THE SHASTA-CHICO SERIES*

BY J. S. DILLER AND T. W. STANTON

(Read before the Society December 27, 1893)

CONTENTS

	Page
Historical Review.....	435
Sections of the Series.....	438
Elder Creek Section.....	438
Section on Cold Fork of Cottonwood Creek.....	442
Section on North Fork of Cottonwood Creek.....	442
Faunas of the Series.....	444
Chico Fauna.....	444
Horsetown Faunas.....	445
Upper Horsetown.....	445
Lower Horsetown.....	446
Knoxville Fauna.....	447
Acellæ of the Knoxville Beds.....	447
Other Knoxville Fossils.....	448
Flora of the Series.....	450
Unity of the Series.....	451
Distribution of the Series.....	452
Deformations.....	453
Subsidence during the Shasta-Chico Epoch.....	453
Coast Range Uplift at Close of Jurassic.....	455
Subsidence of the Sacramento Valley.....	456
Relation of Knoxville and Mariposa Beds.....	457
Time Range of the Series.....	459
Correlation of the Series.....	461
Nanaimo and Queen Charlotte Island Groups.....	461
Potomac.....	461
Comanche Series of Texas Cretaceous.....	462
Correlative Movements.....	463
Résumé and Conclusions.....	463

HISTORICAL REVIEW.

Of all the formations on the Pacific coast none have received greater attention than those which belong to the Cretaceous. The earliest ex-

* Published by permission of the Director of the United States Geological Survey. Read before the Geological Society of Washington, D. C., December 20, 1893.

tensive investigations in this field are published in the reports of the California Geological Survey, under the direction of Professor Whitney. Mr Gabb, of that survey, recognized four horizons in the Cretaceous, and the names given them by him are noted in the first column of the accompanying table. The Téjon,* Martinez and Chico were considered to belong to the Upper Cretaceous. All the Cretaceous below the Chico, composed of the beds exposed at Horsetown, on the north fork of Cottonwood creek, in Shasta county, and at a number of points in the Coast range, was grouped together under the name Shasta.

	Gabb,† in California.	White,‡ in California.	Diller and Stanton,§ northern California and Oregon.
Eocene.....			Téjon.
Upper Cretaceous..	Téjon..... Martinez. Chico.	Chico-Téjon.....	(Hiatus and unconformity.)
		Probable place of the Wallala formation.	Shasta-Chico Series. { Chico. Horsetown.
		(Hiatus of White. Unconformity of Becker.)	
Lower Cretaceous..	Shasta.....	Shasta. { Horsetown.... Knoxville (including Mariposa).	{ Knoxville.
Jurassic.....	Mariposa		Mariposa.

The investigations of Conrad, Jules Marcou and Heilprin have shown that the Téjon, instead of being Cretaceous, belongs to the Eocene.¶

In connection with the investigations of the United States Geological Survey, with special reference to the quicksilver deposits of the Pacific

* The proper pronunciation of this Spanish word is "tahone."

† Geol. Survey of California, Paleontology, vol. ii, preface by Whitney, p. xiii.

‡ U. S. Geol. Survey, Bulletin no. 82, pp. 184 and 241.

§ Bull. Geol. Soc. Am., vol. 4, pp. 205-224 and 245-256.

¶ Hyatt: Bull. Geol. Soc. Am., vol. 5, pp. 395-434; see also Smith: Ibid., pp. 243-258.

* For a more complete reference to the literature of the Cretaceous of the Pacific coast, see U. S. Geol. Survey, Bulletin no. 82, by Dr C. A. White, and Bull. Geol. Soc. Am., vol. 4, pp. 245-249, by T. W. Stanton.

coast and to the Gold belt of the Sierra Nevada, the studies of Dr White* and Dr Becker† resulted in changing the grouping of the Cretaceous sediments. They recognized both the Téjon and the Chico, but they considered them as belonging to the same continuous series of beds, the upper or Téjon portion belonging to the Eocene, the Chico to the Cretaceous. They gave the joint name Chico-Téjon to this set of beds, as indicated in the second column of the table.

Dr Becker discovered near Wallala, on the coast some miles north of San Francisco, a series of interesting fossils containing forms which had not been previously recognized. The beds in which they were found he called the Wallala beds. Dr White described the fossils, of which the most characteristic is *Coralliochama orcutti*, and concluded, from paleontologic grounds alone, that these beds belong immediately beneath the Chico. According to Dr Becker they rest unconformably upon the metamorphic rocks.

The beds exposed at Horsetown and elsewhere in Shasta county they called the Horsetown beds, while others, in which the characteristic fossil is of the genus *Aucella* and well exposed near Knoxville, in Napa county, they called the Knoxville beds. At first, although the Knoxville was recognized by paleontologic evidence as being older than the Horsetown beds, it was supposed that there was a considerable interval of time between their periods of deposition. Owing to the investigations of Dr Becker at Riddles, in Oregon, as well as those of Mr Diller at the same place and in Shasta and Tehama counties, California, it was shown‡ that these two sets of beds were more closely related than had been previously supposed, so that in his correlation bulletin§ of the Cretaceous formations of the United States Dr White suggests that their successive deposition took place without a time interval.

During the last ten years the writers have had an excellent opportunity to study the Cretaceous of the Pacific coast, especially in northern California and Oregon, and also to some extent in the state of Washington. The results are expressed in the fourth column of the accompanying table.

In Oregon the Téjon is entirely distinct from the Chico. It rests with a marked unconformity on the Cretaceous of that region, and is separated from it by a time interval during which there was considerable erosion. In northern California the Téjon is absent, but in middle and southern California it is well represented, and, according to many observers, is conformable with the Chico.

It has recently been shown by Mr Gilbert D. Harris|| that the Téjon

* U. S. Geol. Survey, Bulletins nos. 15, 22 and 82.

† Ibid., Monograph XIII and Bulletin no. 19.

‡ Bull. Geol. Soc. Am., vol. 2, pp. 201-208.

§ U. S. Geological Survey, Bulletin no. 82, p. 164.

|| Science, vol. 22, p. 97, August 18, 1893.

fauna at its typical localities may be correlated with the lower Claiborne fauna of the Gulf states. This is not the oldest Eocene fauna, as it occurs in Alabama about 1,200 feet above the base of the Eocene. On the other hand, the Chico fauna as typically developed in the Sacramento valley does not indicate the latest Cretaceous time, so that a considerable time interval is suggested by the paleontologic evidence. The evidence of the reported commingling of the Chico and Téjon faunas has been obtained in the neighborhood of mount Diablo and northward, where the strata are much dislocated and folded and the true stratigraphic succession often obscured.

The Chico, Horsetown and Knoxville beds have been found to grade into one another in such a way as to show that they are simply different phases of one continuous series of deposits extending without an important interruption of any kind from the bottom of the Knoxville to the top of the Chico. For this set of beds the term Shasta-Chico series has been proposed.*

SECTIONS OF THE SERIES.

ELDER CREEK SECTION.

The thickest section of this series that has yet been measured, and in fact the thickest section yet known, is well exposed on Elder creek, in Tehama county, California, where the Knoxville beds have an apparent thickness of 20,000 feet, the Horsetown beds approximately 6,000 feet, and the Chico beds 4,000 feet, so that the total thickness of the Cretaceous section in that region appears to be 30,000 feet.†

In the accompanying table the section is given in some detail, including the fossils which occur at different horizons.‡

* Bull. Geol. Soc. Am., vol. 4, pp. 205-224, and 245-256. Since the papers referred to were written we have spent several months in the field, completely reviewing the Cretaceous of northern California. The results fully confirm our previous views.

† This enormous thickness seems incredible, and yet, after going over the section several times, we have not been able to find reliable evidence for its reduction. No duplication of strata could be recognized either upon lithologic or paleontologic grounds, but, on the contrary, there seems to be a regular succession without repetition in both rocks and fossils from top to bottom. The evidence, however, is not strong, for in the Knoxville beds, which comprise the greater portion of the series, there are few if any distinct lithologic horizons by which repetition could be certainly recognized, and very few fossils were found in them along the line of the section. Small folds and faults, both normal and thrust, were observed so related to the dip of the strata as in some cases to increase and in others diminish the thickness of the section. The effect of the one, as nearly as could be estimated, counterbalanced the other. It is important to note in this connection that the complete series of Shasta-Chico beds is not exposed in this section. At the eastern end of the section the Chico beds disappear unconformably beneath the later deposits of the Sacramento valley, which covers its topmost layers. The western end of the section is terminated by serpentine which is probably of later eruption.

‡ This section was measured in 1889 by J. S. Diller and J. Stanley-Brown. Am. Jour Sci., vol. xl, p. 476.

Feet.	Rocks.	Fossils.
Chlico beds.	500 Shales with some thin sandstones.	{ <i>Inoceramus</i> . <i>Pecten</i> , sp. a.
	1,000 Sandstones.	{ <i>Amm. (Pachydiscus) newberryanus</i> . <i>Inoceramus whitneyi</i> .
	1,500 Shales containing one 25-foot bed of sandstone.	
	2,000 Massive sandstone.	
	2,500 Conglomerate.	{ <i>Thetis annulata</i> . <i>Chione varians</i> . <i>Tellina ashburneri</i> . <i>Tellina parilis</i> . <i>Gyrodes expansa</i> . <i>Anchura californica</i> .
	Massive sandstone with thin conglomerate.	{ <i>Pecten operculiformis</i> . <i>Exogyra parasitica</i> . <i>Cucullæa truncata</i> . <i>Trigonia leana</i> . <i>Trigonia evansana</i> . <i>Meekia sella</i> . <i>Coralliochama orcutti</i> . <i>Chione varians</i> . <i>Caryatis nitida</i> . <i>Thetis annulata</i> . <i>Dentalium stramineum</i> . <i>Lunatia avellana</i> . <i>Gyrodes expansa</i> . <i>Anchura californica</i> . <i>Anchura falciformis</i> . <i>Cinulia matthewsoni</i> . <i>Actæon inornatus</i> .
	3,000 Shales.	{ <i>Pecten operculiformis</i> . <i>Cucullæa truncata</i> . <i>Nemodon vancouverensis</i> . <i>Trigonia evansana</i> . <i>Trigonia leana</i> . <i>Trigonia equicostata</i> (?) <i>Pectunculus veatchi</i> . <i>Meekia sella</i> . <i>Chione varians</i> . <i>Caryatis nitida</i> . <i>Coralliochama orcutti</i> . <i>Dentalium stramineum</i> . <i>Lunatia avellana</i> . <i>Anchura californica</i> . <i>Amm. (Desmoceras)</i> , sp. a.
	Conglomerate with limestone pebbles.	
	3,500 Sandstone, shale and conglomerate.	
	Chiefly conglomerate.	
Horsetown beds.	4,000 Shales with thin sandstones.	
	4,500 Shales.	
	5,000 Sandstone.	
	Shales.	
	5,500 Shales.	
	6,000 Shales.	{ <i>Pecten operculiformis</i> . <i>Nemodon vancouverensis</i> .
	6,500 Shales.	
	7,000 Shales and thin sandstones.	
	7,500 Shales.	
	8,000 Shales.	
	8,500 Shales.	
	9,000 Shales.	
	9,500 Shales and sandstones.	{ <i>Inoceramus</i> sp. <i>Amm. (Desmoceras)</i> , sp. c.
	10,000 Sandstones.	

Feet.	Rocks.	Fossils.
Knoxville beds.	10,500 11,000 11,500 Shales twisted and veined.	
	12,000 12,500 13,000 Shales	{ <i>Belemnites impressus</i> . <i>Ammonites (Desmoceras)</i> sp.
	13,500 14,000 14,500 with Calcareous	{ <i>Belemnites impressus</i> . <i>Ammonites (Lytoceras)</i> batesi.
	15,000 15,500 16,000 16,500 layers.	
	17,000 17,500 18,000 18,500 Shales with Calcareous	{ Ferns and other plants. (Locality d.)
	19,000 19,500 20,000 20,500 21,000 21,500 22,000 layers in places much folded.	
	22,500 23,000 23,500 24,000 24,500 Shales and shaly sandstones with Calcareous layers.	
	25,000 25,500 26,000 26,500 27,000 27,500 28,000 Shales and shaly sandstones with small sand- stones increasing.	<i>Aucella piochi</i> .
	28,500 29,000 29,500 30,000 Shales and thin sandstones.	
	Serpentine (Peridotite).	

In the Knoxville beds shales predominate, although there are a large number of thin sandstones interstratified with the shales. The great majority of these sandstones are less than a foot in thickness, and they rarely, if ever, attain ten feet along the north fork of Elder creek. Sand-

stones are most abundant in the lower half of the Knoxville; in the upper half they are uncommon. Both north and south of Elder creek the Knoxville beds contain thick strata of conglomerate which do not appear in the measured section. The base of the section is serpentine, which has resulted from the alteration of an eruptive rock, in all probability belonging to the peridotites.* Ripple marks have been found in this portion of the section showing that the rocks were deposited in shallow water.

The shales of the Knoxville beds, with occasional thin layers of sandstone, continue upward without any interruption either in the character of the sediments or in the position of the strata, into the Horsetown beds. On account of the gradual transition in all respects from the Knoxville to the Horsetown beds it is impossible to draw a sharp line between them. *Aucella* being the most abundant, widely distributed and characteristic fossil of the Knoxville beds, it seems best to draw the line upon a paleontological basis at the upper limits of the *Aucella*-bearing layers. At that horizon fossils are usually abundant.

The Horsetown beds in this section are composed chiefly of shales, although there are some sandstones of considerable size. One was observed 50 feet in thickness, another 12 and a third 8 feet. Few fossils were found in these beds along Elder creek, but a short distance to the southward in the Bald hills, immediately above the Knoxville, they are more fossiliferous and contain the Horsetown species mentioned on page 446. Several miles east of Lowreys, on Elder creek, the basal portion of the Chico is rich in fossils. Here is found an intermingling of numerous Chico and Horsetown forms.

The Chico, which has a thickness of nearly 4,000 feet in this section, is composed chiefly of sandstones and conglomerates. The basal portion is made up of conglomerates altogether. The upper portion for 1,100 feet is composed chiefly of shales, and there are some shales lower down intercalated between the sandstones and conglomerates. The conglomerates at the base contain numerous nodules of limestone which are rich in fossils. Here was found *Coralliochama orcutti*, the characteristic Wallala fossil, in exactly the position predicted for it by Dr White. Its occurrence in the basal portion of the Chico of this section, as well as others upon the western border of the Sacramento valley with a large number of Chico fossils, completely demonstrates, as already urged, that the Wallala beds are only a phase of the Chico.

* A few miles southwest of Paskenta, by the road to Round valley, a large dike of serpentine appears to cut directly across the Knoxville beds, and there can be but little, if any, doubt, as shown also by Fairbanks (*American Geologist*, March, 1892) and Turner (*Bull. Geol. Soc. Am.*, vol. 2, pp. 318-402), that the serpentine of the Coast range are altered eruptive rocks younger than the Knoxville portion of the Shasta-Chico series.

SECTION ON COLD FORK OF COTTONWOOD CREEK.

The Cold fork of Cottonwood creek is about 15 miles north of Elder creek. The section it affords was not measured, but was examined several times with some care. At this point the *Aucella* beds are not so thick as on Elder creek, and yet they must be in the neighborhood of 10,000 feet thick, for they are exposed with a steep dip over a belt of country $3\frac{1}{2}$ miles in width across the strike. The basal beds are shales with local conglomerates and rest directly with a conspicuous unconformity upon the metamorphic rocks. In the adjacent hills the metamorphic rocks are found, and among them are a number of limestones. One of these has afforded an imperfect *Chaetetes*, which Mr Walcott has referred to the Carboniferous. The basal conglomerates of the Knoxville series contain pebbles of these limestones.

Aucella was discovered in this region by Mr H. W. Fairbanks. It occurs rather abundantly in the upper portion of the Knoxville beds. Five-eighths of a mile up a small ravine which enters Cold fork just above Mr Stephenson's house *Aucella* was found in the same bed with numerous other fossils noted on page 449, so that there can be no doubt whatever concerning their association.

The overlying beds in this section differ somewhat from those on Elder creek in containing a fetid limestone about 30 feet in thickness. It contains *Ammonites (Olcostephanus) deansii*, Whiteaves; *Atresius liratus*, Gabb (?); *Modiola major*, Gabb, and *Cyprina* (?), n. sp., and is probably about the same horizon as one of the limestones reported by Whitney and others in Colusa and adjoining counties to the southward, where they are said to be closely related with the *Aucella* beds.*

SECTION ON NORTH FORK OF COTTONWOOD CREEK.

This section has been measured and is given in the accompanying table. It is well exposed along the north fork of Cottonwood creek and its branches above Gas Point. In the vicinity of Ono the Horsetown beds rest with marked unconformity directly on the metamorphic rocks. At the base there is a heavy conglomerate which is derived directly from the metamorphic rocks near by. *Aucella* has not been found in this section, though the fossils of its basal portion are identical with those that occur in beds adjoining the *Aucella* beds in the Bald hills near Elder creek. The Horsetown beds in this section have a thickness of 5,200 feet, and consist chiefly of shales and thin sandstones. They have afforded a large number of fossils, many of which have already been described by the paleontologists of the Geological Survey of California.

* See references by Gabb in *Paleontology of California*, vol. ii, pp. 192, 195, 204.

Feet.	Rocks.	Fossils.
Chico beds.	500 Shales.	<i>Nucula truncata.</i> { <i>Nucula truncata.</i> <i>Ammonites (Schloenbachia) chicoensis.</i>
	Sandstones and shales.	Same as above.
	1,000 Shales, with occasional thin beds of sandstone.	{ <i>Inoceramus whitneyi.</i> <i>Pecten</i> , sp. a. <i>Potamides tenuis</i> (?) <i>Lunatia</i> , sp. <i>Trochospira</i> , sp.
	1,500	{ <i>Pecten operculiformis.</i> <i>Cucullæa truncata.</i> <i>Trigonia evansana.</i> <i>Meekia sella.</i> <i>Chione varians.</i> <i>Caryatis nitida.</i> <i>Gyrodes expansa.</i> <i>Anchura californica.</i> <i>Cinulia obliqua.</i> <i>Ammonites (Acanthoceras)</i> , sp. <i>Amm. (Desmoceras)</i> , sp. a.
	2,000	
	2,500 Conglomerate and sandstone.	
	3,000 Shale.	
	Conglomerate and sandstone.	
	3,500 Shale.	
	Sandstone and shale.	{ <i>Pecten operculiformis.</i> <i>Exogyra parasitica.</i> <i>Nemodon vancouverensis.</i> <i>Cucullæa truncata.</i> <i>Trigonia evansana.</i> <i>Trigonia leana.</i> <i>Coralliochama oreutti.</i>
	4,000 Shales, considerably disturbed, without prominent bed of sandstone.	{ <i>Anchura falciiformis.</i> <i>Amm. (Desmoceras) hoffmanni</i> (?) <i>Amm. (Desmoceras)</i> , sp. a. <i>Amm. (Desmoceras)</i> , sp. b. <i>Exogyra parasitica.</i> <i>Cucullæa truncata.</i> <i>Lunatia avellana.</i> <i>Amm. (Schloenbachia) inflata.</i>
	4,500	
	5,000	
	5,500	
	6,000	
Horsetown beds.	6,500 Sandstone.	{ <i>Pecten operculiformis.</i> <i>Nemodon vancouverensis.</i> <i>Trigonia leana.</i> <i>Trigonia æquicostata.</i> <i>Diptychoceras lævis.</i>
	Shales, with thin beds of sandstone near base.	{ <i>Amm. (Lytoceras) batesi.</i> <i>Amm. (Desmoceras) hoffmanni.</i> <i>Amm. (Phylloceras?) ramosus.</i> <i>Amm. (Hoplites) remondi.</i> <i>Ancylloceras remondi.</i>
	7,000	
	7,500	
	8,000	
	Sandstone.	{ <i>Pecten operculiformis.</i> <i>Plicatula variata.</i> <i>Nemodon vancouverensis.</i> <i>Trigonia æquicostata.</i> <i>Pleuromya lævigata.</i> <i>Lunatia avellana.</i> <i>Potamides diadema.</i> <i>Belemnites impressus.</i>
	8,500	
	Shales.	
	Conglomerate.	
	9,000 Diorite.	

The Chico beds of this section, extending from a short distance above the mouth of Hulen creek to Gas Point, have a thickness of 3,600 feet. In the basal portion, as on Cold fork and Elder creek, conglomerates and sandstones prevail, but with a thickness diminishing northward. They contain near the bottom a large number of characteristic Chico fossils, and associated with these at this point, as well as on Cold fork and Elder creek, have been found the characteristic Wallala form, *Coralliochama orcutti*.

At Gas Point the topmost Chico beds are unconformably overlapped by the post-Cretaceous deposits which fill the Sacramento valley. It is not probable, however, that much of the section is covered, for upon the eastern side of the Sacramento valley, where the upper portion of the Chico is exposed, the fossils indicate approximately the same horizon as the beds at Gas Point. No trace of the T $\acute{e}$ jon has yet been found in California north of the fortieth parallel.

FAUNAS OF THE SERIES.

CHICO FAUNA.

The Chico fauna is most typically developed at Pence's ranch, Butte creek, Chico creek and other localities along the eastern border of the Sacramento valley, where it was first recognized by the California Geological Survey. A great many species were described from this region by Mr W. M. Gabb, a few were described earlier by Dr Trask, and some additions to the fauna have since been made by Dr C. A. White. The strata exposed at these localities are comparatively thin, and on structural grounds they are correlated with the upper portions of the beds referred to the Chico in the sections on the west side of the Sacramento valley. This correlation is supported by the fact that the few fossils, such as *Ammonites* (*Schloenbachia*) *chicoensis* and *Nucula truncata*, found only in the upper parts of these sections, are common at the typical localities above referred to, though the very small number of species makes the comparison with the rich fauna of the east side of the valley less satisfactory than is desirable. On the other hand, the lower 1,000 feet of the Chico in the measured sections are very fossiliferous, and the fauna they have yielded, though not as large as that of the typical Chico localities, has many species in common with it, together with some that have not been found there. Such species as *Cucullæa truncata*, *Trigonia evansana*, *Trigonia leana*, *Meekia sella*, *Pectunculus veatchi*, *Chione varians*, *Anchura falciformis* and others that are common on the east side of the valley occur at the very base of the Chico. This comparatively small change in the fauna indicates that the Chico was a period of rapid sedimentation

in the Sacramento valley, and that the advancing shore of the transgressing sea furnished a uniformly favorable habitat for its littoral fauna.

The lists of the more important fossils given in the tabular descriptions of sections on Cottonwood and Elder creeks show that the Chico fauna ranges through nearly 4,000 feet of strata.

A few of the species in the lower half of the Chico are worthy of special mention. The occurrence of *Coralliochama orcutti* at about the same horizon in all the sections examined fixes the position of the Wallala beds in the lower part of the Chico.

The following occur also in the Horsetown beds, some of them ranging down to the base of that division :

Pecten operculiformis.

Exogyra parasitica.

Cucullæa truncata.

Nemodon vancouverensis.

Trigonia leana.

Trigonia æquicostata (?)

Meckia sella.

Chione varians.

Lunatia avellana.

Ammonites (Desmoceras) hoffmanni.

Ammonites (Desmoceras) sp. a.

HORSETOWN FAUNAS.

Upper Horsetown.—In the sections described the very close connection of the Chico with the preceding Horsetown fauna is not fully shown, because the upper part of the Horsetown beds is not very fossiliferous along the measured sections. 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.* The collections of the past season at these places have added three interesting species of ammonites, viz: *Lytoceras sacya*, Forbes, which is evidently identical with the Queen Charlotte specimens referred to that species; a *Desmoceras* (the same as the one in the Chico listed as *Ammonites (Desmoceras)*, sp. a), that seems referable to *Desmoceras beudanti*, Brongiat, which also occurs in the Queen Charlotte formation; and an *Acanthoceras* that resembles one of the forms of *Acanthoceras mammillare*, Schloth., figured by d'Orbigny.† In connection with these species the *Schloenbachia inflata*, Sowerby, from the top of the Horsetown on Cottonwood creek may be mentioned. This species is reported from the Queen Charlotte formation and it occurs in the Ootatoor group of southern India. Stoliczka's figure‡ seems to agree in every particular with our California specimen which was found associated with two Chico species only a short distance below the assumed base of the Chico. These ammonites, together with

* Bull. Geol. Soc. of Am., vol. 4, pp. 210, 250.

† Pal. Française Terr. Crétacé, t. 1, pl. 73.

‡ Palæontologia Indica, vol. 1, pl. 27.

Ammonites (*Desmoceras*) *breweri* and many species of other classes of mollusca that are associated with them in both California and Queen Charlotte islands, show that at least a part of the lower shales or division *C* of the Queen Charlotte Cretaceous may be correlated with the extreme upper portion of the Horsetown beds, if not with the base of the Chico. They also show indirectly that the upper part of the Queen Charlotte formation and the Vancouver formation must be closely related, since the latter holds the same fauna as the typical Chico; that is, the Vancouver fauna should immediately succeed the latest portion of the Queen Charlotte fauna, instead of being separated by the time interval required for the deposition of the 3,500 feet of strata in divisions *A* and *B* of the Queen Charlotte islands section.

Three of the ammonites above mentioned and a number of other species are represented by identical or closely related forms in the Ootatoor group of India, which is usually correlated with the European Cenomanian, and a similar fauna is found in the Cretaceous of Japan and Saghalin. These forms indicate that in Cretaceous time the faunas of the Pacific were able to migrate from one side of the ocean to the other, probably through the shallow waters of high northern latitudes, and thence along the shores on either side.

Lower Horsetown.—The lower Horsetown beds are characterized by a greater abundance and variety of ammonites with a smaller proportion of other mollusca, though in the occasional sandstone beds that occur in the shales down to the base the fossils are more closely related to the littoral faunas of the upper Horsetown and Chico, and several of the species seem to range through the entire division. There is certainly no faunal break within it. This portion of the Horsetown also is represented at many localities in the lower shales of Queen Charlotte islands.

The exposures below the Chico in the Elder Creek section have not yielded many fossils, but in the Bald hills, two to four miles south of Elder creek, several fossiliferous localities were found, both in the Horsetown and in the Knoxville beds.

At one of these localities near Wilcox's ranch a zone at the base of the Horsetown, not more than from 50 to 200 feet above the Aucella beds, yielded many species that are characteristic of the lower 1,500 feet of the Cottonwood Creek section. They include—

Pecten operculiformis, Gabb.
Plicatula variata, Gabb.
Nemodon vancouverensis, Meek.
Pleuromya levigata, Whiteaves.
Potamides diadema, Gabb.
Helicaulax bicarinata, Gabb.
Actæon impressus, Gabb.
Lunatia avellana, Gabb.

Amm. (*Lytoceras*) *batesi*, Trask.
Amm. (*Phylloceras* ?) *ramosus*, Meek.
Amm. (*Olcostephanus*) *traski*, Gabb.
Amm. (*Olcostephanus*), sp. a.
Crioceras percostatus, Gabb.
Crioceras latus, Gabb.
Belenmites impressus, Gabb.

KNOXVILLE FAUNA.

The beds immediately below this zone contain essentially the same fauna, with the addition of large numbers of *Aucella* (the most characteristic fossil of the Knoxville) and a few other forms. At a locality about two miles north of Wilcox's ranch the following fossils were found in the uppermost strata of the Knoxville beds:

<i>Aucella crassicolis</i> , Keyserling; abundant.	<i>Ammonites (Lytoceras) batesi</i> , Trask.
<i>Aucella piochii</i> , Gabb, var <i>ovata</i> ; rare.	<i>Ammonites (Olcostephanus)</i> , sp. a.
<i>Inoceramus</i> , sp. undetermined.	<i>Crioceras latus</i> , Gabb.
<i>Helicaulax bicarinata</i> , Gabb.	<i>Belemnites impressus</i> , Gabb.

The *Aucellæ* play so important a part in the Knoxville fauna that it is necessary to insert here a few notes on their variations and stratigraphic range.

Aucellæ of the Knoxville Beds.—The most characteristic and by far the most abundant fossils of the Knoxville beds are the various forms of the genus *Aucella*. In many places the rocks are completely filled with them, and they are known to range through almost the entire great thickness of the beds. These *Aucellæ* show a great variety of forms and sizes, but they are easily separable into two groups that are in a general way characteristic of different horizons. One of these groups, which includes the typical form of *Aucella piochii*, Gabb,* is characterized by its slender, oblique form, and is very inequivalve, the left valve being convex, with a long, narrow, incurved beak, while the right valve is nearly flat, and its beak also is narrow. Occasionally a specimen shows faint, radiating striæ, suggesting the older *Aucella erringtoni* of the Mariposa beds. Of the Russian species, *Aucella mosquensis* is its nearest relative, but as there are several differences in form, especially of the umbonal region, it is preferable to leave them under Gabb's name, which was proposed about thirty years ago.

At the lowest horizon in the Knoxville beds from which we have collected in this region the typical *Aucella piochii* occurs alone, but in higher strata, about 3,000 or 4,000 feet below the top of the Knoxville, it is associated with a larger, more convex variety that may be compared with *Aucella mosquensis*, var. *ovata*, or with *Aucella terebratuloides*.† This variety occurs sparingly at first, and at a horizon about 1,000 feet higher it becomes the prevailing form. For convenience this variety is called *Aucella piochii*, var. *ovata*, but it should be stated that there is great individual variation, so that it is difficult to assign limits to any variety or species that may be proposed.

* Figured in Paleontology of California, vol. i, pl. 25, fig. 173.

† See Lahusen, J.: Ueber Russischen Aucellen, Mém. Com. Geol., vol. 8, no. 1, St. Petersburg, 1888, where the Russian species are all figured and described.

At the horizon just mentioned, about 2,000 feet below the top of the Aucella beds, where *A. piochii*, var. *ovata*, is the most abundant form, the first representatives of the second general group of forms of the type of *A. crassicollis*, Keyserling, occur. This includes all the broad, robust, inflated forms in which both valves are almost equally convex and nearly equal in size, such as the forms figured by Gabb* and referred to *Aucella piochii*. Aucellæ of this type occur sparingly at the above-mentioned horizon, the lowest at which they have been observed, while they are the dominant and almost exclusive forms in the upper 1,000 or 1,500 feet of Knoxville beds, only occasional specimens that can be referred to *Aucella piochii*, var. *ovata* occurring with them. In Russia, according to Lahusen, all the Aucellæ occurring in the Cretaceous belong to this group. He recognizes the following species among them: *Aucella crassicollis*, *A. crassicollis*, var. *solida*; *A. crassicollis*, var. *gracilis*; *A. bulloides*, *A. keyserlingi*, *A. piriformis* and *A. piriformis*, var. *majuscula*; also *A. inflata* from the upper Volgian, which is by most authors referred to the Jurassic. Nearly all of these forms can be duplicated in our collections from the Knoxville beds, but as it does not seem possible to separate these California specimens into definable species, they will be referred to *Aucella crassicollis*, Keyserling, which is the earliest valid name† that has been applied to the group.

Dr C. A. White and Mr J. F. Whiteaves in describing the American Aucellæ have both recognized the varietal importance of the two general groups of forms here described. The facts as to their stratigraphic range as we have now determined them justify their recognition as species, even though they are genetically related and connected by many intermediate forms.

It is an interesting fact that the various forms of *Aucella* have appeared in this country in approximately the same order of succession that has been determined by Lahusen for the Russian forms, though if, as we believe, all the Knoxville beds are Cretaceous, they persisted longer here, and each stage of development was considerably later. Lahusen states that in Russia all the slender elongate species like *Aucella mosquensis* are confined to the Jurassic, beginning with the striated *A. bronni* in the beds with *Cardioceras alternans*.

Other Knoxville Fossils.—The brief lists of fossils from the Bald Hills region already given are sufficient to show the intimate connection of the upper Aucella beds with the Horsetown. Other localities in the

* Paleontology of California, vol. ii, pl. 32, figs. 92a, b, c.

† Fischer de Waldheim in *Oryctographie de Moscou* first described and figured such forms under the name *Inoceramus concentricus*, Parkinson. Subsequent authors, finding that Fischer's specimens belonged to a different genus, as well as a different species, have quoted them as *Aucella concentrica*, Fischer, a practice that is unjust as well as confusing. Lahusen has proposed the name *A. piriformis* for the same specimens.

upper part of the beds, with *Aucella crassicollis* in the same neighborhood, have yielded the same forms of *Aucella* with *Ammonites* (*Olcostephanus*), sp. b, related to *Olcostephanus discofalcatus*, Lahusen; *Ammonites* (*Hoplites*), sp. a, related to *Hoplites amblygonius*, Neumayr and Uhlig; *Belemnites impressus*, Gabb; *Leda*, *Astarte*, *Pentacrinus*, etcetera.

The most northerly locality in the Sacramento valley at which *Aucella* has been found is near Stephenson's, on the Cold fork of Cottonwood creek. The horizon is probably very near that of the places just mentioned, and *Aucella crassicollis* is here associated with *Belemnites impressus* and species of *Pentacrinus*, *Rhynchonella*, *Ostrea*, *Lima*, *Nemodon*, *Leda*, *Trigonia*, *Opis*, *Astarte*, *Corbula*, *Helcion*, *Pleurotomaria* and others, none of which can be positively identified with described species, though forms closely related to several of them occur in the Horsetown beds.

Lower in the Knoxville beds *Aucellæ* occur at many horizons almost everywhere, but other fossils have been found associated with them at only a few places. On McCarty creek, a short distance north of Paskenta, about 1,000 feet below the top of the *Aucella* beds specimens of *Ammonites* (*Desmoceras*), sp., related to *Desmoceras breweri* and *Ammonites* (*Hoplites*), sp. b, were found associated with *Aucella crassicollis*.

In the same neighborhood, probably more than 2,000 feet lower, there is a small limestone that has yielded a number of species, including the following.

<i>Aucella piochii</i> , Gabb; abundant.	<i>Turbo</i> .
<i>Aucella piochii</i> , Gabb, var. <i>ovata</i> ; rare.	<i>Chemnitzia</i> (?)
<i>Nucula</i> .	<i>Ammonites</i> sp.
<i>Cyprina</i> .	<i>Belemnites</i> .
<i>Rhynchonella</i> .	

On the South fork of Elder creek, near Cooper's, at nearly the same horizon as the last locality, several species have been collected, as follows:

Aucella piochii, Gabb; very abundant.
Aucella piochii, Gabb, var. *ovata*; rather rare.
Ammonites (*Hoplites*) sp. c; related to *Hoplites* sp. a.
Ammonites (*Lytoceras*) *batesi*, Trask (?) Mere fragments with the form of this species.
Ammonites sp. Same as the ammonites from last-mentioned locality, having the form of *Ammonites* (*Phylloceras*?) *ramosus*, Meek.
Belemnites sp.; fragments.

A few hundred feet higher in the same section, where *Aucella piochii*, var. *ovata*, is the predominant form, several imperfect specimens of an *Ammonites* (*Perisphinctes*) were collected, and at a still higher horizon, where *Aucella piochii*, var. *ovata*, is very abundant, a few small specimens of *Aucella crassicollis* occur with a slender undescribed species of *Belemnites*. In addition to those mentioned, two other species of *Hoplites* are known from the Knoxville beds.

These notes will serve to show that the Knoxville fauna is closely connected in its later portions with the succeeding Horsetown fauna, and that we have no evidence of any faunal break within it, though there is a progressive change in the forms from the lower portions to the top. Of the Cephalopoda at least four species (*Lytoceras batesi*, *Olcostephanus* sp., *Crioceras latus*, and *Belemnites impressus*) pass up into the overlying Horsetown beds, and two other Horsetown species (*Desmoceras breweri* and *Phylloceras* (?) *ramosus*) are represented in the Knoxville by fragmentary specimens that belong to the same or closely allied species. The other Knoxville ammonites, consisting chiefly of *Hoplites*, seem to be most closely related to Neocomian species, though several of them are comparable with European Upper Jurassic (Tithonian) forms. A few of the species belonging to other classes seem to have Jurassic affinities, so it is probable that the oldest Cretaceous is represented in the Knoxville. The undoubted Cretaceous age of the upper part of this division and its evident unbroken continuity make it most natural and reasonable to assign the whole of it to the Cretaceous system. Compared with the fauna of the Mariposa beds, which is of late Jurassic age according to the recent investigations of Professors Hyatt and Smith, it seems to be totally distinct, excepting that the genus *Aucella* is present in both.

A paper in preparation will contain descriptions and illustrations of all the known species from the Knoxville beds, and more definite comparisons and correlation will there be attempted.

FLORA OF THE SERIES.

During the last field season a number of fossil plants were collected in Tehama and Shasta counties of California, chiefly from the Horsetown beds. They were referred for study to Professor W. M. Fontaine, who has identified the species given in the following list:

	Locality.		Locality.
<i>Sagenopteris mantelli</i> .	a.	<i>Cladophlebis inclinata</i> (?)	d.
<i>Pterophyllum californicum</i> , n. sp.	a.	<i>Osmunda dicksonioides</i> (?)	d.
<i>Angiopteridium canmoreense</i> (?)	b, d, e.	<i>Angiopteridium strictinerve</i> (?)	d.
<i>Cephalotoxopsis magnifolia</i> (?)	b.	“ <i>nervosum</i> (?)	d.
<i>Glossozamites klipsteini</i> .	b, d.	<i>Aspidium dunkeri</i> (?)	d.
<i>Abietites</i> (?)	c.	“ <i>heterophyllum</i> .	d.
<i>Dioonites buchianus</i> , var. <i>rarinervis</i> (?)	c.	<i>Aspleniopteris pinnatifida</i> (?)	d.
<i>Equisetum texense</i> (?)	c.	<i>Thinnfeldia variabilis</i> (?)	d.
<i>Pecopteris strictinervis</i> (?)	d.	<i>Dioonites buchianus</i> , var. <i>angustifolius</i> . f, g.	
<i>Thyrsopteris rarinervis</i> (?)	d.	<i>Abietites angusticarpus</i> .	h.
<i>Nageiopsis longifolia</i> (?)	d.	<i>Sagenopteris latifolia</i> .	i.
<i>Sagenopteris</i> , sp. (?)	d.	<i>Abietites californicus</i> , n. sp.	j.
<i>Cephalotoxopsis</i> , sp. (?)	d.	<i>Dioonites dunkerianus</i> .	j.

The localities from which the plants were collected are as follows :

- a. Tehama county, Bald hills, east of Wilcox's ranch, top of the Knoxville beds.
- b. " " Bald hills, near Wilcox's ranch, base of the Horsetown beds.
- c. " " near the school-house southwest of Lowreys, upper portion of Knoxville beds.
- d. " " north fork of Elder creek, above Woody's ranch, upper portion of Knoxville beds.
- e. " " Cold fork, near Stephenson's, upper portion of Knoxville beds.
- f. Shasta " Byron gulch, west of Ono, near base of Horsetown beds.
- g. " " Byron gulch, near Ono, lower portion of Horsetown beds.
- h. " " north fork of Cottonwood creek, below mouth of Eagle creek, middle portion of Horsetown beds.
- i. " " Eagle creek, near Ono, lower portion of Horsetown beds.
- j. " " one and a half miles northeast of Horsetown, upper part of Horsetown beds.

Professor Fontaine remarks that—

"Whatever may be thought of the value of the preceding identifications, it is at least clear that we have in these twenty-six plants different forms. All have their nearest relations in Lower Cretaceous forms, and there is no plant that would indicate an age different from Lower Cretaceous. This alone is strong evidence of the age of the strata, and it is perhaps a better indication than would be identical species, if few in number and not of well marked character.

"But there are some of the plants that are well enough preserved and of sufficiently decided character to permit us to gain some positive proof of age. These are *Sagenopteris mantelli*, *Abietites angusticarpus*, *Dioonites buchianus*, var. *angustifolius*; *Dioonites dunkerianus*, *Aspidium heterophyllum*—five out of twenty-six. Then, *Pterophyllum californicum* and *Abietites californicus* are so much like Lower Cretaceous species that they are in fact representative of them. There can be no hesitation in regarding the plants collected from the Shasta group as being of Lower Cretaceous age."

The plants to which the above statements refer were collected from various horizons ranging through nearly 8,000 feet of strata from within the upper portion of the Knoxville to nearly the top of the Horsetown beds and include none which are dicotyledonous. The only dicotyledonous plant in our collections came from the lower portion of the Chico beds on Elder creek, where a single specimen was obtained.

UNITY OF THE SERIES.

The three sections of the Shasta-Chico series already given show conclusively that there is complete continuity from the bottom of the Knoxville to the top of the Chico. The strata, where all are well exposed in

the same section, are conformable throughout,* and the character of the sediments is also the same. There can be no further doubt concerning the continuity of life throughout the series. Several successive faunas are recognizable, but they are all closely bound together by many comingling species. The Shasta-Chico series, including the Wallala beds, may therefore be considered as a unit in discussing the geology of the Pacific coast.

There is, however, one other argument for its unity to which it is desired to call attention. On the eastern side of the Sacramento valley the Chico beds rest with a conspicuous unconformity directly on the metamorphic rocks of the auriferous series. About the northern end of the Sacramento valley the same is true, but as we move southwestward from Redding, along the foot of the Klamath mountains and Coast range, we find successively older and older beds coming in below and resting with this marked unconformity on the metamorphic rocks. At Texas springs and Horsetown this great unconformity runs beneath the Horsetown beds. Farther south, on Cold fork and elsewhere, the same great unconformity runs beneath the Knoxville beds, so that the Chico, Horsetown and Knoxville beds all hold exactly the same relation to the great unconformity of that region, and thus furnish additional evidence that they belong to the same series.

DISTRIBUTION OF THE SERIES.

The unity of the Shasta-Chico series being admitted from the evidence already adduced, several consequences of importance follow from the vertical and horizontal distribution of the series.

An examination of these deposits in the field shows clearly that the Horsetown beds overlap the Knoxville northward along the western side of the Sacramento valley, and the Chico beds in like manner overlap the Horsetown in the same direction, so as to reach not only the western base of the Sierra Nevada, but extend northeastward between the Sierra Nevada and Klamath mountains far into Oregon, connecting, in all probability, with the Chico of the Blue mountains in that state, as well as with that of Washington, Vancouver and Queen Charlotte islands.

In Oregon also, as already noted in California, the Horsetown beds overlap the Knoxville, well exposed in the vicinity of Riddles, in Douglas county, and extend as far southeastward as Graves creek, where they rest

* Mr Fairbanks recognizes a small unconformity between the Knoxville and Chico beds, due to the eruption of the peridotitic rocks from which the serpentine has been derived (Eleventh Report State Mineralogist of California, p. 67; also American Geologist, March, 1892, p. 166); but the great unconformity which Dr Becker (U. S. Geol. Survey, Bulletin no. 19, p. 12) places at this horizon belongs below the Knoxville.

directly and with a marked unconformity on the metamorphic rocks. In like manner the Chico extends beyond the Horsetown in Oregon, for at Jacksonville and Ashland, southeast of the Horsetown locality on Graves creek, we find the Chico beds resting with a conspicuous unconformity directly on the metamorphic rocks. This overlapping to the northeast in California and southeast in Oregon finally resulted during the Chico epoch in connecting the two areas through Lassen strait,* which separated the Klamath mountains from the Sierra Nevada.

To the southward the Shasta-Chico series has been identified by Turner,† Lindgren,‡ White,§ Fairbanks,|| and Dall¶ in the Coastal region as far as Todos Santos bay of Lower California. Emmons** and Merrill have recognized it as far south as 29° 30', and believe it extends still further in the same direction.

DEFORMATIONS.

SUBSIDENCE DURING THE SHASTA-CHICO EPOCH.

On the accompanying map are indicated the coast lines at the close of the Horsetown and Chico epochs. The Knoxville coast has been traced both in Oregon and northern California to but a limited extent. The same is true also of the Horsetown shoreline, which lay only a short distance farther inland, but during the Chico epoch the invasion of the sea reached its maximum and extended far inland, as indicated by the position of the coast line at the close of that time. This successive overlapping landward of the newer and newer beds of the Cretaceous system shows that during the period of deposition of the Shasta-Chico series the continent was subsiding and the sea transgressing.

Dr Dawson †† has shown from observations in British Columbia that a similar movement was in progress at the same time in that country. The sea was transgressing to the southward in the Puget Sound region during the Chico, and the concomitant subsidence was undoubtedly connected with that great invasion, which reached as far eastward as the Blue mountains, in Oregon.

To the south, as in the north also, the sea was evidently transgressing. From Tehama county, in California, the Knoxville, Horsetown and Shasta beds may be traced southward through Colusa, Napa and other counties

* U. S. Geol. Survey, Eighth Ann. Rep., p. 412.

† The American Geologist, May, 1893, pp. 307-324.

‡ Proc. Cal. Acad. Sci., 2d ser., vol. i, pp. 180-182.

§ U. S. Geol. Survey, Bulletins 22 and 82.

|| Am. Jour. Sci., vol. xlv, pp. 475-477, June, 1893.

¶ Bull. Geol. Soc. Am., vol. 4, p. 207.

** Bull. Geol. Soc. Am., this vol., post.

†† Trans. Roy. Soc. of Canada, vol. viii, sec. iv, 1890, pp. 3-75.

— — — — — shoreline at close of the Horsetown epoch.
 - - - - - shoreline at close of the Chico epoch.

FIGURE 1.—Map showing approximately the Coast-lines at Close of Horsetown and Chico epochs.

in the central portion of the state. There is evidence of the presence of the Horsetown beds at Benicia, for at that point *Ammonites batesii*, which is one of the characteristic fossils of the lower portion of the Horsetown beds, has been found. The Knoxville beds evidently extend farther to the southward, even as far southward as San Luis Obispo, where Mr Turner* has found *Aucella*, but they do not appear to reach the Santa Ana range of southern California, where Mr Fairbanks† reports that the Upper Cretaceous rests unconformably on the metamorphic rocks, in which, according to him, fossils, probably Carboniferous, have been found. Farther southward only Chico fossils have been found, as far as yet definitely known, extending in that direction through Lower California to near the 29th parallel and perhaps even farther. There is evidence in this distribution of the Knoxville, Horsetown and Chico beds to the southeastward along the coast of southern California that the continent was subsiding in that direction, as it was to the northward, at least as far as Queen Charlotte islands.

The varying thickness of the formations furnishes corroborative evidence. The Knoxville, Horsetown and Chico beds all diminish in thickness to the northward from Elder creek; the Knoxville from

*U. S. Geol. Survey, Monograph xiii, p. 381.

†Am. Jour. Sci., vol. xlv, p. 478. Fairbanks suggests that, although no lower Cretaceous has yet been recognized in southern California, certain local fossiliferous beds on the summit of the Carrejo mountains, 70 miles east of San Diego, may be of that age.

nearly 20,000 to 10,000 feet (estimated) on Cold fork; the Horsetown from 6,100 to 5,200 feet, and the Chico from nearly 4,000 to about 3,600 feet on the north fork of Cottonwood creek. The thinning out is due to the fact that the newer beds overlap to the northward and eastward, and it is evident that all the members of the Shasta-Chico series thin out to an edge toward the Cretaceous land. This relation clearly indicates subsidence of the land and transgression of the sea.

To the southward also the Chico seems to be thinning, for in the region of San Diego, according to Mr Fairbanks, the Chico beds containing *Coralliochama orcutti*, which belongs to the very basal portion of the Chico, is conformably overlain by Eocene containing characteristic fossils of that horizon, and the two appear to be only 1,200 feet in estimated vertical distance apart.* The thickness of the Chico in that region therefore may not be greater than 1,200 feet, and if so, its thickness must have greatly diminished to the southward.

COAST RANGE UPLIFT AT CLOSE OF THE JURASSIC.

Several years ago Mr H. W. Fairbanks † maintained the pre-Cretaceous age of the metamorphic rocks of the Coast range in California, and that the Coast range with the Sierra Nevada was upheaved at the close of the Jurassic.

There is evidence favoring the same conclusion, in that the thickness of the Shasta-Chico series diminishes westward from the Sacramento valley into the Coast range, as it does eastward to the base of the Sierra Nevada. Along the coast north of San Francisco, in the Wallala region, according to Becker, ‡ the Chico (Wallala) beds, some thousands of feet in thickness, § rest unconformably upon the metamorphic rocks. Mr Turner has studied the same region, and regards the Chico at that place as unconformable not only upon the serpentine, of which the conglomerate (Chico) is said to contain pebbles, but also upon the silicious slates and other pre-Cretaceous metamorphic rocks of the Coast range. The relation here is probably the same as it is upon the northern border of the Sacramento valley, where *Coralliochama orcutti* occurs in the Chico beds, which rest with conspicuous unconformity upon the metamorphics. Wherever the Chico beds overlap the Horsetown their basal portion containing the fossils of the horizon exposed near Wallala must come directly and unconformably in contact with the older metamorphic rocks.

The thinning out of the Shasta-Chico series westward from the Sacramento valley shows that the Coast range was uplifted at the close of the

* Am. Jour. Sci., vol. xlv, p. 476, June, 1893.

† American Geologist, March, 1892, and February, 1893.

‡ U. S. Geol. Survey, Monograph xiii, pp. 191, 194.

§ White: U. S. Geol. Survey, Bulletin no. 22, p. 7.

Jurassic, when the Sierra Nevada received its final folding and the great valley of California was outlined thereby. It cannot yet be definitely concluded that the Coast range and the Sacramento valley originated at the close of the Jurassic; their beginnings may date from earlier foldings; but whatever the date of inception, it is evident that during the Shasta-Chico period the Coast range existed, but did not furnish sufficient obstruction to keep the open sea out of the Sacramento valley, for the fossils of that period are everywhere purely marine. That a Coast range island continued in the Wallala region until the close of the Horsetown epoch is indicated by the absence of the Shasta portion of the series at that point. Further northward, however, the waters of the Horsetown epoch crossed between Bully Choop and Yallo Bally, which is now the principal divide west of the Sacramento valley, and connected directly with the open sea possibly in such a way as to separate the island of the Wallala region from that of the Klamath mountains.

Since the above was written a brief but important paper has been published by J. P. Smith,* who concludes from new faunal evidence that "the Mariposa slates are of Upper Jurassic age," and that "the uplift and metamorphism of the Sierra Nevada and of the Coast range occurred in late Jurassic time, before the deposition of the Cretaceous."

SUBSIDENCE OF THE SACRAMENTO VALLEY.

The large extent of this subsidence, from Alaska on the north to Lower California on the south, makes it an epeirogenic movement. There is evidence, however, that the movement, although epeirogenic, was not uniform throughout the whole area.

In the accompanying ideal section there are represented the general observations made on Elder creek, Cold fork and North fork of the Cottonwood, as well as those on the eastern side of the Sacramento valley and at the western foot of the Coast range along the coast at Wallala, and it appears that the subsidence was greater in the Sacramento valley than in the region of the Coast range and Sierra Nevada.

At the time the basal portion of the Knoxville beds was deposited the water was shallow, for there are numerous local conglomerates and sandstones, some of which are ripple-marked. If the subsidence was uniform throughout the whole region it follows that what is now the western foot of the Sierra Nevada, as well as the corresponding portion of the Coast range, where in both cases the Chico rests directly upon the folded pre-Cretaceous rocks, must have been at an elevation of over 25,000 feet above the sea when the basal portion of the Knoxville was deposited in the

* "Age of the Auriferous Slates of the Sierra Nevada." Bull. Geol. Soc. Am., vol. 5, pp. 257, 258.

FIGURE 2.—Ideal Section across the Sacramento Valley.

The section is taken near the 39th parallel and from the western base of the Sierra Nevada across the Sacramento valley, and represents the supposed conditions at the close of the Shasta-Chico period. The vertical and horizontal scales are approximately 18 miles to 1 inch.

Sacramento valley. This hardly seems possible, for we know of no such enormous mountains in the country today. It seems much more probable that the subsidence was not uniform. The Sacramento valley, which then undoubtedly existed, flanked by the Sierra Nevada on one side and the Coast range on the other, was a region receiving a tremendous load of sediments from the mountains on both sides. In accordance with the isostatic condition of the earth's crust, it would be expected that the loading region—that is, the Sacramento valley—would sink, while the unloading region—that is, the Sierra Nevada and the Coast range—would gently rise, and in this way the enormous difference of elevation at the close of the Shasta-Chico period would easily be accounted for by supposing a much smaller original difference at the beginning of that period.

RELATION OF KNOXVILLE AND MARIPOSA BEDS.

The Mariposa beds, as shown by Whitney and others, are sometimes metamorphosed and infolded with the Auriferous slates, which are unconformably overlain along the western base of the Sierra Nevada by the Chico beds. Although the Chico beds have not yet been found in contact with the fossiliferous portion of the Mariposa beds, their relation is such between Folsom and Mariposa that, according to Becker,* Turner and Lindgren, there is no reason to doubt their unconformity. This unconformity, as already stated, can be traced around the northern end of the Sacramento valley and along its western border, where it passes successively beneath the Horsetown and Knoxville beds. The Mariposa and Knoxville beds, so far as yet known, occur nowhere upon opposite sides of the great valley within 30 miles of each other. There is good reason to believe, however, from their relation to

* U. S. Geol. Survey, Bulletin no. 19, p. 19.

the great unconformity that if ever found in contact they will probably not be conformable.

This view is supported by the latest investigation concerning the paleontologic relation of the two sets of beds. The Geological Survey of California recognized the fauna of the Mariposa beds as Jurassic and distinct from the Cretaceous of the Shasta group in the Coast range, although it should be said that the Aucella-bearing portion of the Knoxville had at that time yielded very few fossils other than *Aucella* and *Belemnites impressus*.

The studies of Dr White led him to regard the Aucellæ of both beds as essentially the same species.* Dr Becker accordingly made the Mariposa beds equivalent† to the Knoxville, and finally‡ placed the post-Jurassic (Whitney) but pre-Chico upheaval of the Sierra Nevada and Coast range after the deposition of the Horsetown beds.

The complete faunal and stratigraphic intergradation which, as we § have shown, occurs wherever the Horsetown and Chico beds are found in contact, precludes the existence of a great unconformity between them at any point in northern California and renders it certain that the great upheaval took place before the deposition of the Shasta-Chico series.

Professor Hyatt, who has recently studied the fauna of the Mariposa beds and compared with it the Ammonites and Aucellæ of the Knoxville beds, authorizes us to say that in his opinion "the fauna of the Knoxville beds, on the one hand, is decidedly Cretaceous and clearly related to that of the Horsetown beds, but, on the other hand, is entirely distinct from that of the Mariposa beds."

This conclusion corroborates those drawn from the stratigraphic evidence and establishes upon a firmer basis the view long since entertained by Whitney that the upheaval and metamorphism of the Sierra Nevada occurred at the close of the Jurassic.||

* Ibid., Bulletin no. 15, p. 24.

† Ibid., Bulletin no. 19, p. 18.

‡ Bull. Geol. Soc. Am., vol. 2, p. 206.

§ Bull. Geol. Soc. Am., vol. 4, pp. 207-211 and 249-257.

|| The Aucella beds of the Sierra Nevada are confined, as far as yet certainly known, to the lower portion of the western slope, and their general trend would carry them across the Sacramento valley to the Klamath mountains and Coast range just north of the 40th parallel, where the northern limit of the Knoxville beds in California is known to occur. The Aucella beds are not yet known in contact with the Taylorville Jurassic, which occurs not only upon the northern end of the Sierra Nevada, but also well developed in the Pit river region of Shasta county, California, as well as in southwestern Nevada and the Blue mountains of eastern Oregon (Bull. Geol. Soc. Am., vol. 4, p. 221; also vol. 5, p. 400). There may have been an upheaval of the Sierra Nevada either before or immediately after the deposition of the Taylorville Jurassic by which the Aucellæ were limited to the western part of that range, but the change of level may have been gentle and not accompanied by folding and metamorphosing of the involved strata.

TIME RANGE OF THE SERIES.

The recent investigations of Hyatt and Smith already referred to assign the Mariposa beds to late, though not the latest, Jurassic, while the paleontologic evidence we have given indicates that the Knoxville includes the earliest Cretaceous deposits. It is evident from the faunal relations of these two formations that their epochs of deposition were not separated by a long time interval, but it appears that during this interval the upturning of the Mariposa beds occurred, and some time must have elapsed.

The deposition of that series continued without a general interruption from the beginning of the Knoxville to the close of the Chico, and the time represented by the 30,000 feet of strata which accumulated during that interval must necessarily be long.

The Ammonites of the upper part of the Horsetown to which reference was made in the note on the fauna are either identical with or closely related to forms which in Europe are characteristic of the upper Gault and lowest Cenomanian. *Ammonites inflatus*, especially, is there regarded as the characteristic fossil of a zone that is now placed at the base of the Cenomanian. The other invertebrate fossils from these beds do not conflict with this evidence* of the Ammonites, and it is therefore safe to say that the Knoxville and Horsetown together represent all of the Lower Cretaceous—that is, everything from the Wealden and Neocomian to the Gault, inclusive, with perhaps a small portion of the Upper Cretaceous.

It is somewhat more difficult to fix the time range of the Chico. Its basal portions must have been deposited early in Upper Cretaceous time, but the time of its close is more uncertain. Its large and varied littoral fauna, with a few Ammonites, seems to have no species in common with the American Cretaceous faunas east of the Sierra Nevada, though it is true that several genera are represented in the Montana and Ripley formations (of Senonian age) by similar species; but the known American faunas corresponding to the European Cenomanian and Turonian are comparatively small and do not offer much basis for comparison. As an exception to this general statement we may cite a recently discovered littoral facies of the Fort Benton fauna, locally developed in southern

*Professor Fortaine's study of the small collection of plants taken from several horizons ranging from within the Knoxville to near the top of the Horsetown shows that they are all related to forms in the floras of the Wealden, the Trinity and the Potomac, all of which he regards as oldest Cretaceous. The testimony of the invertebrates agrees with this in a general way, excepting that they show a later age for the upper part of the series. In such comparisons it is well to remember that the known plant-bearing beds do not form as complete and continuous a standard series as is furnished by those containing marine invertebrates, and for this reason correlations made on the evidence of plants alone are frequently not as definite as may be made by the Ammonites, for example.

Colorado, in which there are several species of both Gasteropoda and Pelecypoda that are related to Chico as well as to Ripley species. These are associated with *Inoceramus labiatus* in beds that may be correlated with the Turonian, and they are mentioned here simply to show that many of the Chico types which have been compared with species in the Ripley and Montana formations (Senonian) are also represented by related forms in earlier deposits.

The direct evidence from the Chico fossils cannot be presented fully at this time, as that would require the review of the entire fauna and the description of a number of new species obtained in recent collections. It is a significant fact that the most abundant Ammonites of the Chico belong to the genus *Schloenbachia* (in the broad sense in which the name is used in Europe). *Ammonites chicoensis*, *Ammonites tehamaensis* and two undescribed species belong here and these are all found in the upper beds of the Chico. In other American cretaceous areas this genus does not pass above the top of the Colorado formation and its equivalents, and in Europe it seems not to occur above the "Emscher Mergel" or lowest Senonian. *Ammonites turneri* which was found near Mount Diablo associated with *Anchura californica* and other lower Chico species is an *Acanthoceras* closely related to European species that occur in the Cenomanian. The other Ammonites known from these beds do not resemble those characteristic of the latest Cretaceous. The two abundant species of *Trigonia*, *T. evansana* and *T. leana* likewise have their nearest relatives in the lower part of the Upper Cretaceous of Europe.

The occurrence of *Inoceramus labiatus* in the upper shales (division A) of Queen Charlotte islands is also a suggestive fact in the same direction when considered in connection with the close relationship between the Shasta and the Chico, and consequently between the Queen Charlotte "Lower Shales" and the Chico. The equivalent of the Chico on Vancouver island has yielded a considerable flora which Sir William Dawson* assigns to the older part of the Upper Cretaceous, though he regards it as later than the Dakota. He states that "there would seem to have been a geographical separation between the Pacific coast and the plains, as the latter have not yet yielded anything equivalent to the Vancouver flora."

In Oregon the Téton appears to overlie unconformably the Shasta-Chico series under such conditions as to suggest that a considerable period of erosion occurred between the uplifting of that series and the deposition of the Téton. The faunas of the Chico and the Téton as developed there are entirely distinct. The stratigraphic and faunal evidence tends to show that in the regions in which we have studied it the

* Fossil Floras and Climate. Nature, vol. 47, p. 557, April, 1893.

Chico does not represent the very latest Cretaceous time, perhaps not later than the close of the Colorado epoch, or the Turonian and earliest Senonian of Europe.

For the present, therefore, the Shasta-Chico series may be regarded as representing the whole of the Lower Cretaceous and the earlier half of the Upper Cretaceous, with the proviso that there may be still later Cretaceous beds in middle California where the Chico and Téton are said to be conformable and their faunas have been reported to contain a number of common species.

CORRELATION OF THE SERIES.

NANAIMO AND QUEEN CHARLOTTE ISLAND GROUPS.

The earliest recognition of the Cretaceous upon the western coast of North America was by F. B. Meek,* who described some fossils from Vancouver island. The paleontologists of the Geological Survey of California † early recognized the beds from which these fossils came as Chico. They contain valuable beds of coal, and have received much attention from the members of the Geological Survey of Canada, especially from James Richardson, Dr G. M. Dawson and J. F. Whiteaves.‡ The name Nanaimo group was suggested § for the rocks in question, and the investigations of the Canadian geologists, in connection with those of the United States Geological Survey in California, Oregon and Washington, fully confirm the view that the Cretaceous rocks of the Nanaimo region are Chico.

The Queen Charlotte Island group, division C, D and E of Dr Dawson, has been correlated by Whiteaves with the Shasta. Our investigations in California and Oregon have increased the number of common species and leave no doubt that the Horsetown, and probably also the Knoxville portion of the Shasta-Chico series, is represented in the Queen Charlotte Island group. ||

POTOMAC.

The Kootanie has been placed by Sir J. William Dawson ¶ on approximately the same horizon with Dr G. M. Dawson's subdivision C** of the Queen Charlotte Island formation. According to Fontaine †† and Newberry ‡‡ the Kootanie and Great Falls beds of Montana are to be correlated with each other and also with the Potomac. This correlation,

* Transactions of the Albany Institute, vol. iv, 1857, pp. 37-49.

† Geol. Survey of California, Paleontology, vol. ii, p. xiv.

‡ The Cretaceous System in Canada: Trans. Roy. Soc. of Canada, for 1893, sec. iv, 1893, pp. 1-19.

§ Am. Jour. Sci., vol. xxxix, March, 1890, pp. 180-183.

|| See ante, pp. 445, 446.

¶ Trans. Roy. Soc. of Canada, vol. iii, sec. 4, p. 20.

** Am. Jour. Sci., vol. xxxviii, 1889, p. 122.

†† Proc. U. S. Nat. Mus., vol. xv (1892), pp. 487-495.

‡‡ Am. Jour. Sci., vol. xli, March, 1891, p. 193.

which in a general way makes the Potomac equivalent to a part of the Shasta portion of the Shasta-Chico series, is greatly strengthened by Professor Fontaine's study of the flora. Of the twenty-two species of plants found in the Shasta beds, four, viz., *Dioonites buchianus*, var. *Angustifolius*, *Abietites angusticarpus*, *Sagenopteris latifolia* and *Aspidium heterophyllum*, have been determined as certainly identical with forms found in the Potomac. The one first named is the most abundant plant in the collection from the Shasta beds. Besides these, ten other species have been determined as probably identical with Potomac forms. If not identical they are at least closely related forms. Of some of these forms Professor Fontaine remarks that their identity is marked (?), not because he had any doubt in the matter, but because the amount of material was too small to justify a positive opinion.

COMANCHE SERIES OF TEXAS CRETACEOUS.

This series, consisting mainly of limestones, which has a very great development in Texas and Mexico, underlies the equivalents of the Upper Cretaceous of the Rocky Mountains and Great Plains regions, and therefore holds the same stratigraphic position as the Shasta portion of the Shasta-Chico series. According to Mr R. T. Hill,* the lower portion (Trinity division) of the Comanche has an invertebrate fauna related to the Neocomian of Europe, and consequently of the same age as a part of the Shasta fauna, although these two faunas seem to have nothing in common, and if they were strictly contemporaneous must have been separated by a great land barrier, as White has suggested. The fossil plants furnish more direct evidence for this correlation. The Glen Rose beds, about 250 feet above the base of the Trinity division, have yielded a flora, described by Professor Fontaine,† that is very closely related to that of the older Potomac and contains one species certainly, and two others doubtfully, identified by Professor Fontaine in our recent collections from the Shasta.

The most promising field for the discovery of the direct relations of the Shasta to the Comanche is in southern Mexico, where it seems probable that portions of both series may yet be found together or their faunas intermingled. The Comanche series is known to cover a large part of Mexico, and the Shasta-Chico series certainly extends as far south as 29° 30' on the Pacific coast. The Ammonites described by Dr J. Felix ‡ from the Neocomian near Tlaxiaco, state of Oaxaca, are related to some of those from the Knoxville beds, while those from Tehuacan, in Pueblo, seem to belong to the Comanche fauna.

* Proc. Biol. Soc. of Washington, vol. 8, 1893, p. 20.

† Proc. U. S. Nat. Mus., vol. 16, 1893, pp. 261-282.

‡ Palaeontographica, vol. 37, 1891, pp. 180-189.

There are also Aucella-bearing beds in that region that have been referred by Nikitin* and by Aguilera and Ordoñez† to the Jurassic, which is said by the latter authors to underlie the Cretaceous conformably. The Aucellæ mentioned by Nikitin (*Aucella pallasii*, var. *plicata*, and another with the form of *A. pallasii*, but with radiating sculpture stronger than that of *A. bronni*) are evidently like those of the California Mariposa beds. They came from San Luis Potosi. Aguilera and Ordoñez list six species and three varieties of *Aucella* under the head of Jurassic fossils, referring them all to Russian species, some of which occur in the older Aucella beds of Russia, while others, according to Lahusen, are confined to the Neocomian.

CORRELATIVE MOVEMENTS.

From the general correlation of formations already made some movements of the land may be correlated.

During the lower Cretaceous the whole western half of the North American continent was subsiding and the sea transgressing. In most places this movement continued with or without interruptions during a part of the Upper Cretaceous.

The extensive conglomerate of the Sacramento valley which marks the basal portion of the Chico beds may have resulted from topographic changes connected with the intrusion of the peridotites whose alteration gave rise to the serpentines of the Coast range. It is not, however, certainly known that the eruption of the peridotites occurred at that time.

Between the Horsetown and Chico beds in California there is no unconformity corresponding to that reported by Hill between the Upper and Lower Cretaceous of Texas. It is evident, however, that at the time represented by that unconformity there were widespread topographic changes which are recorded, as noted by Dr Dawson,‡ in the extensive conglomerate of the Dakota group as well as in the Upper Cretaceous of Queen Charlotte islands and in the Chico beds of Oregon and California.

The great post-Laramie disturbance noted by Emmons§ in the Rocky mountain region corresponds to that represented by the unconformity between the Chico and Téton of northern California and Oregon.

RÉSUMÉ AND CONCLUSIONS.

The discovery of *Coralliochama orcutti* in the basal portion of the Chico beds at a number of points in the Sacramento valley completes the demonstration that the Wallala beds are only a phase of the Chico.

* Neues Jahrb. für Mineral. Geol. und Palæont., Bd. 2, 1890, p. 273.

† Datos para la Geología de México, 1893.

‡ Am. Jour. of Sci., vol. xxxviii, p. 125.

§ Bull. Geol. Soc. Am., vol. i, pp. 245-286.

The Shasta-Chico series is composed of the Knoxville, Horsetown and Chico beds, all of which are well exposed in the same sections upon the western border of the Sacramento valley.

The Knoxville, Horsetown and Chico beds are each characterized by its own fauna. The faunas of adjacent beds, however, are so bound together by many common species that there is no paleontologic break anywhere within the series.

The Shasta-Chico series is conformable throughout and the intergradational character of the sediments, taken in connection with the faunal continuity of the series and its relation to the great unconformity beneath, shows that it is the result of continuous deposition.

The attenuation of the Shasta-Chico series westward from the Sacramento valley and the overlapping of the newer beds upon the 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.

The successive peripheral attenuation of the lower beds and the landward overlapping of the upper ones shows that the Pacific coast from Alaska to Mexico was subsiding and the sea transgressing.

The subsidence was probably not uniform throughout the whole region. The deposition of 30,000 feet of sediments in the Sacramento valley under shallow-water conditions apparently indicates a greater subsidence in that region than for the mountains from which the sediments were derived.

The Mariposa and Knoxville beds are faunally distinct and unconformable. The former is Jurassic and the latter Cretaceous.

The final folding of the Sierra Nevada rocks and an uplifting of the range occurred at the close of the Jurassic.

The Shasta-Chico series represents the Cretaceous time from the beginning of the Lower Cretaceous to the middle of the Upper Cretaceous, and it may be closely correlated with the Queen Charlotte Island and Nanaimo groups.

The fact that certainly 4 and possibly 14 out of 22 fossil plants found in the Knoxville and Horsetown beds of California are identical with forms found in the Potomac formation of the Atlantic border indicates that the Potomac epoch is included in that represented by the lower part of the Shasta-Chico series.

The relation which the Comanche series of Texas and Mexico is believed to hold to the Aucella beds of that region and also to the Upper Cretaceous renders it highly probable that it is contemporaneous with a large part of the Shasta-Chico series.

UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., March 20, 1894.