REPORTS

Proposal of Guadalupian and Component Roadian, Wordian and Capitanian Stages as International Standards for the Middle Permian Series

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Introduction

The present proposal of the Middle Permian Guadalupian Series and component Roadian, Wordian and Capitanian stages was prepared for publication in Permophiles and concurrent distribution to SPS Titular Members for formal vote. Qualifications of the Guadalupian as international standard reference have been presented previously (Glenister *et al*., 1992), but the present new formal proposal will add critically important new data on conodont morphoclines, absolute dates, and paleomagnetics.

Historic Preamble

Prolonged deliberation of SPS members culminated in the mandated formal postal vote by Titular (voting) Members that approved subdivision of the Permian System into three series, in ascending order Cisuralian, Guadalupian and Lopingian (Report of President Jin Yugan, Permophiles #29, p. 2). The "——usage of the Guadalupian Series and constituent stages, *i.e.* the Roadian, the Wordian and the Capitanian Stage for the middle part of the Permian." was approved unanimously by 15 voting members. Proposal of the Guadalupian as a chronostratigraphic unit of series rank (Girty, 1902) predates any potential competitors by decades (Glenister *et al*., 1992). Of the three component stages currently recognized, the upper two (Wordian and Capitanian) enjoy comparable priority. Capitanian was first employed in a lithostratigraphic sense by Richardson (1904) for the massive reef limestones of the Guadalupe Mountains of New Mexico and West Texas, and the Word was used by Udden *et al*. (1916) for the interbedded clastic/carbonate sequence in the adjacent Glass Mountains. Both were used in a strictly chronostratigraphic sense first by Glenister and Furnish (1961) as substages of the Guadalupian Stage, referenced by their nominal formations and recognized elsewhere through "ammonoid and fusuline faunas". In studying the Permian faunas of Arctic Canada, Nassichuk *et al*. (1965) concluded "——that probably a separate stage between the Artinskian and Guadalupian could be recognized." The "First limestone member" of the Word Formation, Glass Mountains, was named the Road Canyon Member (Cooper and Grant, 1964) and served subsequently as reference for the post-Artinskian/pre-Wordian Roadian Stage (Furnish and Glenister, 1968, 1970; Furnish, 1973). At the same time, Wilde and Todd (1968) suggested that the basal unit of the original Guadalupian Series, the Cutoff Formation, is correlative with the Road Canyon. Wilde (1990) subsequently placed the Roadian as the basal unit of the Guadalupian Series, a practice now favored by others. The Kubergandian of Central Asia is at least a partial correlative of the Roadian. Although Kubergandian has priority as a named stage, the Roadian "Black, thin bedded-limestone" (=Cutoff Formation) forms the original base of the Guadalupian Series (Girty, 1902).

Prerequisites for GSSP Definition

The present statement contends that there is now adequate detailed information on Middle Permian boundary sequences, worldwide, that selection of Global Stratotypes Sections and Points (GSSP) for the series and component stages is fully justified and timely. We recommend sections within Guadalupe Mountains National Park (Fig. 1), Texas, southwestern United States of America, along the north-western margin of the Delaware Basin (Fig.2). Fundamental principles involved in selection and definition of a GSSP were explored fully in the pioneering investigations of the Silurian-Devonian Boundary Committee (McLaren, 1977), and are expressed clearly in the Guidelines and Statutes of the ICS (Cowie *et al*., 1986; Remane *et al*., 1996a; Remane *et al*., 1996b). SPS authors (Davydov *et al*., 1995) outlined the principles and prerequisites involved in selection of the Aidaralash section of the Southern Urals as GSSP for the base of the Permian, and these are summarized below:

1. succinct reasons for choice of the GSSP in both level and geographic location; preference is for historic priority, but subsidiary to scientific and practical merit, and advanced state of knowledge is implied;
2. continuity of sedimentation through the boundary interval, preferably in a marine succession without major facies changes;
3. freedom from structural complications and metamorphism, thereby providing amenability to superpositional interpretation and use of both magnetostratigraphy and geochemistry, including geochronometry;
4. abundance and diversity of well-preserved fossils, preferably including a chronocline that permits arbitrary selection of a point within a single evolutionary lineage;
5. adequacy and continuity of exposure, providing a succession that can be followed above and below the GSSP, and preferably laterally;
6. compatibility of accessibility with conservation, providing continuous availability without insuperable physical and/or political obstacles for access by any qualified researcher; protocols for sampling and transportation of collections are needed.

The present statement contends that the Guadalupe Mountains sections meet these same qualifications, and that overall scientific and practical merit necessitates their selection as international standards for the Guadalupian Series and component stages. Critically important is the interest the U.S. National Park Service has expressed in encouraging research, and their commitment in providing access to qualified investigators (Glenister, 1993).

Stratigraphy

The Middle Guadalupian series is perhaps the best stratigraphically studied unit in the world, serving as a major paradigm for modern sequence stratigraphy (*e.g.*, Vail *et al*., 1977; Sarg and Lehmann, 1986; Sarg, 1988; Franseen, *et al*., 1989; Handford and Loucks, 1993; Hovorka *et al*., 1993; Mutti and Simo, 1993). The succession is represented by excellently exposed shelf to basin sections in the southern Guadalupe Mountains that generally exhibits shelf evaporite, shoal-water carbonate, deep-water carbonate, and basinal sandstone facies transitions. It is represented by six composite sequences, (Glenister *et al*., 1992, Fig. 1; Fig. 3 herein) in ascending order: San Andres, Grayburg, Queen, Seven Rivers, Yates, and Tansill (named for the shelf facies). The lowermost, San Andres, begins with a transgressive systems tract that consists of a series of progradational grainstones and evolves into grainstone-packstone highstand systems tract that represents carbonate ramp with decoupled, bypass basinal siliciclastics. The oldest Guadalupian platform developed during the Grayburg sequence, forming a distinct platform, shelf margin, slope and basinal facies. The Grayburg and succeeding sequences represent classic unconformity-bounded, shelf-margin-basin type 1 sequences that include distinct lowstand wedges and fans sometimes coupled with shelf siliciclastics, transgressive systems tracts, and highstand systems tracts that include coupled carbonate-siliciclastics higher-order cycles.

The stratigraphic sections selected for definition of the Guadalupian and its stages all represent basinal to lower slope carbonate deposition.

The identifier for the base of the Guadalupian (*Jinogondolella nankingensis*) occurs in the Middle San Andres sequence that begins at the unconformity/omission surface at the base of the El Centro Member of the Cutoff Formation within a monofacial succession of skeletal carbonate mudstone within a meter of the only shale break in the carbonate succession, all of which were deposited in a basinal setting proximal to the slope (Fig. 3). The identifier for the base of the Wordian (*Jinogondolella aserrata*) is within the highstand system tract of the Grayburg sequence, representing the progradation of carbonate slope sediments into the basin, and occurs in the upper part of the Getaway Limestone Member of the Cherry Canyon Formation in a monofacial succession of skeletal carbonate mudstones that represents base of the slope deposition (Fig. 3). The identifier for the base of the Capitanian (*Jinogondolella postserrata*) is the lowermost widespread highstand system tract of the Seven Rivers sequence, similar to carbonate progradation of the Getaway, occurring within the Pinery Limestone Member of the Bell Canyon Formation in a monofacial succession of skeletal wackestone/packstone that represents lower slope deposition (Fig. 3).

Conodont Definitions

The evolution of *Jinogondolella* characterizes the Guadalupian (Middle Permian Series), and the first appearances of *Jinogondolella nankingensis*, *J. aserrata*, and *J. postserrata* define the component stages.

The first member of the genus, *Jinogondolella nankingensis*, evolved from *Mesogondolella idahoensis* through a transitional succession, demonstrated by the Pa element to be a mosaic paedomorphocline (Lambert and Wardlaw, 1992). Lambert (1994) documented this transitional morphocline quantitatively, an approach expanded graphically by Lambert and Wardlaw (1996), who further pointed out that *Jinogondolella aserrata* and *J. postserrata* evolved similarly through transitional morphoclines from their respective predecessors. Wardlaw (1999) has illustrated many examples of these transitional morphotypes. Adult specimens of the Pa element of *M. idahoensis* are characterized by smooth lateral margins, fused anteriormost denticles, a large round, erect cusp, wide well-defined furrows, and a short, open anterior keel on the lower surface. The Pa element of *J. nankingensis* is characterized by common anterior serrated margins on a broad platform with a sharp anterior narrowing, a blunt posterior platform termination with a small cusp and discrete denticles, sharp, narrow well-defined furrows, and a well-defined anterior keel. The transitional morphotype shows progressively longer retention of lateral serrations with growth, increased tapering and narrowing of the anterior platform, narrowing of the lower attachment surface developing a more consistent elevated keel, denticles that progressively become less fused and more discrete, a cusp that subtly migrates posterolaterally and becomes less pronounced, and furrows that thin and become more shallow.

The Pa element of *Jinogondolella aserrata* is characterized by a broad platform with no sharp anterior narrowing, shallow, poorly-defined furrows, few anterior serrations along its platform margin, and a rounded posterior platform termination (typically with an inner lateral indentation). The transitional morphotype from *J. nankingensis* to *J. aserrata* displays a rounded posterior termination, intermediately developed furrows, and a moderately

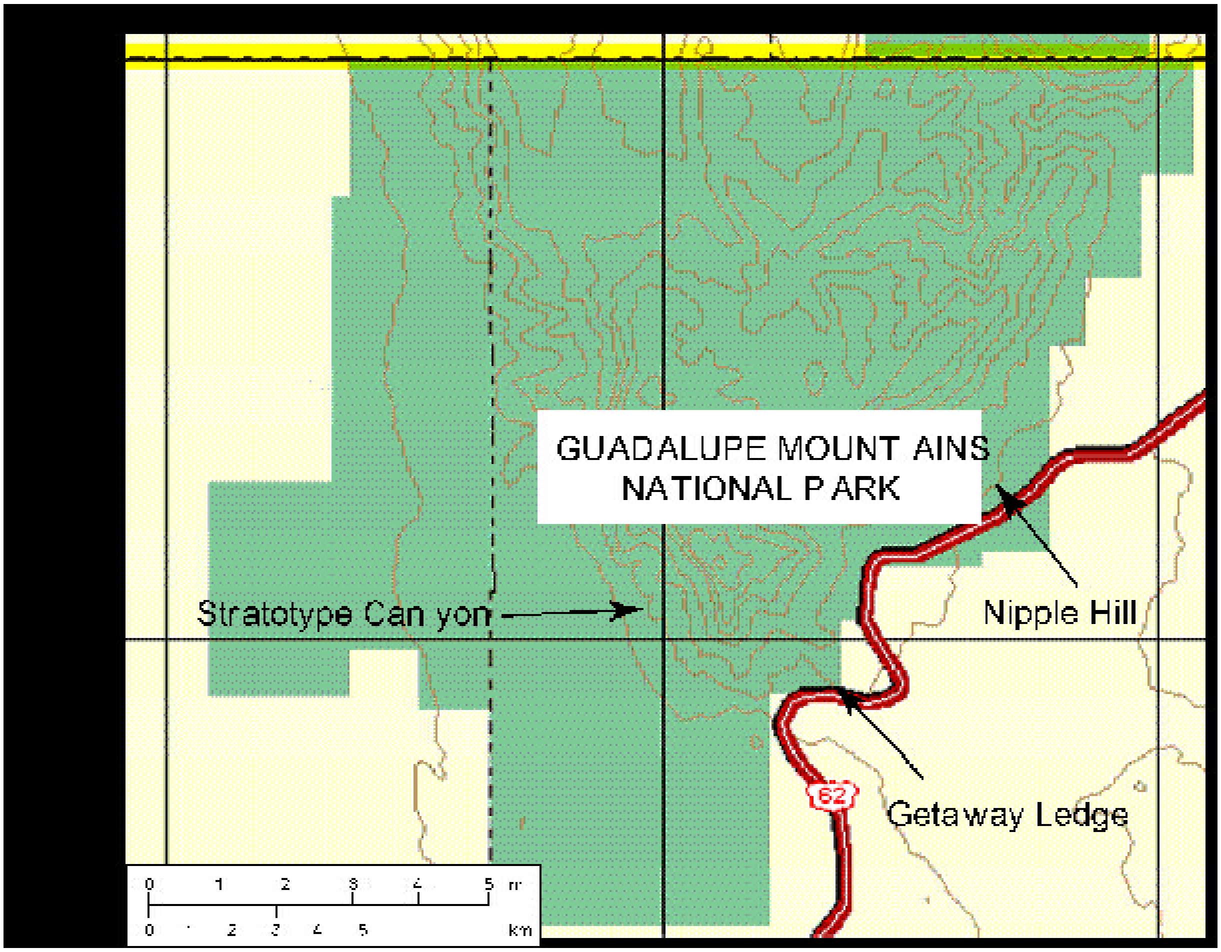

Figure 1. Map showing location of the proposed stratotypes. Guadalupe Mountains National Park is in Green. Yellow line at top of figure represents the Texas-New Mexico state line. Contour interval is 500 feet.

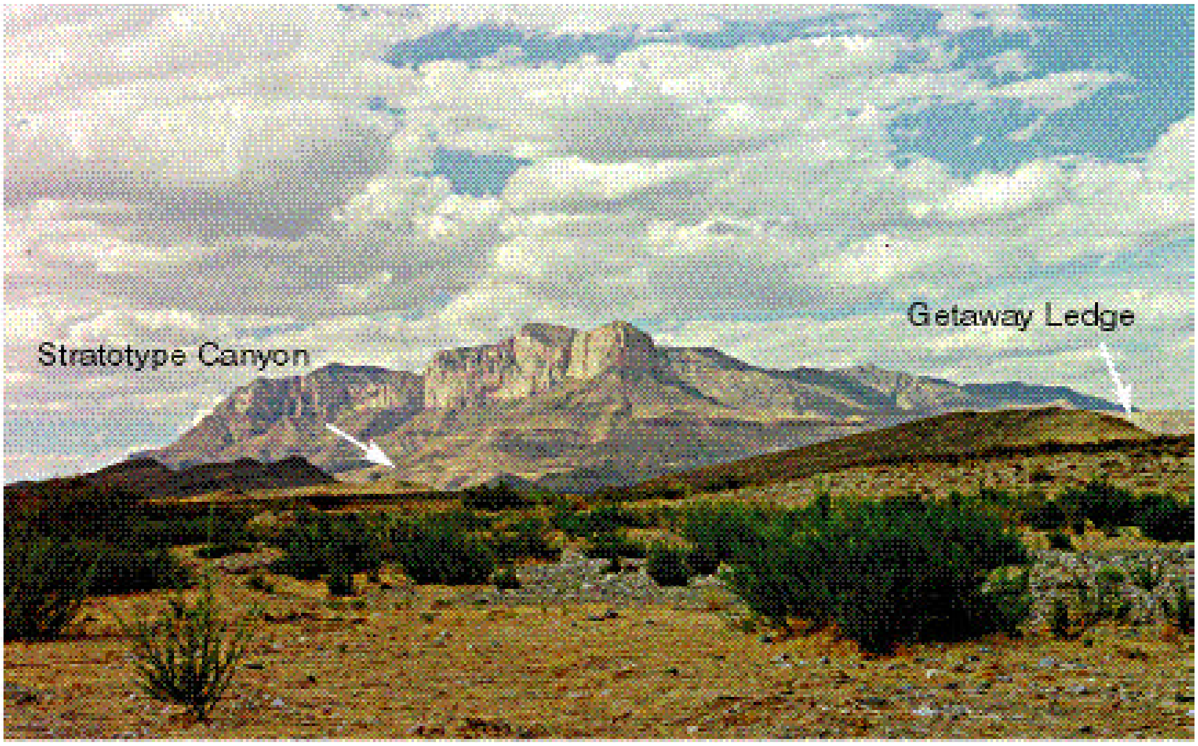

Figure 2. Photograph of the southern front of the Guadalupe Mountains showing location of Stratotype Canyon and Getaway Ledge. Nipple Hill is just outside the right sideof the photograph.

narrowing platform in the anterior with common margin serrations.

The Pa element of *Jinogondolella postserrata* is characterized by a relatively narrow platform with a marked anterior narrowing, sharp, well-defined furrows, common anterior serrated margins (restricted to the anteriorly narrowing part), and a relatively blunt posterior platform termination. The transitional morphotype from *J. aserrata* to *J. postserrata* displays a relatively blunt posterior termination, intermediately developed furrows, and a moderately narrowing platform in the anterior with few serrations on the margin.

The first appearances of adult forms that retain the characteristics of the *Jinogondolella nankingensis, J. aserrata,* and *J. postserrata* in transitional evolutionary morphoclines are used to define the base of the Roadian, Wordian, and Capitanian stages of the Guadalupian Series. Each first appearance is documented from sections that serve as stratotypes, preserved within the confines of Guadalupe Mountains National Park. Specifically, the first appearance of *Jinogondolella nankingensis* is at 42.7 m above the base of the Cutoff Formation in Stratotype Canyon (west face, southern Guadalupe Mountains, located at 31.8767° N., 104.8768° W.), 29 cm below the prominent shale band in the upper part of the limestone unit in the El Centro Member. The first appearance of *Jinogondolella aserrata* is just below the top of the Getaway Limestone Member of the Cherry Canyon Formation in Guadalupe Pass, at 7.6 m above the base of the outcrop section (U.S. Highway 62/180), with the base at 31.8658° N., 104.8328° W. The first appearance of *Jinogondolella postserrata* is in the upper part of the Pinery Limestone Member of the Bell Canyon Formation at the top of Nipple Hill (southeastern Guadalupe Mountains), at 4.5 m in the outcrop section on the south side of the hill with the top at 31.9091° N., 104.7892° W. All of these first appearances along with their respective morphoclines occur within monotonous pelagic carbonates, and are demonstrated by tight sample intervals.

Fusulinacean Biostratigraphy

Sufficient evidence has accumulated in recent years to recognize the Guadalupian Series on the basis of fusulinaceans alone, although definitions of the stage boundaries still will be based on conodonts (Lambert, 1994; Wardlaw, 1999). The long-ranging genus *Parafusulina* evolved from *Schwagerina* (*sensu* Dunbar, 1958; Dunbar and Skinner, 1936) during the Lower Permian Kungurian (Leonardian) Stage, or possibly through *Eoparafusulina* (Coogan, 1960), or a primitive *Monodiexodina* (Sosnina, 1956) such as *M. linearis* (Dunbar and Skinner, 1937). By the close of late Kungurian time, the genus was well established and many species characterize both Roadian and Wordian faunas. No Kungurian species of *Parafusulina*, however, is known to have extended into the Roadian.

The genus *Skinnerina* (Ross, 1964) appeared in the Roadian Stage, possibly derived from *Skinnerella* (Coogan, 1960), a diverse Cisuralian taxon (Skinner, 1971). *Skinnerina* has now been found in the Road Canyon Formation of the Glass Mountains (Ross, 1964); in the Cutoff Formation of the Apache Mountains (Wilde *in* Wilde and Todd, 1968; Skinner, 1971); and in the type section of the Cutoff at Cutoff Mountain in the southern Guadalupe Mountains (Wilde, 1986). In each of these localities, *Skinnerina* is accompanied by from one to all of the following: *Parafusulina boesei, P. splendens, P. attenuata, P. maleyi,* and *Rauserella*.

As noted by Wilde (1988, 1990), serious errors occurred in locality numbering in the classic study by Dunbar and Skinner (1937). These errors have tended to distort understanding of the stratigraphic position of important species of *Parafusulina* from

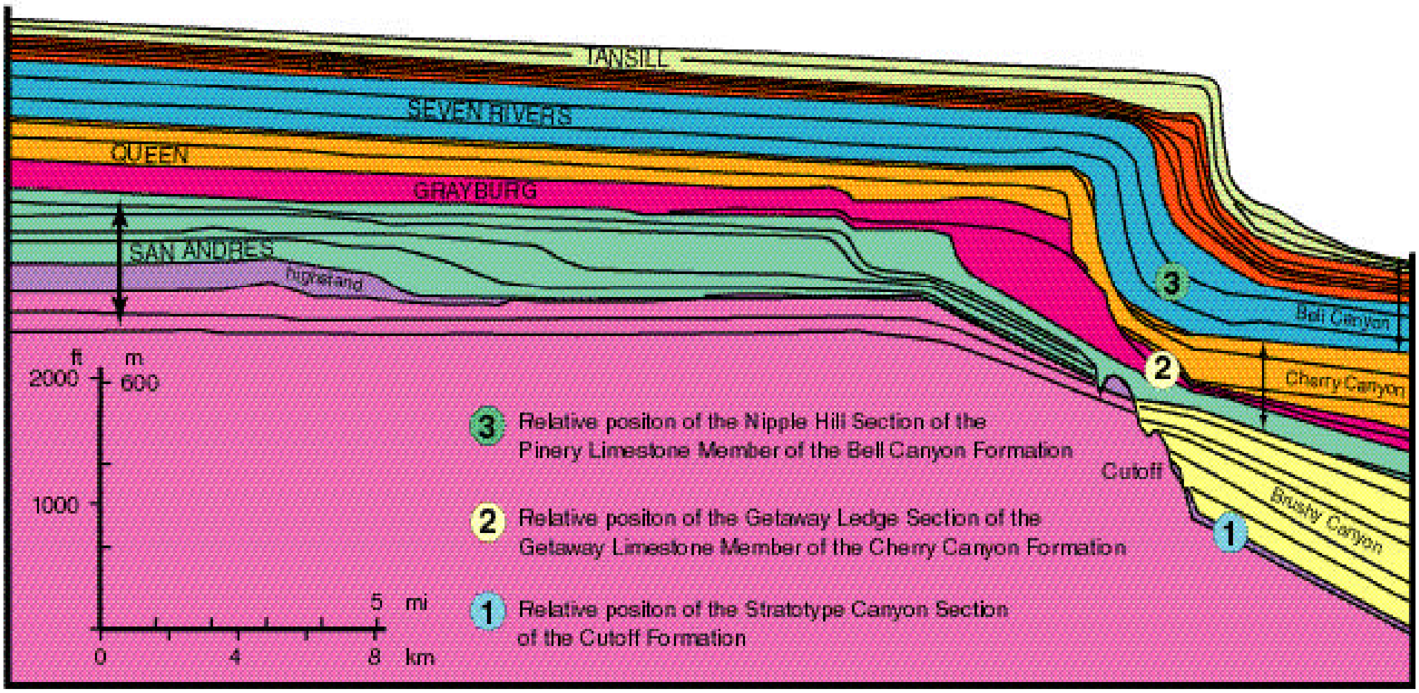

Figure 3. Sequence stratigraphy of Guadalupe Mountains showing depositional position of proposed stratotypes for the Guadalupian (and Roadian) at Stratotype Canyon (1), for the Wordian at Getaway ledge (2), and for the Capitanian at Nipple Hill (3).

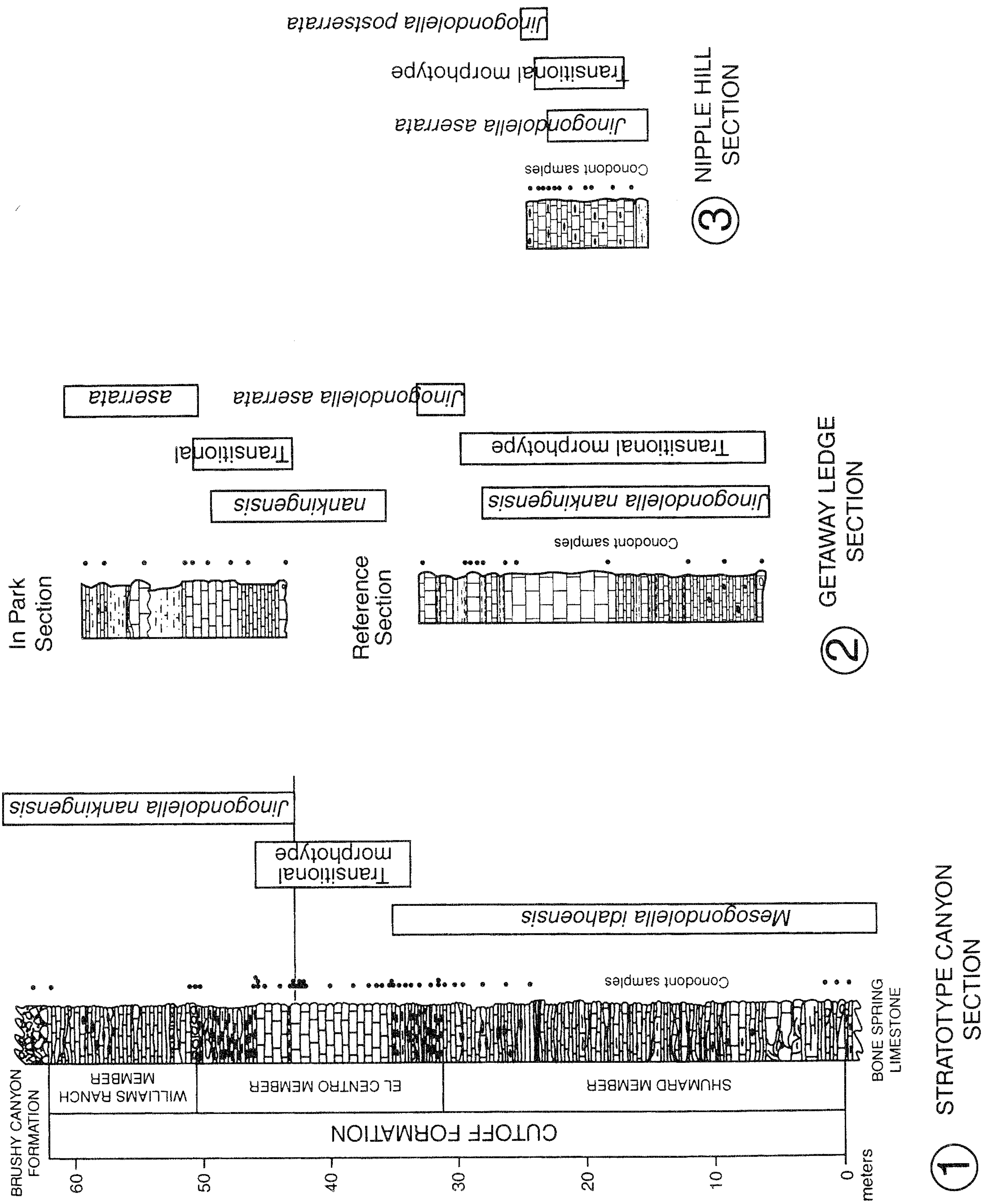

Figure 4. Columnar sections of the propsed statotypes showing conodont samples and distributions. The Getaway Ledge sections represent the entire section of the Getaway Limestone member of the Cherry Canyon Formation exposed just outside the park (reference) and just in the park, 1 km apart. The Nipple Hill section represents the entire section of the Pinery Limestone Member of the Bell Canyon Formation.

both the Brushy Canyon and Cherry Canyon intervals. Simply stated, *Parafusulina rothi* and *P. maleyi* are restricted to the Cutoff and Brushy Canyon, and *Parafusulina lineata* and *P. deliciasensis* are confined to the Cherry Canyon, commonly in association with *Leella fragilis*. *Parafusulina antimonioensis* is another late species (from Sonora, Mexico), displaying the large size and advanced nature of the highest *Parafusulina* (Dunbar, 1953).

The Late Guadalupian (early Capitanian) is characterized by *Polydiexodina*, a large fusulinacean with fully developed multiple tunnels, including a well-defined central tunnel (Wilde, 1998). Derivation was probably from a lineage of *Skinnerina* through the Asian *Eopolydiexodina* (Wilde, 1975). The last named genera developed sporadic multiple tunnels, while losing the well-defined central tunnel of most earlier *Parafusulina*. Associated with *Polydiexodina* is *Leella bellula*, and the beginning of the codonofusiellids (*Codonofusiella paradoxica*). *Codonofusiella* continues to the close of the Permian; *C. extensa* provides a significant middle Capitanian datum (Skinner and Wilde, 1954; Wilde, Rudine and Lambert, in press).

The large and complex fusulinaceans of the *Polydiexodina* zone were succeeded by advanced Neoschwagerinidae that replaced simple tunnels with foramina and parachomata. The zone of *Yabeina* characterizes the Tethys, but is poorly represented in the Permian Basin. However, several occurrences facilitate correlation to the Tethys. In the late Guadalupian the small but distinctive *Yabeina texana* is well developed and is succeeded in turn by *Paradoxiella* and *Reichelina* (Skinner and Wilde, 1954, 1955). *Paradoxiella* occurs in the Tethys with *Yabeina globosa* (Sada and Skinner, 1977), and was reported by Leven (1993) from the Caucasus. In the Guadalupe Mountains, *Paradoxiella* is followed upward by a profusion of *Reichelina* (Skinner and Wilde, 1955) near the top of the Lamar Limestone; this appears to represent the Tethyan zone of *Lepidolina*, although the zonal index has not been found in the region.

The tetrataxoid foraminifer *Abadehella* has been discovered in numerous outcrops of the Permian Basin section, but primarily from the *Reichelina* zone to the top of the non-evaporite Permian section (Wilde, Rudine and Lambert, in press). This important genus, originally described from the Abadeh beds in the Dzhulfa Region of Iran (Okimura, Ishii and Nakazawa, 1975), appears to extend to the top of the Permian, and has been reported to occur as low as the Wordian (Leven, 1993).

The youngest fusulinaceans known from the Permian Basin are abundant *Paraboultonia* from the Reef Trail Member of the Bell Canyon Formation (Wilde, Rudine and Lambert, in press), the “Post-Lamar beds” that directly overly the Lamar Limestone. The associated succession of conodonts duplicates that of the Penglaitan section of South China that will serve for definition of the base of the Upper Permian Lopingian Series, and coincident top to the Middle Permian Guadalupian Series.

Ammonoid Biostratigraphy

Ammonoid zones have served historically as the primary basis for biostratigraphic correlation of Devonian through Mesozoic strata. However, conodonts with their near ubiquity and rapid evolution have now become the preferred taxon for precise correlation and chronostratigraphic definitions for the Paleozoic. Because different taxonomic groups evolve at different rates and times, the defining conodont boundaries commonly do not coincide precisely with established ammonoid zonal boundaries. Ammonoid distributions within the Guadalupian are well known (*e.g.* Spinosa *et al*., 1975). Here we limit treatment to review of occurrences within the type Guadalupian in relation to conodont-defined boundaries.

Ammonoid faunas of the Roadian Stage are characteristically composed of the last holdovers from the preceding Cisuralian and the ancestors of increasingly more common Guadalupian forms. However, these faunas are commonly dominated by species that are provincial in distribution (*e.g.* South China *vs.* West Texas). Nevertheless, *Paraceltites elegans*, the ancestral representative of the Paraceltitina, is present in most faunas and dominant in West Texas, and its appearance near the base of the Roadian Stage in the type region (type Road Canyon Formation) serves to faunally distinguish the Guadalupian as encompassing the appearance and initial diversification of the Ceratitida. Similarly, the concurrent appearance of *Demarezites*, the ancestral representative of the Cyclolobaceae, marks the initiation of diversification of this group throughout the remainder of the Permian. Finally, the paragastrioceratid Subfamily Paragastrioceratinae that distinguishes the entire Cisuralian Series became extinct prior to the Roadian, where the previously obscure Subfamily Pseudogastriocertinae diversified to characterize the remainder of the Permian up to the Permo/Triassic boundary (Mikesh *et al*., 1988).

The basal boundary of the Wordian Stage was recognized traditionally as the lithologic base of the Delaware Mountain Group (Pipeline Shale Member, basal Brushy Canyon Formation). That horizon is well marked by an ammonoid assemblage with mixed morphologic characteristics of latest *Demarezites* (the ancestral cyclolobin) and earliest *Waagenoceras* (Lambert *et al*., 1999). Although this population is interpreted to denote the evolutionary transition between these genera, the conodonts range through apparently unchanged. However, the cyclolobins also diversify markedly near the younger conodont-defined boundary, with the lowest reported occurrences of the genera *Newellites* and *Mexicoceras*, and more advanced species of *Waagenoceras*, including *W. dieneri*.

The boundary marking the basal Capitanian Stage has traditionally been drawn at the base of the Hegler Member of the Bell Canyon Formation. It has come to be recognized more by preceding ammonoid last occurrences than by evolutionary appearances. Originally characterized as marking the base of the *Timorites* Zone, that rare cyclolobin has also been recovered from the preceding Manzanita Member (upper Cherry Canyon Formation). The conodont boundary near the top of the Pinery Member of the Bell Canyon Formation is not associated with an abundant ammonoid fauna in the type region, but is delineated near the first occurrence of the ceratitid ammonoid *Xenaspis*, and follows several last occurrences in the Hegler and lower Pinery members (lower Bell Canyon Formation).

U/Pb Dating

Numerous volcanic ash beds have been recognized in the southern Guadalupe Mountains of Texas since first detailed by King (1948). One such occurrence lies within the proposed type section for the Upper Guadalupian Capitanian Stage, and has recently been dated by U-Pb isotope dilution mass spectrometry applied to zircons (Bowring *et al*., 1998). The ash occurs within the undifferentiated lower unit of the Bell Canyon Formation, below the Pinery Limestone Member, at Nipple Hill in Guadalupe Mountains National Park (Fig. 1, note that these occurrence data supersede those available to previous authors). It is 6-8 cm thick and lies approximately 2 m above the top of the Manzanita Limestone Member of the underlying Cherry Canyon Formation. The horizon is 37.2 m below the base of the *Jinogondolella postserrata* conodont zone, the latter within the Pinery Limestone Member, which defines the base of the Capitanian Stage. Six zircon fractions were analyzed to define a concordant cluster. The best estimate for the age of the ash, based on five fractions, is 265.3 +/- 0.2 Ma, which provides a maximum estimate for the base of the Capitanian Stage. The upper boundary of the Capitanian is currently poorly constrained in terms of absolute age. The next available younger date is for the base of the Changhsingian Stage in South China, which has been dated at the type section as 253.4 +/- 0.2 Ma (Bowring *et al*., 1998). Several additional beds within the lower part of the type Lopingian and elsewhere in South China are currently being investigated.

Magnetostratigraphy

Initial investigations on magnetostratigraphy within the Delaware Basin were focused on the back-reef facies of the Guadalupe Mountains (Peterson and Nairn, 1971), the Seven Rivers Formation demonstrating reversed polarization and the overlying Yates Formation normal polarity. Projecting these data into the interfingering slope facies that would subsequently serve to define the base of the Capitanian Stage, the Illawarra Reversal could then be demonstrated to lie close to the Wordian/Capitanian boundary.

More detailed investigations will be needed to maximize the value of paleomagnetic studies in both the Middle and Lower Permian series, in the North American southwest as well as elsewhere, as both biostratigraphic and regional interrelationships are still problematic (*e.g*., Jin *et al*., 1997). However, current studies (Menning *et al*., in prep.) provide additional information on the type Guadalupian succession. All definitive tests of Cutoff Formation samples indicate reversed polarity, and suggest reference to the Carboniferous-Permian Reversed Megazone Kiaman Superchrone. Similarly, the Getaway Limestone and Manzanita Limestone of the overlying Cherry Canyon Formation also display reversed polarity. Finally, normal polarity has been demonstrated for a few samples from the Pinery Limestone and Lamar Limestone of the Upper Guadalupian Bell Canyon Formation, confirming the approximate position of the Illawarra Reversal.

Summary

Formal Proposal. For the reasons cited, the first appearance of the conodont *Jinogondolella nankingensis,* in the evolutionary continuum from *Mesogondolella idahoensis,* at 42.7 m above the base of the Cutoff Formation in Stratotype Canyon, west face of southern Guadalupe Mountains, is hereby proposed as the GSSP for the base of the Middle Permian Guadalupian Series and coincident Roadian Stage. The first appearance of *Jinogondolella aserrata,* in the transitional continuum from *J. nankingensis,* at 7.6 m above the base of the Guadalupe Ledge (in Park) outcrop section in Guadalupe Pass, southeastern Guadalupe Mountains, is hereby proposed as the GSSP for the base of the Middle Guadalupian Wordian Stage. Finally, the first appearance of *Jinogondolella postserrata* within the transitional continuum from *J. aserrata,* in the upper Pinery Limestone Member of the Bell Canyon Formation at 4.5 m in the outcrop section at the top of Nipple Hill, southeastern Guadalupe Mountains, is hereby proposed as the GSSP for the base of the Upper Guadalupian Capitanian Stage. The coincident tops of the Guadalupian and Capitanian will be recognized, primarily on conodont evidence, to correspond to the GSSP for the bases of the Upper Permian Lopingian Series and coincident Wuchiapingian Stage, expected to be defined in the Penglaitan sections, Honghsui River, central Guangxi, South China (Mei, *et al*., 1998). Conodont successions closely similar to those to be used in the definition of the base of the Lopingian are known already in the Reef Trail Formation (and its West Texas equivalents) that overlies the uppermost Capitanian Lamar Limestone.

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