should be standardized to avoid future problems. Because this unit takes its name from *Arroyo Hueso,* the spelling on the Arroyo Tapiado Quadrangle by the U. S. Geological Survey, the name is emended to *Hueso Formation.* The Vallecito Member of Woodard (1963) is included in the Hueso Formation, in agreement with Winker's (1987) suggestion. Cassiliano (1998a) left unresolved the status of the Diablo, Olla, and Tapiado Members, a situation this paper corrects.

G. T. Jefferson (1998, personal correspondence), in a preliminary review of this paper, pointed out several problems with regard to the stratigraphic nomenclature of the Palm Spring Formation. The main point of his argument is that the Palm Spring Formation was extended by Woodard (1963) beyond the original stratigraphic and geographic limits conceived by Woodring (1932) and that Woodard misinterpreted or ignored the work of Dibblee (1954) on the Canebrake Conglomerate and its relationship to the Palm Spring Formation. According to Jefferson, Woodard's nomenclatural error was then continued by many other geologists and paleontologists working in the Salton Trough.

In view of the vague descriptions of the Palm Spring Formation originally given by Woodring (1932) and Dibblee (1954), nearly all subsequent workers (e.g., White and Downs 1961; Downs and White 1968; White 1968, 1969, 1984; Opdyke *et al.* 1977; Becker and White 1981; Johnson *et al.* 1983; Lindsay *et al.* 1987; Winker 1987; Martin and Prince 1989; Norell 1989; Downs and Miller 1994; Cassiliano 1994, 1997, 1998a, 1998b, 1999) have accepted an expanded concept of the Palm Spring Formation.

The term *Palm Spring Formation* has been used somewhat carelessly in some areas of the Salton Trough, areas where the Palm Spring Formation (restricted concept; Arroyo Diablo Formation of this paper) lithology does not occur. One such area is the Mecca Hills (7 in figure 1). Dibblee (1954) reported that the Palm Spring Formation crops out in the Mecca Hills and that in this area, the Palm Spring Formation grades into the Canebrake Conglomerate, as he defined that unit. Winker (1987) also noted that the term *Palm Spring Formation* has been used in the Mecca Hills for nonmarine, terrigenous rocks overlying the Imperial Formation. However, he stated that these rocks are lithologically unlike those included in the Palm Spring Formation (restricted concept). Winker's field observations show that the Palm Spring Formation in the Mecca Hills is composed of coarse-grained, conglomeratic rock, unlike the finer-grained sandstones, siltstones, and claystones of the Palm Spring Formation (restricted concept). Winker (1987, fig. 7.1) shows the Mecca Hills stratigraphic section above the Imperial Formation to be formed by an unnamed lithostratigraphic unit formed by locally derived, basin-margin alluvium.

Clearly, the stratigraphy of the Mecca Hills proposed by Dibblee (1954) conflicts with that proposed by Winker (1987). This problem remains unresolved in this paper because the author has not field-checked the Mecca Hills. The Mecca Hills terrigenous rocks may eventually be assigned to the Canebrake Conglomerate of the Palm Spring Group, or to the Ocotillo Formation, or to a new lithostratigraphic unit. This problem does illustrate the need to standardize the stratigraphic nomenclature in the Salton Trough.

PROVENANCE SUITES IN THE PALM SPRING GROUP

Provenance studies place the Palm Spring Group and other sedimentary units in their proper context within the overall geologic history of the Salton Trough (figure 3). Woodring (1932) speculated that the Palm Spring Formation, as he conceived it, represented deposits of the ancestral Colorado River. Basing his observations on composition and texture, Woodard (1963) suggested that the clastic rocks in the Salton Trough had two probable sources, the nearby Peninsular Ranges and the drainage of the Colorado River.

Reworked late Cretaceous foraminifera (Merriam and Bandy 1965) and reworked Cretaceous pollen, spores, and dinoflagellates (Fleming 1994) provide evidence that some of the clastic rocks have a provenance outside the Salton Trough. These fossils occur within the Imperial Formation and Arroyo Diablo Formation. Sources for these fossils on the Colorado Plateau led Merriam and Bandy (1965) and Fleming (1994) to suggest that the Imperial Formation and parts of the Palm Spring Group were deposited by the Colorado River.

Winker's (1987) petrographic study indicates that most clastic sedimentary rocks in the Salton Trough can be grouped into two descriptive classes, *L-suite* and *C-suite* (Cassiliano 1998a, table 2). C-suite rocks are attributed to sediment brought into the Salton Trough by the Colorado River from sources on the Colorado Plateau. L-suite rocks are attributed to sources in the surrounding mountain ranges and deposited by local stream systems. Winker's (1987) results do not directly apply to claystone. Claystone in the Salton Trough is assigned to the C- or L-suite based on the associated sandstone, siltstone, or conglomerate. However, as noted above, some claystones can be assigned to the C-suite based on their reworked microfossil content.

The textural, compositional, and color-value differences Winker described (1987) are readily observable in the field, create unique mappable lithologies, and provide a means of subdividing the Palm Spring Group into lithostratigraphic units that may be regarded as formations.

THE PALM SPRING GROUP

Elevation of the Palm Spring Formation to group rank accommodates both the restricted and expanded concepts regarding the content of the original Palm Spring Formation. The original name is preserved and the rocks of both concepts are included in the unit as separate formations. The Palm Spring Group preserves the original, if vaguely stated, concept of this rock unit that Woodring (1932) proposed. The Palm Spring name is taken from the spring of the same name in Mesquite Oasis (MO on plate 1).

The Arroyo Diablo Formation retains Dibblee's (1954) restricted concept of the Palm Spring Formation. Recognition of the Olla Formation, Tapiado Claystone, and Hueso Formation as subdivisions of the Palm Spring Group accommodates the expanded concept of Woodard (1962, 1963, 1974), Winker (1987) and Cassiliano (1994, 1997, 1998a, 1999) and results in restriction of the Canebrake Conglomerate of Dibblee (1954) to its dominantly conglomeratic lithology. In addition, placement of the Canebrake Conglomerate in the Palm Spring Group retains the unity of the Canebrake Conglomerate with the Olla Formation, Tapiado Claystone, and Hueso Formation.

Because this is a revision, the stratotype of the Palm Spring Group is the same as that of the original Palm Spring Formation (NASC, 1983, Articles 19e and 22c). As discussed above, there is debate over the lithologic content of the original Palm Spring Formation, its stratigraphic extent, and, by extension, the stratotype. The problem arises from Woodring's (1932) vague description of the unit. A literal reading of Woodring places the stratotype in the lower part of the valley of Vallecito Creek (MO on plate 1), even though he did not describe

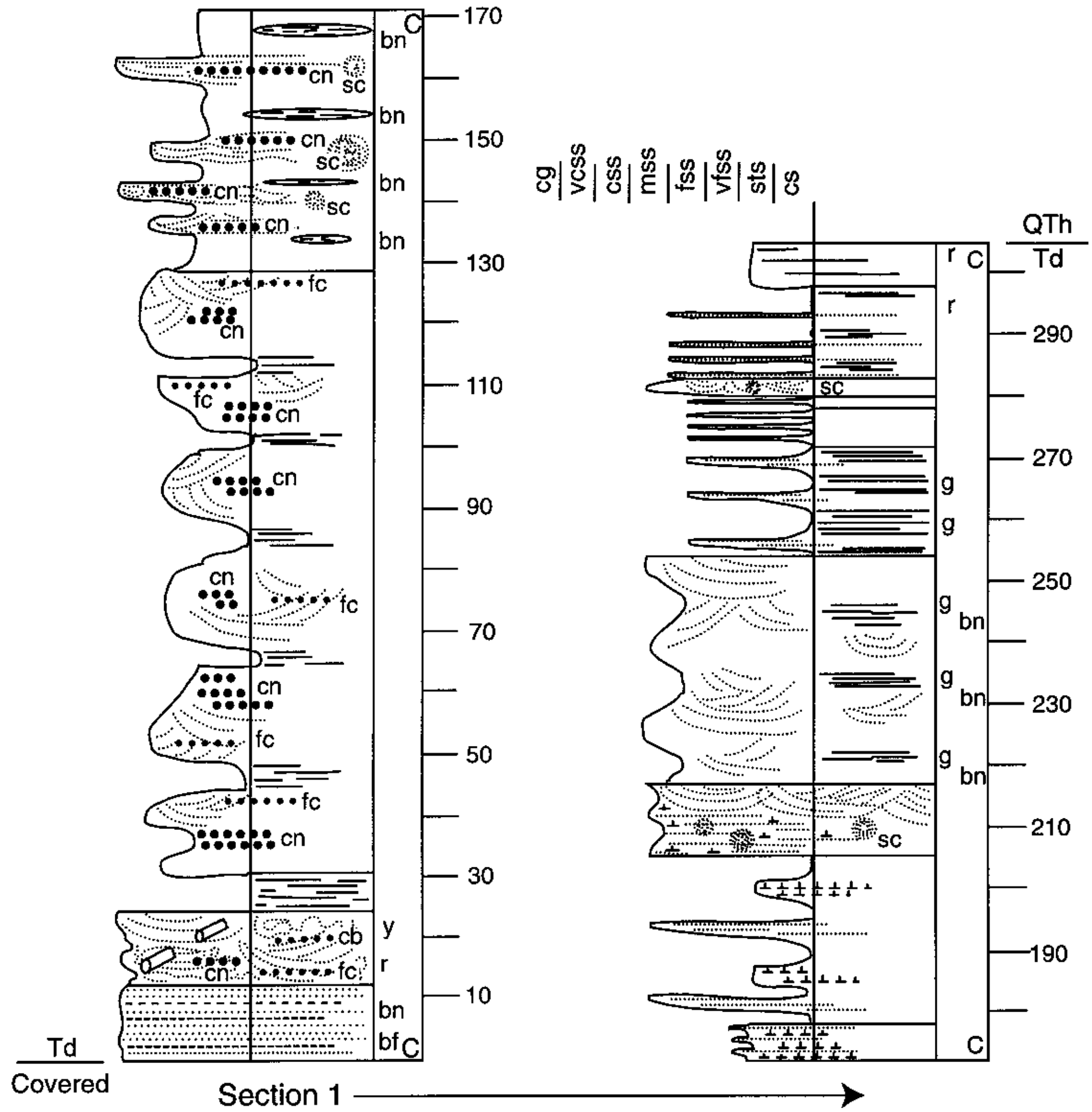

Figure 6. Graphic log of the stratotype of the Arroyo Diablo Formation (1 on plate 1), showing the contact between the Arroyo Diablo Formation (Td) and the Hueso Formation (QTh). Thickness in meters. Based on log (table 1) of Woodard (1963). Used with permission of C. D. Winker. C = C-suite rock, fc = ferruginous concretions, cn = calcareous nodules, cb = clayballs, sc = sandstone concretions, bn = brown, r = red, g = gray or greenish gray.

the rocks in Vallecito Creek. Another consequence of this is that the rocks described by Woodring in the original Palm Spring Formation, those near the stage station in Carrizo Creek (CS on plate 1), are not in the area he designated as the stratotype.

To accommodate the proposed revision, the author expands the stratotype to include the area from Mesquite Oasis to the area of Carrizo Creek where Woodring actually described rocks included in the original Palm Spring Formation (CS to MO on plate 1). Although a single continuous stratotype section for the whole Palm Spring Group cannot be measured because of faulting, terraces, and erosion, expansion of the type area results in inclusion in the stratotype of rocks typical of both the restricted and expanded concepts.

Arroyo Diablo Formation of the Palm Spring Group

The name *Arroyo Diablo Formation* is taken from *Arroyo Seco del Diablo,* a dry wash in the FCVC area of Anza-Borrego Desert State Park in California. Woodard (1963) proposed the name as the informal *Diablo Member.* As Jefferson (personal correspondence, 1998) noted, the name *Diablo* is preoccupied (Clark 1944; Ferguson *et al.* 1953). Thus, Woodard's original name is here modified to *Arroyo Diablo Formation* and is restricted to Woodard's (1963) lower submember of the Diablo Member. The Arroyo Diablo Formation is equivalent to the rocks included in the restricted interpretation of the original Palm Spring Formation.

Stratotype.—Woodard (1963) measured and described a portion of the Arroyo Diablo Formation in Section 33, T. 14 S., R. 8 E., Arroyo Tapiado 7.5 Minute Quadrangle, 1:24,000, San Diego County, California (1 on plate 1). This section is typical of the Arroyo Diablo Formation and represents Woodard's concept of the unit, and so should be regarded as the stratotype (figures 5 and 6; table 1). The stratotype is located in fault block E in FCVC, about 6.6 km west of the stage station in Carrizo Creek where Woodring (1932) first described the Palm Spring Formation. This section shows the contact between the Arroyo Diablo Formation and the overlying Hueso Formation but not the contact between the Arroyo Diablo Formation and the underlying Imperial Formation. Substantial cover of the Arroyo Diablo Formation by upper Pleistocene terrace gravels (plate 1) prevents measurement of a continuous section from the base to the top of this unit in FCVC. However, reference sections that provide additional information about the lithologies and bedding structures of the Arroyo Diablo Formation were measured by Winker (1987, figs. 4.30, 5.3–5.10) (2–4 on plate 1; figures 7–9) in Fish Creek Wash, Diablo Canyon, and Arroyo Tapiado. These reference sections cover significant portions of the Arroyo Diablo Formation below the level measured by Woodard (1963) and show the contacts with the Tapiado Claystone (figure 9) and the Imperial Formation (figure 7).

Unit Description.—The lithologic description of the Arroyo Diablo Formation is based on information in Woodard (1963) and Winker (1987) and supplemented by field reconnaissance. Throughout its stratigraphic and geographic extent, the Arroyo Diablo Formation is a homogeneous unit easily recognized by its color and lithology. Sandstone and siltstone are pale orange or pink; claystone is reddish-brown with occasional thin layers that are green-gray to blue-gray (figure 10). Color values of the Arroyo Diablo Formation and other units in the Palm Spring Group are made without reference to standard color charts. The actual color values of the rocks vary considerably, depending on the angle of sunlight, whether the rock is wet or dry, and whether the surface is weathered or exposed by recent digging.

The Arroyo Diablo Formation comprises two lithofacies. Lithofacies 1 constitutes about 80 percent of the Arroyo Diablo Formation and consists of fine- to very fine-grained, massive to thick-bedded C-suite sandstone (Winker 1987), usually occurring as upward-fining cycles that are 5 to 10 m thick. The bases of sandstone horizons are sharply defined and usually discordant with subjacent strata. The top of a sandstone horizon may be sharp where it is truncated by another sandstone or gradational into siltstone and claystone where an upward-fining cycle is completely preserved. Sandstone

TABLE 1. Measured section through the stratotype of the Arroyo Diablo Formation in Section 33, T 14 S., R 8 E., Arroyo Tapiado 7.5 Minute Quadrangle, 1:24,000. Beginning along the south wall of Arroyo Tapiado southwest to the contact with the Hueso member section(1 in plate 1). From Woodard (1963, 53–55). Original measurements in feet.

1. Silty Sandstone:	medium to fine grained, evenly textured, moderately to well-consolidated, brown and buff.	+12 m
2. Feldspathic Arenite:	medium and fine grained, massive or crossbedded, well-consolidated; yellowish- and reddish-brown ferruginous concretions, clayballs, silicified wood, calcareous siltstone nodules.	12 m
3. Claystone:	compact, brown, massive.	6 m
4. Silty Sandstone:	mainly fine grained, compact, massive or crossbedded, interlaminated lensing dark-brown claystones; ferruginous cemented sandstone concretions; nodular gray calcareous siltstone lenses.	98 m
5. Siltstone:	drab gray and brown, massive; interbedded brown claystone lenses, 0.6 to 1.8 meters thick; medium or fine grained arkosic sandstones; sandstone concretions; calcareous nodules.	43 m
6. Siltstone:	brown and drab gray, calcareous; fine-grained, gray arkosic sandstone laminae; moderately to poorly consolidated.	6 m
7. Claystone:	brown, massive and compact; interlaminated medium-grained silty sandstone lenses; gray, massive, calcareous siltstones.	27 m
8. Sandstone:	gray, nodular, calcareous; grades into massive crossbedded arkosic sandstone.	12 m
9. Silty Sandstone:	massive, crossbedded, medium to fine grained; interbedded gray and brown mudstone and sandstone lentils.	37 m
10. Claystone:	dark brown and buff, massive and well-laminated; gypsiferous claystone, greenish gray; arkosic sandstone, fine grained, loosely consolidated, well-sorted.	18 m
11. Claystone:	brown, massive and compact; interlaminated fine-grained gray sandstone lenses.	6 m
12. Claystone:	brown and gray, massive lenses; interbedded gray calcareous sandstones.	3 m
13. Sandstone:	gray, massive and crossbedded, medium to fine grained, poorly consolidated and obscurely bedded; sandstone concretions.	3 m
14. Claystone:	dark brown and reddish, massive or poorly bedded, compact; interbedded sandstone laminae.	15 m
15. Siltstone:	reddish-brown, massive, compact.	6 m
Total Thickness:		+304 m

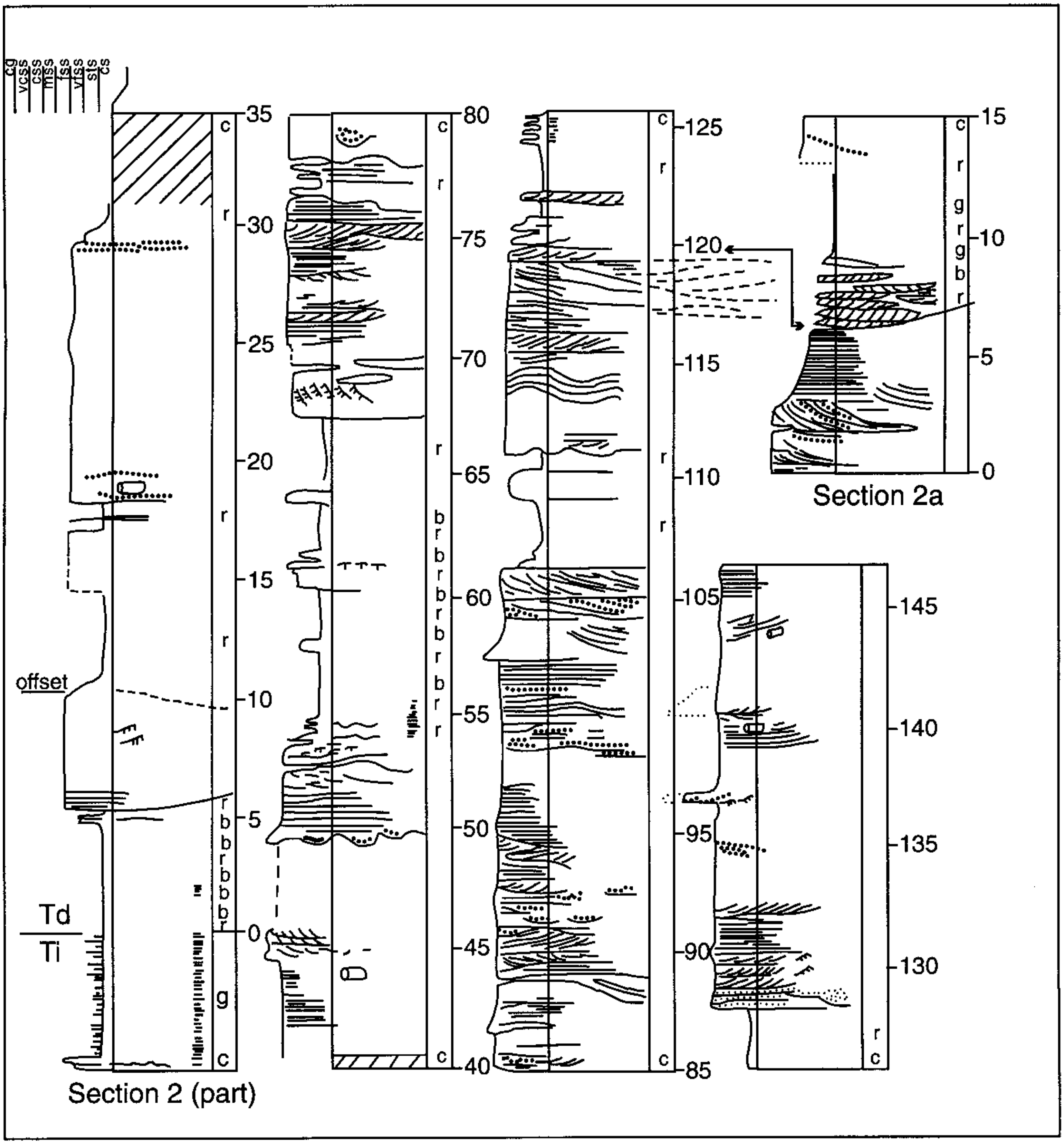

Figure 7. Graphic log of Arroyo Diablo Formation reference section (2 on plate 1) showing the contact between the Arroyo Diablo Formation (Td) and the Imperial Formation (Ti). Used with permission of C. D. Winker. C = C-suite rock, r = red, b = blue or blue-green, g = gray or olive-gray. Reproduction, with slight modification, of fig. 4.30 of Winker (1987).

horizons exhibit a lenticular geometry and commonly coalesce to form thick bodies of sandstone. Bedding structures in lithofacies 1 sandstone include low-angle trough cross-stratification, ripple and parallel lamination, and convolute lamination up to 2 m thick.

Lithofacies 2 forms about 20 percent of the Arroyo Diablo Formation and comprises massively bedded, reddish-brown claystone with interbedded siltstone and sandstone (Winker 1987). In some areas mud cracks, calcareous nodules, and calcareous intraclasts are common. Ripple and climbing-ripple lamination are the common bedding types in these beds.

Contacts.—The contact between the Arroyo Diablo Formation and the subjacent Imperial Formation is gradational, as Woodring (1932) noted. According to Woodard (1963) and Winker (1987), the main criterion to distinguish the Arroyo Diablo Formation from the

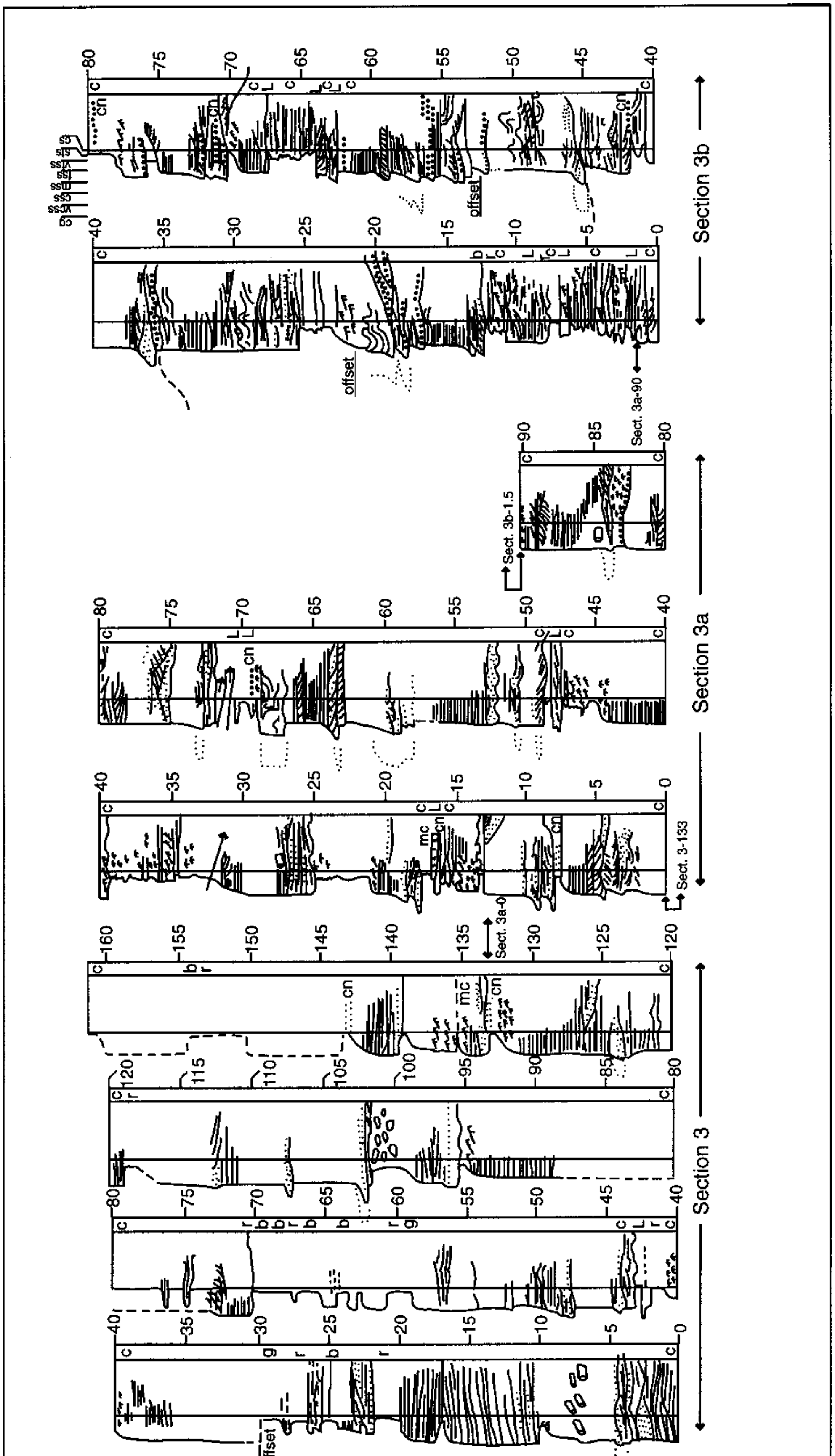

Figure 8. Graphic log of Arroyo Diablo Formation reference section (3 on plate 1). Thickness in meters. Reproduction, with slight modification, of figs. 5.3, 5.4, and 5.5 of Winker (1987). Used with permission of C. D. Winker. C = C-suite rock, L = L-suite rock, r = red, b = blue or blue-green, g = gray or olive-gray, mc = mud cracks, cn = calcareous nodules.

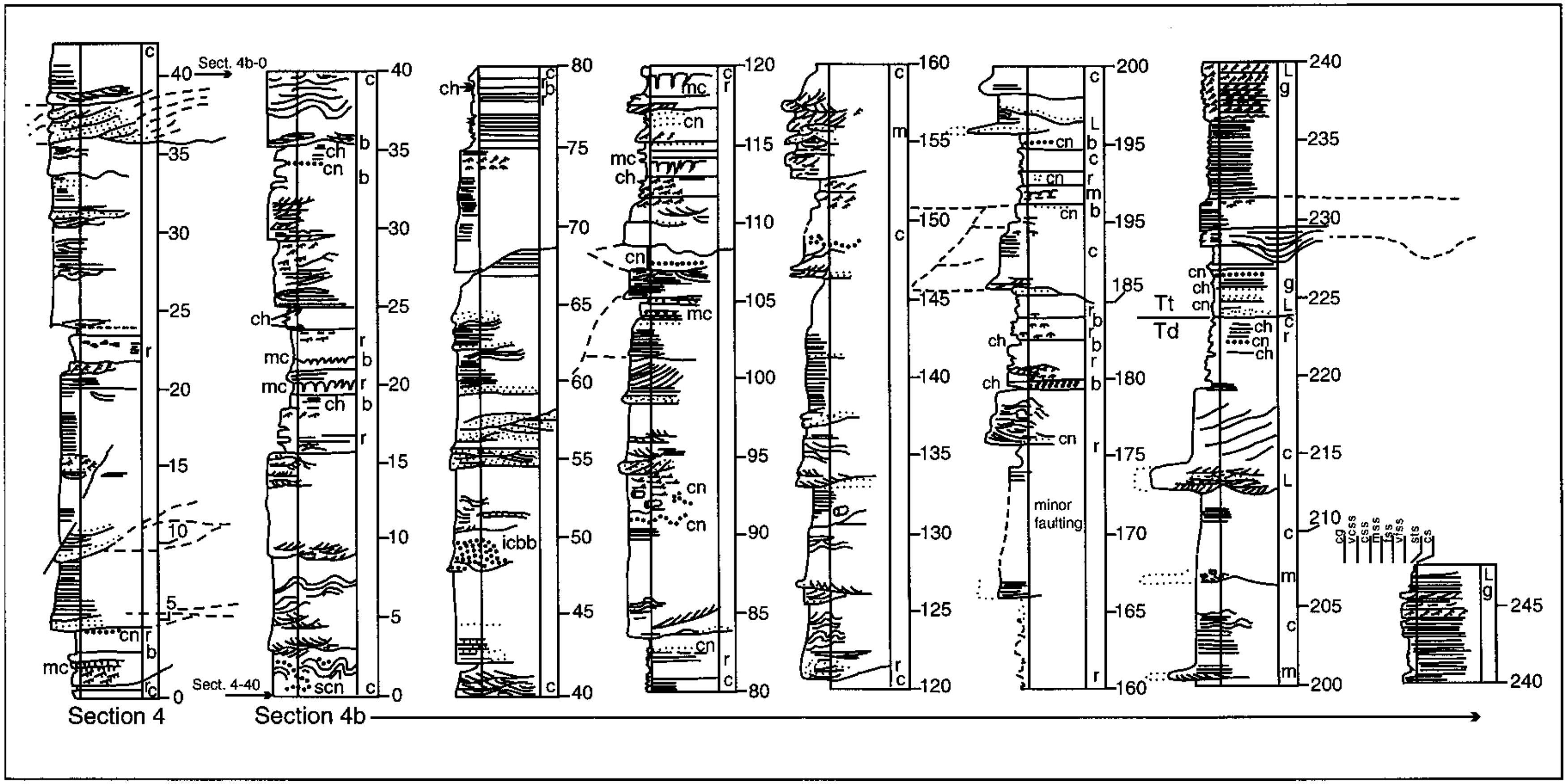

Figure 9. Graphic log of Arroyo Diablo Formation reference section showing the contact between the Arroyo Diablo Formation (Td) and Tapiado Claystone (Tt) (4 on plate 1). Thickness in meters. Reproduction, with slight modification, of figs. 5.7 (part), 5.8, and 5.9 of Winker (1987). Used with permission of C. D. Winker. C = C-suite rock, L = L-suite rock, M = mixed C- and L-suite rocks, r = red, b = blue or blue-green, g = gray or olive-gray, mc = mud cracks, ch = calcareous horizon, cn = calcareous nodules, icbb = intraclast boulder bed, scn = septarian calcareous nodules.

Figure 10. Typical exposure of the Arroyo Diablo Formation seen in Arroyo Seco del Diablo; channel sandstone of lithofacies 1 cutting into overbank claystone and siltstone of lithofacies 2.

Imperial Formation is a change in color. Over a thickness of about 300 m in the uppermost Imperial Formation, sandstone and siltstone change from yellow-gray to pale orange or pink, and claystone changes from gray to reddish-brown. Additionally, wavy bedding, characteristic of the uppermost Imperial Formation, does not occur in the Arroyo Diablo Formation (Winker 1987). Woodard (1963) did not present a specific means of locating the contact within the transition between the Arroyo Diablo Formation and Imperial Formation. Winker (1987) placed the contact at the base of the lowest pale-orange sandstone or reddish-brown claystone at least 2 m thick or at the top of the highest gray claystone at least 2 m thick. The author's field observations corroborate Winker's (1987) criterion.

The contact between the Arroyo Diablo Formation and Olla Formation is also gradational and so must be arbitrarily defined. Winker's (1987) criterion is that the occurrence of at least 20 percent L-suite sandstone and siltstone indicates the change from the Arroyo Diablo Formation to the Olla Formation.

The contact between the Arroyo Diablo Formation and the Hueso Formation and Tapiado Claystone is well defined and laterally persistent. Winker (1987) and Cassiliano (1998a) placed the contact at the top of the stratigraphically highest pale-orange sandstone, pale-orange siltstone, or reddish-brown claystone. This description contrasts with Woodard's (1963), which considered the contact between the Arroyo Diablo Formation and the Hueso Formation and Tapiado Claystone to be gradational.

In the BSFB, the Arroyo Diablo Formation grades laterally and upsection into the lacustrine Borrego Formation (Dibblee 1954, 1984; Winker 1987).

Thickness and Regional Distribution (figures 1 and 2).—The section measured by Woodard (1963) for the stratotype of the Arroyo Diablo Formation is about 304 m thick. Continuous exposure of the Arroyo Diablo Formation in FCVC is limited by upper Pleistocene and Holocene gravels forming West, Middle, South, and East Mesas (plate 1). The approximate thickness of the Arroyo Diablo Formation in the FCVC area is 2,250 m. This figure is based on exposures between and northwest of the mesas, using map distances between the lower and upper contacts with the Imperial Formation and the Hueso Formation, and using an average dip of 24° to the southwest. The thickness of the Arroyo Diablo Formation in other areas in the Salton Trough is comparable to that in FCVC (Winker 1987). The Arroyo Diablo Formation thins to 0 m where it grades laterally into the Olla Formation in the northwest part of the FCVC Basin adjacent to the southeast flank of the Vallecito Mountains.

The distinctive lithology and color of the Arroyo Diablo Formation make it the most recognizable unit in the Palm Spring Group (Winker 1987). Most rocks recognized as the Palm Spring Group in other areas of the Salton Trough are assigned to the Arroyo Diablo Formation (figure 2).

Fossils.—Vertebrate fossils are uncommon in the Arroyo Diablo Formation. Only thirteen localities in the Arroyo Diablo Formation, all from FCVC, have yielded fossils that can be identified to some taxonomic level; other sites produce only unidentifiable fragments (Cassiliano 1997). The taphonomy and ecology of the environment of deposition of the Arroyo Diablo Formation is probably responsible for the rarity of vertebrate fossils (Cassiliano 1997). Invertebrate fossils are also uncommon. Woodard (1963) reported occurrences of the bivalves *Ostrea vespertina*, *Anomia subcosta*, and *Pecten deserti* in outcrops on the north side of Fish Creek, which range from collecting units 8.5 to 26.4 (see Cassiliano 1999 for an explanation of collecting units in the Palm Spring Group). The importance of these fossils lies in their relation to probable shallow marine transgressions in the northern Salton Trough (Cassiliano 1994, 1998a). Silicified wood is locally common in the Arroyo Diablo Formation, especially in FCVC (Remeika *et al.* 1988; Remeika 1994).

Age.—The age of the Arroyo Diablo Formation is constrained by fossil and magnetostratigraphic data in FCVC. Terrestrial vertebrate fossils indicate that the Arroyo Diablo Formation was deposited during the early and early late Pliocene (Downs and White 1968; Cassiliano 1999). Opdyke *et al*. (1977) measured a magnetostratigraphic section through the Palm Spring Group. Johnson *et al.* (1983) tied the section to the Geomagnetic Polarity Time Scale via a fission track date of 2.3 ± 0.4 Ma obtained from a tuff in the Tapiado Claystone. In terms of magnetic chrons, the Arroyo Diablo Formation was deposited during the late Gilbert Chron (Cochiti subchron) and Gauss Chron. Revised absolute dates for chron and subchron boundaries by Cande and Kent (1995) indicate that the Arroyo Diablo Formation was deposited between 4.29 and 3.11 Ma. In terms of NALMAs, the Arroyo Diablo Formation corresponds to the late early to early late Blancan (Cassiliano 1994, 1999).

Outside FCVC, the age of the Arroyo Diablo Formation is not well constrained, because of a lack of fossil, radioisotopic, and magnetostratigraphic data. However, the occurrence of the Arroyo Diablo Formation stratigraphically above the lower Pliocene Imperial Formation (Durham 1950) throughout the Salton Trough, and stratigraphically below the upper Pleistocene Ocotillo Conglomerate (Remeika and Jefferson 1993) in the BSFB suggests a late Pliocene and/or Pleistocene age in this basin. Outside the FCVC basin, the Arroyo Diablo Formation may span the late Blancan to early or middle Irvingtonian NALMAs.

Provenance and Depositional Environment.—Nearly all the rocks in the Arroyo Diablo Formation are assigned to the C-suite by Winker (1987). However, L-suite tongues from the Olla Formation may extend into the Arroyo Diablo Formation where the two units intertongue between Fish Creek and the south flank of the Vallecito Mountains (Winker 1987). Lithofacies 1 is interpreted as paleochannel deposits; lithofacies 2 is interpreted as overbank deposits (Winker 1987). These two fluvial depositional environments were constituents of the subareal delta plain of the Colorado River (Winker 1987). Intercalated with the fluvial deposits are thin sandstone beds deposited in a shallow, brackish marine environment (Cassiliano 1994).

Olla Formation of the Palm Spring Group

The name *Olla Formation,* proposed by Winker (1987), is taken from Olla Wash, a dry tributary of Fish Creek Wash in the FCVC area of Anza-Borrego Desert State Park, California. The Olla Formation is synonymous with Woodard's (1963) upper submember of the Diablo Member.

Stratotype.—Winker (1987, figs. 5.11–5.14) measured several sections in the Olla Formation but did not designate a stratotype. Based on Winker's (1987) measured sections, written description, and the author's field observations, the stratotype for the Olla Formation is taken as Winker's (1987, figs. 5.11–5.12) measured section along Layer Cake Wash (figure 11), a dry wash in the FCVC area of Anza-Borrego Desert State Park. This measured section, about 266 m thick, is the most complete of the measured sections and exhibits the distinctive alternation of C- and L-suite rocks that distinguishes the Olla Formation from other formations of the Palm Spring Group. The stratotype is located in FCVC in Section 12, T. 14 S., R. 7 E. and Sections 6 and 7, T. 14 S., R. 8 E., Arroyo Tapiado 7.5-Minute Quadrangle, 1:24,000, San Diego County, California (5 on plate 1).

Unit Description—The description of the Olla Formation is based on Woodard (1963) and Winker (1987), supplemented by field reconnaissance. The C-suite rocks of the Olla Formation are identical to those in the Arroyo Diablo Formation, except for a larger percentage of L-suite gravel and sand in the basal parts of fining-upward cycles. The presence of intertonguing strata of L-suite rocks gives the Olla Formation its characteristic appearance (figure 12).

The L-suite rocks in the Olla Formation consist of light-gray to olive-gray sandstone, biotite-rich siltstone, and dark-olive siltstone and claystone. Near the contact with the Canebrake Conglomerate, coarse-grained, conglomeratic sandstone becomes the dominant lithology. Of particular interest are beds referred to as *banded silts* by field parties from the Natural History Museum of Los Angeles County. These beds are dark-olive, biotite-rich, parallel-laminated siltstones from which most vertebrate fossils in the Olla Formation have been collected in FCVC (Cassiliano 1997).

Individual L-suite sequences vary from less than 1 m to 20 m thick. Commonly, the L-suite sequences are lenticular rather than laterally persistent. Both upward-fining and upward-coarsening cycles are locally observed. Bedding types include ripple lamination, parallel/subparallel lamination, low-angle cross-stratification, and small-scale scour-and-fill. Large-scale tangential cross-stratification is abundant in L-suite sandstone in the lower part of the Olla Formation in FCVC.

Contacts.—Wherever it occurs in the Salton Trough, the Olla Formation is a laterally intervening unit between the Canebrake Conglomerate and more distal rock units. The contact between the Olla Formation and Arroyo Diablo Formation has already been discussed. The change from the Olla Formation to the Canebrake Conglomerate is gradational and difficult to place accurately. Winker (1987) placed the contact where the dominant lithology changes from sandstone to conglomerate as seen along the south flank of the Vallecito Mountains in FCVC. Similar gradational and intertonguing lateral contacts are seen in other areas of the Salton Trough where the Olla Formation occurs between the Arroyo Diablo Formation and the Canebrake Conglomerate, such as in the BSFB (Winker 1987).

The upper contact in FCVC is with the Hueso Formation. The contact between the Olla Formation and Hueso Formation is sharp, well defined, and marked by the top of the uppermost pale-orange C-suite sandstone beds. In the upper part of Arroyo Tapiado the contact is easily seen in a series of low hogbacks in Sections 10, 11, and 13, T. 14 S., R. 7 E., Arroyo Tapiado 7.5-Minute Quadrangle (figure 13). In the area of Canyon Sin Nombre (section 3 in figure 2), east-southeast of FCVC, the Olla Formation and Hueso Formation intertongue and the contact is placed at the uppermost C-suite sandstone.

In the BSFB, the Olla Formation shows intertonguing lateral contacts with the C-suite, lacustrine Borrego Formation (Winker 1987). Additionally, the Olla Formation is overlapped by the Borrego Formation in its upper reaches (Dibblee 1954, 1984; Winker 1987) (figure 2).

In FCVC, the lower contact of the Olla Formation is gradational with an L-suite, basin-margin clastic facies of the Imperial Formation (Winker 1987) (figure 3). Because this contact is gradational, it too cannot be accurately placed. In other areas of the Salton Trough, the lower contact of the Olla Formation is either erosional on basement rocks (BSFB) or gradational with underlying sediments (Borrego Mountain Canyon) (Winker 1987).

Thickness and Regional Distribution (figures 1 and 2).—The Olla Formation is of variable thickness. The unit thins to 0 m where it intertongues with the Arroyo Diablo Formation and the Canebrake Conglomerate south of the Vallecito Mountains. In the northwest part

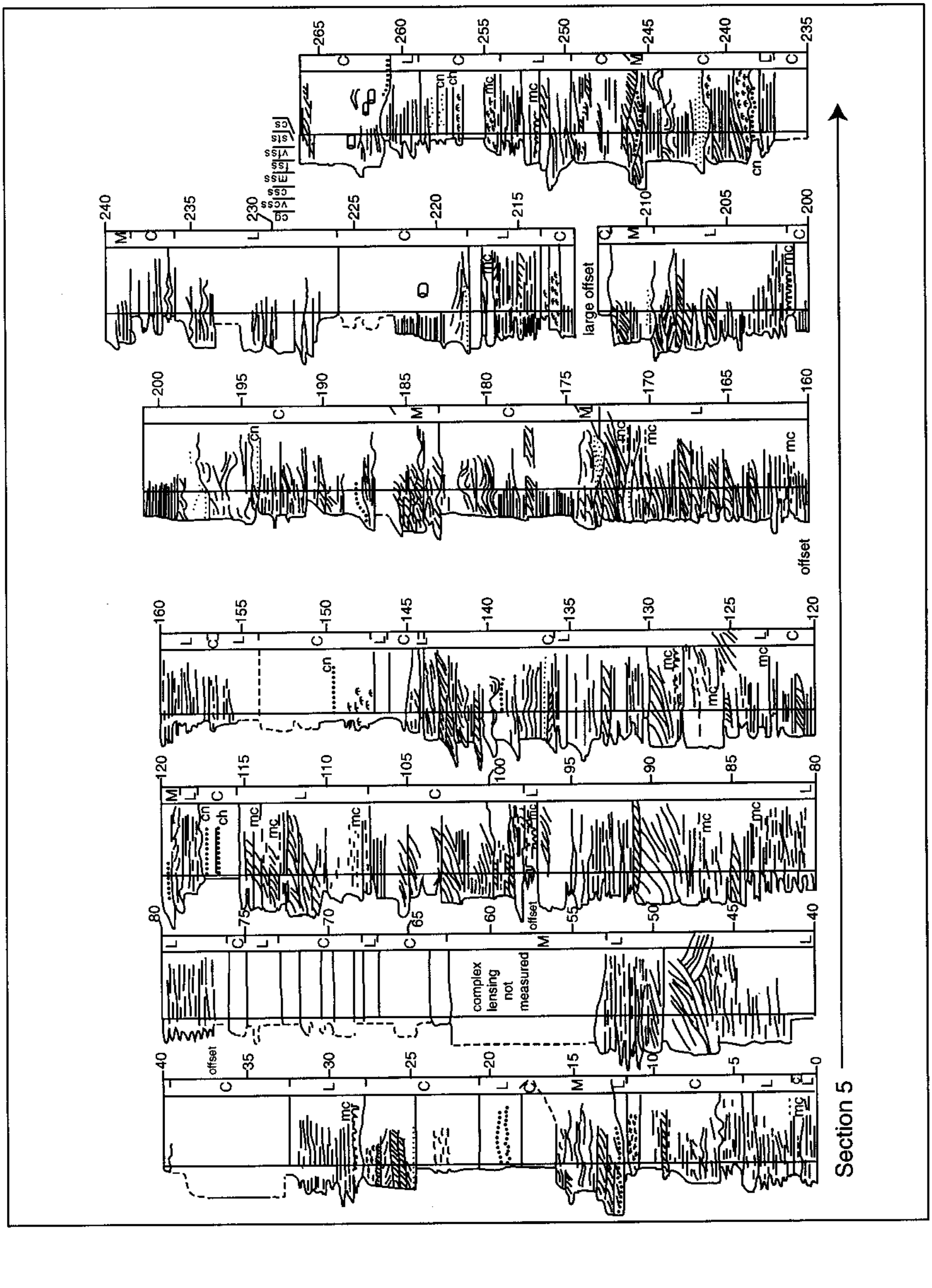

Figure 11. Graphic log of the stratotype of the Olla Formation in Layer Cake Wash (5 on plate 1). Thickness in meters. Reproduction, with slight modification, of figs. 5.11 and 5.12 of Winker (1987). Used with permission of C. D. Winker. C = C-suite rock, L = L-suite rock, M = mixed C- and L-suite rocks, mc = mud cracks, ch = calcareous horizon, cn = calcareous nodules.

Figure 12. Outcrop of the Olla Formation. This outcrop shows the typical alternation of lighter-colored C-suite sandstone with darker-colored L-suite siltstone. Staff is 1.5 m high.

of FCVC, the Olla Formation is about 2,250 m thick. The maximum thickness of the Olla Formation in other areas of the Salton Trough approximates that of the Arroyo Diablo Formation.

The Olla Formation is best exposed in the FCVC Basin and to the east-southeast of FCVC in Sweeney Pass and Canyon Sin Nombre. In the Borrego Badlands, San Felipe Hills, and Santa Rosa Mountains, Dibblee (1954, 1984) recognized a transitional facies between the Canebrake Conglomerate and Palm Spring Formation (Arroyo Diablo Formation) and included it in the Canebrake Conglomerate. Winker (1987) mapped this transitional facies as the *Olla Member,* here designated as the *Olla Formation.* Other places in the Salton Trough where Winker (1987) recognized the Olla Formation include Borrego Mountain Canyon and northwest of the Coyote Mountains. The Olla Formation is not exposed, or was not deposited, in the Yuha Buttes.

Fossils.—The Olla Formation has been prospected for fossils in FCVC. Recent reviews of the vertebrate paleontology and taphonomy of the Olla Formation can be found in Cassiliano (1994, 1997, 1999). The Olla Formation is more fossiliferous than the Arroyo Diablo Formation; nearly all the vertebrate fossil sites are located in L-suite rocks, especially the *banded silts.* Winker (1987) reported that silicified logs occasionally occur in the C-suite rocks.

Age.—The Olla Formation is a lateral equivalent of the Arroyo Diablo Formation and so has the same age. Age control is best in the FCVC basin. The age of the Olla Formation in other areas of the Salton Trough is, at present, only implied. The Olla Formation is equivalent to the late early to early late Blancan NALMA (Cassiliano 1994, 1999).

Provenance and Depositional Environment.—The distinguishing characteristic of the Olla Formation is its alternating sequences of C- and L-suite rocks indicating that the Olla Formation has two separate sediment sources (Winker 1987). The Olla Formation is a fluvial deposit formed by the Colorado River (C-suite rocks) and local stream systems (L-suite rocks). Winker (1987) concluded that the Olla Formation is a transitional lithofacies between the Canebrake Conglomerate (a basin-margin bajada) and the Arroyo Diablo Formation (delta plain) and that the position of the Colorado River with respect to the margin of the basin was the main control on deposition. When the Colorado River was near the basin margin, C-suite sediments were dominant. When the Colorado River shifted to other areas in the basin, L-suite sediments were dominant.

Tapiado Claystone of the Palm Spring Group

The Tapiado Claystone was proposed by Woodard (1963) as the *Tapiado Member* for a predominantly claystone lens that occurs stratigraphically above the Arroyo Diablo Formation and is otherwise enclosed by the Hueso Formation. The name is derived from

Figure 13. Contact between the Olla and Hueso Formations as seen in Sections 10, 11, 13, T. 14 S., R. 7 E., Arroyo Tapiado 7.5-Minute Quadrangle. The darker colored hogbacks are formed by C-suite sandstone of the Olla Formation. The lighter colored rocks in the foreground are L-suite sandstones and siltstones of the Hueso Formation. Contact is the base of the hogbacks.

Arroyo Tapiado, a dry wash in the FCVC area (plate 1). The very fine-bedded green claystones of the Tapiado Claystone make it the most distinctive component of the Palm Spring Group and warrant its designation as a formation.

Stratotype.—Woodard (1963) placed the stratotype for the Tapiado Claystone in FCVC in Sections 29 and 30, T. 14 S., R. 8 E., Arroyo Tapiado 7.5-Minute Quadrangle, 1:24,000, San Diego County, California (6, in part, on plate 1). Woodard's stratotype begins at the south wall of Arroyo Tapiado in Section 29 and continues to the southwest where it grades upsection into the Hueso Formation. The stratotype is entirely within fault block A where the Tapiado Claystone is continuously exposed from its base to its top. Unfortunately, Woodard did not illustrate the stratotype by means of a measured section. Figure 14 shows a composite reference section along Arroyo Tapiado (6 to 7 on plate 1) for the Tapiado Claystone. This section is based on field observations and illustrates the typical lithology of the Tapiado Claystone from its base to where it grades into the Hueso Formation.

Unit Description.—The description of the Tapiado Claystone is based on Woodard (1963) and Winker (1987), supplemented by field observations. The Tapiado Claystone is easily distinguished from the Hueso Formation and Arroyo Diablo Formation by its color and lithology. The dominant lithology is olive-green, blue-gray, and gray claystone (figure 15). Subordinate lithologies include gray and tan siltstone, olive-green, gray, and tan, very fine- to fine-grained sandstone, white, micritic limestone lenses, and white, porcellaneous tuff beds (figure 16). The colors contrast strongly with the red and orange of the Arroyo Diablo Formation and the tan and buff of the Hueso Formation. The Tapiado Claystone is more lithologically homogenous in its lower 231 m where it does not grade into the Hueso Formation (7 on plate 1, figure 14). Sandstone and siltstone are biotite-rich, indicative of Winker's (1987) L-suite rocks, which differentiate the Tapiado Claystone from the Arroyo Diablo Formation. The dominance of claystone, siltstone, and fine-grained sandstone separates the Tapiado Claystone from the Hueso Formation. Where the Tapiado Claystone grades into the Hueso Formation, the number of claystone beds decreases, the number of sandstone beds increases, the sandstone becomes coarser grained, and the color changes to tan or buff (figure 14). Woodard (1963) described the claystone as gypsiferous. Cassiliano (1994), however, noted that the gypsum is not primary, but occurs as secondary linings in joints that cut across the bedding of the claystone.

Bedding in the Tapiado Claystone is laterally continuous and parallel, whereas the Arroyo Diablo Formation shows more lenticular bedding (Winker 1987). The laterally continuous beds of the Hueso Formation are coarser grained and of different color (Cassiliano 1998a). Claystone beds in the Tapiado Claystone are either massive or very finely laminated. Siltstone and sandstone beds are commonly ripple-laminated, usually in the form of climbing ripples.

Contacts.—The Tapiado Claystone-Arroyo Diablo Formation contact is sharp, laterally persistent, and marked by the stratigraphically highest pale-orange sandstone, pale-orange siltstone or reddish-brown claystone (Winker 1987) (figure 14). Woodard (1963)

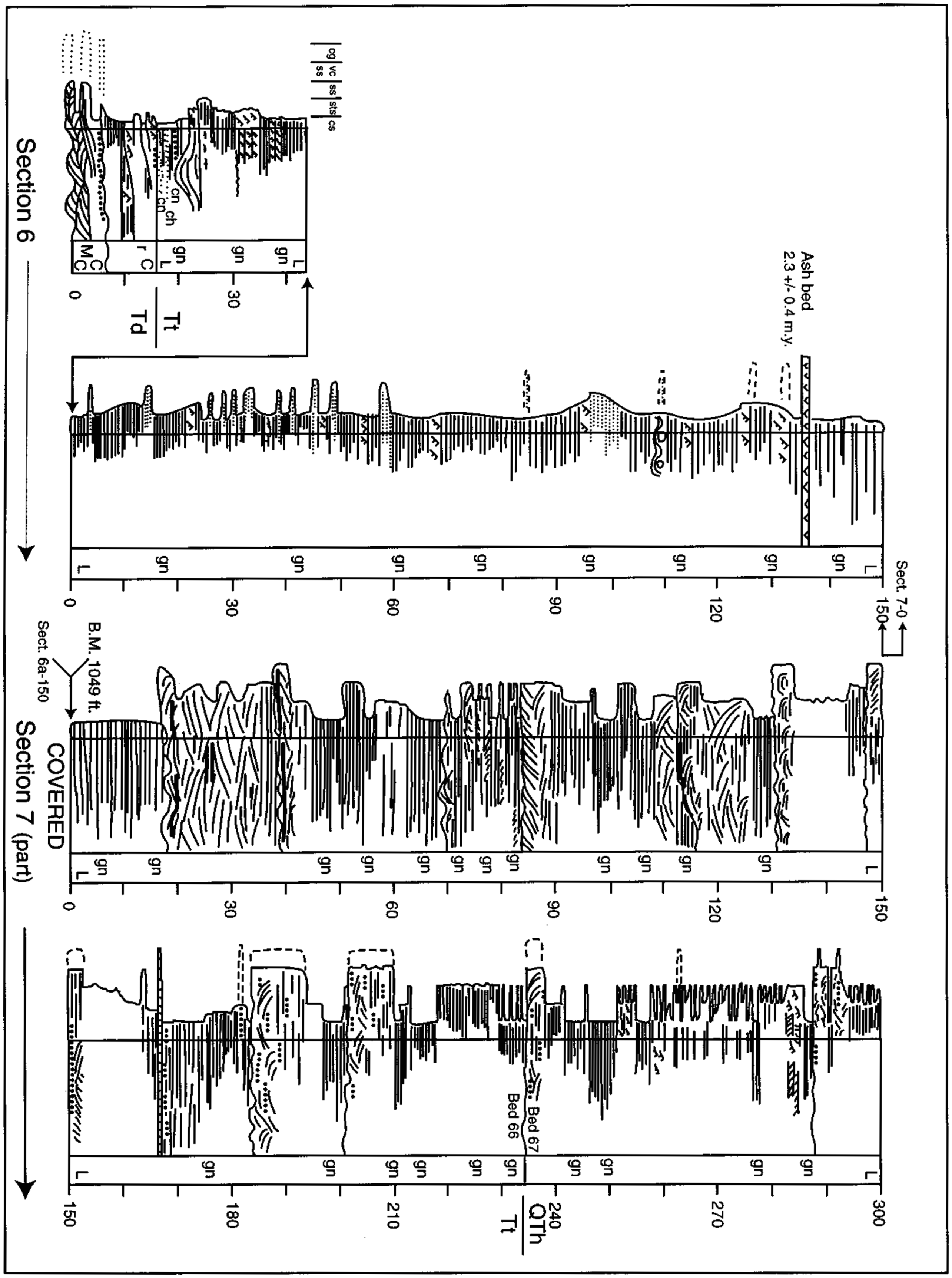

Figure 14. Graphic log showing a composite section through the Tapiado Claystone (6; 7, in part, on plate 1). Thickness in meters. Base of Section 7 covered by gravel on West Mesa. Section 6 based on Winker (1987, fig. 4.9) and field observations by the author. Section 7 based on Cassiliano (1998a, fig. 5). C = C suite rocks, L = L-suite rocks, M = mixed C- and L-suite rocks, gn = olive-green or green.

Figure 15. Typical outcrop of the lower, lithologically homogeneous part of the Tapiado Claystone about 30 m northwest of the 1,049 foot benchmark in Arroyo Tapiado.

placed this contact at a fossiliferous calcareous sandstone bed above reddish-brown mudstones and siltstones. Winker (1987) showed that this bed is a basal lag of gravel and reworked fossils from the Imperial Formation in an upward-fining cycle in the Arroyo Diablo Formation. The difference between Woodard's and Winker's placing of the Tapiado Claystone-Arroyo Diablo Formation contact is about 16 m.

The Tapiado Claystone-Hueso Formation contact is gradational. This makes it difficult to map accurately, as noted by Woodard (1963), Winker (1987), and Cassiliano (1998a, fig. 9). Cassiliano (1998a) placed this contact where the rocks change from dominantly claystone and siltstone to dominantly sandstone. Laterally, to the northwest and southeast of the stratotype, the Tapiado Claystone pinches out within the Hueso Formation (figure 17). Upsection, the top of a 5-m-thick bed (Bed 66 in Cassiliano 1998a) (figures 14 and 18) of olive-green claystone with thin horizons of very fine-grained sandstone, 233 m above the 1,049 ft benchmark in Arroyo Tapiado, is arbitrarily chosen as the Tapiado Claystone-Hueso Formation contact. A measured section (Cassiliano 1998a) (figures 14 and 18) shows that blue-gray and olive-green claystone/siltstone constitute approximately 3 percent of the thickness in the measured section above the contact and 21 percent of the section's thickness below the contact to the base of the measured section. Field observations show that below the base of the measured section, Tapiado Claystone strata are nearly all olive-green and blue-gray claystone.

Thickness and Regional Distribution.—Because the contact between the Tapiado Claystone and Hueso Formation is gradational, the thickness of the Tapiado Claystone is only approximate. Woodard (1963) measured a maximum thickness of 431 m in fault block A (figure 4). Winker (1987) estimated the maximum thickness to be 200–250 m. Using the upper and lower contacts proposed in this paper, the Tapiado Claystone has a maximum thickness of 415 m. The discrepancy in thickness reported by Woodard (1963), Winker (1987), and this paper is explained by noting where each author placed the upper contact between the Tapiado Claystone and Hueso Formation. Comparing Woodard's (1963) 1:24,000 geologic map with that of Winker (1987, plate 4) shows that Winker included only the lower rocks of the Tapiado Claystone in his concept of the unit, i.e., the most lithologically homogeneous part of the unit. Woodard (1963) and this paper also include the stratigraphically higher, more lithologically varied rocks of the Tapiado-Hueso transition in the Tapiado Claystone.

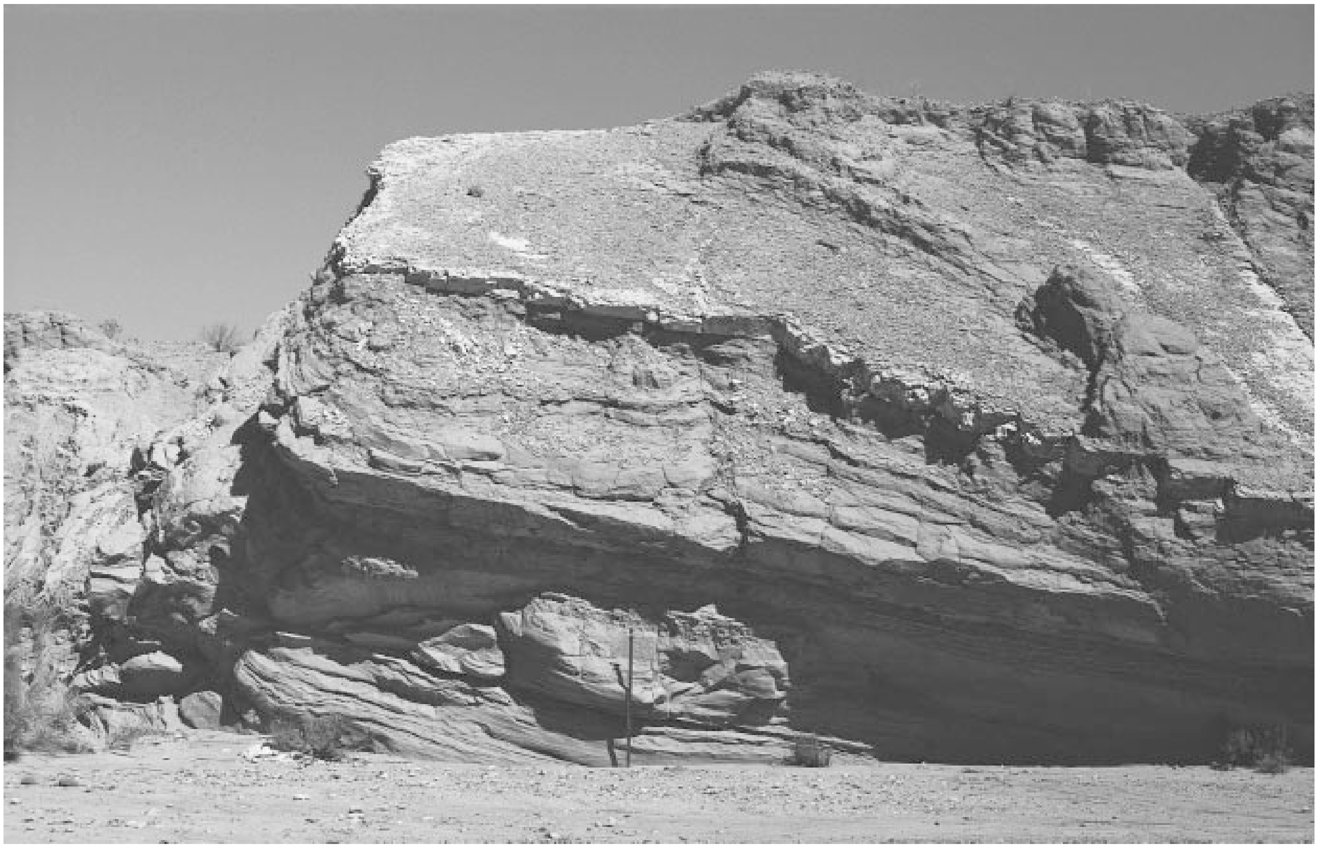

Figure 16. Lower part of the Tapiado Claystone in Arroyo Tapiado showing the porcellaneous white ash bed dated as 2.3 ± 0.4 Ma by Johnson *et al.* (1983). Staff is 1.5 m high.

The Tapiado Claystone occurs only in the FCVC area and is a unique local rock unit. Southeast of the stratotype, the Tapiado Claystone thins, grades into the Hueso Formation, and is broken into offset sections by several en echelon faults (Woodard 1963; Winker 1987). Northwest of the stratotype, the Tapiado Claystone is well exposed west of Arroyo Tapiado; however, on the east side of the arroyo, terrace gravels capping West Mesa cover the lowermost part of the unit (plate 1). Thus, the base of the measured section at the 1,049 ft benchmark in figure 18 is not the base of the Tapiado Claystone; the actual base is about 180 m downsection.

Fossils.—The Tapiado Claystone is more fossiliferous than the Olla Formation or Arroyo Diablo Formation. Almost all of the 115 fossil sites that can positively be located in the Tapiado Claystone occur in rocks in the Tapiado Claystone-Hueso Formation transition (shoreline and fluvial facies) (Cassiliano 1997). Abundant remains of vertebrates occur at these sites as well as fresh-water ostracodes and gastropods.

Age.—The age of the Tapiado Claystone is constrained by its fossil content and magnetostratigraphy, tied to the Geomagnetic Polarity Time Scale by a fission track date of 2.3 ± 0.4 Ma on zircon from a tuff bed in the upper part of the Tapiado Claystone (Johnson *et al.* 1983). Mammalian fossils indicate that the Tapiado Claystone was deposited during the late Pliocene (late Blancan NALMA) (Cassiliano 1994, 1999). Magnetostratigraphic correlation suggests that the Tapiado Claystone was deposited during the late Gauss and early Matuyama Chrons, from approximately 3.11 Ma to 2.12 Ma (Cande and Kent 1995).

Provenance and Depositional Environment.—Winker's (1987) study shows that the sandstone and siltstone, and by association, the claystone in the Tapiado Claystone are all of L-suite provenance. This is evident in the high biotite content of the sandstone and siltstone. Several lines of evidence suggest that the bulk of the Tapiado Claystone forms a lacustrine deposit: extremely limited occurrence; lens-shape to the entire outcrop pattern; very thin parallel laminar bedding in claystone; laterally extensive beds; dominance of claystone over other lithologies; and presence of fresh-water fish, gastropods, and ostracodes. Where the Tapiado Claystone grades into the Hueso Formation, the lacustrine facies intertongues with shoreline and fluvial facies (Cassiliano 1998a, fig. 9).

Winker (1987) speculated that a topographic barrier formed by *porpoise structures* along strike-slip faults created the conditions that formed the lake in which the Tapiado Formation was deposited. This barrier excluded the Colorado River and so precluded the deposition of C-suite sand and silt resulting in an L-suite lacustrine unit. Tectonics also explains the sharp contact between the Arroyo Diablo and Tapiado Formations because it implies an abrupt cutoff of the Colorado River from the FCVC basin.

Hueso Formation of the Palm Spring Group

Cassiliano (1998a) proposed the *Hueso Member,* originally named by Woodard (1963), as a formal lithostratigraphic unit of the Palm Spring Formation. In light of the nomenclatural changes proposed in this paper, the Hueso Member is raised to the rank of a formation. Cassiliano (1998a) discussed the lithologies and inferred provenance and depositional environments of the dominantly fluvial Hueso Formation. Because of the paleontologic, biostratigraphic, and paleoecologic importance of this unit, and its distinctive lithology, the

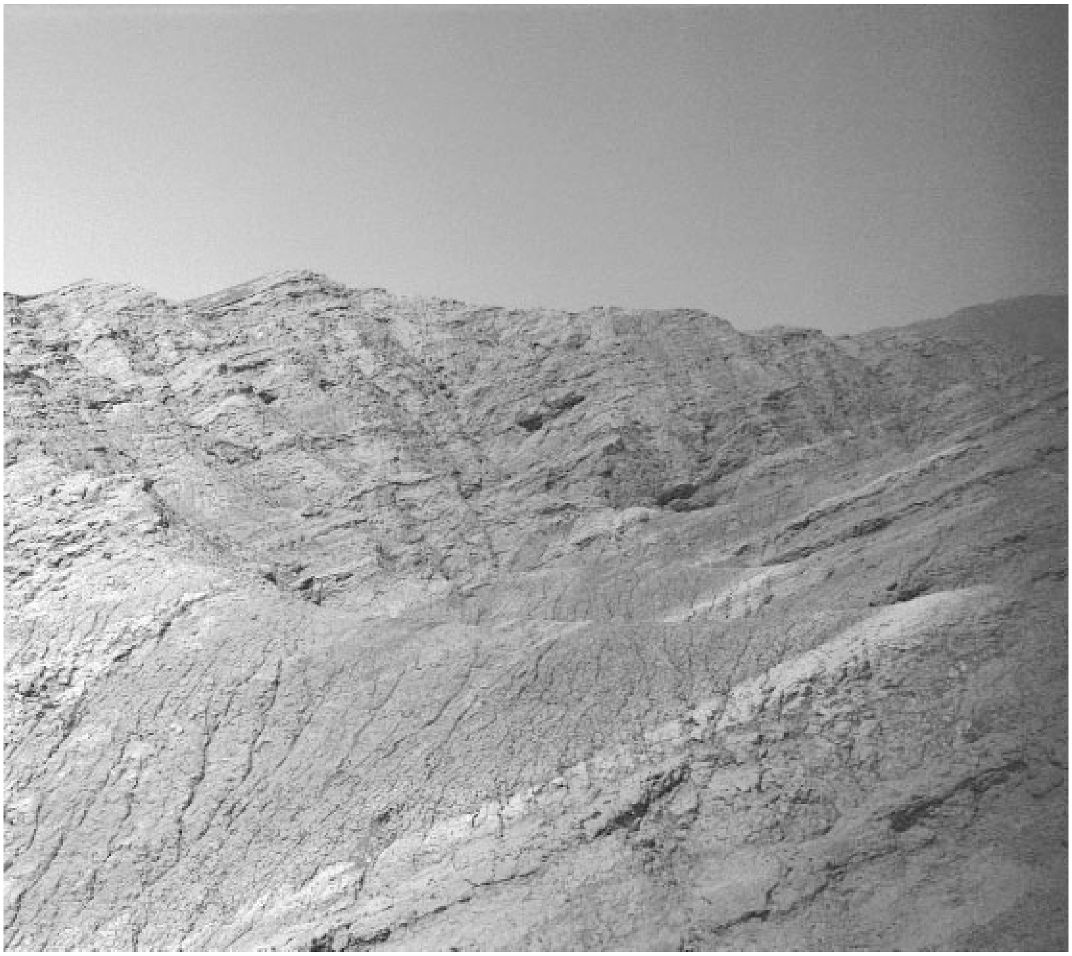

Figure 17. Gradational contact between the Tapiado Claystone and Hueso Formation. Between the north ends of Arroyo Tapiado and Arroyo Hueso.

Hueso Formation warrants separation from the Canebrake Conglomerate. The discrepancy in spelling the name of this unit was discussed previously. The following paragraphs summarize Cassiliano (1998a).

Stratotype.—The Hueso Formation stratotype, originally selected by Woodard (1963) is in Section 25, T. 14 S., R. 7 E., Arroyo Tapiado 7.5-Minute Quadrangle, 1:24,000, San Diego County, California (7 on plate 1; figure 18).

Unit Description.—The Hueso Formation consists mainly of tan and buff micaceous sandstone and silty-sandstone; brown and buff micaceous siltstone; gray and buff very coarse-grained sandstone, and subordinate olive-green, gray, and tan claystone (figures 19 and 20). Sandstone forms about 60 percent of the Hueso Formation. Grain size, sorting, and roundness of the sand grains are highly variable. Grain sizes range from very fine to very coarse. Angular to subangular grains are most common. Very coarse-grained sandstone beds tend to be better cemented and form a series of parallel, along-strike ridges. The internal structure of the sandstone beds is complex. Bedding types include laminar bedding, massive or obscure bedding, trough cross bedding, convoluted bedding, small-scale scour-and-fill, low-angle planar cross bedding, and climbing ripple lamination. The high percentage of sandstone beds distinguishes the Hueso Formation from the Tapiado Formation and the Canebrake Conglomerate. The drab brown and buff colors distinguish this unit from the Arroyo Diablo and Olla Formations.

Siltstone forms about 35 percent of the Hueso Formation. Biotite grains are common, and their presence clarifies bedding and sedimentary structures. Bedding tends to be massive, but occasionally laminar bedding or planar cross bedding can be observed.

Claystone and conglomerate are uncommon lithologies in the Hueso Formation. Claystones are most often observed where the Hueso Formation grades into the Tapiado Claystone. Conglomerates occur as small lenses and thin stringers of pebbles. The only conglomerate bed of note is the one that supports the View of Badland Ridge (figure 21).

Contacts.—The contact between the Hueso Formation and the Olla Formation is variable. In the vicinity of FCVC the Hueso Formation overlies the Olla Formation and the contact is sharp, conformable, and laterally persistent, not gradational as suggested by Woodard (1963). This contact is marked by the highest occurrence of pale-orange and reddish sandstone, siltstone, and claystone (C-suite). Above this, the rocks abruptly change to arkosic sandstone and micaceous siltstone (L-suite), which are buff, brown, or gray (figure 13).

In the area of Canyon Sin Nombre the Hueso Formation is a lateral equivalent to the Olla Formation, occurring between that unit and the Canebrake Conglomerate. In this situation, the Hueso Formation intertongues with and grades into the Olla Formation (Winker 1987).

The contact between the Hueso Formation and the Tapiado Claystone was discussed above. The contact between the Hueso Formation and the Canebrake Conglomerate is gradational (Woodard 1963; Winker 1987) (figure 22). This contact is arbitrarily placed where the dominant lithology changes from conglomerate to sandstone (Winker 1987).

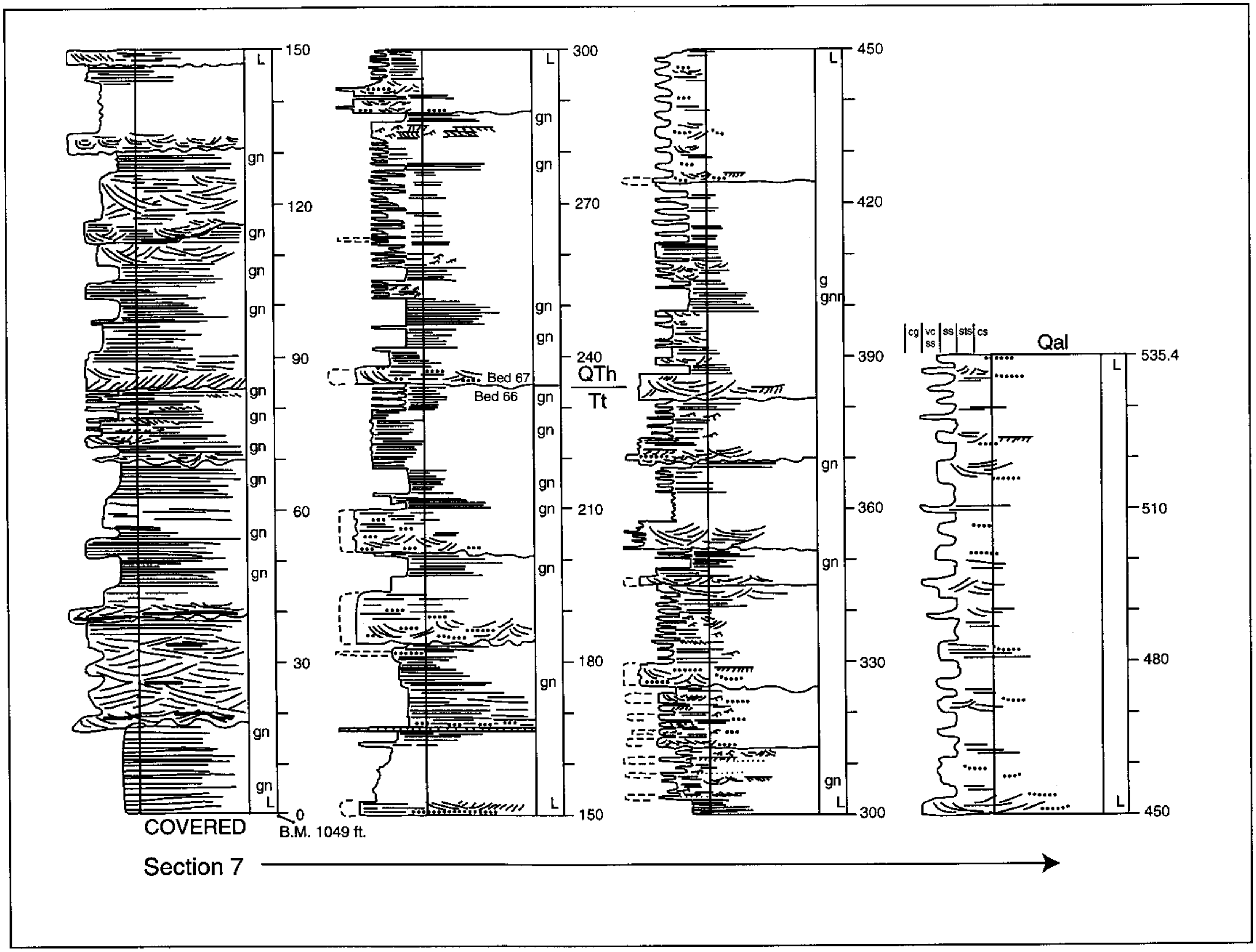

Figure 18. Graphic log showing the upper part of the Tapiado Claystone (Tt) as it grades into the Hueso Formation (QTh) (7 on plate 1). Based on fig. 5 of Cassiliano (1998a). Contact arbitrarily placed at top of Bed 66. The section also shows the stratotype of the Hueso Member. L = L-suite rocks, gn = olive-green or green. Thickness in meters. Base covered by gravel on West Mesa.

Figure 19. Looking southwest from Arroyo Tapiado across Fault Block B at a typical outcrop of the Hueso Formation.

Thickness and Regional Distribution (figures 1 and 2).—The maximum thickness of the Hueso Formation in FCVC measured by Cassiliano (1998a, fig. 6) is 1,320 m. The Hueso Formation is very well exposed in the areas of FCVC, Sweeney Pass, and Canyon Sin Nombre. In other areas in the Salton Trough where the Palm Spring Group occurs, the Hueso Formation has not been recognized.

The Ocotillo Conglomerate in the Borrego Badlands is lithologically similar to the Hueso Formation and, based on mammalian fossils, is partially correlative with the Hueso Formation (Remeika and Jefferson 1993). However, the Ocotillo Conglomerate is not considered part of the Palm Spring Group. Dibblee (1954, 1984) and Sharp (1972) showed that the Ocotillo Conglomerate is separated from underlying rock units of the Palm Spring Group by an unconformity and that it does not grade or wedge into any rock unit that is or might be included in the Palm Spring Group. This suggests that the Ocotillo Conglomerate is the product of a depositional cycle separate from that that formed the Palm Spring Group and that this unit, despite its occupying a stratigraphic and chronological position analogous to that of the Hueso Formation, is a distinct lithostratigraphic unit (Winker 1987).

Fossils.—The vast majority of terrestrial vertebrate fossils in FCVC were collected from the Hueso Formation (Cassiliano 1994, 1997). Most of the specimens are of mammals (Cassiliano 1999), although a diverse assemblage of reptiles (Norell 1989) and birds Howard (1963) was collected from the Hueso Formation. Woodard (1963) reported occurrences of brackish marine invertebrates at several outcrops in the Hueso Formation.

Age.—The age of the Hueso Formation is constrained by mammalian fossils and magnetostratigraphy. The mammalian fossils indicate that the Hueso Formation was deposited during the late Blancan and Irvingtonian NALMAs (Cassiliano 1999). Magnetostratigraphy shows that the Hueso Formation was deposited between approximately 3.16 and 0.78 Ma (middle of the Gauss Chron to the Brunhes Chron) (Opdyke *et al.* 1977; Johnson *et al.* 1983; E. H. Lindsay, personal communication, 1993). The biostratigraphy and magnetostratigraphy both correlate with an age of late Pliocene to early to mid-Pleistocene (Cassiliano 1998a, 1999).

Provenance and Depositional Environment.—The conglomerates, sandstones, and siltstones of the Hueso Formation are clearly of Winker's (1987) local or L-suite provenance. The rocks of the Hueso Formation are virtually identical to the L-suite rocks of the Olla Formation. The difference between the two formations is primarily the presence of C-suite rocks in the Olla Formation. The L-suite provenance of the claystone is inferred. The strata in the Hueso Formation were deposited mainly by local fluvial systems that dominated the FCVC basin after the Colorado River changed course (Woodring 1932; Dibblee 1954; Woodard 1963, 1974; Winker 1987; Cassiliano 1998a). The Hueso Formation can be interpreted as a braidplain deposit that developed beyond the inflection point of the bajada, preserved as the Canebrake Conglomerate, which formed against the Vallecito and Tierra Blanca Mountains.

Canebrake Conglomerate of the Palm Spring Group

Dibblee (1954) named this formation for a cobble and boulder conglomerate in FCVC. The name is taken from Canebrake Wash on the west side of FCVC. Analyzing lithology and stratigraphic relationships, Dibblee (1954) recognized the Canebrake Conglomerate

Figure 20. View to the southwest across the Hueso Formation taken from the conglomerate at View of Badland.

in other areas of the Salton Trough (figures 1 and 2), although the outcrops are not contiguous. Difficulties with the interpretation of Dibblee's (1954) description of the Canebrake Conglomerate and its relationship to the Palm Spring Formation as described by Woodring (1932) have already been noted. Inclusion of the Canebrake Conglomerate in the Palm Spring Group emphasizes this unit's relationship to other Plio-Pleistocene fluvial and lacustrine rocks in the Salton Trough by uniting it with other lithologically distinct, yet genetically related lithostratigraphic units. Dibblee (1954, 23) recognized that the Canebrake Conglomerate "is the coarse marginal conglomerate facies of the Palm Spring and Imperial formations." This revision proposes to remove the distinctive finer-grained facies in FCVC of the Canebrake Conglomerate as the Hueso, Olla, and Tapiado Formations, thus leaving the Canebrake Conglomerate as a truly coarse-grained unit.

Although extensively mapped by Dibblee (1954, 1984), the Canebrake Conglomerate is one of the least studied formations in the Salton Trough. Because the redefined Canebrake Conglomerate does not contain any known fossil localities in FCVC, the author did not examine it in detail in the field. The author's main field observations studied where and how the Canebrake Conglomerate and Hueso Formation wedge and grade into each other. Therefore, the following comments on the Canebrake Conglomerate are based primarily on the published and unpublished literature.

Stratotype.—Dibblee (1954, 23) designated the type section of the Canebrake Conglomerate "at the southeastern base of Vallecito Mountain, 3 miles west of Fish Creek Wash, where the conglomerate is about 7,000 feet thick" (8 on plate 1). He did not, however, publish a columnar section of the type section.

Unit Description.—All published and unpublished descriptions of the Canebrake Conglomerate are brief, providing little detail about the lithology and sedimentology. However, all these descriptions are consistent, particularly with regard to the formation's lithology along the flanks of the mountains adjacent to the subsidiary basins in the Salton Trough. Dibblee (1954, 1984) described the Canebrake Conglomerate as a gray conglomerate and massive granitic fanglomerate. He also noted (1954, 23) that in FCVC the Canebrake Conglomerate extends basinward as a "gray pebble and cobble conglomerate that rests on the Palm Spring formation." The different facies of the basinward extension are here proposed as the Olla, Tapiado, and Hueso Formations.

Woodard (1963, 66) provided a brief description of the Canebrake Conglomerate as a "massive boulder and cobble fanglomerate, and subordinate pebbly arenite strata." He noted that the unit consists of granitic boulders and cobbles set in a poorly-sorted, well-consolidated pebble-to-sand size matrix.

Winker (1987, 233) described the Canebrake Conglomerate as "gray to grayish-tan, crudely bedded, polymictic, pebble to boulder conglomerate." He wrote that the clasts were usually subrounded to subangular, primarily granitic but with subordinate gneiss and other metamorphic rocks. The matrix consists of "poorly sorted, angular, feldspathic sandstone." Winker also observed that, compared to other very coarse-grained units in FCVC, the Canebrake Conglomerate contains very few debris-flow beds and that the contacts between beds are poorly defined.

Both Woodard (1963) and Winker (1987) restricted the Canebrake Conglomerate in FCVC to the very coarse-grained rocks of Dibblee's (1954) formation by proposing informal lithostratigraphic

Figure 21. Hueso Formation, conglomerate at View of Badland. This conglomerate is the location of the Plio-Pleistocene boundary as determined by the magnetostratigraphy of Opdyke *et al.* (1977) and Johnson *et al.* (1983).

units for the finer-grained facies of the Canebrake Conglomerate. Previous sections of this paper formalize the opinions of Woodard (1963) and Winker (1987). Additionally, Winker (1987) separated the transitional mixed L- and C- suite facies of the Canebrake Conglomerate as the Olla Formation (informal member in Winker's paper) in the Borrego Badlands, the San Felipe Hills, the southeastern side of the Santa Rosa Mountains, and Borrego Mountain Canyon (4 in figure 1).

Contacts.—Dibblee's (1954) original description of the Canebrake Conglomerate stated that in FCVC this formation grades basinward into the Palm Spring and Imperial Formations and laps onto and against the crystalline basement rocks of the surrounding mountains.

Woodard (1963) noted that the contact between the Canebrake Conglomerate, as he redefined it, and the basement rocks is variable. In the western area of outcrop in FCVC, the unit either laps onto the basement rocks or is faulted against them. He describes the easterly exposures of this formation as resting unconformably on granite. Basinward, Woodard observed that the formation wedges into the Imperial Formation and Palm Spring Formation (Olla and Hueso Formations).

Winker (1987) noted that the Canebrake Conglomerate tends to have a depositional contact, a high-angle nonconformity, with the basement rocks. He also observed that in FCVC the Canebrake Conglomerate grades basinward into the Olla and Hueso Formations (informal members in his paper). He reported that in other areas of the Salton Trough (Borrego Badlands, San Felipe Hills, southeastern side of the Santa Rosa Mountains), the Canebrake Conglomerate is gradational with the Olla Formation which, in turn, grades into the Arroyo Diablo Formation. Of necessity, the gradational contact between the Olla Formation and Canebrake Conglomerate is arbitrary and is placed where the dominant lithology changes from conglomerate to sandstone.

Dibblee (1954) and Woodard (1963) observed that the Canebrake Conglomerate grades or wedges into the Imperial Formation. Winker (1987), however, assigned the conglomeratic rocks grading and wedging into the Imperial Formation to the informal *Jackson Fork Member* and *Stone Wash Member.* These terms are not formalized in this paper.

Thickness and Regional Distribution (figures 1 and 2).—The Canebrake Conglomerate is widely distributed throughout the Salton Trough. It is found in most areas where the Arroyo Diablo Formation is found: the Borrego Badlands, the San Felipe Hills, the southeastern side of the Santa Rosa Mountains, Borrego Mountain Canyon, Sierra de los Cucapas, and the Indio Hills (Dibblee 1954, 1984; Woodard 1963; Winker 1987) (figures 1 and 2). The thickness of the unit varies from 0 m where it wedges into the Olla, Hueso, or Arroyo Diablo Formations to more than 3,500 m along the flanks of the various mountain ranges in the Salton Trough. The greatest thickness is seen in FCVC. Figure 4 in Cassiliano (1998a) gave the misleading impression that the Canebrake Conglomerate extends for an additional 2,100 m above the Hueso Formation. This figure was meant to indicate the maximum thickness of the entire unit as reported by Woodard (1963).

Woodard (1963, figs. 2 and 4) also reported that the Canebrake Conglomerate overlies the Hueso Formation on the south flank of the Carrizo Syncline, immediately south of FCVC, between the Coy-

Figure 22. Transition zone between the Hueso Formation and Canebrake Conglomerate in June Wash. The lower part of the outcrop is typical of the Hueso Formation; the upper part is typical of the distal Canebrake Conglomerate. Staff is 1.5 m high.

ote Mountains and the Carrizo Badlands (2 in figures 1 and 2). This observation has not been corroborated by others, such as Hoggatt (1979) and Winker (1987). Cassiliano (1998a, fig. 4) followed Woodard (1963) and showed the Canebrake Conglomerate overlying the Hueso Formation. Further study has convinced the author that this is not the case (figures 2 and 3).

Fossils.—Downs (1957) listed taxa from a late Cenozoic vertebrate fauna from the Canebrake Conglomerate, as the unit was defined by Dibblee (1954). In 1962, Downs and Woodard listed additional taxa from this fauna but wrote that they were collected from the upper Palm Spring Formation (Hueso Formation). This shows that they accepted the stratigraphic revision in FCVC proposed by Woodard (1962). As a result of the revisions proposed by Woodard (1962, 1963, 1974), Winker (1987), and this paper, there are no reported fossils from the Canebrake Conglomerate.

Age.—Because the Canebrake Conglomerate, as revised in this paper, has no fossil localities known to the author, its age must be inferred from that of laterally equivalent units. In FCVC the age of the Canebrake Conglomerate is readily constrained by fossil and magnetostratigraphic data in the laterally equivalent Imperial, Arroyo Diablo, Olla, Tapiado, and Hueso Formations. These data indicate that the age of the Canebrake Conglomerate in FCVC is Pliocene to middle Pleistocene, Blancan to middle Irvingtonian NALMAs (Opdyke *et al.* 1977; Johnson *et al.* 1983; Lindsay *et al.* 1987; Cassiliano 1994, 1998a, 1999).

In other areas of the Salton Trough the age of the Canebrake Conglomerate is not so tightly constrained. In the northwestern part of the Salton Trough (the Borrego Badlands, the San Felipe Hills, the southeastern side of the Santa Rosa Mountains, Borrego Mountain Canyon) neither the Canebrake Conglomerate nor its lateral equivalents, the Olla and Arroyo Diablo Formations, have any fossil localities known to the author. Dibblee (1954, 1984) considered the Canebrake Conglomerate to be Pliocene in this area. Even though they are lithologically very similar, the outcrops of the Palm Spring Group in FCVC and the northwestern Salton Trough are not contiguous. Hence, it is not appropriate to extend the age of the Canebrake Conglomerate or any other unit in the Palm Spring Group from FCVC to other areas of the Salton Trough.

One constraint on the age of the Canebrake Conglomerate in the Borrego Badlands is provided by the vertebrate fauna from the Ocotillo Conglomerate (Remeika and Jefferson 1993). The Ocotillo Conglomerate, named by Dibblee (1954), unconformably overlies the Palm Spring Group in the Borrego Badlands. Remeika and Jefferson (1993) reported that, based on mammalian fossils and magnetostratigraphy, the Ocotillo Conglomerate ranges in age from 1.25 to 0.37 Ma. This is correlative with the middle and late Pleistocene. The inference from Remeika and Jefferson's (1993) paper is that the Canebrake Conglomerate is older than middle Pleistocene in the Borrego Badlands. Arnal (1961) reported that foraminifera from the Borrego Formation suggest a late Pliocene or early Pleistocene age. The Borrego Formation is a lateral equivalent of the Canebrake Conglomerate in this area. By inference, the Canebrake Conglomerate in the Borrego Badlands is also probably late Pliocene or early Pleistocene in age (i.e., equivalent to the late Blancan to early or middle Irvingtonian NALMAs).

In the Indio Hills and Mecca Hills the Canebrake Conglomerate is also unconformably overlain by the Ocotillo Conglomerate (Dibblee 1954). Dibblee (1954) suggested a Pliocene age for the Canebrake Conglomerate in these areas. A lack of fossil specimens from either the Canebrake Conglomerate or Ocotillo Conglomerate in these areas precludes any firm age for either unit.

Provenance and Depositional Environment.—The Canebrake Conglomerate primarily comprises sediments derived from the various mountain ranges surrounding the small subsidiary basins within the Salton Trough (Dibblee 1954, 1984; Woodard 1963; Winker 1987). Winker (1987) also noted that in some areas, such as the southern flank of the Vallecito Mountains, the Canebrake Conglomerate also contains clasts different from the underlying plutonic basement. This suggested to him that the Canebrake Conglomerate had a source area larger than that of the surrounding mountains. Winker (1987) placed the Canebrake Conglomerate within his L-suite group of rocks.

Dibblee (1954, 1984) considered the Canebrake Conglomerate to represent the coarse marginal facies of the Imperial and Palm Spring (restricted sense) Formations formed under torrential depositional conditions. Woodard (1963) agreed with Dibblee's conclusion, adding that he viewed the Canebrake Conglomerate as a pediment fanglomerate. Winker (1987), with some reservations, considered the Canebrake Conglomerate to represent an alluvial fan deposit. He based this conclusion on the rapid decrease in clast size, within a few kilometers, from the margins of the local depositional basins. However, the extremely rare occurrence of debris-flow beds and poorly defined bedding contacts suggested to him that a gravelly braided-stream system might be a more appropriate model for the Canebrake Conglomerate.

SUMMARY

The author proposes changing the Plio-Pleistocene Palm Spring *Formation* of Woodring (1932) to the Palm Spring *Group.* The Palm Spring Group includes five formations: the Arroyo Diablo Formation (new), the Olla Formation (new), Tapiado Claystone (new), the Hueso Formation (change in rank), and Canebrake Conglomerate (in part) of Dibblee (1954). This proposed revision is based on observations of rocks in the FCVC basin. The names of the lithostratigraphic units proposed here are also extended to other areas of the Salton Trough where lithologically identical rocks occur. In these cases the new names are replacements of older ones (Arroyo Diablo and Olla Formations for the Palm Spring Formation in its restricted sense). The Borrego Formation of Tarbet and Holman (1944), a lateral equivalent of the Arroyo Diablo Formation and Canebrake Conglomerate in the BSFB, probably also belongs in the Palm Spring Group. Because the author has not field-checked this basin, however, the Borrego Formation remains outside the Palm Spring Group. The main results of this proposal are to resolve the debate over the restricted and expanded concepts of the original Palm Spring Formation and to include in a single lithostratigraphic unit the products of a major depositional system in the Salton Trough in southern California.

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