Permian fusulinids from Cobachi, central Sonora, Mexico

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ABSTRACT

Upper Paleozoic rocks in the Cobachi area of central Sonora, Mexico, include the Picacho Colorado and La Vuelta Colorada formation of Carboniferous?-Permian age. A 155 m carbonate succession of the Picacho Colorado Formation, exposed on the east side of Cerro Picacho Colorado, a few kilometers southeast of Cobachi, consists of pinkish and reddish limestone, cherty limestone with some recrystallization, and bioclastic gray limestone. Crinoids, bryozoa, brachiopods and foraminifers are present indicating a marine shallow water shelf depositional environment. Well preserved fusulinaceans occur near the top of the section, but are scarce, partially silicified, and poorly preserved in the middle part and the base of the section. Skinnerella cobachiensis n. sp., Paraskinnerella cf. P. durhami, Parafusulina P. cf. P. multisepta and three unnamed species of Parafusulina of early Permian (Leonardian) age are described from this succession. The fusulinacean assemblage from this area has affinities with forms found in rocks with similar age in east central California, west Texas, southeast Mexico, and Central and South America

Key words: fusulinids, Permian, Cobachi, Sonora, Mexico

RESUMEN

Las rocas del Paleozoico Superior en el área de Cobachi, Mexico incluyen las formaciones Picacho Colorado y La Vuelta Colorada de edad Carbonífero? Pérmico. Una secuencia de 155 m de espesor, en la Formación Picacho Colorado expuesta hacia el este del Cerro Picacho Colorado, algunos kilómetros al sureste de Cobachi, consiste en calizas rosáceas y rojizas, calizas con pedernal ligeramente recristalizadas y calizas grises bioclásticas. Están presentes Crinoideos, briozoarios, braquiópodos y foraminíferos indicando un ambiente marino de plataforma somera. Fusulínidos bien preservados ocurren cerca de la cima de la sección, pero son escasos, parcialmente silicificados y pobremente preservados en la parte media y en la base de la sección. Se describen en esta secuencia: Skinnerella cobachiensis n. sp., Paraskinnerella cf. P. durhami, Parafusulina P. cf. P. multisepta y tres especies de Parafusulina del Pérmico Temprano (Leonardian). Los fusulínidos descritos en esta área muestran afinidades con formas descritas en Norteamérica incluyendo el área centro-oriental de California, el oeste de Texas, el sureste de México, así como áreas de Centro y Sudamérica.

Palabras clave: fusulínidos, Pérmico, Cobachi, Sonora, México

INTRODUCTION

The Cerro Cobachi area in central Sonora is approximately 116 km southeast Hermosillo, and about 12 km southeast of the village of Cobachi (Figure 1). Various authors have studied the stratigraphy and structural aspects of the rocks in this area. On Cerro Cobachi, Dumble (1900) described quarzites and marbles considered as Cambrian rocks, in contact with Silurian rocks. King (1939) present a geologic cross section from Las Tinajas through Cerro Cobachi in which he noted Permian limestone lying with an angular unconformity above Cambrian rocks. At La Casita, west of Cerro Cobachi and at Cerro Cobachi, he reported massive limestone of Ordovician age and Permian rocks described as "a massive reef limestone grading laterally into a 530 m thick, a thin-bedded dark granular limestone, with abundant crinoidal fragments and fusulinids". He also reported a thinner-bedded limestone containing two species of fusulinaceans including *Parafusulina* resembling a species from the Leonard Formation of Trans-Pecos, Texas, and crinoid stems.

Noll (1981), in the most complete study of the northern Sierra Cobachi and Picacho Colorado area, mapped the stratigraphy and structure. He reported about 2,900 m of Paleozoic sedimentary rocks and stated that it was difficult to measure continuous stratigraphic sections because of structural complications. In the Cerro Cobachi area of central Sonora, the thick Paleozoic strata have been structurally deformed mainly by low-angle contractional faults or thrust faults (Noll, 1981; Ketner, 1986; Ketner and Noll, 1987).

Noll (1981) recognized an Ordovician to Permian carbonate and quartzite platform assemblage and Ordovician to Permian siliceous deeper water facies within two kilometers of each other on opposite sides of Cerro

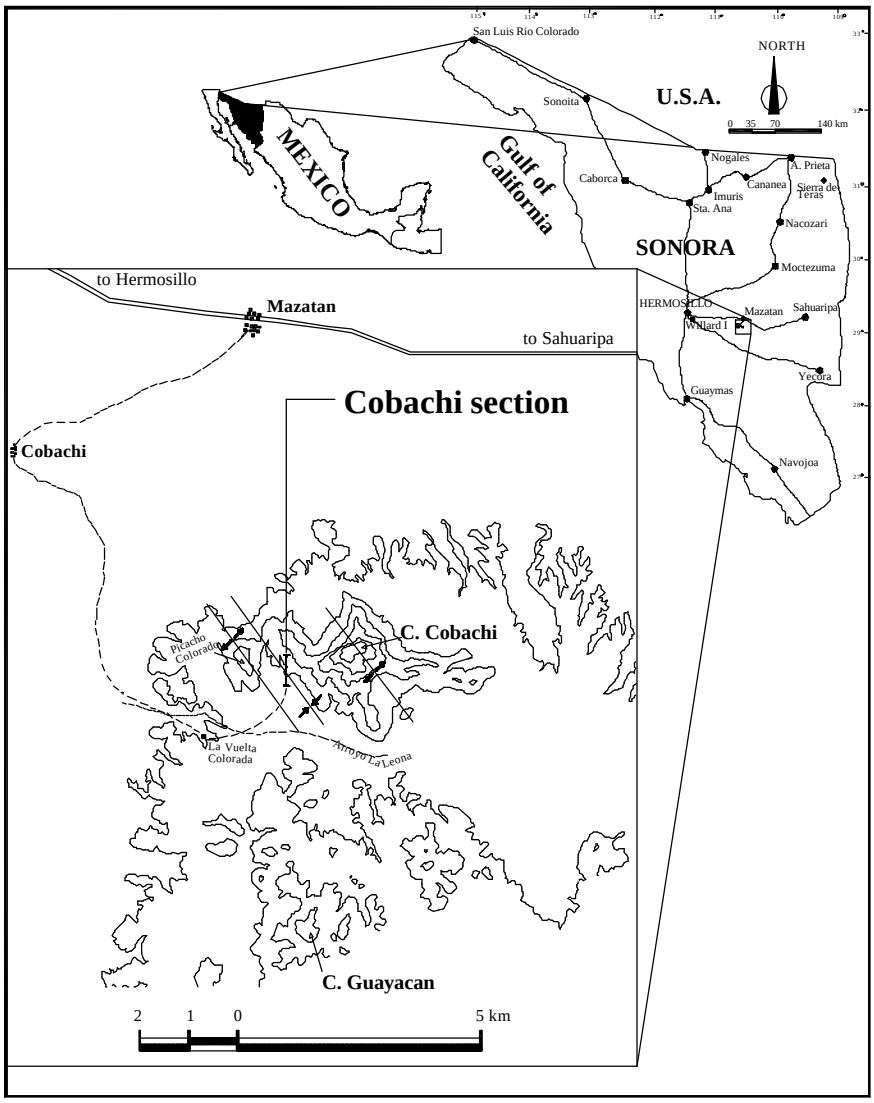

Figure 1. Location map of the Cerro Cobachi area.

Cobachi. The distinct lithological contrast between these assemblages suggests that their sites of deposition were originally separated, later juxtaposed by a large thrust fault, and subsequently sealed by a Late Cretaceous biotite-horblende granodiorite intrusive that locally metamorphosed the sedimentary section (Peiffer-Rangin, 1979; Noll, 1981; Ketner and Noll, 1987; Peiffer 1987). The Paleozoic section is divided into 3 stratigraphic units: the Guayacán Group (Lower Paleozoic), the Picacho Colorado Limestone, and the La Vuelta Colorada Formation (Carboniferous?-Permian).

The Guayacán Group includes Lower Paleozoic rocks (Late Ordovician to Devonian) located along the western side of Cerro Guayacán on the southern flank of Cerro Cobachi (Figure 1), and it is composed of eugeosynclinal strata 288 m thick. This group has been divided into four unmapped lithostratigraphic units including graptolitic shale, siliceous shale, bedded chert, stratiform barite and associated terrigenous clastic rocks and limestone (Noll,1981).

The Picacho Colorado Formation (Mississippian?-Permian) is mostly exposed northeast of Cerro Picacho Colorado and adjacent areas (Figure 1), and was described by Noll (1981) as thin to thick bedded limestone and marble over 1,450 m in thickness, containing bryozoans, gastropods, crinoids and fusulinaceans, an assemblage typical of shallow-water marine deposition. Is difficult to establish the exact stratigraphic succession and thickness of this formation because of metamorphism and structural complications. According to Noll (1981) and Peiffer (1987), the Permian age of this formation was established on the basis of fusulinaceans. Rugose corals, of probable uncertain Mississippian age (Sando, 1980, personal communication in Noll 1981) were also reported.

The Vuelta Colorada Formation is found in thrust fault contact with the Picacho Colorado Formation. Exposures are difficult to find; outcrops, mainly near Rancho La Vuelta Colorada (Figure 1), consist of coarse-grained siltstone, fine-grained sandstone and sandy limestone (Noll, 1981). The limestone contains abundant fragments of echinoid plates, crinoid stems and unidentifiable fusulinaceans indicating a probable middle or late Permian age (Noll, 1981). The thickness varies from 250 to 1,225 m, but is difficult to determine precisely because of faulting (Noll, 1981; Ketner, 1986).

Poole and Madrid (1986,1988) reported about 2,000 m of allochthonous Ordovician to Permian marginal ocean-basin siliceous strata thrusted over shelf carbonate rocks at Barita de Sonora and Cerro Cobachi. Peiffer-Rangin (1979) and Peiffer (1987) noted that the Permo-Carboniferous strata overlie folded Lower Paleozoic rocks throughout central Sonora and that allochthonous Paleozoic strata in this area have similarities with Paleozoic strata from the western and southern continental margin of North America. Bartolini (1993) proposed that rocks of the Cobachi area constitute a separate, Cordilleran tectonostratigraphic terrane, similar in some aspects to the Roberts Mountains and Golconda allochthonous terrane of central Nevada in North America.

METHODOLOGY

The section was measured and samples taken using the tape and compass method. A base map was constructed from the 1:50,000 Cobachi topographic map H12D53. Samples were collected through the section at different intervals at lithologic changes, and rock textures were recorded using the general field textural classification of Dunham (1962). Thirty thin sections were stained with Alizarin-red to determine dolomite content. The microfacies study was done with a petrographic microscope and using the classification of Folk (1974) for limestones. Approximately 150 oriented thin sections were prepared for identification and description of the fusulinaceans. Measurements of the specimens are included in Table 1.

STRATIGRAPHY

According to Noll (1981) and Peiffer (1987), the stratigraphic position of Paleozoic sections in Cobachi area has been difficult to ascertain due to structural complications, as the allochthonous sections are complexly folded and faulted, consequently, good measured sections in Picacho Colorado have been hard to trace.

Permian rocks in Picacho Colorado area are represented by the Picacho Colorado Limestone defined as: "thinly to very thickly bedded cherty limestone and marble exposed on Picacho Colorado and in adjacent areas" (Noll, 1981). The formation is well exposed on the eastern side of Picacho Colorado, cut by low angle faults within an uplifted fault block. Strata below the thrust are locally recrystallized and altered to hornfels in some places. Rocks above the thrusts are considered to be allochthonous, contain well preserved fusulinaceans and do not show effects of thermal metamorphism. Strata below the thrusts also contain abundant fusulinaceans and are considered to be autochthonous. The depositional environment of both sequences is shallow marine shelf. An allochthonous 94 m thick section of fusulinacean and crinoidal limestone is emplaced over locally metamorphosed carbonates (Noll, 1981), east and below of the summit of Picacho Colorado (Noll, 1981). The petrographic study of limestones from the Picacho Colorado sequence shows stylolitic structures produced by pressure solution. These can be seen in the crinoidal columns. Partially silicified fusulinaceans collected from this area were identified as: *Paraskinnerella* cf. *P. skinneri* (Dunbar, 1939a), *Skinnerella* cf. *S. magna* (Skinner), as well as other unidentifiable species of *Parafusulina*, indicating a Leonardian age (Douglass in Noll, 1981). Autochthonous rocks described by Noll (1981), south of the summit of Picacho Colorado, are

Table 1. Measurements (in milimeters) of fusulinid specimens.

Skinnerella cobachiensis n. sp.

Specimen	L	W	Prol.	volution #	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
					radius vector									half length									volution height								
Cobachi C01 (1)	11.75	4.00	0.450		0.29	0.41	0.58	0.89	1.08	1.32	1.63	1.95	-	0.66	0.96	1.22	1.88	2.38	3.04	3.83	4.74	5.70	0.12	0.16	0.20	0.30	0.29	0.30	0.31	-	-
Cobachi C01 (2)	12.59	3.34	0.340		0.39	0.57	0.77	1.09	1.36	1.70	2.02	-	-	0.60	0.88	1.22	1.78	2.28	3.43	5.29	6.30	-	0.22	0.18	0.20	0.31	0.27	0.34	0.32	-	-
Cobachi C01 (3)	8.88	3.19	0.445		0.27	0.44	0.68	1.00	1.34	1.62	-	-	-	0.60	1.10	1.80	2.28	3.10	4.28	-	-	-	0.09	0.18	0.24	0.32	0.34	0.28	-	-	-
Cobachi C01 (4)	10.80	3.50	0.410		0.24	0.36	0.54	0.76	0.98	1.26	1.67	-	-	0.39	0.86	1.32	1.96	3.10	3.91	5.34	-	-	0.06	0.12	0.18	0.22	0.22	0.28	0.36	-	-
Cobachi C01 (5)	10.66	3.40	0.446		0.26	0.34	0.51	0.68	0.94	1.26	1.61	-	-	0.48	0.84	1.32	1.72	2.66	3.70	4.80	-	-	0.04	0.08	0.17	0.16	0.27	0.31	0.36	-	-
Cobachi C01 m)	10.8	4.10	0.320		0.24	0.30	0.44	0.58	0.20	1.00	1.20	1.60	1.94	0.52	0.76	1.10	1.52	2.22	2.68	3.22	4.54	5.52	0.09	0.04	0.18	0.14	0.20	0.21	0.20	0.38	0.36
Cobachi C01 (n)	11.30	3.28	0.420		0.21	0.32	0.52	0.75	1.20	1.38	1.72	-	-	0.44	1.02	1.54	1.88	2.98	4.42	5.68	-	-	0.09	0.04	0.18	0.14	0.20	0.21	0.20	0.38	0.36
					cumulative septal count									tunnel width									wall thickness								
Cobachi C01 (1)					10	22	25	27	34	38	42	44	-	-	-	0.21	0.29	0.41	0.52	0.69	0.88	-	0.02	0.04	0.04	0.04	0.06	0.09	0.09	0.10	-
Cobachi C01 (2)					15	18	26	34	36	40	44	-	-	-	-	-	0.17	0.26	0.41	0.58	0.69	-	0.01	0.02	0.02	0.05	0.06	0.08	0.10	0.09	-
Cobachi C01 (3)					14	21	26	32	36	43	-	-	-	-	0.06	0.15	0.21	0.30	-	-	-	-	0.04	0.04	0.07	0.08	0.08	0.09	-	-	-
Cobachi C01 (4)					7	16	22	30	33	35	38	-	-	-	-	-	0.13	0.34	0.60	-	-	-	0.02	0.02	0.04	0.05	0.06	0.10	0.09	-	-
Cobachi C01 (5)					12	23	28	29	32	40	48	-	-	-	-	-	-	-	0.53	0.77	-	-	0.01	0.01	0.05	0.05	0.06	0.09	0.08	-	-
Cobachi C01 m)					9	18	23	28	36	40	45	49	57	0.24	0.26	0.34	0.40	0.48	0.56	0.64	0.76	0.86	0.01	0.01	0.01	0.02	0.05	0.06	0.08	0.08	0.08
Cobachi C01 (n)					8	20	24	27	32	36	40	-	-	-	0.22	0.26	0.36	0.52	0.68	0.92	-	-	0.01	0.01	0.02	0.04	0.06	0.08	0.08	-	-

Paraskinnerella cf. *P. durhami*

Specimen	L	W	Prol.	volution #	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
					radius vector									half length									volution height								
Cobachi C03 (1)	14.10	3.59	0.320		0.20	0.30	0.44	0.86	1.16	1.42	1.78	-	-	0.41	0.74	1.72	2.70	3.72	5.05	6.38	6.02	-	0.04	0.09	0.14	0.2	0.23	0.28	0.27	0.34	-
Cobachi C03 (2)	12.61	3.72	0.320		0.17	0.28	0.42	0.60	0.81	1.07	1.31	1.58	-	0.23	0.73	1.35	1.78	2.66	4.18	5.17	6.06	-	0.04	0.14	0.18	0.21	0.27	0.29	0.29	0.32	-
					cumulative septal count									tunnel width									wall thickness								
Cobachi C03 (1)					-	-	-	-	-	-	-	-	-	-	-	0.22	0.36	0.48	0.86	1.16	1.36	-	0.01	0.02	0.03	0.04	0.08	0.09	0.09	0.07	-
Cobachi C03 (2)					-	-	-	-	-	-	-	-	-	-	0.13	0.16	0.25	0.41	0.63	0.83	1.04	-	0.01	0.02	0.03	0.06	0.07	0.07	0.09	0.08	-

Parafusulina sp. A

Specimen	L	W	Prol.	volution #	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
					radius vector									half length									volution height								
Cobachi C03 (1)	10.48	2.40	0.280		0.18	0.22	0.24	0.40	0.58	0.80	1.00	-	-	0.38	0.64	1.12	1.86	2.64	3.82	5.40	-	-	0.04	0.04	0.02	0.16	0.18	0.2	0.22	-	-
Cobachi C03 (2)	13.40	2.28	0.200		0.12	0.14	0.24	0.32	0.50	0.66	0.96	1.18	-	0.20	0.72	1.08	1.48	2.33	3.16	4.46	6.50	-	0.06	0.04	0.08	0.09	0.18	0.16	0.3	0.22	-
Cobachi C03 (3)	13.20	2.20	0.200		0.16	0.22	0.40	0.62	0.82	1.04	-	-	-	0.68	1.58	2.96	4.60	5.92	6.20	-	-	-	0.08	0.06	0.16	0.23	0.20	0.22	-	-	-
Cobachi C03 (4)	12.10	2.52	0.300		0.20	0.24	0.40	0.60	0.86	1.10	-	-	-	0.72	1.60	2.98	4.90	5.98	6.80	-	-	-	0.01	0.01	0.01	0.02	0.02	0.02	-	-	-
					cumulative septal count									tunnel width									wall thickness								
Cobachi C03 (1)					-	-	-	-	-	-	-	-	-	-	-	-	0.12	0.22	0.54	0.48	-	-	0.01	0.01	0.01	0.02	0.04	0.08	0.06	-	-
Cobachi C03 (2)					-	-	-	-	-	-	-	-	-	-	-	-	-	0.28	0.46	0.74	0.96	-	0.01	0.01	0.01	0.02	0.04	0.06	0.07	0.07	-
Cobachi C03 (3)					-	-	-	-	-	-	-	-	-	-	0.20	0.30	0.46	0.50	0.54	-	-	-	0.01	0.02	0.04	0.05	0.08	0.08	-	-	-
Cobachi C03 (4)					-	-	-	-	-	-	-	-	-	-	0.22	0.36	0.50	0.62	0.66	-	-	-	0.01	0.02	0.04	0.05	0.08	0.08	-	-	-

Parafusulina cf. *P. multisepta*

Specimen	L	W	Prol.	volution #	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
					radius vector									half length									volution height								
Cobachi C03 (1)	10.50	3.52	0.160		0.12	0.20	0.32	0.43	0.66	0.92	1.26	1.56	1.80	0.20	0.62	0.98	1.20	1.80	2.40	3.28	4.20	5.34	0.08	0.09	0.12	0.22	0.28	0.28	0.30	0.30	-
Cobachi C03 (2)	9.96	3.90	0.220		0.12	0.24	0.40	0.56	0.80	1.09	1.40	1.78	2.12	0.56	0.94	1.40	2.22	2.96	3.86	4.74	5.22	-	0.04	0.1	0.12	0.18	0.22	0.26	0.32	0.40	0.32
					cumulative septal count									tunnel width									wall thickness								
Cobachi C03 (1)					-	-	-	-	-	-	-	-	-	-	-	0.12	0.20	0.34	0.54	0.74	0.94	1.14	0.01	0.02	0.02	0.04	0.06	0.08	0.11	0.09	0.10
Cobachi C03 (2)					-	-	-	-	-	-	-	-	-	0.1	0.22	0.38	0.54	0.7	0.92	-	-		0.01	0.02	0.04	0.07	0.10	0.07	0.12	0.08	-

Table 1. Continued.

Parafusulina sp. B

	volution #			1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
Specimen	L	W	Prol.	radius vector									half length									volution height								
Cobachi C02 (1)	9.2	3.40	0.100	0.10	0.20	0.30	0.51	0.72	1.20	1.34	1.53	-	0.38	0.92	1.28	2.20	3.24	4.62	5.90	6.40	-	0.10	0.14	0.18	0.20	0.22	0.30	0.34	-	-
Cobachi C02 (2)	10.40	3.94	0.110	0.12	0.18	0.36	0.53	0.88	1.14	1.48	1.84	-	0.52	1.04	2.18	3.70	5.00	6.40	6.90	-	-	0.08	0.12	0.18	0.18	0.38	0.28	0.34	0.34	-
				cumulative septal count									tunnel width									wall thickness								
Cobachi C02 (1)				-	-	-	-	-	-	-	-	-	0.22	0.28	0.42	0.54	0.70	0.90	1.10	-	-	0.01	0.02	0.02	0.03	0.04	0.06	0.08	-	-
Cobachi C02 (2)				-	-	-	-	-	-	-	-	-	-	-	0.28	0.54	0.72	0.98	1.18	-	-	0.01	0.02	0.04	0.04	0.06	0.07	0.08	0.08	-

Parafusulina sp. C

	volution #			1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
Specimen	L	W	Prol.	radius vector									half length									volution heigth								
Cobachi C02 (1)	10.30	2.28	0.120	0.08	0.18	0.24	0.38	0.52	0.68	0.88	1.14	-	0.42	0.92	1.22	1.96	2.60	3.44	4.40	5.48	-	0.08	0.10	0.08	0.14	0.14	0.18	0.2	0.24	-
				cumulative septal count									tunnel width									wall thickness								
Cobachi C02 (1)				-	-	-	-	-	-	-	-	-	-	0.12	0.20	0.25	0.30	0.42	0.56	0.75	-	0.01	0.01	0.01	0.01	0.02	0.04	0.04	0.06	-

composed of limestone, partially or completely recrystallized, cherty limestone and isolated exposures of coarse grained calcite, marble, wollastonite and hornfels. The limestone beds contain bryozoans, gastropods, shell fragments, crinoids and horizons with fusulinaceans identified as *Parafusulina* sp. and possible *Skinnerina* suggesting an Early Wordian age. Northeast of Picacho Colorado, Noll (1981) noted specimens similar to *Schwagerina crassitectiria* described in rocks of Early Leonardian age from Texas. Partially deformed, silicified and highly fractured solitary corals, referred to the genus *Amplexizaphrentis*, suggesting a Carboniferous (Mississippian?) age (Sando, personal communication in Noll, 1981), were found northeast of the fusulinid localities, along the base of the eastern side of Picacho Colorado.

LITHOSTRATIGRAPHY AND MICROPALEONTOLOGY

The Permian rocks studied in this work belong to allochthonous strata exposed between Picacho Colorado and Cerro Cobachi (Figure 1). The measured section is located on the east side of Picacho Colorado at El Polvorín and situated on the eastern flank of an anticline (Figure 1). Precise measurement of the thickness of the section was difficult due to fracturing of the beds; but an approximate thickness of 155 m is estimated. The strike of the beds at the top the section is N-S; with the beds dipping 43º W (Figure 2).

The base of the section consists of thin to thick bedded limestone with karst weathered surface and irregular alternations of nodular and interbedded pinkish and orange chert with some stylolites present between small fractures. Limestone beds are dark gray on fresh surfaces, and pinkish on weathered surfaces. The medium-grained limestone has sparse crinoidal debris and poorly preserved silicified fusulinaceans. There is a transitional change to the top of the section with a considerable increase in faunal content and thickness of the limestone beds (from 10 to 80 cm and 1m or more), that are blocky and strongly fractured near the top. The limestone beds are rich in crinoidal debris with a packstone-grainstone texture and the fusulinacean fauna is well preserved. Most beds of the section are similar in lithology from base to top with variations in proportion of chert; sharp contacts are observed between unfossiliferous chert beds and crinoidal limestones. Scarce laminations of organic material and micrite also are present. Fusulinaceans are most abundant at the top of the section, are randomly oriented, and mostly well preserved. Some are partially silicified so that it is difficult to obtain oriented well preserved specimens in sections. Although the fusulinaceans are abundant in the limestone beds, they were also found interbedded with chert beds throughout the section, sometimes in association with well preserved crinoids, bryozoans and brachiopods.

Petrographically, the samples studied are recrystallized biomicrite and strongly silicified, hematized and slightly dolomitized biomicrudite. Some authigenic quartz was observed, but terrigenous components are not present. Fracture fillings with ferric oxide and recrystallized calcite; as well as hematized stylolitic boundaries between skeletal grains are present. Limestones at the top of the section contains a great abundance of crinoid stems and plates, echinoid spines and randomly oriented fusulinaceans. Other foraminifers include representatives of paleotextularids hemigordiopsids, the foraminifer genus *Biseriella*. Ramose bryozoans, brachiopods, sponge spicules and calcareous algae (dasycladaceans and coralline algae) as well as ostracods, are present in lesser amounts.

Fusulinid specimens for systematic study were mainly collected near the top of the section (see Figure 2) where the best preservation was found. Specimens described in this collection, *Parafusulina, Paraskinnerells and Skinnerella*, indicate a Leonardian age and

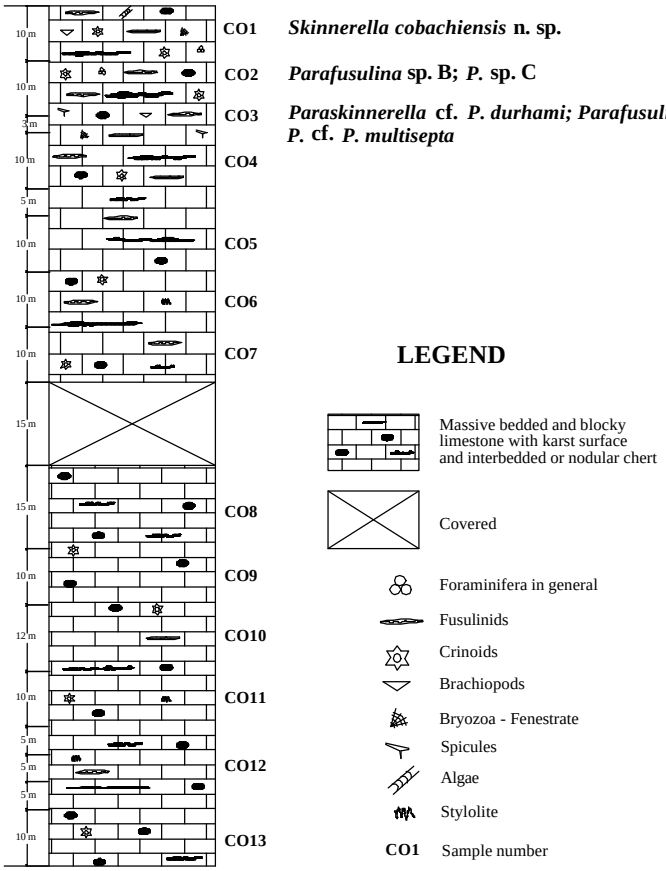

Figure 2. Stratigraphic column of Picacho Colorado, Cobachi.

have affinities with forms described by a number of workers from sections in southwestern and western North America, southern Mexico and Guatemala (Dunbar and Skinner, 1937; Dunbar, 1939a; Thompson and Miller, 1944; Coogan, 1960; Ross, 1962, 1995; Magginetti *et al.*, 1988; Vachard *et al.*, 2000).

ENVIRONMENT OF DEPOSITION

The absence of terrigenous material in the Cobachi section, as well as the increase of thickness in several limestone beds and abundance of fusulinaceans near the top of the section suggest periods of general marine transgresion. The abundance of bioclastic debris including crinoidal plates, some complete stems and unbroken fusulinaceans, suggest currents with moderate energy. The crinoid-fusulinacean association observed falls within the range of fossil assemblages commonly found in offshore normal marine waters (Stevens, 1966, Yancey and Stevens, 1981). The abundance of chert nodules, along with interbedded chert in the limestone, and the preservation of fusulinaceans in the chert beds strongly suggests the diagenetic replacement of limestone by silica.

SYSTEMATIC PALAEONTOLOGY

Specimens from the Cerro Cobachi area described in this study are housed in the Geology Department, at the University of Sonora (abbreviation Uni-Son), and bear catalog numbers of that institution.

Order Foraminiferida Eichwald, 1830
Superfamily Fusulinacea von Möler, 1978
Family Fusulinidae von Möller, 1878
Genus *Skinnerella* Coogan, 1960 emend.
Skinner, 1971 emend.

Skinnerella cobachiensis n. sp.

(Plate 1, Figures 1-11)

Description. Shell of medium size with thick fusiform shape, regular outline, and convex lateral slopes with slightly rounded pointed ends. Specimens of 6 to 8 volutions reach 8.8 to 12.5 mm in length and 3.1 to 4.2 mm in diameter. Proloculus spherical, thin-walled, ranges from 320 to 450 microns in outside diameter. First volution wide of irregular shape; following volutions gradually increase in size with rather thickly fusiform shape and pointed or rounded extremities. Some speci-

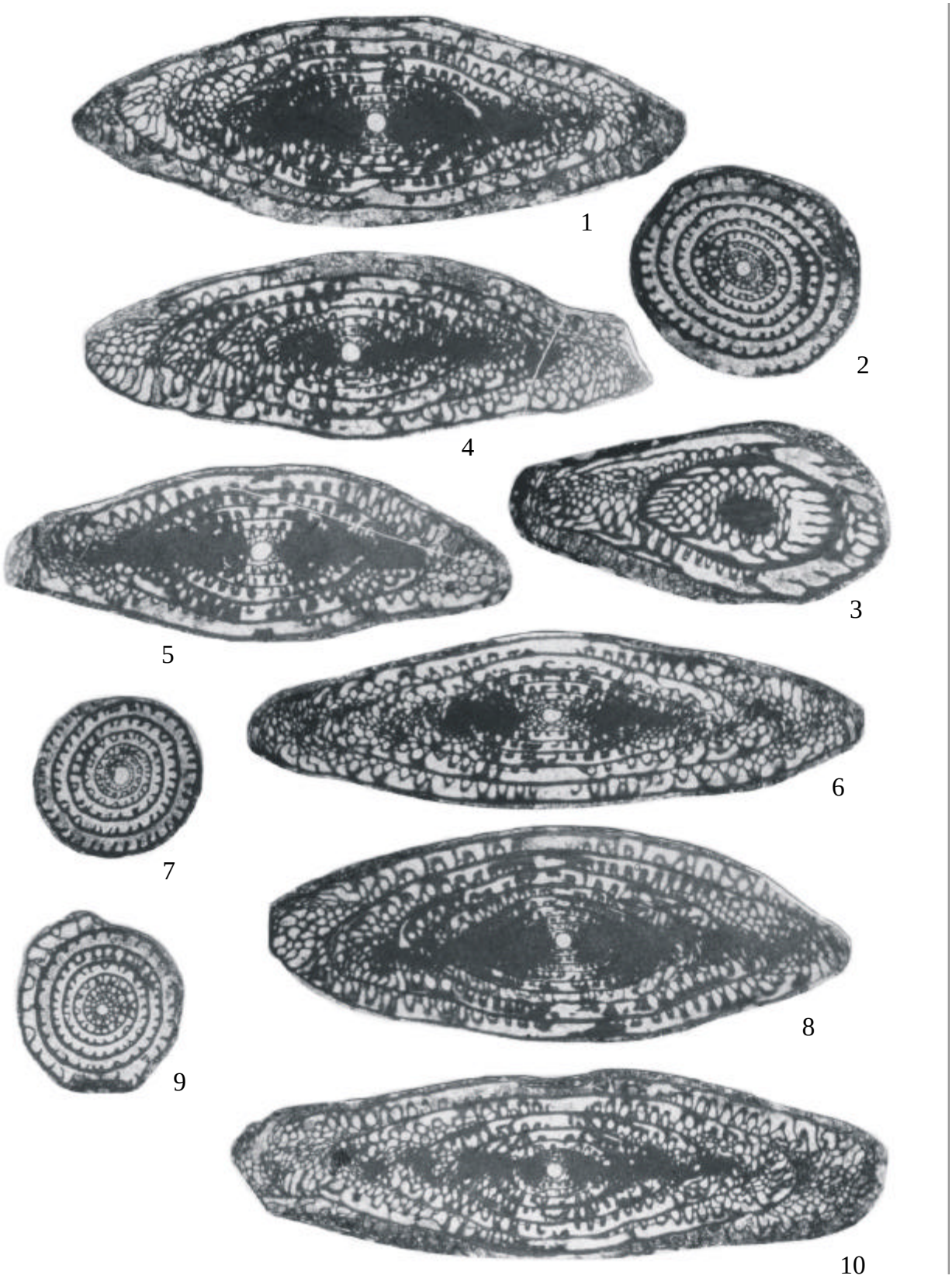

Plate 1. Fusulinaceans from Cobachi, central Sonora (all figures X 10). Figures 1-10 *Skinnerella cobachiensis* n.sp. upper part of Picacho Colorado section. 1. Axial section of holotype, locality CO1, collection Uni-Son 172 (1). 2. Sagittal section, collection Uni-Son 173. 3. Tangential section showing cuniculi, collection Uni-Son 174. 4. Axial section of Paratype, collection Uni-Son 175 (5). 5. Axial section, collection Uni-Son 176 (3). 6. Axial section, collection Uni-Son 177 (n). 7. Sagittal section, collection Uni-son 178. 8. Axial section, collection Uni-Son 179 (m). 9. Sagittal section, collection Uni-Son 180. 10. Axial section, collection Uni-Son 182 (2).

mens show slight constriction in the middle of shell in outer whorls (Plate 1, Figures 1, 5). Wall composed of tectum and fine alveolar keriotheca. Spirotheca thick, finely alveolar, becoming slightly thinner in the inner whorls, up to the fourth volution. Wall thickness in early volutions is 0.020, 0.040 and 0.060 mm to 0.090, 0.090 and 0.100 in sixth, seventh and eighth volutions respectively. Intense fluting, with low and high septal folds unevenly disperse throughout the shell, decreasing in tunnel area.

Tunnel is of medium width, increasing gradually in early volutions with an irregular path. Cuniculi well developed in outer volutions. Some specimens show moderately developed phrenothecae (Plate 1, Figure 10). Strong axial fillings on either side of tunnel and along middle plane; secondary deposits coat septa. Proloculus bordered with rudimentary chomata.

Size, shape of the shell as well as type of secondary deposits are diagnostic of this species (Plate 1, Figures 1, 4, 5 and 8).

Remarks. Coogan (1960) considered *Skinnerella* as a subgenus of *Parafusulina* Dunbar and Skinner, 1937. Skinner (1971) argued that according to the lineages of evolution, *Skinnerella* should be considered as a genus, including species having: 1) strong secondary deposits that may completely fill the chambers of the early volutions and tend to spread away from the axis to outer whorls; 2) low cuniculi and phrenothecae commonly well developed; 3) microspheric specimens about same size as their megalospheric counterparts. The microspheric forms are usually small in *Skinnerella*. In contrast, specimens of *Parafusulina* described from middle Permian rocks normally have microspheric specimens two or more times as large as their megalospheric forms (Dunbar and Skinner, 1936; Skinner, 1971, Stevens, 1995). Ross (1995), Vachard and Fourcade (1997) and Vachard *et al.* (2000) regroup all *Skinnerella* species to range from lower to middle Leonardian, whereas *Parafusulina* is commonly found in rocks of Leonardian to Guadalupian age (Dunbar and Skinner, 1937; Thompson, *et al.*, 1946; Skinner and Wilde, 1965; Ross, 1967; Wilde, 1975, 1990; Douglass, 1977).

Specimens from Cobachi are similar to *Skinnerella gruperaensis* (Thompson and Miller, 1944) described from Chiapas and noted by Kling (1960) from Guatemala, but they differ in ontogeny, being smaller and wider, with smaller proloculi, and different distribution of secondary deposits. *Schwagerina guembeli* Ross, 1960 from the Leonard Formation of Texas, is slightly smaller and lacks cuniculi. *Skinnerella diabloensis* (Dunbar and Skinner, 1937) from the Bone Spring Formation, (Leonardian) Texas, is larger, slightly wider and has a larger proloculus. Some specimens can be compared to *S. schucherti* (Dunbar and Skinner, 1937); but they differ from that species in being smaller and having larger proloculus. One specimen from this collection is similar in size and general shape to *Parafusulina deltoides* Ross, 1960 (Leonardian) from Texas; the latter differs in having a smaller proloculus and less strong secondary deposits.

The specific name is given because the species described was collected near Cobachi community, on which this report was based.

Occurrence. Specimens from this collection are abundant and well preserved in limestone from locality CO1, top of the section at Cobachi area.

Types. Holotype Uni-Son 172, (Plate 1, Figure 1). Paratypes Uni-Son 175-180. (Plate 1, Figures 4-9). Syntype Uni-Son 182 (Plate 1, Figure 10).

Subfamily Schwagerinidae Dunbar and Skinner, 1931
Genus *Parafusulina* Dunbar and Skinner, 1931

***Parafusulina* sp. A**
(Plate 2, Figures 1-4)

Description. Shell large, elongate fusiform with irregular outline and sharply pointed ends. Specimens with 6 or 7 volutions reach from 10.4 to 13.2 mm in length and 2.2 to 2.5 mm in diameter. Proloculus small, spherical, ranging from 200 to 300 microns. Spirotheca thick with coarsely alveolar keriotheca in outer volutions sometimes thinning toward the polar ends, thin in earliest volutions. Wall thickness range from 0.010 mm in early volutions, gradually increasing to 0.060 and reaching 0.080 mm in the sixth volution. First volutions of highly fusiform shape, increasing gradually in size, with rather pointed ends and irregular outline. Septa regularly fluted with mostly low folding in the middle section and polar ends. Proloculus bordered by rudimentary chomata. Secondary deposits along axial section irregularly distributed; also these deposits coat some septa. Tunnel low and wide of irregular path. Phrenothecae present but usually not conspicuous (Plate 2, Figure 2). Low cuniculi well displayed in tangential sections.

Remarks. Specimens from this collection resemble *Parafusulina nosonensis* Thompson and Wheeler, 1946, (Guadalupian), from California in general shape, and some internal features; however *P.* sp. A is smaller in size and has a smaller proloculus bordered by chomata. *Parafusulina* sp. A Magginetti *et al.*,1988 (Leonardian) from California is larger. *P. guatemalaensis* Dunbar 1939b (middle Permian) from Central America is slightly smaller, has stronger axial fillings and lacks chomata and phrenothecae.

Occurrence. *Parafusulina* sp. A, is fairly abundant and well preserved in partially silicified limestone beds at locality CO3 near top of the section associated to *P.* cf. *P. durhami* and *P.* cf. *P. multisepta* in the Cobachi area. (Uni-Son 183).

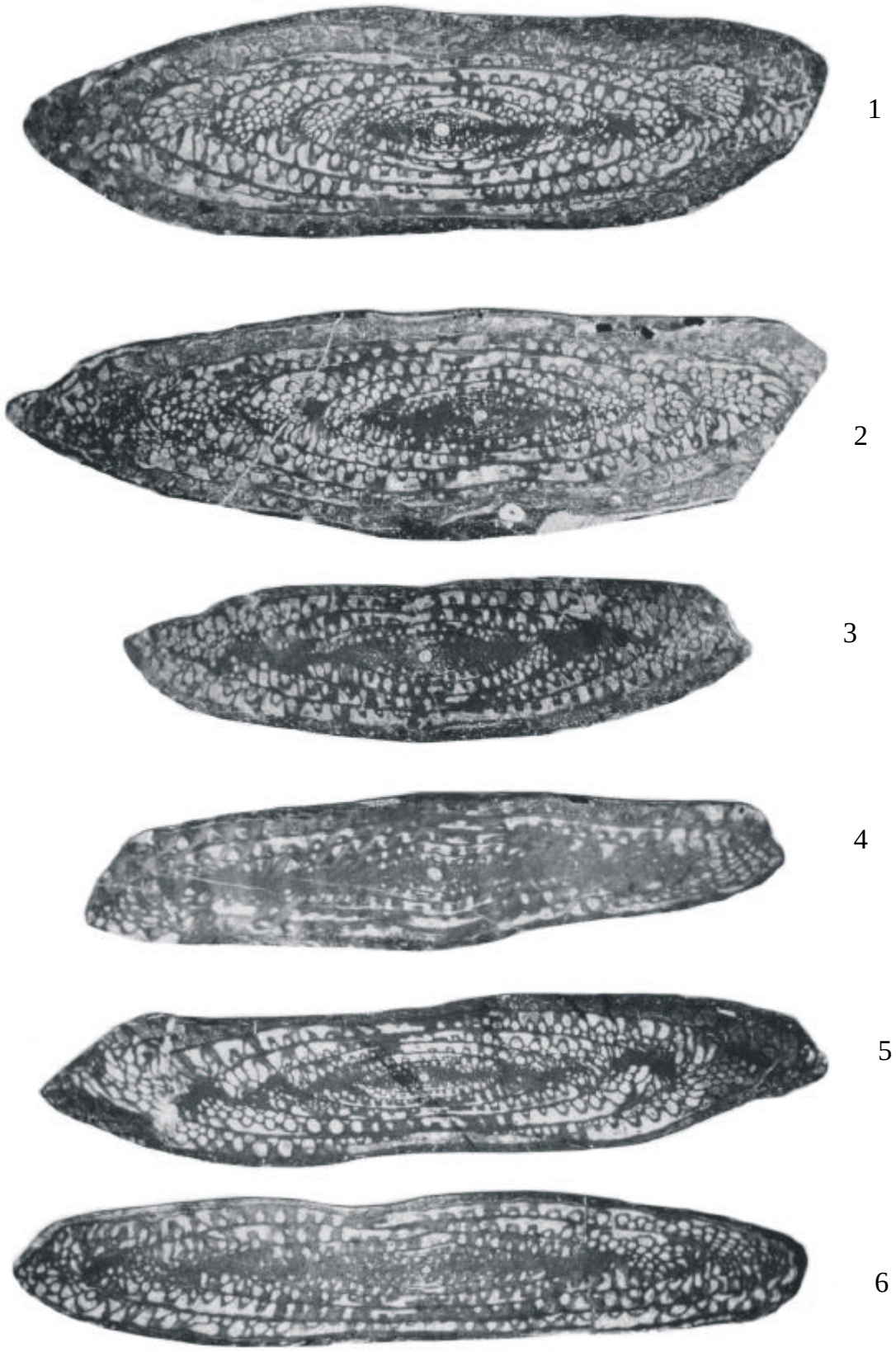

Plate 2. Fusulinaceans from Cobachi, central Sonora (all figures X10. Figures 1-4 *Parafusulina* sp. A locality CO3, Picacho Colorado section. 1. Axial section, collection Uni-Son 183 (3). 2. Axial section, collection Uni-Son 184 (2).3. Axial section, collection Uni-Son 185 (4). 4. Axial section, collection Uni-Son 186 (1).5, 6. *Paraskinnerella* cf. *P. durhami* locality CO3 Picacho Colorado section. 5. Axial section, collection Uni-Son 190 (1). 6. Axial section, collection Uni-Son 191 (2).

Paraskinnerella cf. *P. durhami*
(Plate 2, Figures 5, 6)

Description. Large subcylindrical shell with irregular outline and bluntly pointed ends; specimens with 7 to 8 volutions reach 10.4 to 14.1 mm in length and 2.4 to 3.5 mm in diameter. Proloculus spherical, thin-walled ranges from 200 to 300 microns outside diameter. Spirotheca thick finely alveolar, becoming thicker after the fourth volution; wall thickens from 0.10 mm in first whorl to 0.080 and 0.090 in seventh to eighth volutions. Earliest volutions of highly fusiform shape loosely coiled, later with a sudden expansion of the next whorls with rounded ends.

Intense low septal folding throughout, except near middle of shell, some vesicular folding in extremities. Tunnel wide with irregular path. Proloculus bordered by rudimentary chomata. Phrenothecae are moderately to well developed (Plate 2, Figure 6). Light axial fillings observed in inner volutions, irregularly distributed in midplane.

Remarks. According to Bensh, in Vachard *et al.* (2000), *Parafusulina* is a polyphyletic genus and primitive species of *Parafusulina* should be considered as *Paraskinnerella*, including *Parafusulina skinneri*, Dunbar, 1939; *P. durhami* Thompson and Miller, 1949 and *P. leonardensis* Ross, 1962. Specimens from this collection compare to *Paraskinnerella skinneri* (Dunbar, 1939a) (Leonardian) from Sonora, in general shape and size, but the latter has stronger secondary deposits and rather subcylindrical internal volutions. This species also closely resembles *Paraskinnerella durhami* Thompson and Miller, 1949 (Leonardian) from South America and Texas; however *P. durhami* differs in having stronger axial filling, no phrenothecae and chomata. *Skinnerella magna* Skinner, 1971 (Leonardian) from Bone Spring Formation, Texas, is considerably larger, septa folding higher and stronger axial fillings. *Parafusulina sapperi* (Staff) (middle Permian) from central America (Dunbar, 1939b) is larger, with stronger axial filling and a larger proloculus without chomata.

Occurrence. Only a few well-preserved specimens were found in partially recrystallized limestones at locality CO3, associated to *Parafusulina* sp. A, and *P.* cf. *P. multisepta* in the Cobachi area (Uni-Son 191).

Parafusulina cf. P. *multisepta*
(Plate 3, Figures 1-3)

Description. Shell of medium size, thickly fusiform shape, of irregular outline, with broadly rounded or pointed ends and slightly concave lateral slopes. Specimens with 9 volutions attain a length of 9.9 to 10.5 and a diameter of 3.5 to 3.9 mm. Proloculus measures 160 to 220 microns outside diameter. Spirotheca thick, with coarsely alveolar keriotheca. Thickness of wall varies from 0.010 to 0.060 in the first to fifth volutions and 0.080 to 0.100 in the sixth and ninth volutions. Early volutions have elliptical shape, later gradually increase in size with small axial constriction and subrounded extremities. Intense fluting with high and low septal folds, except in tunnel area, forming small tubular projections or chamberlets in polar extremities. Proloculus bordered with rudimentary chomata.

Tunnel wide with irregular path. Secondary deposits in middle plane along axis or in early volutions and coating or filling the septa folds. Some phrenothecae are present. Cuniculi well developed in outer volutions.

Remarks. Specimens described closely resembles the type species of *Parafusulina multisepta* Magginetti *et al.*, 1988 (Leonardian) from California in size and general features, but the latter has stronger axial fillings, higher folding and lack phrenothecae.

Occurrence. Only a few partially silicified specimens were found in limestone near the top of the section at CO3 locality, associated to *Parafusulina* sp. A and *Paraskinnerella* cf. *P. durhami* in Cobachi area (Uni-Son 192).

Parafusulina sp. B
(Plate 3, Figures 4,5)

Description. Shell large, cylindrical of thickly fusiform shape and irregular outline. Two broken specimens measure 9.2 to 10.4 mm in length and 3.4 to 3.9 mm in diameter in 7 to 8 volutions. Proloculus 120 microns in diameter. First three volutions are ellipsoidal; following volutions expand rapidly with rather fusiform shape and small constriction in the middle of shell with pointed or rounded extremities.

Spirotheca thick, finely alveolar, becoming slightly thinner in the inner whorls, up to the fourth volution. Wall thickness in early volutions is about 0.010, 0.020 to 0.080 mm in seventh and eighth volutions. Intense fluting, with low and sometimes high septal folds unevenly dispersed throughout the shell, forming chamberlets at the polar ends, decreasing in the tunnel area. Proloculus small circular. Tunnel wide of irregular path. Axial filling along mid plane irregularly distributed. Cuniculi were not seen in the available material.

Remarks. Specimens described above are incomplete; but they may be compared with *Paraskinnerella skinneri* (Dunbar, 1939a) (Leonardian) from northeast Sonora; however, the latter has narrower tunnel area and higher septa fluting.

Occurrence. *Parafusulina* sp. B is partially silicified and poorly preserved in cherty limestone at the CO2 locality, associated with *P.* sp C, near top of the section in Cobachi area. (Uni-Son 196).

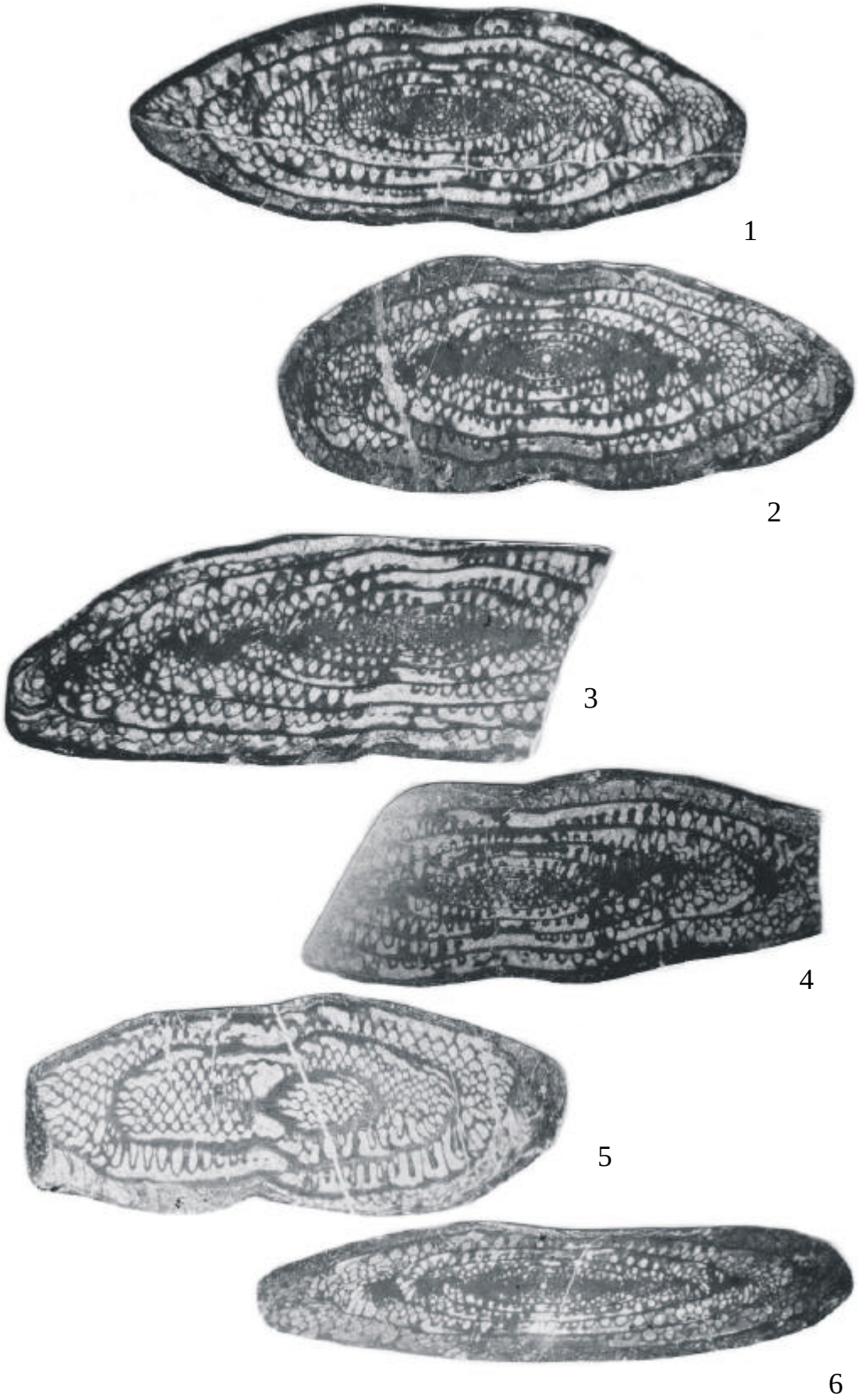

Plate 3. Fusulinaceans from Cobachi, central Sonora (all figures X10. Figures 1-3 *Parafusulina* cf. *P. multisepta* locality CO3 Picacho Colorado section. 1. Axial section collection, Uni-Son 192 (1). 2. Axial section, collection Uni-Son 193 (2).3. Tangential section showing cuniculi, collection Uni-Son 194. Figures 4,5 *Parafusulina* sp. B, locality CO2 Picacho Colorado section. 4. Axial section collection Uni-Son 196 (2), 5. Axial section, collection Uni-Son 197 (1). Figure 6 *Parafusulina* sp. C locality CO2 Picacho Colorado section. 6. Axial section, collection Uni-Son 198.

***Parafusulina* sp. C**
(Plate 3, Figure 6)

Description. Shell small, of fusiform shape and bluntly pointed ends. Specimen of 8 volutions about 9.9 mm length and 2.2 mm in diameter. Proloculus small, about 120 microns in diameter. Spirotheca finely alveolar moderately thin in first 3 or 4 volutions, slightly thicker in outer volutions. The wall thickness ranges from 0.010 mm in first volution to 0.060 in the eighth volution. Early volutions have highly fusiform shape, following by abrupt change to larger elongated whorls with pointed to slightly rounded ends. Fluting with low and wide septal folds unevenly spaced mainly in last whorls; extremities with some vesicular fluting. Proloculus thin-walled. Tunnel wide of regular path. Secondary deposits fill early whorls, irregularly distributed along mid plane.

Remarks. *Parafusulina* sp. C is similar to *P.* sp. A from this collection, in shape and general features, but the former is larger and has low and high fluting with phrenothecae.

Occurrence. Only one partially silicified specimen was found in cherty limestone, associated to *P.* sp. B at CO2 locality. (Uni-Son 198).

DISCUSSION AND CONCLUSIONS

Rocks of Permian age are widely distributed in northern and central parts of Sonora, but because formal stratigraphic units have not been established, it is difficult to correlate these strata with rocks from the Cobachi area. According to Álvarez (1949), Hewett (1978), Schmidt (1978) and López-Ramos (1985) the El Tigre Formation in Sierra de Teras, along Cañón Santa Rosa, northeastern Sonora (Figure 1), should be considered as typical of the Permian strata of Sonora. There, about 1,800 m of limestone is present with chert and interbedded shales rich in brachiopods and fusulinaceans (Imlay, 1939) including *Paraskinnerella skinneri* (Dunbar) and *Skinnerella sonoraensis* (Dunbar), formally described by Dunbar (1939a) as Leonardian in age. However, according to Noll (1981), the Cobachi area should be considered to have typical sections of lower Permian rocks of central Sonora. Pérez (1992) reported *Parafusulina*, *Paraskinnerella* and *Skinnerella* at a locality Willard I, east of Hermosillo in west central Sonora (Figure 1), and species of the same genera are here described from the Cobachi area in central Sonora. Permian sections from both of these areas contain rocks of Leonardian age and these rocks can be correlated with similar age strata from the El Tigre Formation (Imlay, 1939) in northeastern Sonora.

Bartolini (1993) proposed that the Upper Paleozoic rocks of the Cobachi area are similar in their stratigraphy and structural style to those exposed in the southwestern corner of North America. Some morphological similiarities in the fusulinacean fauna described from Cobachi area indicate their definite paleogeographic affinities with similar forms known Permian strata of similar age located in the southwestern and western part of the United States and west Mexico, and also Chiapas. and Central and South America.

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