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FAUNAL STUDIES IN THE CRETACEOUS OF THE SANTA ANA MOUNTAINS OF SOUTHERN CALIFORNIA

BY

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INTRODUCTION

The large number of fossiliferous localities occuring within the Cretaceous beds flanking the western slope of the Santa Ana Mountains afford an unusual opportunity for faunal studies in the Upper Cretaceous of the Pacific Coast. Detailed studies of the faunal successions in this region were carried on by the writer in connection with the work of the University of California Summer Session class in Palaeontology in 1913. Collections in the Cretaceous were made at seventy-two localities, for nearly all of which the stratigraphic position is definitely known. These stations are well distributed throughout the two thousand feet of strata in the section and are situated along a strip about thirteen miles in length. The large fauna is divisible into three zones, each of which has been designated by the name of a characteristic species. This section may be regarded as a type region for reference of faunal zones of the Chico group.

The writer wishes to thank Professor John C. Merriam for his interest in, and general supervision of, this study, and to acknowledge the assistance given him in the field by Dr. Roy E. Dickerson and the other members of the field party.

Review of the Literature

The first recognition of faunal differences in the Cretaceous of California should be credited to W. M. Gabb,[1] who divided the Cretaceous into the Shasta and Chico groups on the basis of faunal differences. C. A. White[2] in 1885 divided the Shasta group of Gabb into the Knoxville and Horsetown beds. The fauna obtained from White's[3] Wallala group, which was then thought to be intermediate in age between that of the Horsetown and Chico, is now considered to be but a phase of the lower Chico.[4] Dr. T. W. Stanton has studied the California Cretaceous in its various aspects, and has contributed largely to our knowledge of the different faunas.

The classification of the California Cretaceous as given by White remained unchanged until in 1902 F. M. Anderson divided the Knoxville into an upper, or Paskenta horizon, and a lower, less fossiliferous one to which he applied the term Sub-Knoxville.[5]

Anderson recognized two faunal stages in the Chico, under the names of Upper and Lower Chico. His conclusions were derived from compiled and revised lists of species, which were, as he states, "massed from a number of the more significant localities."[6] Regarding the Horsetown and the Chico Anderson writes that "the transition of faunas is more gradual than it has been in any other basin of the Pacific border; and for that reason the faunas representative of the

[1] Gabb, W. M., Palaeontology of California, vol. 2, p. xiii, 1869.

[2] White, C. A., On the Mesozoic and Cenozoic Palaeontology of California, U. S. Geol. Surv. Bull. 15, p. 19, 1885.

[3] White, C. A., On new Cretaceous Fossils from California, U. S. Geol. Surv. Bull. 22, 1885.

[4] Willis, Bailey, Index to the Stratigraphy of North America, U. S. Geol. Surv. Professional Paper 71, p. 647, 1912.

[5] Anderson, F. M., Cretaceous Deposits of the Pacific Coast, Proc. Calif. Acad. Sci., Third Series, Geol. vol. 2, p. 47, 1902.

[6] *Op. cit.*, p. 25.

different horizons are not so easily distinguished."[7] Anderson chose therefore the following localities outside of the Great Valley as typical of the Lower Chico:[8] San Diego, California, Silverado Cañon, (Santa Ana Mountains) Henley, California, and Phoenix, Oregon. He assigned the type Chico of Chico Creek, Pence's Ranch, Texas Flat, and Tuscan Springs to the Upper Chico. All of these localities are in the upper portion of the Sacramento Valley.

The Silverado Cañon fauna apparently includes only the lowermost fauna from that region. The fauna listed from San Diego, obtained from Point Loma and Point La Jolla, is comparable to the fauna from the lower zone of the Santa Ana Mountains. The different faunas which are considered as equivalent to the upper Chico include the fauna from Chico Creek. It thus appears that Anderson recognized that the Chico Creek fauna represented but a portion of the Upper Cretaceous of California.

A review of the geologic literature dealing especially with the Santa Ana region has been amply covered in a recent paper by Dr. Roy E. Dickerson entitled "The Martinez and Tejon Eocene and Associated Formations of the Santa Ana Mountains."[9]

Geology of the Region

GENERAL GEOLOGIC RELATIONS

In the rocks of the Santa Ana Mountains the following geological divisions are represented; a basement complex of questionably Triassic age; Upper Cretaceous, Chico; Lower Eocene, Martinez; Upper Eocene, Tejon; the lowermost Miocene, Vaqueros; and alluvium of probable Pleistocene age. The intrusives and the metamorphosed sedimentaries of the basement complex comprising the core of the range are unconformably overlain by the Cretaceous sandstones and conglomerates. Both the Martinez and the Tejon are represented by small remnants, which are shown by Dickerson[10] to be discordant with both the underlying Cretaceous and the overlying Miocene. The latter strata successively overlap the Tejon, Martinez, and Chico, and at Arroyo Trabuco are in contact with the basement complex.

The Cretaceous occurs on both sides of the range. It outcrops on the western flank of the mountains in a band having a maximum width

[7] *Op. cit.*, p. 25.

[8] *Ibid.*, p. 26.

[9] Univ. Calif. Publ. Bull. Dept. Geol., vol. 8, pp. 257–274a, pls. 26–28, 1914.

[10] *Op. cit.*, pp. 263–267.

of about three and one-half miles, tapering to a point at a distance of about thirteen miles to the southeast. On the eastern side of the range the strip is narrower, being about a mile in width and three in length.

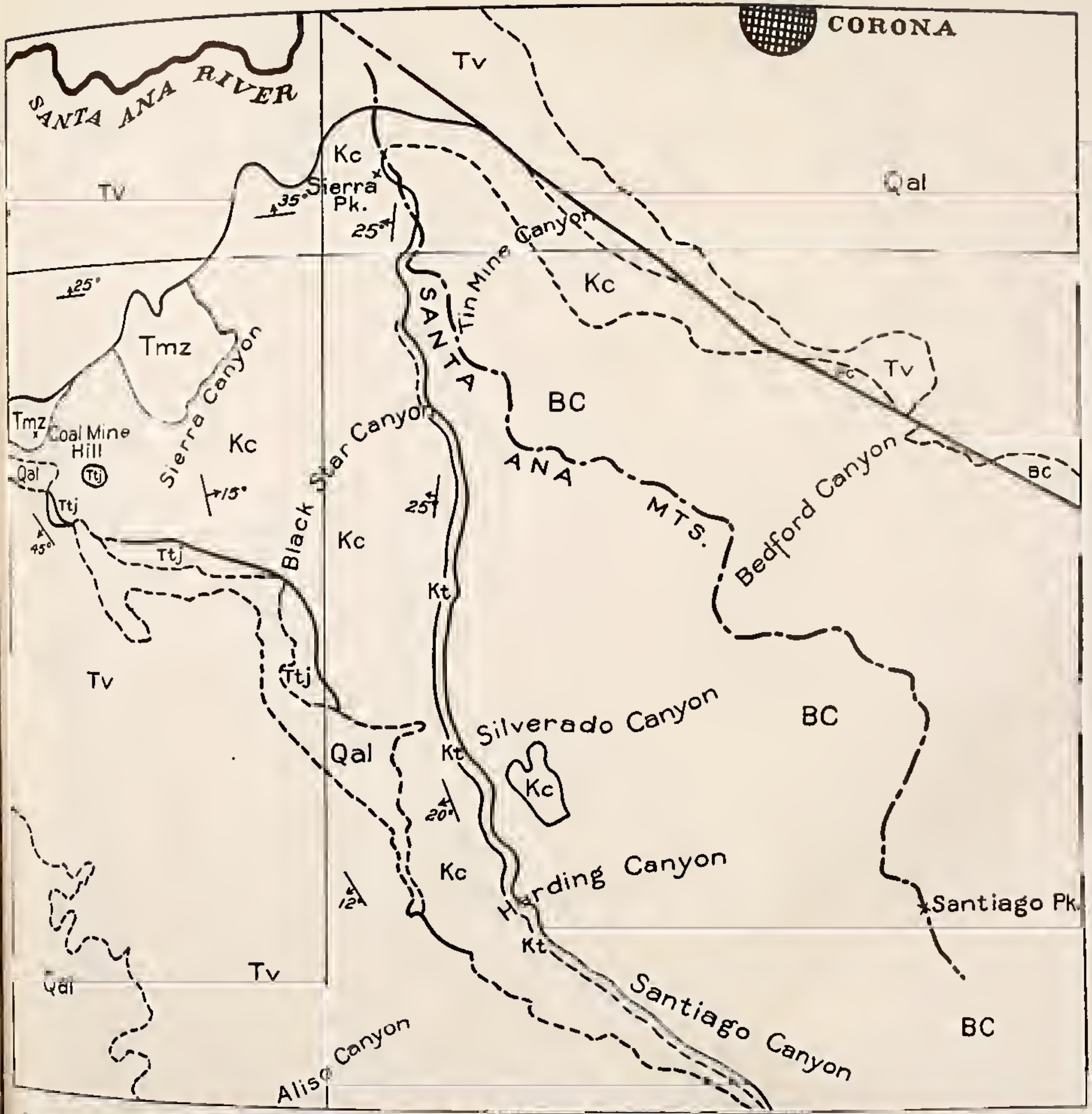
The structure of the Cretaceous of the Santa Ana Mountains appears to be that of an asymmetric anticline, the eastern limb of which has been faulted down and partly concealed by subsequent formations. The strata of the western limb of this fold south of Black Star Cañon have a strike of about N 45° W and a westerly dip of 25° to 30°. On the west side of this cañon the beds are gently inclined, the dip in places not exceeding ten or fifteen degrees. Still farther north the structure becomes complicated by gentle minor folds. Northeast of Coal Mine Hill a carbonaceous stratum marks one limb of a small anticline. Coal Mine Cañon, north of Sierra Cañon, is nearly parallel to the axis of a pre-Tejon fold which involved the Martinez and Chico strata.

THE TRABUCO FORMATION

The basement complex comprising the core of the Santa Ana Mountains is unconformably overlain by a massive red conglomerate, which is traceable as a distinct mapable unit for a distance of about ten miles along the strike. It occurs as a narrow belt three or four hundred feet in width, extending from North Star Cañon nearly to Trabuco Cañon. The term Trabuco formation is here proposed as a local name for these red beds so well exposed along the western flank of the Santa Ana Mountains.

The best section of the Trabuco formation may be seen in Harding Cañon, where the beds have a dip of about 45° S and a strike of N 15° W. The metamorphosed sedimentaries of the basement complex dip about 45° N and strike N 15° W. In places the low dip carries the red basal conglomerates some distance up the slope of the ridges into the area of the basement complex in such a way that small isolated patches of the beds may be found, separated by erosion from the main mass, or connected with it by a thin veneer of residual gravels.

The loosely cemented conglomerates of the Trabuco formation develop upon weathering a rounded topography which is in marked contrast to the abrupt cliffs formed by the gray conglomerates of the overlying Chico. The conglomerates of the basal Chico lie in apparent conformity upon those of the Trabuco, but in most localities the change from the red to the gray beds is very abrupt, suggesting an erosion interval. Direct evidence for such a structural break is lacking. That



Sketch map of a portion of the Santa Ana Mountains, California, a part of the Corona Quadrangle. Qal, Alluvium and Pleistocene terrace deposits; Vv, Tertiary Miocene; Ttj, Tertiary, Tejon Eocene; Tmz, Tertiary, Martinez Eocene; Kc, Cretaceous Chico; Kt, Cretaceous Trabuco; BC, Basement Complex. Scale, ½ inch = 1 mile.

the Chico conglomerates are conformable upon those of the Trabuco appears to be indicated at one locality where a gradation from a red to a gray conglomerate was noted.

These red Trabuco conglomerates are composed of both angular and water-worn boulders varying in size up to those having a diameter of three feet. The boulders represent a considerable range of rock types, the majority of the igneous rocks being basic. In places subordinate bands of red sandstone occur interbedded with the conglomerates.

The peculiar color, the angular form of most of the pebbles and sand grains, and the lack of marine fossils suggests that the Trabuco formation was deposited upon a narrow coastal plain, by torrential streams arising in a mountainous region but a short distance to the eastward. After about two hundred feet of this material had been laid down, marine conglomerates of the basal Chico accumulated within the waters of the transgressing sea.

The age of the Trabuco horizon is not definitely known, since as yet it has yielded no fossils. Judging from its stratigraphic relations the formation is probably but slightly older than the Chico group and presumably represents some phase of the pre-Chico Cretaceous.

THE CHICO GROUP

Resting with apparent conformity upon the Trabuco formation is a series of conglomerates differing from those of the lower formation, in the lighter color of the matrix, in the firmer cementation, in the greater abundance of pebbles of quartzites and slates, and in the inclusion of marine fossils in the matrix and in the rounded boulders. The fossils from the boulders comprise fragments of *Inoceramus* and of an indeterminate gastropod, suggesting the occurrence of earlier Cretaceous deposits now completely removed by erosion.

The conglomerate resting upon the Trabuco grades upward into coarse, light-colored sandstones with subordinate strata of hard, fine-grained calcareous sandstone bearing a characteristic fauna. Following these are several hundred feet of laminated, bluish shales, often containing limestone nodules. The nodules are occasionally fossiliferous. Above the shales the strata again become coarser, being composed of sandstones, which in places grade laterally into conglomeratic lenses. These beds are succeeded by a series of alternating strata of sandstone and shale, which in turn are replaced in the upper portion of the section by hard, fine-grained, calcareous sandstones, fine tan-colored shales and lenses of carbonaceous shales, interstratified in places with seams of coal of an inferior quality.

The most complete section of the Chico group was obtained along the divide between Santiago and Aliso cañons, the details of which are given below. This section in descending order follows.

SECTION OF THE CRETACEOUS ALONG THE SANTIAGO–ALISO DIVIDE

Description of the Lithology	Faunal Zones	Estimated Thickness
Fine-grained, calcareous, tan shales		65 feet
Covered by Vaqueros		120
Tan sandstone intercalated with a resistant, laminated, micaceous, gray, sandstone	Tellina ooides zone	130
Hard, gray, micaceous sandstone		45
Brownish-gray, sandy shales		140
Coarse white sandstone, with a few rounded pebbles	Turritella pescaderoensis zone	60
Light-colored conglomerate, alternating with bands of gray sandy shale, weathering to a dark red		200
Fine-grained, steel-gray shale with lenses of calcareous sandstone		125
Fine-grained gray shale with calcareous nodules		550
Laminated sandstone, slightly conglomeratic, interbedded with gray shale	Actaeonella oviformis zone	50
Gray, conglomeratic sandstone		100
Heavy, gray conglomerates		200
Total thickness of the Chico group		1600
Trabuco formation		
Red conglomerates with subordinate bands of red sandstone		200
Total thickness of the Chico and the Trabuco		1800

FAUNA

GENERAL CHARACTER

The Cretaceous fauna recently obtained from the Santa Ana Mountains includes eighty species and varieties of Pelecypoda, thirty-three of Gastropoda, eleven of Cephalopoda, one of Scaphopoda, besides a few specimens belonging to the Molluscoidea, Vermes, Echinodermata, Arthropoda and Vertebrata. The entire fauna comprises one hundred and thirty-one forms, of which twenty-two are new. The fauna from this region is further increased by other workers who obtained in the same field a number of species not recognized in our collections.

The bivalves are represented by the largest number of species as well as by the largest number of individuals of all the groups enumerated above. *Trigonoarca*, a genus commonly collected in the Trichinopoli group of the Indian Cretaceous, is represented in the Santa Ana Mountains by three new species. Two other genera, *Liopistha* and *Gastrochaena*, have not heretofore been reported from the Cretaceous of California. Members of the genera *Tellina, Crassatellites, Meretrix, Lima*, and *Pecten* are frequently obtained from the Santa Ana region.

The gastropods are most abundantly represented by members of the families Turritellidae, Aporrhaidae and Volutidae. The Turritellas are very abundant in this southern region, whereas in more northern Upper Cretaceous localities of California and especially in Washington and British Columbia they are rare.

The cephalopods are represented in our collections by a number of imperfect specimens. Two or possibly three large nautiloids, resembling certain Indian species, occur in calcareous nodules within the lower shales. Several ammonoids have been found within these shales. Of these forms the genus *Schloenbachia* is most commonly obtained.

FAUNAL ZONES

Faunal studies of marine life carried on within the North Sea,[11] at Woods Hole[12] and elsewhere show intimate relationship between the distribution of marine organisms and the factors of their environment. The character of the bottom, or in geologic terms the type of deposition, determines in a large measure the facies of a given fauna. Thus the different types of bottom are characterized by different faunal associations.

It seems highly probable that under conditions of littoral deposition a sand-dwelling fauna would be replaced by a quite different fauna if conditions of sedimentation were changed. Upon the return of favorable conditions the earlier fauna might again occupy the same region. This effect of the changing conditions is seen in the vertical distribution of a number of large gastropods belonging to the Volutidae. These forms are most abundant within the Santa Ana Mountains in the "lower" shales, and apparently were forced to migrate during

[11] Peterson, C. G. Joh., Valuation of the Sea 11, Report of the Danish Biological Station 21, pp. 1–44, 1915.

[12] Sumner, F. B., Osburn, R. C., Cole L. J., and Davis, B. M., A biological survey of the waters of Woods Hole and vicinity, Bull. U. S. Bur. Fish., 31, pp. 1–860, 1913.

the time that certain sandstones were being deposited, appearing again in the shales above.

Strata that yield a fauna possessing distinctive characters due to evolutionary change rather than to environmental difference may be designated a faunal zone. The distinctive character of the zone is due, then, primarily to the species whose vertical range is restricted to that zone, and secondarily to those species which having reached their height of development are often more abundant than at any other period in the life of the species. The zone may thus be said to possess restricted and characteristic species, besides many unimportant long-range forms.

The fossiliferous Cretaceous rocks of the Santa Ana Mountains are divisible into three zones, each of which will be designated by the name of a representative species.

The lowermost zone of the Cretaceous of this southern region is named the Actaeonella oviformis zone from the presence of a very characteristic gastropod. The fauna associated with this species occurs in the basal conglomerate and sandstone, which lie below the "lower" shales, representing about three hundred and fifty feet of sediments. The fauna obtained from these beds is based upon collection made at the following University of California localities: 2130, 2131, 2134, 2139, 2140, 2141, 2142, 2143, 2191.

This zone is characterized by the abundance of *Actaeonella oviformis,* which appears to be restricted to the zone and by *Pecten operculiformis, Pecten californica, Trigonoarca,* n. sp. *c* and *Astarte,* n. sp. *a* which are occasionally collected within the higher zones although they are nowhere so abundant as within these lower beds (see Table 1).

The faunal zone above the Actaeonella oviformis zone is named after its most characteristic species, *Turritella pescaderoensis* Arnold. The strata through which this fauna ranges include about eleven hundred feet of shale, sandstone and conglomerate.

This zone includes two faunas which are distinguished mainly by characters due to differences in bathymetric conditions. The shales just above the basal conglomerate and sandstone yield a number of gastropods and cephalopods not found abundantly in the coarser sediments of the underlying or overlying strata. This deeper-water fauna appears to be replaced by a fauna of shallower water characterized by the abundance of such species as *Turritella pescaderoensis, Crassatellites lomana,* and *C. conradiana* var. *tuscana,* but it again appears in a slightly modified form in certain higher shale beds. This deeper-water faunal phase is best represented at the following University of California localities: 2136, 2147, 2153, 2156, 2166, and 2170.

The deeper-water phase of the Turritella pescaderoensis zone is noteworthy for the number of species of the Volutidae and Aporrhaidae that it contains. *Opis triangulata* commonly occurs in the shales at a horizon about the middle of this zone. Several poorly preserved ammonids and nautiloids occur more abundantly here than elsewhere.

The shallower-water phase of the Turritella pescaderoensis zone replaces in part the fauna from the shales below. The strata through which this assemblage ranges comprise about six hundred feet of sandstones, heavy conglomerates, and occasional subordinate bands of shale. The following University of California localities have been selected as being characteristic of this phase of the Turritella pescaderoensis zone: 2135, 2146, 2148, 2150, 2151, 2152, 2159, 2160, 2162, 2167, and 2172. *Crassatellites lomana* and *C. conradiana* var. *tuscana* together with *Turritella pescaderoensis* form a large proportion of the fauna of a fossiliferous stratum that is traceable for a distance of several miles.

The uppermost zone is known as the Tellina ooides zone. The fauna is characterized by the great abundance of specimens of *Tellina* and occurs within the uppermost three hundred feet of the section. The strata consist primarily of fine-grained sandstones. The fauna from these upper beds is imperfectly known, due to the concealment of much of this part of the formation by the overlying Vaqueros. The fauna of this zone listed in the table below was obtained from the University of California localities 2168 and 2169.

This zone yields a large number of pelecypods and relatively few gastropods. The lack of cephalopods is noteworthy, especially since fragments of ammonites are frequently collected in the beds below this horizon. *Perissolax brevirostris* is quite characteristic of the zone. *Meekia sella* was found only within these uppermost beds, although it has been reported elsewhere from the lower Chico.

The fauna of the different zones is indicated in the table below. A fifth column is given for those species whose stratigraphic position is unknown. An asterisk indicates species characteristic of the zone in which this convention appears.

TABLE I

LIST OF CRETACEOUS SPECIES FROM THE SANTA ANA MOUNTAINS

	Actaeonella oviformis zone	Deep water phase of Turritella pescaderoensis zone	Shallow water phase of Turritella pescaderoensis zone	Tellina ooides zone	Zonal position uncertain
Acila truncata (Gabb)	×	×	×	*	....
Anatina (?)	×	....	....	....	....
Anomia lineata Gabb.	×	....	×	....	....
Astarte, n. sp. *a*	*	×	×	....	....
Astarte, n. sp. *b*	....	....	....	....	×
Astarte, sp. *c*	....	....	....	....	×
Cardium, sp. *a*	×	....	....	....	....
Cardium, sp. *b*	×	....	....	....	....
Cardium, sp. *c*	×	....	....	....	....
Cardium, cf. remondianum Gabb	×	....	....	....	....
Clisocolus dubius (Gabb)	×	×	×	×	....
Coralliochama, sp.	....	....	....	....	×
Corbula traskii Gabb	×	....	?	....	....
Crassatellites lomana (Cooper)	....	×	*	....	....
Crassatellites conradiana, var. tuscana (Gabb)	×	×	*	×	....
Cucullaea, n. sp. *a*	....	....	....	....	×
Cucullaea, n. sp. *b*	×	....	....	....	....
Cucullaea truncata (Gabb)	×	×	×	×	....
Cucullaea decurtata (Gabb)	×	....	?	....	....
Cucullaea ponderosa Whiteaves	....	....	....	....	×
Dosinia inflata Gabb	×	....	×	?	....
Exogyra, n. sp. *a*	*	×	....	....	....
Exogyra, sp. *b*	*	×	×	....	....
Gastrochaena, sp.	....	....	....	....	×
Glycymeris pacificus (F. M. Anderson)	×	....	....	....	....
Glycymeris veatchii (Gabb)	×	×	×	×	....
Homomya, n. sp. *a*	×	....	....	....	....
Inoceramus, cf. digitatus (Sowerby)	×	....	....	....	....
Inoceramus, sp.	....	....	....	....	×
Inoceramus whitneyi Gabb	....	....	....	....	×
Isocardia, sp.	×	....	....	....	....
Lima, sp. *b*	....	....	....	×	....
Lima, sp. *c*	....	....	....	....	×
Lima microtis Gabb	....	....	....	....	×
Lima, cf. shastaensis Gabb	×	....	....	....	....
Liopistha anaana (F. M. Anderson)	×	....	....	....	....
Martesia (?) parvula Whiteaves	....	....	....	×	....
Meekia sella Gabb	....	....	....	×	....
Meretrix arata Gabb	×	....	....	....	....
Meretrix lens Gabb	×	....	×	×	....
Meretrix nitida Gabb	×	....	×	×	....

TABLE I—(*Continued*)

	Actaeonella oviformis zone	Deep water phase of Turritella pescaderoensis zone	Shallow water phase of Turritella pescaderoensis zone	Tellina ooides zone	Zonal position uncertain
PELECYPODA—					
Meretrix, sp. *a*	....	....	×	×	....
Meretrix (?) sp. *b*	....	....	×	....	....
Modiolus siskiyouensis Gabb	×	....	....	....	....
Modiolus, sp. *a*	....	....	×	....	....
Mytilus, sp.	....	....	×	....	....
Nemodon vancouverensis (Meek)	....	×	....	....	....
Opis triangulata (Cooper)	....	×	....	....	....
Ostrea, n. sp. *a*	×	*	×	....	....
Ostrea, n. sp. *b*	×	....	*	....	....
Ostrea, n. sp. *c*	×	....	....	....	....
Ostrea brewerii Gabb	×	×	....	....	....
Panope, n. sp. *a*	×	....	....	....	....
Pecten californicus Gabb	×	....	....	....	....
Pecten operculiformis Gabb	×	....	....	....	....
Pecten, sp. *a*	....	....	....	....	....
Pecten, sp. *b*	×	....	....	....	....
Pecten (?), sp. *c*	....	....	....	....	×
Pinna, cf. calamitoides Schumard	×	....	×	....	....
Plicatula, n. sp. *a*	×	....	....	....	....
Siliqua, n. sp. *a*	....	....	....	×	....
Solen, sp.	×	....	×	....	....
Spisula ashburnerii (Gabb)	....	....	×	*	....
Spisula chicoensis Packard	....	....	....	×	....
Spisula gabbiana (F. M. Anderson)	....	....	×	....	....
Spondylus, sp.	....	....	....	....	×
Spondylus, n. sp. *a*	×	....	....	....	....
Tellina, n. sp. *a*	....	....	....	*	....
Tellina, n. sp. *b*	....	....	....	....	×
Tellina, sp. *c*	....	....	....	×	×
Tellina, sp. *d*	×	....	....	×	×
Tellina ashburnerii Gabb	....	....	....	....	×
Tellina, cf. hoffmanniana Gabb	....	....	....	×	×
Tellina ooides Gabb	....	....	....	×	×
Teredo, sp.	....	....	....	....	×
Trigonoarca, n. sp. *a*	×	....	....	....	...
Trigonoarca, n. sp. *b*	....	....	....	....	×
Trigonoarca, n. sp. *c*	×	....	....	....	....
Trigonia evansana Meek	×	×	×	×	....
Trigonia tryoniana Gabb	....	....	×	....	....
GASTROPODA—					
Acmaea, sp.	×	....	?	....	....
Actaeonella oviformis Gabb	*	?	....	....	....

TABLE I—(*Continued*)

	Actaeonella oviformis zone	Deep water phase of Turritella pescaderoensis zone	Shallow water phase of Turritella pescaderoensis zone	Tellina ooides zone	Zonal position uncertain
Alaria condoniana (F. M. Anderson)	×	....	....	....	....
Alaria falciformis (Gabb)	×	....	....	....	....
Amauropsis, n. sp. *a*	×	....	×	....	....
Amauropsis oviformis Gabb	×	....	×	....	....
Aporrhais, n. sp. *a*	×	....	....	....	....
Aporrhais, n. sp. *b*	×	....	....	....	....
Aporrhais, n. sp. *c*	×	....	....	....	....
Bullaria, n. sp. *a*	×	....	....	....	....
Cerithium, n. sp. *a*	....	....	....	....	×
Cerithium, sp.	....	....	....	....	×
Cinulia obliqua Gabb	....	....	×	*	....
Chrysodomus, sp. *a*	×	....	....	....	....
Epitonium, n. sp. *a*	×	....	....	....	....
Eulima, sp.	....	....	....	×	....
Fusus (?), sp. *a*	....	....	....	....	×
Fusus (?), sp. *b*	....	....	×	....	....
Gyrodes expansa Gabb	×	....	×	....	....
Lyria (?)	×	×	×	....	....
Lysis (?), n. sp. *a*	....	....	×	....	....
Margarites ornatissima (Gabb)	....	....	....	....	×
Natica, sp. *a*	....	....	×	....	....
Perissolax brevirostris Gabb	....	....	....	×	....
Potamides, sp.	....	....	....	....	×
Turritella, n. sp. *a*	×	....	....	....	....
Turritella, n. sp. *b*	×	....	....	....	....
Turritella, sp. *c*	....	....	....	....	×
Turritella, sp. *d*	×	....	....	....	....
Turritella pescaderoensis Arnold	×	×	*	×	....
Volutoderma, sp. *a*	....	*	....	....	....
Volutoderma, n. sp. *b*	....	*	×	....	....
Volutoderma, n. sp. *c*	....	*	×	....	....
Volutoderma, cf. californica Dall	....	....	×	....	....
Scaphopoda—					
Dentalium, sp.	....	....	....	....	×
Cephalopoda—					
Ammonites, sp. *a*	....	×	....	....	....
Ammonites, sp. *b*	....	×	....	....	....
Ammonites, sp. *c*	....	×	....	....	....
Ammonites, sp. *d*	....	×	....	....	....
Baculites chicoensis (Trask)	....	....	×	....	....
Hamites (?)	....	....	×	....	....
Helicancylus, sp.	×	....	....	....	....

TABLE I—(*Continued*)

	Actaeonella oviformis zone	Deep water phase of Turritella pescaderoensis zone	Shallow water phase of Turritella pescaderoensis zone	Tellina ooides zone	Zonal position uncertain
Nautilus, sp. *a*	....	....	....	....	×
Nautilus, sp. *b*	....	....	....	....	×
Placenticeras californicum F. M. Anderson	....	....	....	....	×
Schloenbachia knighteni F. M. Anderson	....	....	....	....	×
ASTEROIDEA—					
Ophioglypha, n. sp. *a*	....	....	....	....	×
ECHINOIDEA—					
Schizaster, n. sp. *a*	×	....	....	....	....
BRACHIOPODA—					
Terebratula, sp.	×	....	....	....	....
VERMES—					
Worm tubes	....	....	....	....	×
CRUSTACEA—					
Crustacean	×	....	....	....	....
PISCES—					
Lamna, sp.	....	....	....	....	×

To this list may be added the following species that have been reported by Bowers,[13] Cooper,[14] and Anderson[15] from the Santa Ana Mountains. The stratigraphic situation of these forms is uncertain.

Asaphais multicostata Gabb
Clisocolus cordatus Whiteaves
Crenella santana Cooper (?)
Cucullaea bowersiana Cooper
Cucullaea inermis Gabb
Pecten traskii Gabb
Pholadomya sonorensis Gabb
Cominella lecontei White
Fulgar hilgardi White
Globiconcha remondii Gabb
Potamides tenuis Gabb
Scobinella dilleri White
Turritella seriatim-granulata Roemer
Acanthoceras compressus F. M. Anderson
Ammonites stoliczkanus Gabb
Ammonites traskii Gabb
Baculites fairbanski Anderson

[13] Bowers, Dr. Stephen, Orange County, 10th Annual Report State Mineralogist, California State Mining Bureau, p. 399, 1890.

[14] Cooper, J. G., Catalogue of California Fossils, California State Mining Bureau, Bull. 4, pp. 33, and 36–51, 1894.

[15] Anderson, F. M., Cretaceous Deposits of the Pacific Coast, Proc. Calif. Acad. Sci., Third Series, Geol., vol. 2, pp. 27–32, 1902.

Desmoceras sugatum (Forbes)
Lytoceras jacksonense F. M. Anderson
Nautilus texanus Schumard
Placenticeras californicum F. M. Anderson
Placenticeras pacificum J. P. Smith
Schloenbachia knighteni Anderson
Terebratula abesa Gabb

The relationships of the above defined zones are shown in summary in Table II.

TABLE II

	Actaeonella oviformis zone	Turritella pescaderoensis zone: Deep water phase	Turritella pescaderoensis zone: Shallow water phase	Tellina ooides zone	Chico Creek fauna
Number of forms	65	25	41	26	79
Number of determined species	47	16	28	18	79
Number of determined species appearing in the Actaeonella oviformis zone	47	11	18	4	12
Number of determined species appearing in the Turritella pescaderoensis zone. Deep water phase	11	16	13	7	6
Number of determined species appearing in the Turritella pescaderoensis zone. Shallow water phase	18	13	28	12	16
Number of species appearing in the Tellina ooides zone	4	7	12	18	17

RELATION TO OTHER CRETACEOUS FAUNAS OF CALIFORNIA

Anderson recognized the Chico affinities of the fauna obtained in Silverado Cañon on the western slope of the Santa Ana Mountains, but more recent collecting has revealed a large number of species as yet unknown from the typical Chico of northern California. The majority of the forms peculiar to the southern fauna occur in the lowermost beds of that region, suggesting that this stage represents a lower horizon than that known at Chico Creek. This raises a question as to the definition of the beds of the Chico and also as to reasons for the difference between the faunas of the Chico and the Santa Ana Mountains.

In considering the relation between the faunal stages of the typical Chico and the Cretaceous of the Santa Ana Mountains it is necessary to review briefly the relationships of the Chico fauna of Shasta and Tehama counties to that of the underlying Horsetown.

The apparent conformable sequence of beds of the Shasta-Chico series as exposed on Elder and Cottonwood Creeks in Tehama and Shasta counties, together with the recognized faunal continuity make the definition of the different groups difficult. Diller and Stanton who have most carefully considered this question make the following statement: "The faunas of adjacent beds, however, are so bound together by many common species that there is no palaeontologic break anywhere within the series."[16]

The Knoxville may for the purposes of this paper be defined in the words of Stanton as "the Aucella-bearing Cretaceous beds on the Pacific Coast of the United States."[17] No specimens of *Aucella* have been reported from the Santa Ana region and therefore this phase of the Cretaceous need not be discussed further.

The Horsetown was first defined in a paper by Charles A. White entitled "Notes on the Mesozoic and Cenozoic Palaeontology of California."[18] On page 19 of this paper he writes:

> I shall therefore, for the present, retain the name Shasta group in the general sense in which it was used by the geologists of the California survey; but for purposes of convenience in references which I must necessarily make in this article to those divisions, I shall designate them as the Horsetown beds and the Knoxville beds, respectively. These names are suggested by the localities from which the best collections of fossils of each division were obtained.

On the next page he states regarding the fauna: "It is especially rich in Cephalopoda, as will appear by referring to the California reports, where the fossils of this division are recorded as coming from "The North Fork of Cottonwood Creek, Horsetown, etc." A few sentences below this White lists thirteen of Gabbs' species which he would exclude from the Horsetown because of their occurrence at doubtful Horsetown localities. Five of these, *Potomides diadema* Gabb, *Ringinella polita* Gabb, *Liocium punctatum* Gabb and *Lima shastaensis* Gabb are later reported by Anderson[19] from the Horsetown, although their occurrence is not definitely given. It thus appears that the type section of the Horsetown beds includes beds of the Shasta

[16] Diller, J. S. and Stanton, T. W., The Shasta-Chico Series, Bull. Geol. Soc. Am., vol. 5, p. 464, 1894.

[17] Stanton, T W., The Fauna of the Knoxville beds, U. S. Geol. Surv. Bull. 133, p. 12, 1895.

[18] White, C. A., U. S. Geol. Surv. Bull. 15, pp. 19–20, 1885.

[19] Anderson, F M., Cretaceous Deposits of the Pacific Coast, Proc. Calif. Acad. Sci., Third Series, Geol., vol. 2, p. 41, 1902.

group recognized by the California Survey and exposed on the North Fork of the Cottonwood Creek and at the locality at Horsetown. In 1888 Diller and Stanton[20] state:

> At Horsetown and Texas springs, however, only a few miles northeast of the Cottonwood section, many fossils have been found that evidently belong very near the top of the Horsetown beds. Lists of species from these localities showing a commingling of the Horsetown and Chico faunas have already been published.

Yet in 1901 Stanton is quoted by Merriam[21] in regard to a John Day, Oregon, fauna to the effect that

> A similar fauna, with some additions, occurs in the sandstones at Texas Springs and near Horsetown, Shasta County, California, and has been regarded as proof of the blending of the Shasta and Chico faunas, partly because the beds at Horsetown had long been thought to belong to Gabb's Shasta group and had even given the name, Horsetown beds, to the upper division of the Shasta. It is evident, however, from White's somewhat vague definition of the Horsetown beds, that the term was meant to include the strata immediately above the Knoxville that contain the fauna so well developed on the north fork of Cottonwood Creek, in the neighborhood of Ono, and which really has no close relationship with this basal Chico fauna of Texas Springs, Horsetown, and elsewhere.

As far as the writer is aware, this phase of the Shasta–Chico problem has not been discussed elsewhere.

Such an interpretation is in accord with an earlier statement made by Diller and Stanton[22] to the effect that the Chico beds extend from "a short distance above the mouth of Hulen Creek to Gas Point," for, in the writer's opinion, the fauna from the locality on Hulen Creek is very closely related to the one near Horsetown, but it is not considered that these represent Chico faunas.

The strata at the Hulen Creek locality just above its confluence with the North Fork of the Cottonwood are composed of conglomeratic sandstones lying apparently conformably upon sandy shales, which but a short distance stratigraphically below contain a typical Horsetown fauna. These psephitic strata grade above into shales similar to those just below. These upper shales grade upward into a massive conglomerate of several hundred feet in thickness which outcrops in the gorge just below the junction of Hulen and Cottonwood creeks. These conglomerates have yielded the writer no determinable fossils. The

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20 Diller, J. S., and Stanton, T. W., *op. cit.*, p. 445.

21 Merriam, John C., A Contribution to the Geology of the John Day Basin, Univ. Calif. Publ. Bull. Dept. Geol., vol. 2, pp. 283, 284, 1901.

22 Diller, J. S., and Stanton, T. W., *op. cit.*, p. 444.

base of these beds just below the mouth of Hulen Creek might well be taken as the base of the Chico group. This apparently agrees with White's original idea of the location of the base of that group judging from the fauna obtained above and below the horizon.

The differences of opinion as to the location of the base of the Chico group tend to substantiate the view of Diller and Stanton[23] regarding the stratigraphic continuity of the Shasta-Chico series, and show the necessity of detailed faunal studies within this region before the Horsetown and Chico faunas can be clearly defined. Regardless of the final decision on this point, it seems advisable for the purposes of this paper to consider the fauna obtained at Horsetown and its correlative on Hulen Creek as uppermost Horsetown.

In compiling a list of Horsetown species for comparison with the fauna from the Santa Ana Mountains only those species have been included that are known to have come from the Horsetown beds as defined above. Such a procedure considerably reduces the published Horsetown fauna.

A comparison of such a list with the faunal list from the Santa Ana Mountains reveals the following species in common: *Cucullaea truncata* Gabb, *Nemodon vancouverensis* (Meek), *Trigonia evansana* Meek, *Pecten operculiformis* Gabb. These species have a long range, occurring in the Chico of Chico Creek. From this very small representation of common forms it would appear that the latter fauna is not the equivalent of the Horsetown as it is now imperfectly known.

The term Chico was first used by Gabb in a paper read before the National Academy of Sciences in August, 1868.[24] The type locality as designated by Gabb in the *Palaeontology of California*[25] is very indefinite, including beds most extensively represented in Shasta and Butte counties, California. The group was named for Chico Creek, along which a number of fossiliferous localities occurred.

Recent studies made by C. K. Studley show that the three fossiliferous localities on Chico Creek contain faunas so closely related that they may be considered as a unit.[26] The faunas already published by Gabb[27] and Turner[28] have been greatly increased through the collec-

[23] *Op. cit.*, p. 464.

[24] Gabb, W. M., Palaeontology of California, vol. 2, p. xii, 1869.

[25] *Op. cit.*, p. xiii-xiv.

[26] Studley, C. K., MS thesis, University of California, 1914.

[27] Gabb, W. M., Palaeontology of California, vols. 1 and 2, 1864–1899.

[28] Turner, H. W., The rocks of the Sierra Nevada, Fourteenth Annual Report U. S. Geol. Surv., pt. 2, p. 460, 1892–1893.

tions made by Mr. Studley. The two published lists supplemented by Studley's list are taken as the basis of comparison with the fauna from the Santa Ana Mountains.

A comparison of these faunas reveals the following species in common between Chico Creek and the Santa Ana Mountains:

Acila truncata (Gabb)
Anomia lineata Gabb
Clisocolus dubius (Gabb)
Crassatellites conradiana, var. tuscana (Gabb)
Cucullaea truncata (Gabb)
Dosinia inflata (Gabb)
Glycymeris veatchii (Gabb)
Inoceramus whitneyi Gabb
Meekia sella Gabb
Meretrix lens Gabb
Meretrix nitida Gabb
Spisula ashburnerii (Gabb)
Spisula chicoensis Packard
Spisula gabbiana (Anderson)
Tellina ashburnerii Gabb
Tellina hoffmanniana Gabb (?)
Tellina ooides Gabb
Trigonia evansana Meek
Alaria falciformis (Gabb)
Cinulia obliqua (Gabb)
Gyrodes expansa Gabb
Perissolax brevirostris Gabb
Volutoderma californica Dall
Baculites chicoensis Trask

The number of species in common between the Santa Ana Mountains and Chico Creek represent but about thirty-one per cent of the number of determined species of the southern fauna, being nearly the same per cent of the Chico Creek fauna. This small per cent of identical species from the two localities is due in part to the fact that the southern fauna, composed of three faunal zones, is compared with the fauna from Chico Creek, represented probably by a single zone. Seventeen out of the eighteen described species from the Tellina ooides zone of the Santa Ana Mountains appear in the above list of common species. On the other hand, there are but twelve out of twenty-eight described species from the Aetaeonella oviformis zone of the southern fauna occurring at Chico Creek.

The much larger number of species in common between these localities than was noted above in the comparison with the Horsetown fauna indicates that the southern fauna is equivalent to at least a part of the Chico from Chico Creek.

The faunal differences may be more apparent than real, for the fauna from Chico Creek is but imperfectly known and will be undoubtedly increased by subsequent workers. Nevertheless the differences demand consideration.

It appears to be the consensus of opinion that differences of temperatures due to the geographic positions of these two localities were not as great during the Cretaceous as at present. This factor would therefore have had but little weight in determining the character of the Chico faunas. Temperature would be a factor in so far as it was associated with oceanic currents, the courses of which are determined largely by the distribution of land and water.

There appears to be little evidence that salinity played an important role in determining the peculiar features of these two faunas, for neither in the Santa Ana Mountain basin nor in that of the Sacramento Valley do we find indications of brackish-water conditions, except very locally during comparatively short periods of coal formation.

The direct and indirect effect of the type of the bottom is a generally recognized factor influencing the life upon the floor of the sea. A comparison of these basins of deposition reveals the fact that the strata of the more southern one are more conglomeratic than are those of the northern basin. The fauna as well as the lithology indicates that the Cretaceous beds of the Santa Ana Mountains were deposited largely within shallow waters. The species types from Chico Creek and the considerable amounts of carbonaceous material also argue for shallow-water conditions within the northern basin. It thus appears that the faunal differences can not definitely be attributed to differences in the character of the bottom. However, to a collector of Recent Mollusca this may not appear very conclusive, for quite diverse faunas exist under present conditions on types of sediments in which after induration the differences would probably not be particularly marked.

The areal extent of the Upper Cretaceous sea is such as to suggest that there was direct communication between these two basins of deposition. If this is a correct inference, isolation did not play an important part in causing the faunal dissimilarities.

The differences in environment, then, resolve themselves primarily into the effects of temperature due to oceanic currents, and possibly to differences of types of sediments. These all directly or indirectly were affected by the distribution of land during this period. That the shore line during the Upper Cretaceous was only a short distance east of the present summit of the Santa Ana Range is inferred by the type of sediments composing the Chico group of this region, and by the absence of Chico strata at any considerable distance east of those mountains. The Trabuco formation and the lower part of the Chico have been described above as being decidedly conglomeratic, both containing boulders apparently derived from rocks similar to those comprising the core of the present range. The character of the contact of the Trabuco formation with the basement complex, as shown in detail and by areal mapping, indicates a land surface of low relief, but the character of the sediments contradicts this in a measure, for streams of considerable gradient must have existed in order to have transported the coarse sediments characterizing these strata. This apparent conflict may possibly be reconciled upon the assumption of a rather narrow coastal plain, adjacent to a mountainous country of considerable relief. If no land existed west of this shore-line, as seems probable, the physical environment of this region differed considerably from that of the present Sacramento Valley region.

The Upper Cretaceous beds of northern California were deposited in an inland sea protected from the open ocean by an archipelago, occupying the region of the present Siskiyou Mountains and the northern end of the Coast Ranges. Regarding this Diller and Stanton say

> The attenuation of the Shasta–Chico Series westward from the Sacramento Valley and the overlapping of the newer beds upon older crystalline rocks of the Coast Range shows that the Coast Range was formed before the deposition of the Shasta–Chico series, and probably at the close of the Jurassic when the Mariposa beds were upturned.[29]

Such a distribution of land might have had a marked effect upon the local oceanic currents, thereby producing temperature differences sufficiently great to account in part for the faunal dissimilarities noted above. Such a factor accompanied by others of lesser rank, concerning which but little is as yet known, is perhaps of sufficient importance to make it unnecessary to consider that the faunal peculiarities of the Santa Ana Mountains and northern California basins of deposition are due solely to different faunal stages.

RELATION TO FOREIGN CRETACEOUS FAUNAS

Various writers, including Gabb, White, Smith, Stanton, Hamilton, Whiteaves, and Anderson, have expressed opinions regarding the equivalents of the Chico group. This problem is complicated; therefore, only a few of the more recent, views upon this subject will be considered in this discussion.

Anderson, following in part the conclusions of Gabb and Whiteaves, considered that "the Chico, the Nanaimo, and the Phoenix and

[29] Diller, J. S., and Stanton, T. W., *op. cit.*, p. 464, 1894.

Henley beds may be shown to be homotaxially equivalent, and equivalent also to the beds of the Colorado group in the interior basin.''[30]

Anderson gives parallel lists of identical or closely related species found in the Chico and the Island of Ezo. His view of the relationships of the Chico to the European Cretaceous is best expressed in his own words:

> On the whole, however, the strongest affinities are undoubtedly with the Turonian; and if one remembers the great stratigraphical range of some of the species of the Sacramento Valley, it does not seem remarkable that Cenomanian or even Gault types are found occasionally in the Chico.[31]

A correlation table shows that Anderson considered the Chico as including the Arrialon, Trichinopoli and a part of the Ootatoor groups of Southern India.[32]

Stanton[33] takes issue with Anderson regarding the geographic relation of this western fauna to that of the interior basin.

> Whiteaves and F. M. Anderson have argued for a connection during Chico time between the Pacific and interior seas, but the evidence brought forward in support of this view is based upon types that have a world-wide distribution and on those that are only similar, not specifically identical. In my opinion direct connection has not been proved.

Stanton believes, however, that the Chico began a little earlier than the Colorado group, including all of the Colorado and continuing a little longer than that group.

These citations are sufficient to indicate the major problems involved in the correlation of the Chico with beds outside of the Pacific Coast region. Further discussion of this problem will be considered in a future paper.

AGE

The Cretaceous beds of the Santa Ana Mountains yield a fauna that is more closely related to that from Chico Creek than to the fauna from the Horsetown beds. The relationships of these faunas are shown in the following table, in which there is indicated the number of species from the southern fauna common to these northern faunas as defined above.

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30 Anderson, F. M., Cretaceous Deposits of the Pacific Coast, Proc. Calif. Acad. Sci., Third Series, Geol., vol. 2, p. 57, 1902.

31 *Op. cit.*, p. 62.

32 *Op. cit.*, p. 62.

33 Stanton, T. W., Later Mesozoic Invertebrate Faunas, *in* Outlines of Geologic History, Willis and Salisbury, p. 190, 1910.

TABLE REPRESENTING NUMBER OF SPECIES FROM CRETACEOUS OF SANTA ANA MOUNTAINS KNOWN ALSO IN HORSETOWN AND CHICO

	Horsetown	Chico Creek
Number of species of Pelecypoda	4	19
Number of species of Gastropoda	0	5
Number of species of Cephalopoda	?	1
Total number of species in common	4	25
Per cent of species in common	5	31

The small percentage of typical Chico species represented in the southern fauna is due in part to the fact that the fauna from the Actaeonella oviformis zone is undoubtedly older than any horizon thus far reported from Chico Creek. This lowermost fauna is more closely related to the fauna from the beds immediately overlying the Horsetown group in Shasta and Tehama counties than to the type Chico. If the term Chico is made to include the known Cretaceous faunas of California that are younger than the Horsetown fauna as previously defined in this paper, the fauna from the Santa Ana Mountains may be properly designated as Chico. Such a procedure does not conflict with the generally accepted, though rather vague definition of the Chico. It thus appears that the type Chico in the restricted sense represents, as was pointed out by Anderson, but a portion of the Upper Cretaceous column of California.

SUMMARY

The Cretaceous strata of the Santa Ana Mountains are divisible into at least two groups. The lowermost one, consisting of about two hundred feet of red, non-fossiliferous conglomerates and sandstones, is here designated as the Trabuco formation. Conformably overlying these beds is a series of conglomerates, sandstones, and shales aggregating about two thousand feet in thickness, which have yielded a rich invertebrate fauna.

The Cretaceous fauna from the Santa Ana Mountains has certain affinities with that of the uppermost Horsetown beds but is much more closely related to the fauna from the Chico of Chico Creek. The small per cent of typical Chico species represented in the southern fauna is due in part to the fact that the fauna from the lowermost beds of the Santa Ana Mountains is undoubtedly older than any fauna thus far reported from Chico Creek, and also due in part to environmental differences resulting from the distribution of land on this Coast during the Upper Cretaceous.

Three faunal zones have been recognized in the Cretaceous of the Santa Ana Mountains. The lowermost, the Actaeonella oviformis zone, yields a large fauna which is older than that from the type Chico on Chico Creek, but younger than that of the uppermost Horsetown. The second, or Turritella pescaderoensis zone, possibly represents a part of the Chico known at Chico Creek; while the uppermost, the Tellina ooides zone, yields a fauna that is certainly included in the typical Chico.

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