FAUNA OF THE MERYCHIPPUS ZONE, NORTH COALINGA DISTRICT, CALIFORNIA

Thesis

by

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SUMMARY

The Merychippus zone occurs at the top of the Temblor sandstones on Domengine Creek, twelve miles north of Coalinga, California. The fauna includes a significant representation of ungulates and carnivores, with the Equidae far outnumbering all other forms.

The stratigraphic position of the Merychippus zone in the Tertiary marine series, exposed on the west side of the San Joaquin Valley, lies within a zone whose assignment either to the middle Miocene Temblor or the upper Miocene Monterey is at present disputed among geologists familiar with the area. That its position is close to the dividing line between Temblor and Monterey is deemed significant for this report. In its stage of evolution and in its relationships with Tertiary assemblages of the Great Basin Province, the fauna of the Merychippus zone occupies a position intermediate between the middle Miocene Mascall of eastern Oregon and the upper Miocene Barstow of the Mohave Desert.

A study of the occurrence of the material leads to the conclusion that the accumulation of fossil remains took place in the foreset portion of a delta of a large river, where remains of land mammals were mingled with those of marine vertebrates. The suggestion is made that during the period of accumulation of the deposits and of the organic remains, the land area contributing this material was one of low relief and characterized by a rainfall of approximately 30 inches. The fauna is described in detail.

TABLE OF CONTENTS

THE FAUNA OF THE MERYCHIPPUS ZONE NORTH OF COALINGA, CALIFORNIA

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INTRODUCTION

The fauna from the Merychippus zone, north of Coalinga, California, was first described by J. C. Merriam[1] in 1915. The assemblage as listed by Merriam included four genera of mammals, namely, Merychippus, Prosthennops, Procamelus, and Tetrabelodon. As recognized by Dr. Merriam, the discovery of remains of land mammals in the marginal marine series of California possesses particular significance as furnishing an important aid in determining the time relationships between the marginal marine deposits of the Pacific Coast and the continental formations of the Great Basin and Great Plains areas of North America. The present studies were initiated, therefore, with a view to enlarging the fauna from this horizon and to establishing more accurately the time relationships of the assemblage. Moreover, it seemed desirable to ascertain fuller information concerning the conditions of accumulation of the fossiliferous deposits and of the ecologic conditions under which the fauna existed.

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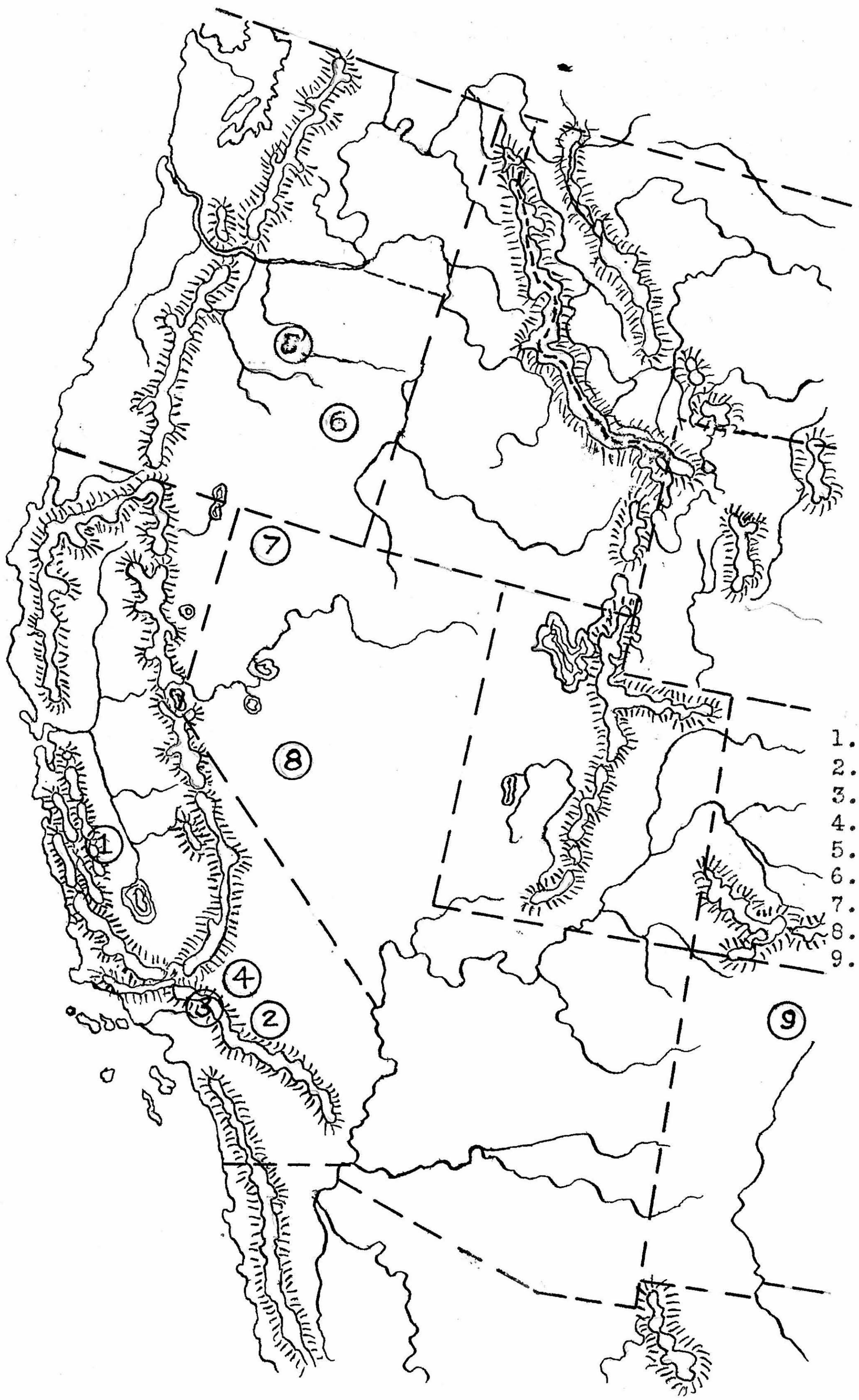
[1] Merriam, J. C., Trans. Amer. Philos. Soc., N. S., vol. 22, 1915.

Field work was conducted by the California Institute of Technology from 1928 to 1932, with the exception of the summer seasons. Much of the fossil material on which the present report is based was obtained by the late E. R. Inglee. A study of the assemblage from the Merychippus zone was suggested by Dr. Chester Stock, to whom the writer is indebted for helpful suggestions in the course of the investigation. Dr. R. D. Reed furnished valuable information regarding the stratigraphic position of the Merychippus zone in the marine Tertiary section exposed near Coalinga and in oil well sections of the north dome of the Kettleman Hills.



Vertertebrate
Horizons

1. Merychippus Zone
2. Barstow
3. Mint Canyon
4. Ricardo
5. Mascall
6. Skull Spring
7. Virgin Valley
8. Cedar Mountain
9. Santa Fe

INDEX MAP

Showing geographic location of Miocene vertebrate horizons in the Western United States.

GEOGRAPHIC LOCATION

The geographic location of the Merychippus zone with reference to known occurrences of continental deposits of Miocene age in California and The Great Basin Province is shown on the accompanying chart. The horizon from which the fossil material was obtained is located on Domengine Creek, on the east flank of the Diablo Range, twelve miles north of Coalinga, California, and approximately twenty-five miles northwest of the north dome of the Kettleman Hills. The Diablo range, bordering the San Joaquin Valley on the west, is comprised of a series of sedimentary rocks, more than 23,000 feet in thickness, representing formations which date from Jurassic in the center of the Range to the Recent alluvium in the Valley along its flank. With exception of the Coalinga anticline, six miles south of the fossil locality, the sediments along the front of the range dip regularly off the flank with a strike more or less parallel to the San Joaquin Valley. Domengine Creek is an intermittent stream flowing eastward down the flank of the Diablo range and discharges upon the usually dry floor of the San Joaquin Valley. Its general course is perpendicular to the strike of the sediments, but at a point four miles from the mouth the stream turns and flows south along the strike for nearly one-quarter mile, thence resuming its easterly direction.
The fossiliferous beds of the Merychippus zone outcrop along this north-south course and the type locality occurs on the

east bank of Domengine Creek at an elevation approximately fifty feet above its bed.

OCCURRENCE

The original material described by Merriam from the Merychippus zone was obtained from sandstones and conglomerates, two to three feet in thickness, lying at the top of the middle Miocene Temblor section on Domengine Creek and immediately below Miocene beds known locally as the "Big Blue". This field locality has been recorded in the catalogues of the California Institute of Technology as No. 108. The major portion of the material obtained by the Institute was collected from pockets at this same stratigraphic level. In addition, however, a considerable quantity of material was collected at a point farther south along the strike of the beds and approximately twenty feet stratigraphically below the level of locality 108. This locality is known as No. 129. No differences have been noted between the two assemblages. The position of locality 129 in the series gives added reason for regarding the Merychippus fauna as occurring within the Temblor as indicated by Merriam and not in the base of the Big Blue.

The sediments of the upper one hundred feet of the Temblor increase gradually in coarseness as they approach the Big Blue contact, the deposits changing gradually from alternating shales and fine sandstones, to sandstones, and then to coarse sandstones and pebble conglomerate lenses. Throughout the upper twenty feet cross-bedding is visible in the sandstone. The three feet of sediments underlying the Big Blue consist for the most part of sandstones containing lenticular pebble conglomerates. Here the lenses are numerous and give a false appearance of a continuous bed. Closer examination reveals, however, that none of them extends along strike for more than twenty feet. Their continuous appearance is due largely to their abundance. Excavations show that the average width of these lenses, down the dip, is usually equal to one-half their length along the strike, giving them a lateral ellipsoidal area with an elongation approximately in the direction of strike. Frequently small pockets of clay are found within and underlying the conglomerates. Clay pockets not associated with pebble lenses have also been observed. While fossil mammalian remains are found scattered throughout the upper hundred feet of the Temblor, the material does not become abundant until within twenty feet of the Big Blue contact. At this level the material is usually concentrated in the conglomerates and is most abundant at the top of the section. Here the number of horse teeth frequently exceeds that of the larger pebbles. Small concentrations of specimens have also been found in clay pockets not associated with the conglomerates. Fossil material has been found northward from the lower bend on Domengine Creek to a point where the fossiliferous strata disappear under the grassy mantle of the top of a ridge, a distance of nearly a thousand feet. Only scattered remains were found along the strike of the beds, on the south and west side of Domengine Creek. In this direction the conglomerate lenses disappear, leaving the Big Blue in contact with sandstones. The zone of maximum concentration has a lateral extent along the strike of approximately four hundred feet. Its extent in the direction of the dip of the beds is unknown.

With the exception of three horse rami, the material from the Merychippus zone consists entirely of scattered teeth and fragments of limb elements. But few of the teeth show signs of abrasion, although many of the specimens exhibit a tendency to shatter into many fragments when removed from the matrix. The skeletal material, on the other hand, is usually so well rounded that few characters of taxonomic value are available. The relatively compact carpal and tarsal bones are the most numerous skeletal parts represented. In this collection the astragali far outnumber other elements. As with the teeth, the skeletal material is assignable principally to the Equidae. Upper limb material is rare and is represented by one complete horse metapodial and a score or more of fragments of the articulatory portions.

Among upper limb specimens, camel and horse are equally well represented, offering a point of contrast with remaining parts of the skeleton which belong chiefly to members of the Equidae. Presence of rhinoceroses and of mastodonts is indicated by remains of cheek-teeth. No large limb material referable to these forms has been found. Bone material of large size is completely absent in the deposits, the larger fragments never exceeding a maximum size of four inches. Sharks teeth are plentiful and are associated with an occasional tooth fragment of the aquatic mammal Desmostylus in all the quarries. No skeletal parts of these forms have been found. Mud casts of a gastropod and of a lamellibranch were found in one of the fossiliferous pockets at locality 129.

FAUNA OF THE MERYCHIPPUS ZONE

The following species are now recognized in the collections from the Merychippus zone:

Carnivora

Tomarctus sp.
Aelurodon sp.
Amphicyon sp.
Hemicyon sp.

Rodentia
Monosaulax? sp.

Proboscidea
Miomastodon or Trilophodon sp.

Perissodactyla
Hypohippus sp.
Parahippus brevidens Marsh
Archaeohippus mourningi (Merriam)
Merychippus brevidontus Bode
Merychippus californicus Merriam

Rhinoceratid cf. Aphelops

Artiodactyla
Prosthennops sp.
Procamelus sp.
Oxydactylus? or Alticamelus? sp.
Miolabis? sp.
Blastomeryx (Dyseomeryx) sp.

Marine vertebrates as follows:
Cetacean remains
Desmostylus cf. hesperus Marsh
Selacian teeth
Cacharodon
Lamna
Isurus
Odontaspis
Gymnodontidae

FREQUENCY OF OCCURRENCE OF INDIVIDUALS

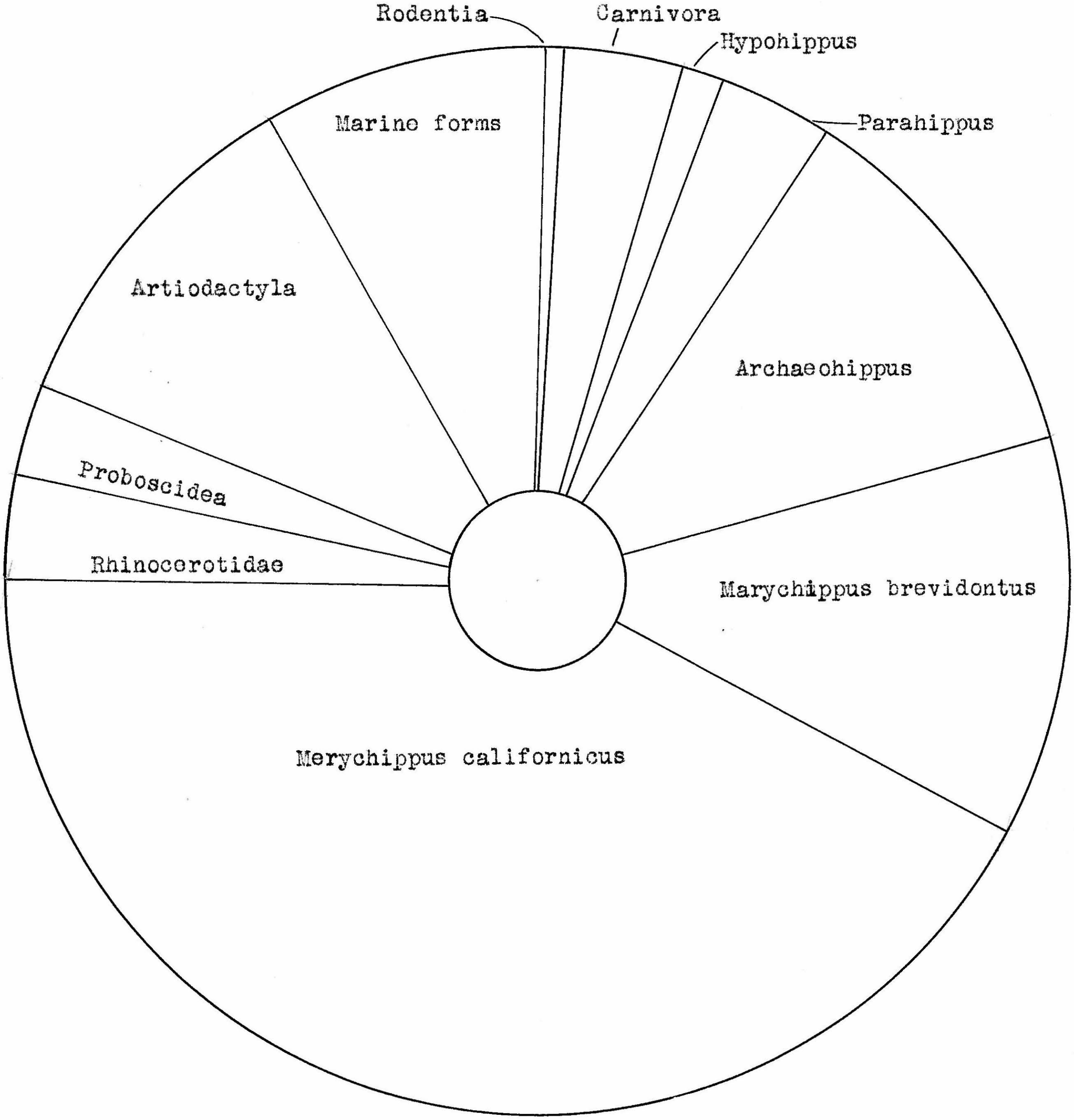
Individuals assigned to the species *Merychippus californicus* far outnumber all other forms in the fauna from the Merychippus Zone, this species being represented in the collections by more than two thousand well preserved cheek-teeth. At least five hundred additional teeth were discarded because of their fragmentary preservation, when the collections from the field were prepared in the laboratory. Moreover, many specimens, too incomplete to collect, were discarded in the field. According to E. R. Inglee the numerical relation of complete and incomplete teeth encountered to those actually shipped was well over five to one. It appears safe to assume that more than five thousand teeth were encountered during the progress of the excavations. On the basis of the scattered distribution of the teeth removed from the Merychippus Zone it seems likewise safe to assume that not all of the twenty-four cheek-teeth assignable to one individual are included in the collections. A reasonable estimate of the minimum number of individuals obtained may be placed at two hundred and fifty. The number of individuals indicated by third upper molars of the right side is one hundred and twenty. However, because of the teeth discarded and the probability that not all individuals in the collections are represented by the third molar, the former estimate is regarded as being nearer the actual number.

The number of individuals of species other than Merychippus californicus, has been determined from the total number of teeth in the collections after taking into account the size, shape, and stage of wear of all teeth occupying opposite but similar positions in the skull or mandible. The possibility of duplication of number arising from counts of lower and upper teeth actually representing the same individual has been taken into consideration.

With the exception of Merychippus californicus all other species in the collection are represented by less than one hundred teeth. The volume of rock excavated to obtain the present collection was well over a thousand cubic yards. Since the teeth were distributed rather uniformly through this volume and over an area of at least six thousand square feet, it seems likely that not many of the specimens belong to the same individual. In the case of all species the number of individuals is probably a minimum. However, since the same procedure has been followed for all forms and since the number of merychippine teeth greatly exceeds that of all other forms, the relative frequency of occurrence of all forms is considered to be essentially correct.

On the basis of present estimates that at least two hundred and fifty individuals of the species Merychippus californicus have been found, the Equidae comprise seventy per cent of the total number of individuals collected from the Merychippus zone. The accompanying chart shows graphically the representation of individual groups, but for those mammals in which relatively few individuals per species are known only the size of the family is shown.

Chart showing frequency of occurrence of individuals in the fauna of the Merychippus Zone



MODE OF ACCUMULATION

The relative abundance of sharks teeth and the presence of <u>Desmostylus</u> and of several other marine forms, indicates the marine origin of the deposits containing the Merychippus zone. The preponderance of remains of land mammals, on the other hand, suggests that the accumulation took place in an area close to shore, at a locality where fragments of these forms were readily obtainable. That the accumulation occupied a period of time of greater duration than a few years is suggested by the fact that the fossil material is found distributed throughout the upper hundred feet of the Temblor beds in the Domengine creek section. The gradual increase in coarseness of the sediments, accompanied by a similar increase in concentration of fossil material toward the top of the section may be interpreted as indicating the approach of the land area. The Temblor section on Domengine Creek has a thickness of four hundred and eighty feet. Six miles south, on the Coalinga anticline, this formation has a thickness of approximately six hundred feet[2]. In axial wells on the north dome of the Kettleman Hills

[2] G. C. Gester and John Galloway, Bull. Amer. Assoc. Petrol. Geol., vol. 17, 1180, 1933.

the Temblor has increased in thickness to approximately fifteen hundred feet.[3] This southward increase in thickness

[3] op. cit.

suggests that the land area from which the material was derived lay to the north and possibly to the northwest. The northwest derivation of the material forming the Big Blue may be regarded as corroborative evidence.[4]

[4] Robert Anderson and Robert W. Pack, U. S. G. S. Bull., 603, 83, 1915.

As previously mentioned, the fossil material occurs as scattered teeth and small fragments of limb elements buried in ellipsoidal conglomerate lenses. It would appear quite likely, from the nature of the occurrence, that the fossil material accumulated on a sandy surface of the sea floor over which were scattered more or less ellipsoidal pebbly areas. Within the latter and especially at their bottoms occurred small concentrations of mud. These areas evidently lay in slight depressions on the floor. Apparently other small depressions contained only mud. Employing the terms defined by Twenhofel,[5] the pebble conglomerates

[5] Treatise on Sedimentation", The Williams and Wilkins Co., 155, 1926.

are composed of a heterogeneous mixture of pebbles, granules, varying sizes of sands, and small quantities of mud. The sediments exposed on the surface surrounding the pebble areas were comprised mainly of medium to fine grained sands. The maximum diameter of the pebbles rarely exceeds one inch, although particles closely approximating this size are numerous in the upper three feet of the Temblor sediments. In the pebbly areas and infrequently in the few clay pockets, fossil vertebrate specimens were found lodged between pebbles or were buried almost entirely in the clay. Invertebrate fossils are absent.

As indicated by the presence of marine forms, the surface on which the accumulation took place, lay submerged beneath salt water. The maximum strength of the currents during the period of deposition is indicated by the size of the largest pebbles. These pebbles probably were rolled along the bottom, coming to rest ultimately in shallow depressions on the sandy floor. The clay or mud within the gravels may be regarded as material caught and protected from further movement after sinking through the interstices between the pebbles and coarse sands. Fossil material rolled along the bottom would also become lodged between the pebbles and thus resist further movement. The presence of fossils of slightly greater size than the pebbles may be accounted for by the lower density of this material.

In reviewing the types of deposits under which the Merychippus zone may have accumulated, at least four possibilities present themselves. These may be indicated, with regard to the environmental conditions under which they are formed, as littoral, marginal lagoon, estuarine, and delta accumulations.

The stratigraphic position of the Merychippus zone at the top of the Temblor, the type and distribution of the sediments, and the thickness of the deposit may be regarded as indications favoring a littoral origin of the deposits. However, several features are opposed to this type of origin of the Merychippus zone. While the absence of marine invertebrate forms may have no significance, it seems more probable from the presence of other marine forms, that shell fragments would have been in evidence if the concentration north of Coalinga occurred under littoral conditions. The deposits laid down under a littoral environment are largely the result of wave action. Lack of abrasion of most of the fossil teeth from the Merychippus zone, some specimens preserving intact their long, thin roots below the base of the crown, and the perfect preservation of the delicate structures of small teeth as in Archaeohippus, are some features of the organic remains which appear to mitigate against the postulate of accumulation on a wave-pounded beach. Moreover, it is difficult to conceive of large concentrations of fossil specimens (horse teeth sometimes outnumbering the pebbles), as forming on a beach.

A "marginal lagoon" is a body of water partially separated from the sea by a bar or barrier beach. Sediments from the land are brought in by fresh water and those from the sea by tidal currents. The water is usually salty. This type of environment might be regarded as favorable for the accumulation of sharks teeth and remains of land mammals. However, in a marginal lagoon the waters are quiet and as they periodically receive new sediments brought in by tides, the deposits become well stratified at the time of accumulation. The stratification of lagoonal deposits are even and regular and the sediments consist for the most part of fine mud and silts. Remains of invertebrates are usually abundant. These characteristics are not in accord with those exhibited by the deposits of the Merychippus zone.

Estuarine deposits are laid down in an enlargement of a river channel near its mouth, when the latter has been drowned through coastal subsidence. Tidal currents are commonly more active here than along the shores of the open sea. This leads to strong currents resulting in much scouring of the bottom. Remains of marine invertebrates are uncommon. The sediments riverward are usually sands and silts, while those seaward are not unlike marine deposits. The intermediate estuarine area may have a bottom quite similar in appearance to that which probably prevailed in the locality of the Merychippus zone. With the exception of the absence of evidences of scoured channels, the deposits north of Coalinga present no other characteristics opposed to those seen in the bottoms of estuaries. However, an estuary, primarily resulting from a subsidence of the coast, is in direct opposition to the probable conditions obtaining in the vicinity of the Merychippus zone during the time represented by the upper part of the Temblor.

On the other hand, the deposits at the Merychippus zone present no characters serving to distinguish them from those of delta deposition. Delta deposits are by no means unusual, the total present area receiving sediments of this type being estimated by Twenhofel[6] to aggregate approximately

[6] op. cit., 600.

two million square miles. According to Barrell[7] several periods

[7] Barrell, J., Bull. Geol. Soc. Amer., vol. 36, 377-446, 1912.

of geologic time have been marked by the accumulation of extensive deposits of this type. Delta deposits are divided into four classes[8]; the topset beds of the subaerial plain, the topset

[8] Twenhofel, W. H., op. cit., 591-595.

beds of the subaqueous slope, the deposits of the foreset slope, and the bottomset beds beyond the foreset slope. Sediments of the first two are characterized by sands and clays with gravel uncommon in the first. The bottomset deposits are similar to those deposited entirely under marine conditions.

Both river and marine waters are concerned with the deposition of sediments on the foreset slope, the former adjacent to the ends of the river distributaries and the latter over the intervening areas. The coarsest materials of the delta are found here. These are usually deposited with an initial inclination, although the angles of inclination are usually low in large bodies of water. The upper portions of the foreset beds are deposited above wave base and the lower portions may be below that level. In turbid waters marine organisms may be absent. The sediments of the foreset slope are poorly sorted but stratified, in contrast to evidence of scour channels seen in the subaqueous topset beds. Strong ocean currents and fine waste give wide distribution of sediments and extensive development of the bottomset beds as compared to the other components. These conditions obtain about the mouth of the Mississippi. Streams entering bodies of water whose currents have energy sufficient to dispose of all sediments brought to them may have no subaerial plain. Deep waters about a delta front, with weak current action, lead to the deposition of most of the material in the foreset beds. These conditions prevail at the deltas of the Ganges and Bramaputra Rivers. Strong wave action, great extent of delta front and a slowly rising sea-level favor the development of a wide subaqueous plain. These conditions are thought to exist about the Nile. Weak waves, coarse abundant sediments, and a shallow sea lead to the development of an extensive subaerial plain. The delta of the Rhine and adjacent rivers illustrate these conditions. Other combinations of these factors lead to varying results.

The above descriptions, taken largely from Barrell and Twenhofel[9], indicate that a variety of conditions may

[9] op. cit.

prevail when sediments accumulate under a delta environment. The deposits containing the fossil vertebrates of the Merychippus zone fall within this range of variation. Beds lower than one hundred feet below the top of the Temblor can be regarded as having had a bottomset origin, while the last hundred feet of sediments represent the foreset portion of delta deposits. The rather uniform stratification of the last hundred feet of the Temblor on Domengine Creek, the gradual increase in coarseness toward the top of the section, the uniformity of size of the pebbles and of their disposition along the strike, the presence of cross-bedding, the association of fossil types, and the lenticular disposition of the conglomerates, are all in accord with this type ofdeposition. As judged in the light of the characters mentioned above, the Merychippus zone may be interpreted as an accumulation which took place in the foreset beds of a large river emptying into fairly deep water with currents of medium strength. The subaerial and subaqueous slopes would in this case be poorly developed. The overlying Big Blue obliterates, however, any indication of these two stages.

The foreset region of a delta deposit appears to account for all the characteristics of occurrence exhibited by the fossil material at the vertebrate localities north of Coalinga. The scene of deposition may be visualized as the region in front of the mouths of distributory streams and below the level of the sea, with a total area of accumulation approximating one thousand feet in width and with a central area in which most of the material was concentrated within approximately four hundred feet. The marine water above accounts for the presence of the sharks' teeth and other forms. The constant movements of sand and pebble particles along the bottom afforded the probable agent preventing population by marine invertebrates. The currents of the river over the subaerial part possessed a maximum strength capable of bringing pebbles up to one inch in diameter to the scene of accumulation. Within the areas of accumulation of the foreset beds, the water had sufficient strength to continue movement of the pebbles, but as these progressed seaward, less and less movement occurred. The specific areas of pebbles resulted from a trapping of this sedimentary material in shallow depressions from which the currents were unable to remove it. Clay, silt, and slightly coarser particles, on sinking into the interstices between the pebbles, were thus protected from further movement. In like manner, isolated teeth and fragments of bones of land mammals were rolled seaward along the bottom. When a tooth or fragment became lodged between pebbles, it was able to successfully resist further movement. As the pebbly areas were built up obstructions were developed which hindered for a time a seaward movement of the finer material behind them. Eventually, however, a stage was reached where the fine sediments washed over and buried the gravel areas, protecting them from further disturbance. A new depression to the side or behind probably originated by this action with consequent initiation of a new cycle of accumulation.

The lower density of the teeth and especially of the bone material accounts for their larger size in comparison with that of the pebbles. As mentioned under occurrence, the teeth rarely show signs of rounding, many of the specimens still possessing all of their root portions. Transportation with rock material for a considerable distance would certainly be expected to remove all signs of the more fragile structures. This feature is suggestive of a relatively gentle process of transportation and seems to indicate that the river bringing down the material carried very little large material. This type of stream is generally characteristic of a country well covered by vegetation. The angularity and excellent preservation of the teeth indicate further that in all probability many of the teeth did not fall from an individual jaw or skull, to which they belonged, until these organic remains had reached a position close to the area of burial. The skeletal elements are nearly always rounded.

This is to be expected, for after lengthy immersion bone becomes a jelly-like substance, whereas teeth retain their hard structure for a much longer period of time. The rounding of the bone fragments is thus probably due as much to long immersion before burial as to abrasion during transportation.

None of the limb bones are complete, and large elements belonging to such forms as a mastodon or rhinoceros are entirely lacking. Skulls are also absent. These large skeletal parts were probably too heavy for transportation and were thus forced to lie upstream until disintegration developed fragments small enough to be transported.

The organic remains were probably acquired originally by the stream as material washed from its sides and from tributaries. This appears to be a normal process, since animals frequently die near or immediately adjacent to stream courses. Unlike the case observed by Matthew[10] in his study of

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[10] Matthew, W.D., Bull. Amer. Mus. Nat. Hist., vol. 50, 1924.

Merychippus primus from the Sheep Creek horizon of western Nebraska, the equine teeth from the Merychippus zone of California do not show ontogenetic stages of wear. Seasonal floods are thus insufficient to account for the acquisition of the material, rather does the acquisition appear to have been a continuous process. The type of deposit and its thickness suggest that the material required a period considerably longer than a brief span of years to be concentrated.

The large number of individuals of the Equidae obtained from the Merychippus zone may be misleading from the standpoint of actual representation of these mammals in the contributing area. It is quite probable that these forms were abundant on the land areas, but it must be remembered also that the structure of an equine tooth is such as to withstand better the vicissitudes of time than that of teeth of many other types.

ENVIRONMENT OF FAUNA

While the merychippine horses were unquestionably the most prevalent mammals in the fauna of the Merychippus zone, their presence does not necessarily point to the existence of a widespread plain or steppe environment. These forms, in contrast to their living descendants, possessed quite clearly a number of more primitive structural characteristics in skull, skeleton and dentition, in which respect they were less favorably adapted to open country and to a diet comprised chiefly of gritty grasses. As a matter of fact, the hypsodont horses of to-day exist not only on the desolate plains of central Asia but are found also in open wooded country of South Africa and in the Himalayas. Thus a wooded region with interspersed grass-covered areas may be postulated as an environment particularly advantageous to the development of large numbers of merychippine horses.

In this connection it is significant to recognize likewise the presence and diversity of the brachydont horses in the fauna. Among the latter, Hypohippus with its broad feet and brachydont teeth, seems well adapted to life in a wooded environment. Parahippus, with teeth similar to those of Hypohippus, was probably also a browsing type. Archaeohippus may well have occupied an environment similar to that of the present day deer, forms more typical of wooded areas than of a plains environment. On the other hand, *Archaeohippus* with its slender limbs can hardly be regarded as having a range restricted to small tree-covered areas along stream courses. Similar suggestions are offered by members of the camelidae and by *Dyseomeryx*. These are all brachydont forms, whose habits are presumably akin to modern types occupying wooded areas.

The presence of rhinoceroses is not necessarily indicative of swampy ground since two of the living Indian species and both of the African forms are found in wooded areas adjacent to grassy plains. The living types feed on grasses and on the leaves of small shrubs and young trees. Judged in the light of its long limbs and brachydont teeth, *Aphelops* may have occupied a habitat featured by an oak forest and its floral association including an undergrowth of grass.

The Proboscidea as represented in the fauna by the mastodonts were without much question browsing forms. Like the rhinoceroses, brachydont horses and camels, these forms were certainly not restricted to tree-covered areas adjacent to stream courses. The type of environment as here conceived readily admits of the presence of peccaries.

The character of the carnivore assemblage suggests a plentiful food supply. Doubtless these forms found ample opportunity to stalk their prey.

Comparison of the fossil assemblage with a characteristic living assemblage of South Africa tends to emphasize the essentially normal numerical representation of individual types in the former. In accounting for the large number of merychippine horses, two suggestions may be stressed. In the first place, the protohippine horses may have been more susceptible than other forms to the processes which brought about their ultimate entombment in the record. Secondly, the structure of the teeth in these types enhances to a distinctly greater degree, than in the case of brachydont species, the preservation of the material.

The fauna regarded as a unit suggests the presence of wooded country with sufficient ground cover of grass to be attractive to both browsing and grazing types. An analysis of the fauna gives no special reason for recognition of a highly variable external environment. In view of the mobility of the types occurring in the fauna of the Merychippus zone, this assemblage doubtless furnishes a representative cross-section of the regional life of that time.

Additional information concerning the climate and vegetational cover of this region of California during Temblor time may be drawn from the fields of invertebrate paleontology and paleobotany. Thus Kleinpell[11] has pointed out that the

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[11] Kleinpell, R.M., paper on "A Proposed Biostratigraphical Classification of the California Miocene", presented at a meeting of the Micropaleontological Society in Los Angeles, Nov. 1933.

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foraminifera of the upper Temblor sea indicate warm and almost tropical conditions. Warm water during this period is indicated also by the megafossil fauna.

According to Chaney[12] the fossil floras of western North America indicate rather uniform climatic conditions during the Miocene. Chaney considers the Mascall flora and its equivalents as related to the oak-madrono forests of California, where topographic conditions of low relief have no particular influence upon a vegetation resulting from a rainfall of approximately thirty inches.

12 Chaney, R., Carnegie Inst. Wash. Publ. No. 349, 25, 1925.

STAGE OF EVOLUTION AND RELATIONSHIPS OF FAUNA

On the basis of present age-determinations of Tertiary vertebrate horizons in western North America, the Merychippus zone assemblage may be regarded as late middle Miocene in age. In its stage of evolution and in its relation to faunas of the Great Basin Province the Merychippus zone occupies a position intermediate between the upper Miocene Barstow of the Mohave Desert and the middle Miocene Mascall of eastern Oregon. The Virgin Valley and Skull Spring faunas of northwestern Nevada and eastern Oregon respectively are currently regarded as approximately equivalent to the Mascall and their relationship to the fauna from the north Coalinga district is approximately comparable to that which the Mascall bears to the latter. The Merychippus zone fauna represents an intermingling of genera found either in the Barstow or in the Mascall. In general, the more progressive Mascall forms are found also in the horizon north of Coalinga. Likewise, types having affinities with Barstow species are usually found to be related to the more primitive forms in the fauna from the Mohave Desert. This relationship is particularly interesting in view of the fact that the Barstow fauna is distinctly advanced beyond that of the Mascall.

The Equidae afford an excellent illustration of this intermediate position on the part of the fauna from the

Merychippus zone. Parahippus brevidens is a species commonly occurring in the Mascall but not found in the Barstow. The Coalinga Hypohippus is considerably smaller than that found in the Barstow. However, the Archaeohippus material from the Merychippus zone is clearly distinct from the Mascall species, A. ultimus, and is specifically inseparable from the Barstow form, A. mourningi. Within the Merychippus group the small species, M. brevidontus, is found also at Skull Spring and Virgin Valley. M. brevidontus represents a more primitive species than any of the Barstow forms. Among two thousand teeth representing the species Merychippus californicus a considerable number present characters which are indistinguishable from those of M. isonesus of the Mascall. An equal number of these teeth, on the other hand, possess characters identical with those of M. sumani from the Barstow. Thus the characters displayed by this species reflect the intermediate position of the fauna. The primitive Mascall species, M. seversus and M. relictus are absent from the Coalinga fauna, as is also the progressive species M. intermontanus which is characteristic of the Barstow.

Among the carnivores the Amphicyon material is close to A. sinapius, a species recognized in the Mascall fauna. Amphicyon has not been recorded from the Barstow. Tomarctus from the Merychippus zone is not clearly distinguishable from either the Mascall or Barstow types. The presence in the Coalinga fauna of a large dog referred to the genus Aelurodon and similar to A. wheelerianus from the Santa Fé, is another indication of Barstow affinities. Aelurodon is a more progressive form than related canids from middle Miocene horizons of the northwest. Hemicyon has not been recorded from the Mascall or Virgin Valley. However, a single upper carnassial from Skull Spring has been identified as belonging to this form. A lower molar from North Coalinga is comparable to the corresponding tooth of Hemicyon barstowenses from the Mohave Desert horizon.

The mastodont teeth, referred questionably to Miomastodon or Trilophodon, are similar in size to specimens from Virgin Valley. The Proboscidean material from the Barstow is noticeably larger, although the difference in size may have no special significance.

Among the Artiodactyla, the camels offer some indications of the intermediate position of the Merychippus zone fauna. The largest of the Coalinga forms is comparable in size to the smallest members of the group referred to Procamelus from the Barstow.

Curiously, the genera Dromomeryx and Merycodus, although found in the Barstow assemblage and in the middle Miocene faunas of northwestern Nevada and eastern Oregon, are absent in the Merychippus zone. Possibly ecological conditions are responsible for this absence at the Coalinga locality.

A detailed comparison of the Merychippus zone fauna with the more important Miocene assemblages of the western Great Plains is unsatisfactory, due to incompleteness of information regarding a number of species occurring in the California horizon. On the basis of the stage of evolution of the Equidae from the Temblor beds, this horizon represents an advance beyond the Sheep Creek or Merychippus primus zone of western Nebraska, although it is earlier than the stage of the lower Snake Creek fauna. The latter assemblage differs also from that of the Merychippus zone in absence of Aelurodon and presence of more progressive camels.

The following comparative lists give the mammalian faunas of five Miocene horizons of western North America, including the Merychippus zone.

MASCALL (M) VIRGIN VALLEY (V) SKULL SPRING (S)	MERYCHIPPUS ZONE	BARSTOW
Carnivora		
Tomarctus cf.brevirostris Cope (S)	Tomarctus sp.	Tomarctus near temerarius (Leidy)
Tomarctus cf. rurestris (Condon) (V) and (M)		
Tomarctus kellogi (Merriam) (V)		
Tomarctus sp. (V)		
Aelurodon sp. (V)	Aelurodon sp.	Aelurodon near wheelerianus Cope
Amphicyon sinapius Matthew (M) and (S)	Amphicyon sp.	
Amphicyon frendens Matthew (S)		
Hemicyon n. sp. (S)	Hemicyon sp.	Hemicyon barstowensis Frick
Mustelid sps. (S) and (M)		Hemicyon californicus Frick
Proboscidea		
Miomastodon merriami Osborn (V)	Miomastodon or Trilophodon (?)	Trilophodon barstonis Frick
Mastodont sp. (M,V,& S)		
Perissodactyla		
Hypohippus near osborni Gidley (V); sp(S)	Hypohippus sp.	Hypohippus near affinus (Leidy)
Parahippus near coloradensis Gidley (S)		
Parahippus avus Marsh (M)		
Parahippus brevidens Marsh (M)	Parahippus brevidens Marsh	
Archaeohippus ultimus (Cope) (M)	Archaeohippus mourningi (Merriam)	Archaeohippus mourningi (Merriam)
Merychippus isonesus (Cope) (M, V, & S)	Merychippus teeth similar to type of M. isonesus	
Merychippus relictus (Cope) (M, V, & S)		
Merychippus seversus (Cope) (M, V, & S)		
Merychippus brevidontus Bode (V and S)	Merychippus brevidontus Bode	
	Merychippus californicus Merriam	

MASCALL (M) VIRGIN VALLEY (V) SKULL SPRING (S)	MERYCHIPPUS ZONE	BARSTOW
<u>Perissodactyla</u> (cont)		
	Merychippus teeth similar to type of M. sumani	Merychippus sumani Merriam
		Merychippus intermontanus Merriam
		Protohippus? or Pliohippus
Rhinocerotid sp. (S)	Rhinocerotid cf Aphelops	
Aphelops? sp. (V)		
Diceratherium oregonense Marsh (M)		
Chalicothere? sp (S)		
Moropus merriami Holland and Peterson (V)		
<u>Artiodactyla</u>		
Perchoerus? sp. (V)	Prosthenops? sp.	Prosthenops sp.
Platygonus sp.* (S)		
Ticholeptus sp. (S)		
Merychyus? sp. (V)		
Merycoidodont? sp. (M)		
Merycochoerus sp. (M)		Merycochoerus? buwaldi Merriam
Miolabis transmontanus Cope (M)	Miolabis? sp.	
Alticamelus altus Marsh(M)	Alticamelus? sp.	Alticamelid?
	Procamelus sp.	Procamelus sp.
		Pliauchenia sp.
Dromomeryx near borealis (Cope) (M, V, & S)		Dromomeryx or cervus sp.
Blastomeryx mollis Merriam (V)	Blastomeryx (Dyseomeryx)sp.	
Blastomeryx? sp. (S)		
Merycodus sp A and B (S)		
Merycodus near furcatus (Leidy) (V)		
Merycodus nevadensis Merriam (V)		Merycodus near necatus (Leidy)

* Probably referrable to <u>Desmathyus</u> Matthew

STRATIGRAPHIC POSITION IN MARINE TERTIARY SERIES

In the Coalinga region the Miocene section is relatively thin, a considerable portion of the section including the Monterey Shales, found elsewhere in the Coast Ranges, being here omitted. The Merychippus zone lies at the top of the Temblor and immediately below the Big Blue on Domengine Creek. At this locality the beds assigned to the Temblor stage have a thickness of approximately five hundred feet. These beds lie unconformably above sandstones which in turn overlie the "Leda Zone" of the Kreyenhagen Group. The Temblor section is composed for the most part of alternating shales and sands which increase in coarseness toward the conglomerates at the top of the section.

On Domengine Creek the following recognisable units are found outcropping in the Temblor section: A thin zone of black or coaly clays sixty feet above the base. A reef bed containing Scutella merriami, one hundred and sixty feet above the top of the coaly clay member. White siliceous and diatomaceous shales fifteen feet in thickness, the "Indicator" bed of Arnold and Anderson,[13] forty-five feet above the top of the reef bed. This bed of shales may be traced southward across

[13] Arnold, R. and R. Anderson, Bull. U.S. Geol. Survey 398, 1910.

the Coalinga Anticline. The fossiliferous conglomerates at the top of the section lie one hundred and twenty feet above the indicator bed. The overlying Big Blue is a large lens within the Temblor having a lateral extent of approximately twenty miles. This member is unusual in view of the fact that throughout most of its extent it consists of a compact mass of fine detritus dust, flakes, and pebbles of serpentine. At some localities the Big Blue contains conglomerates formed almost entirely of serpentine boulders, some of which reach many feet in diameter. On Domengine Creek the Big Blue has a thickness of approximately two hundred and fifty feet and is unconformably overlain by beds of upper Miocene, Santa Margarita age. In a southerly direction the Big Blue varies in thickness from two hundred to forty feet and finally lenses out on the south flank of the Coalinga anticline, north of Coalinga. Farther south, in the vicinity of Oil Creek, Galloway[14] reports the

[14] Galloway, John, Paper present before Amer. Assoc. Petrol. Geol., Los Angeles, Nov., 1933.

presence of <u>Turritella ocoyana</u> in beds stratigraphically higher than the base of the Big Blue in the vicinity of the Merychippus zone locality. North of Domengine Creek, in the vicinity of Salt Creek, the Big Blue attains a maximum thickness of more than a thousand feet. According to Reed[15], north of Domengine

[15] Reed, R.D., personal communication.

Creek sandstones containing <u>Turritella ocoyana</u> are found overlying the Big Blue. Pack and Anderson[16] state that the fauna

[16] Anderson, Robert and Robert W. Pack, op. cit., 83, 1915.

of the marine beds underlying the typical serpentinous shale occurs also in sandy beds interstratified with or overlying the Big Blue. The Big Blue and the underlying Merychippus zone are thus placed within the stratigraphic range of <u>Turritella ocoyana</u>.

The following correlation chart attempts to show the position of the Merychippus zone in the Temblor on Domengine Creek, with reference to a portion of the Tertiary section for the south flank of the Coalinga anticline and to a typical section penetrated by oil wells on the north dome of the Kettleman Hills. The data for the Domengine Creek section are based on field observations by the writer, as well as from the section illustrated by Merriam[16] and from information furnished by Reed.[17] Information concerning the Coalinga anti-

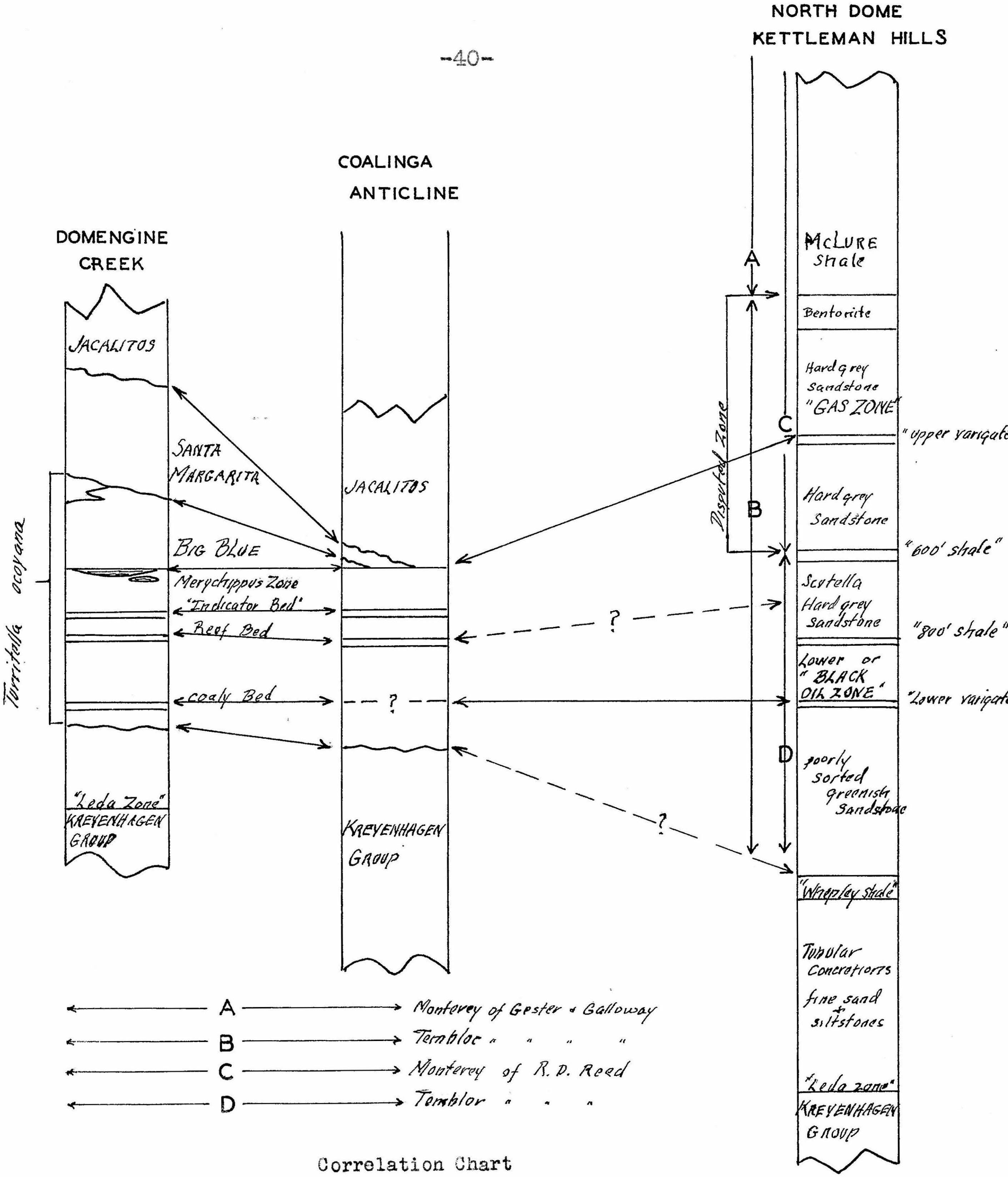
[16] Merriam, J.C., op. cit., 5, 1915.

[17] Reed, R.D., personal communication.

cline section was derived from Reed's "Geology of California."[18]

[18] Reed, R.D., Publication of Amer. Assoc. Petrol. Geol., 1933.

Data for the Kettleman Hills were fur-



Correlation Chart

Showing the position of the Merychippus Zone in the Miocene section exposed on Domengine Creek and its relations to similar sections from the south flank of the Coalinga Anticline, East Side Field, and from an axial well on the North Dome of the Kettleman Hills. The chart represents a compilation of data obtained from field observations of the writer and from references to publications by Merriam, Reed, and Gester and Galloway.

ops. cit.

nished by Dr. Reed and were obtained also from correlation charts illustrating a recent report on the geology of this area by Gester and Galloway.[19] A correlation of the coaly

[19] Gester, G.C. and John Galloway, Bull. Amer. Assoc. Petrol. Geol., vol. 17, 1169-1180, 1933.

member in the Temblor section of Domengine Creek with the "lower variegated" in the Kettleman Hills was suggested by Dr. Reed.[20] The correlation of the base of the Big Blue

[20] Reed, R.D., personal communication.

with the "upper variegated" follows the chart published by Gester and Galloway.[21]

[21] Gester, G.C. and John Galloway, op. cit., 1169, 1933.

Unfortunately, the exact position of the upper part of the "Temblor" in the geologic column of the Kettleman Hills is a matter of considerable dispute among geologists familiar with the area. In the Miocene of California the "Temblor" is now regarded as a stage name for beds containing the species *Turritella ocoyana*. The next higher stage is the Monterey, where deposits so called are regarded as the equivalent of beds found in the type section of the Monterey shales on the Monterey peninsula. At the base of the type section occurs the foraminiferal zone characterized by *Valvulineria californica*, one of the most widespread microfaunal zones known in the

Coast Ranges of California. Unfortunately, this zone is absent in the Coalinga and Kettleman Hills sections.

Goudkoff[22] inferred that the six or seven hundred feet

[22] Goudkoff, P.P., Bull. Amer. Assoc. Petrol. Geol., vol. 15, 839-842, 1931.

of sandstones above the "upper variegated" zone in the Kettleman Hills are equivalent to the Valvulineria californica zone. Gester and Galloway[23] state, however, that the upper

[23] Gester, G.C. and John Galloway, op. cit., 1180-1181, 1933.

fifty to one hundred feet of these sands are possibly the correlative in part of the two hundred feet of shale lying between the base of the Valvulineria californica zone and the top of the "button bed", at the top of the type Temblor section on Carneros Creek, northwest of McKittrick, California. In other words, Gester and Galloway believe that all of these upper sands in the Kettleman Hills should be included in the Temblor. Their correlation of the base of the Big Blue with the "upper variegated" would then place the Merychippus zone in the Temblor section. Again, according to a personal communication of Goudkoff to Reed,[24] the "600 foot

[24] Goudkoff, P.P., op. cit., 220, 1933.

shale" underlying the "upper variegated" in the Kettleman Hills section is younger than the "button bed" on Carneros Creek. This correlation would place the Merychippus zone in the Monterey. R. D. Reed considers the upper part of the oil zone or the upper sandstones in the Kettleman Hills to be stratigraphically equivalent to the Big Blue and to the Merychippus zone. And again, according to Reed[25] there

[25] Reed, R.D., op. cit., 219, 1933.

remains the possibility that the lower part of the Valvulineria californica zone and the uppermost portion of the Turritella ocoyana zone are equivalent. These correlations place the Merychippus zone in the middle of the disputed section. Reed[26]

[26] Reed, R.D., op. cit., 215, 1933.

also suggests that in the Coalinga region, "....the Big Blue serpentinous member of the 'Temblor' is younger than, or belongs within, the Valvulineria californica zone and is therefore Monterey rather than Temblor; and that the 'gas zone' of the Kettleman Hills is largely Monterey in age, and the 'black oil zone', Temblor." The Merychippus zone lies within the Turritella ocoyana stage. Its exact position in the marine section remains indefinite. To quote from Reed:[27]

[27] Reed, R.D., op. cit., 220, 1933.

"As the matter stands at present, however, all that can be said is that the Merychippus zone is very near the exact dividing line between Temblor and Monterey, more probably ~~above~~ above than below it in the opinion of the writer, but in any case not far from it."

The evidence as afforded by the relations of the vertebrate fauna from the Merychippus zone to known Miocene mammalian assemblages may throw some light on this problem. As previously discussed, the Merychippus zone is in stage of evolution intermediate between the Mascall of eastern Oregon and the Barstow of the Mohave Desert, California. The Mascall has always been regarded by vertebrate paleontologists as possessing a fauna typical of the middle Miocene. Chaney, on the basis of evidence derived from fossil floras, has placed the age of the Mascall as middle or upper Miocene. One may conclude therefore that the Merychippus zone can not be older than late middle Miocene. The position of the Barstow is not so definite. In his original description of the fauna from this locality, Merriam[28] assigned an uppermost Miocene age to this horizon and referred the distinctly younger beds of the Ricardo to the lower Pliocene. Since these age determinations were made Maxson[29] has found several of the horses peculiar to the Ricardo in beds of the Mint Canyon formation, which presumably underlie marine sediments of Cierbo or upper Miocene age. If the age de-

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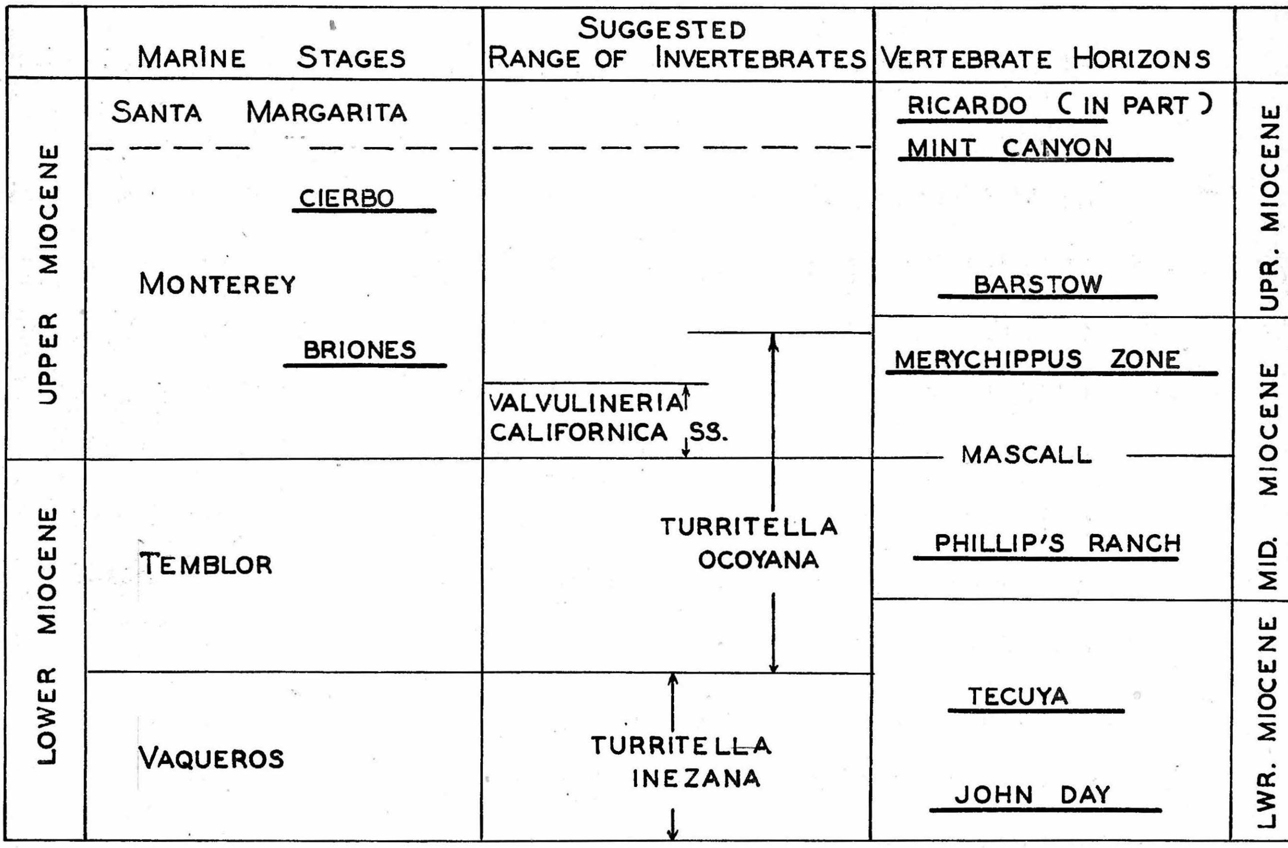
[28] Merriam, J.C., Univ. Calif. Publ., Dept. Geol. Sci., vol. 11, 454, 1919.

[29] Maxson, J.H., Carnegie Inst. Wash., No. 404, 77-112, 1930.

termination of the marine horizon is essentially correct, this relationship tends to push the Barstow lower into the Miocene. The Barstow is distinctly closer in stage of evolution to the Merychippus zone than it is to the Ricardo. The position of the Merychippus zone can not then be assigned to a period of time younger than early upper Miocene.

On the accompanying chart, the several Miocene vertebrate faunas are shown in relation to the sequence of invertebrate faunas of this period. On the basis of present age determinations of closely related vertebrate faunas, the assemblage from the Merychippus zone may have a position in the Miocene high enough to place it within the lower Monterey rather than in the Temblor. It is clear that the upward range of Turritella ocoyana in the Tertiary section north of Coalinga is greater than has been regarded heretofore to be the case. The relation of the vertical range of T. ocoyana to that of Vulvulineria californica is suggested.



Correlation chart showing time relationships of Miocene Marine and Continental stages for Western North America.

SYSTEMATIC DESCRIPTION OF FAUNA

Carnivora

The carnivore material from the Merychippus zone consists almost entirely of isolated sectorial teeth. With the exception of a single tooth, referable to Hemicyon, the specimens fall naturally into three group sizes. These groups are referred to Tomarctus, Aelurodon, and Amphicyon. Unfortunately, the characters displayed by the carnassial teeth of members of the Canidae are usually only of generic significance. Comparisons with known types emphasizes the fact that the present material is too incomplete to serve as a satisfactory basis for specific determinations.

Tomarctus sp.

The teeth of this small carnivore are referred without question to the genus Tomarctus. While a critical study of the relationships of Tomarctus Cope and Tephrocyon Merriam have not been attempted, there appears to be no reason why Matthew's[30] suggestion of generic identity of the two forms

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[30] Matthew, W.D., Bull. Amer. Mus. Nat. Hist., vol. 50, 88-81, 1924.

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should not be accepted. In the following discussion the name Tephrocyon is regarded as a synonym of Tomarctus.

The material from the Merychippus zone consists of four upper carnassials (Nos. 1603, 1604, 1605, and 1606), two lower sectorial teeth (Nos. 1607 and 1608) lacking the anterior portions of the trigonids, the greater portion of an M1 (No. 1609), and a single premolar (No. 1610). In the superior carnassials the parastyle is a small cusp or elevation on the anterior ridge of the paracone. The protocone has been broken away on three of the specimens, but is present on the fourth (No. 1603). In this tooth the position of the protocone is anterior to that of the paracone and the cusp is rather small and low. A distinct cingulum is present on the external side of the metacone in all four teeth. The upper molar is rectangular in shape, the lingual side having approximately the same anteroposterior diameter as the external side. The paracone and metacone are low cusps connected by a slight ridge. The metaconule and protoconule are well developed. These cusps become connected at an early stage of wear and form an anteroposterior ridge across the middle of the tooth. The protocone is represented by a relatively heavy ridge, which runs across the entire lingual side of the tooth. In the two specimens presumably representing M1, the entoconid and hypoconid are equally developed. When slightly worn these two cusps evidently form a transverse ridge with a small basin in front and a valley behind. In one of the teeth (No. 1608) the metaconid is distinctly larger than in the second specimen (No. 1607).

In size and arrangement of cusps these teeth compare favorably with several of the species referred to Tephrocyon or Tomarctus. The teeth are smaller than in the type of

T. rurestris (Condon) from the Mascall, and slightly larger than those of the specimen referred by Merriam to T. temerarius Leidy from the Barstow. T. kelloggi Merriam from the middle Miocene beds of Virgin Valley is a larger form. Compared to species from the Great Plains region the Coalinga specimens approach T. optatus Matthew more closely in size than they do any of the other known types. T. brevirostris Cope is larger and the type of T. confertus Matthew lacks the strong development of the proto- and metaconules seen in M1 from the Merychippus zone. Apart from size differences there appears to be very little to distinguish the Coalinga species from most of the described forms. The material compares most favorably with T. optatus and may represent a species closely related to or identical with this form.

Aelurodon sp.

Four upper carnassials (Nos. 1611, 1612, 1613, and 1618), three of them complete, and three lower sectorial teeth (Nos. 1614, 1615, and 1617), one of which is perfectly preserved (No. 1615), are assigned to Aelurodon. In the upper teeth the parastyle is distinct, though small. The protocone is also small and occupies a position slightly anterior to that of the parastyle. The shearing blade is robust and heavy. In the lower teeth the metaconid is a distinct and well-developed cusp. The paraconid is smaller than the protoconid. The transverse diameter of the talonid region is smaller than that across the posterior side of the trigonid. The talonid possesses two cusps of which the hypoconid is the larger.

The superior carnassials are almost identical in size, shape, and in arrangement of cusps with those of *Borophagus littoralis* Vander Hoof,[31] described from Santa

[31] Vander Hoof, V.L., Univ. Calif. Publ., Bull. Dept. Geol. Sci., vol. 21, 15-24, 1931.

Margarita beds near McKittrick, California. The lower jaw of this form is not known and it is principally for this reason that the material from the Merychippus zone is not referred to *Borophagus*. The specimens from north Coalinga, although slightly smaller, agree also with upper teeth of *Borophagus cynoides* (Martin) from the Hempill quarries, Texas. The lower teeth of this species are distinguished by larger size of talonid, relative to the trigonid. However, this Pliocene species obviously represents an advance over forms from the Miocene. It seems possible that the lower teeth of the Coalinga form may represent an ancestral stage to the later hyaenognathoid dogs. These specimens from the Merychippus zone are considerably larger than those of any species of *Tomarctus*, although the dental characters offer but little to distinguish them from that genus.

When compared with *Aelurodon wheelerianus* Cope, the teeth from north Coalinga appear to be quite similar. In fact, no clear distinctions can be made between the two types. The lower teeth are practically identical and the principal difference in the upper teeth is presented by the slightly smaller parastyle of the Coalinga specimens. Because of the agreement between the Coalinga form and A. wheelerianus in both upper and lower teeth and because the lower teeth of B. littoralis are unknown, the Coalinga material is referred to Aelurodon. However, the relative heaviness of the upper carnassials coupled with the presence of a parastyle that is relatively smaller than in most Aelurodons, is rather suggestive. In view of the late middle Miocene position of the Merychippus zone it may be possible that this material represents a form, larger although not otherwise clearly distinguishable from Tomarctus, and ancestral to either or both Borophagus and Aelurodon. The Coalinga type is considerably smaller than A. haydeni Leidy and the Ricardo form, A. aphobus Merriam.

Amphicyon sp.

Amphicyon is represented by two upper molars, an M1 (No. 1619) and an M2 (No. 1616), the trigonid and talonid portions of two lower carnassials (Nos. 1620 and 1621 respectively), a well worn M2 (No. 1622), a canine tooth (No. 1623), and a premolar (No. 1624). M2 (No. 1616) is a well preserved tooth of the right side. In this tooth the paracone is more than twice as large as the metacone. The protoconule and metaconule are only slightly developed and form a small ridge on the internal occlusal surface. The protocone is a heavy ridge which runs across the entire lingual side and halfway up the posterior side of the tooth. The paracone has been lost from the M1 (No. 1619). The metacone in this tooth was probably equal in size to the paracone. In this tooth the protoconule-metaconule ridge is well developed and encloses a distinct basin behind the paracone. The protocone has been damaged by abrasion and its exact form is therefore not represented.

In the lower carnassial fragments, the trigonid is considerably compressed in an anteroposterior direction. The metaconid is small and is essentially a part of the protoconid. The talonid is well worn; however, the hypoconid seems to have been the only important cusp, although some damage by abrasion has removed any indications of an entoconid if present. A well worn M2 (No. 1622) is also assigned to this genus. The characters of this tooth have been largely obliterated by wear, however, the tooth appears to have had two anterior cusps and a single posterior cusp as in *Amphicyon*. The antero-external corner of this tooth probably possessed a cusp sufficiently prominent to account for the small pocket worn in this area. This character was noted by Gazin[32] in a fragmentary M2 referred to *A. sinapius* Matthew

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[32] Gazin, C.L., Carnegie Institution of Wash., Publ. No. 418, 52, 1932.

from the Skull Spring deposits of eastern Oregon. A small pocket worn on the postero-internal corner of the tooth may represent either a small entoconid or the worn surface may be due to an occlusion of the tooth with a cusp of an upper molar.

These teeth are smaller than those of Amphicyon frendens Matthew. The fragmentary material available compares favorably in size and in arrangement of cusps with A. sinapius from the Great Plains. This species has also been recognized in the Mascall fauna. It seems probable that the Coalinga specimens represent this species.

Hemicyon? sp.

A lower second molar (No. 1625) from the Merychippus zone resembles closely the corresponding tooth of the type of Hemicyon barstowensis Frick[33] from the Barstow Miocene of the Mohave Desert, California. The cusps in this tooth are low and lack the trenchant character seen in Amphicyon. The tooth is still further distinguished from that in the latter genus in the more posterior position of the protoconid-metaconid ridge with reference to the anterior edge. Moreover, the hypoconid is a small low cusp, only slightly larger than the distinct entoconid. The exact relationships of the form

[33] Frick, C., Bull. Amer. Mus. Nat. Hist., vol. 56, 28, 1926.

characterized by this tooth are uncertain. However, the resemblances are more with *Hemicyon* than with any other genus. The tooth quite certainly does not belong to any of the described canid types from the Merychippus zone. In *Tomarctus*, *Aelurodon*, and in *Borophagus* the anterior cusps of M2 stand higher and have a considerably more trenchant character than in this tooth.

RODENTIA

Monosaulax sp.

Among the rodents only the beaver group is recorded in the collections. A single cheek-tooth (No. 496), and a fragment of a ramus (No. 653) with two teeth were referred to this castorid genus by R. A. Stirton of the University of California. This genus has been recognized by Mr. Stirton in the Miocene of the Great Plains and in the Cedar Mountain fauna of Nevada.

PROBOSCIDEA

Miomastodon or Trilophodon?

The proboscidean material in the collections consists of the following specimens: Four deciduous premolars (Nos. 1626, 1627, 1628, and 1629), 3 fourth upper premolars (Nos. 1630, 1631, and 1632), an upper M1? (No. 1633), a partially complete M2? (No. 1634), and a number of miscellaneous tooth fragments. No tusk or skeletal materials were found during the course of the excavations. The milk teeth and the permanent premolars possess four cusps, with each cusp remaining distinct and isolated until the tooth is worn almost to the base of the crown. Very few secondary cusps are present and these are extremely small, being minor tubercles situated between the major cusps near the base of the crown. On several teeth the enamel of the four cusps is perfectly smooth. The crown of the first molar, No. 1633, possesses three rows of two cusps each, although the individuality of the cusps disappears with wear. The partially complete M2? (No. 1634) is considerably larger than M1 but is otherwise essentially similar.

No. 1634 compares favorably with the type of *Miomastodon merriami* Osborn from the Virgin Valley beds of northwestern Nevada. In 1915 Merriam[33] tentatively assigned a milk molar and a fragment of a permanent molar to *Tetrabelodon*. While the present material offers little in contradiction to Merriam's determination, the mastodont genera now recognized in the middle Miocene are *Miomastodon* and *Trilophodon*. Satisfactory generic determination can not be made, however, on the basis of available specimens from the Merychippus zone. Mr. E. H. Colbert of the American Museum of Natural History,

[33] Merriam, J.C., op. cit., 13, 1915.

who has examined the materials, has kindly made the following comment:[34] "I believe the choice narrows down to Miomastodon

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[34] Colbert, E.H.: Personal communication to Dr. Chester Stock.

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or Trilophodon. It is pretty difficult to be definite." It is interesting to note, however, that the relationships of the Coalinga form appears to be with the more primitive members of the Proboscidea found in North America. Absence of representatives of the group on this continent prior to middle Miocene time may furnish a basis for regarding the presence of these primitive forms in California as an indication of middle Miocene age for the Merychippus zone.

PERISSODACTYLA

Equidae

Remains of horses are the most abundant fossils found in the Merychippus zone, individuals of this group comprising approximately seventy percent of the total population recorded from this horizon. Five species have been recognized, three anthitheriine genera, Hypohippus, Archaeohippus, and Parahippus, and two species of Merychippus. The major part of the collection consists of isolated teeth referable to the species Merychippus californicus, the type specimen which was described by Merriam from this locality. The remaining species are represented by considerably smaller numbers of specimens. The Equidae are of particular interest in that they clearly demonstrate the intermediate position of the Merychippus zone with respect to the Mascall and the Barstow. Three of the Species, Hypohippus, Parahippus, and Merychippus brevidontus are found in the Mascall and in other middle Miocene horizons of eastern Oregon and northwestern Nevada, while the Archaeohippus is unquestionably a Barstow species. The material determined as Merychippus californicus includes teeth that show close resemblance to specimens from the Barstow and the Mascall. The Equidae from the Merychippus zone have been described in detail in two previous papers by the writer.[35] A resume of these descriptions are included in

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[35] Bode, F.D., Carnegie Inst. Wash. Publ. No. 440, 1933. Second paper in preparation for publication.

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the present paper.

Hypohippus sp.

An upper molar (No. 885) and three lower premolars (Nos. 886, 887, and 888) belong to the genus Hypohippus. The material is unfortunately inadequate for more than a generic determination. The Coalinga specimens are considerably smaller than the few teeth described as Hypohippus near affinus (Leidy) by Merriam from the Barstow, and they are unquestionably specifically separable from this form. Hypohippus has not been recorded from the Mascall. Hypohippus near osborni Gidley from the Virgin Valley beds is similar in most respects though somewhat larger than teeth from the Merychippus zone. The relationships of the north Coalinga form as based upon these teeth seem rather to be with the Virgin Valley form than with the Hypohippus from the Barstow.

Archaeohippus mourningi (Merriam)

Next to Merychippus, Archaeohippus is one of the more commonly occurring forms in the collections from the Merychippus zone. To this genus have been assigned over fifty upper and lower cheek-teeth and a well preserved ramus with P3-M3 (No. 484). Archaeohippus mourningi, with higher-crowned cheek-teeth, from the north Coalinga locality, is a decidedly more advanced type than the Archaeohippus ultimus (Cope) from the Mascall. In A. ultimus the hypostyle consists of a single cusp, while in the Coalinga teeth this structure is triangular in shape and encloses a small fossette. M3 in the type of A. ultimus is not reduced in size. On the other hand, the upper third molars of Archaeohippus from the Merychippus zone show considerable reduction when compared to the two preceding molars. In the Coalinga teeth the protocone and hypocone widen toward their base to an extent which considerably obstructs the opening of the valley between protoloph and metaloph. In the Mascall form this valley is widely open, and the two internal cusps are smaller. None of the teeth from the Merychippus zone exhibits the heavy internal cingulum seen in the type of the Mascall species.

The teeth from the Merychippus zone agree in almost all respects with the type and paratype of _A. mourningi_ (Merriam) from the Barstow. The only noticeable difference appears to be the absence of an external cingulum on the lower jaw of the paratype. This character varies considerably in the large collection of teeth from the Merychippus zone and appears to have no diagnostic value. The Coalinga material is referred unquestionably to _A. mourningi_ and is clearly distinct from the Mascall species.

Parahippus brevidens Marsh

Parahippus is represented in the collections by some twenty well preserved upper and lower cheek-teeth. That the material should be assigned to a progressive parahippine form is indicated by the relatively high crowns, abundant cement, and progressive character of the ptychoid crenulations of the walls of the metaloph. These features serve to isolate the Coalinga form from most of the species of Parahippus. In development of the crenulations on the walls of the metaloph, the teeth from the Merychippus zone agree closely with Parahippus crenidens Scott. They differ from P. crenidens, however, in their less strongly developed ectoloph, shape of protoloph, and heavy coating of cement. The deciduous teeth of Parahippus cognatus, while similar in some characters, represent a much larger horse. Comparisons with this form are inadequate, since no milk teeth of Parahippus have been recognized in the collections from the Merychippus zone.

Several teeth in the collections of the California Institute of Technology from the Mascall and referred to Parahippus brevidens Marsh are practically identical with the Parahippus teeth from North Coalinga. A comparison with the type of P. brevidens as well as with the topotype material failsto disclose any characters which may serve to separate the Coalinga form from this species. Parahippus has not been recorded from the Barstow nor, so far as the writer is aware, from any Miocene horizon as late in age as the Barstow. The presence of Parahippus may therefore have some significance in pointing toward a close time relationship between the faunas from the Merychippus zone and the Mascall.

Merychippus brevidontus n.sp.

This species is known by approximately seventy-five upper and lower cheek-teeth. The specimens, although representing fully hypsodont teeth, possess exceptionally low crowns and exhibit extreme complexity of the enamel pattern. The characters seen in these teeth do not intergrade with those of the larger and more abundant species, M. californicus, and are employed therefore in the recognition of a new specific type. Teeth referable to this species are relatively abundant in middle Miocene collections from eastern Oregon and northwestern Nevada. Teeth similar to M. brevidontus are absent in the Barstow and related upper Miocene horizons.

Merychippus californicus Merriam

The Merychippus zone derives its name from the abundant representation of this species in the north Coalinga horizon. Cheek-teeth of Merychippus californicus comprise nearly half of all the specimens collected from this zone.

The degree of variation of the cheek-tooth characters as seen in this collection makes it difficult to determine the exact affinities of this species. The average grouping of characters seems to be generally distinct from the average grouping of characters seen in similar large collections from other horizons. Individual teeth can frequently be assigned to any one of several species of this genus from North American Miocene horizons. In general, the variations more frequently represented are those which would include *Merychippus isonesus* (Cope) from the Mascall and *M. sumani* Merriam from the Barstow.

Rhinocerotid cf. Aphelops

Some fifteen teeth in the collections are referable to the Rhinocerotidae. A generic determination is questionable. However, the brachydont character of the dentition tends to affiliate this form with Aphelops rather than with Teleoceras. The teeth show a slight development of the crochet and antecrochet. The two features of the enamel pattern were not found associated in a single tooth. Two tarsal elements (Nos. 1636 and 1637) are also present in the collections. These elements resemble those of *Aphelops* more closely than they do *Teleoceras* and may afford corroborative evidence for the present determination.

ARTIODACTYLA

Prosthennops? sp.

A dicotyline form previously known by a few teeth is represented in the collections by fifteen upper and lower molars and premolars. Definite generic determination of the form on the basis of this material is not trustworthy, but certain characters of the premolars are suggestive of *Prosthennops*. The four-cusped arrangement on the occlusal surface in the premolars, in contradistinction to a fewer number of cusps seen in species of *Desmathyus*, and the tendency of the four cusps to remain distinct rather than to develop into cross-crests as in *Platygonus* are characters in which the Coalinga genus resembles *Prosthennops*. A deciduous fourth premolar (No. 1638) and two specimens assigned to Dp3 (Nos. 1639 and 1640), are similar to corresponding teeth in the type of *Desmathyus validus* Matthew. The permanent teeth are bunodont with a tendency to become multi-cuspid, which distinguishes them from teeth of *Platygonus* in which the cusps are simpler, higher, and fused into cross-crests. Several astragali in the collection are also referred to this form. These specimens are approximately comparable in size to similar elements in the Barstow collections.

Camelidae

The collections from the Merychippus zone contain nearly one hundred teeth referable to the Camelidae. These teeth do not fall into any distinctive groups according to size but appear to be gradational in this character from the smallest to the largest. The dentition is brachydont. In addition to the teeth, however, the collection contains a representation of carpal and tarsal elements. Within this collection there appear to be three types of sizes represented, although specimens intermediate in size between those of individual groups are not lacking.

The characters displayed by the cheek-teeth, as for example size and strength of the external styles, have little value in attempting to make a generic determination. Most of the skeletal material has suffered considerably from abrasion. As a result, the diagnostic characters are for the most part but poorly defined. The astragali offer perhaps the best basis for the grouping of the forms. The larger astragali are comparable in size to those from the Barstow referred by Merriam to Procamelus. The larger premolars in the collection are of a size nearly comparable to that seen in average specimens of species of this genus. The larger cheek-teeth present no characters which would serve to separate them from Procamelus. In view of the relative abundance of specimens representing this genus in most upper Miocene collections it seems reasonable to suppose that these very similar teeth from the Merychippus zone represent Procamelus.

The second form has been recognized largely by the characters of the astragali. Approximately fifteen of these elements in the collection, slightly smaller in size than the material referred to *Procamelus*, are distinguished from the latter by their narrowness. These narrow astragali may represent an alticamelid in the collections. To this type has been assigned teeth which seem to occupy also an intermediate size position. The narrow astragali certainly indicate the presence of a form differing specifically from that known by the material referred to *Procamelus* and the smallest camelid. The group of smaller forms compares in size and in structure of cheek-teeth to some undescribed specimens of *Miolabis californicus* Maxson from the Mint Canyon beds of California. It appears possible that the small teeth and limb elements in the collection from the Merychippus zone may belong to this genus.

Pliauchenia and *Protolabis* differ from the types recorded in the present collection in larger size and hypsodont cheek-teeth.

Blastomeryx (Dyseomeryx) sp.

One upper (No. 1641) and four lower molars (Nos. 1642, 1643, 1644, and 1645), a third or fourth lower premolar (No. 1646), and two deciduous upper premolars (Nos. 1647 and 1648) together with several astragali, are referred to Dyseomeryx Matthew, known from the Sheep Creek beds of western Nebraska. All of the teeth are short-crowned and are thus excluded from the genus Merycodus. The metaselene and protoselene of the milk teeth (Nos. 1647, 1648) remain isolated throughout most of the wear of the tooth. These crescents are connected to the ectoselene in the permanent molar, but are apparently not joined together until a late stage of wear. In M3 (No. 1642) the internal talonid cusp is more or less completely united with the hypoconid as in D. riparius Matthew. There is practically no indication of a basal cusp between the outer crescents of the lower molars. An anterior basal cingulum is but slightly developed on these teeth. The development of the cross-crests in P3 or P4 (No. 1646) is similar to that found in many of the species of Blastomeryx. This specimen is somewhat larger than in the ramus of D. riparius, illustrated by Matthew[36]. The

[36] Matthew, W.D., Bull. Amer. Mus. Nat. Hist., vol. 50, 196-199, 1924.

median transverse crest is expanded internally with an incipient pillar developing from the postero-internal side of the main pillar. The remaining crests have a simple rectilinear appearance. The astragali are small but present no other distinguishing characteristics.

The character of brachydonty excludes this form from *Merycodus*. Compared to teeth in species of *Blastomeryx* the Coalinga specimens are considerably larger. The latter are almost identical in appearance to *Blastomeryx* (*Dyseomeryx*) riparius Matthew from the Sheep Creek beds of western Nebraska. This subgenus was erected by Matthew to include large species otherwise referred to *Blastomeryx*. The enamel walls of the teeth are slightly rugose, but this character is not so well developed as in *Dromomeryx*.

Marine Vertebrates

Presence of marine vertebrates in the Merychippus zone is particularly interesting since these forms ~~may~~ furnish valuable suggestions as to the mode of accumulation of the deposits. No attempt has been made to determine the exact affinities of these forms. The excavations by the California Institute of Technology have not brought to light noteworthy additional material representing Desmostylus, for the collections contain only a few, fragmentary portions of teeth. Recent studies by Kellogg[37] have

[37] Kellogg, R., Proc. Calif. Acad. Sci., 4th ser., vol. 19, 221-222, 1931.

tended to lessen the importance of Desmostylus as a stratigraphic marker, since this genus has a vertical range in Tertiary formations of California from lower to upper Miocene.

Presence of whales in the Merychippus zone may be indicated by specimens tentatively regarded as fragments of ear-bones. A preliminary attempt to determine the Selacian material suggests the presence of at least four genera, namely, Carcharodon, Lamna, Isurus, and Odontaspis. In addition to shark teeth, several flat, plate-like teeth or jaws seem to indicate the presence of a teleostine fish related to the family Gymnodontidae.

THE STRUCTURAL GEOLOGY OF THE SAN JOAQUIN HILLS, ORANGE COUNTY, CALIFORNIA

Thesis

by

Francis D. Bode

In Partial Fulfilment of the Requirements for the Degree of

Doctor of Philosophy

California Institute of Technology

Pasadena, California

1934

THE STRUCTURAL GEOLOGY OF THE SAN JOAQUIN HILLS, ORANGE COUNTY, CALIFORNIA

By

Francis D. Bode

INTRODUCTION:

A study of the geology of the San Joaquin Hills, southeastern Orange County, was undertaken originally, in collaboration with Mr. W. A. Findlay, as a research problem to be completed in fulfilment of the requirements for the degree of Bachelor of Science at the California Institute of Technology. The original investigation served mainly to arouse an interest in the problem for Mr. Findlay and the writer. In May, 1932, Mr. Findlay submitted a report on the general areal geology of the area as a thesis for the degree of Master of Science. It was then decided that mapping should be continued in the area in detail, with Mr. Findlay devoting time to a preparation of a thesis on the sedimentary petrography and the writer continuing his study of the structural geology. This paper presents the results of the structural investigation and is submitted as a minor thesis in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

The writer wishes to express his indebtedness particularly to Mr. Findlay for his whole-hearted cooperation

in the furtherance of the completion of this study. Dr. J. P. Buwalda, under whose supervision this work has been carried on, has contributed valuable advice and criticism. Dr. G. H. Anderson and Mr. W. P. Popenoe have rendered valuable photographic assistance in reproducing the maps and cross-sections.

Unfortunately the U.S.G.S. topographic map of the Santa Ana Quadrangle was found to contain a number of errors. On the other hand, areal photographs were found to be extremely satisfactory and served as an excellent basis for the recording of the details submitted on the map with this report.

In so far as the writer is aware, no report has been published dealing directly with the geology of the San Joaquin Hills. In addition to incidental remarks with reference to the geology of the area, two papers mentioning the region include a reconnaissance map.

A map, showing the northern part of the area, described in this paper, was published by R. P. McLaughlin and C. A. Waring[1] in connection with a report on the petroleum

[1] Calif. State Mining Bureau, Bull.69, 1914

industry of California. This map presents the results of a rapid reconnaissance survey on a base having no topographic expression. The geology is almost entirely incorrect.

A. O. Woodford's[2] paper on the San Onofre Breccia

[2] Univ. Calif. Publ., Bull. Dept. Geol. Sci., vol. 15, 159-280, 1925.

includes an index map showing the distribution of the San Onofre Breccia along the coast between San Pedro and San Diego. In the region north of Laguna, where Woodford has designated rocks of Vaqueros age, the writer has found Temblor fossils. The areal extent of the San Onofre facies of the Temblor is also greater than the map suggests. The distinctions drawn by Woodford between sediments derived from the east and those from a now submerged land mass to the west have been of considerable value in establishing the structural relationships of strata exposed in the San Joaquin Hills.

Topography:

The San Joaquin Hills and their eastward extension, the Niguel Hills, constitute an isolated elevation, bounded on the north and west by the Santa Ana Coastal Plain, on the south by the Pacific Ocean, and on the east by the San Juan Capistrano Valley. The topography is, in general, that of low, gently rounded hills, rising gradually from the surrounding plain. Along the coast this topography is modified.

Here the canyon walls steepen and the almost flat tops of the hills drop abruptly towards the sea. With the exception of the north side, marine-cut terraces are in evidence upon the outer fringes of the hills. The highest elevation is recorded on Signal Peak (1185 feet), lying slightly to the west of the center of the area shown on the map. From Signal Peak a median ridge with average elevation of 900 feet runs in a southeasterly direction to Laguna Canyon, the eastern boundary of the San Joaquin Hills. If streams draining into Laguna Creek are included, the drainage of the San Joaquin Hills may be regarded as radial in pattern.

STRATIGRAPHY:

In a consideration of the stratigraphy of the region only brief descriptions will be given of the sequence and field characteristics of the several mapable units employed in delineating the structure.

With the exception of Pleistocene terrace deposits, all of the sediments exposed in the San Joaquin Hills are assignable to the Miocene. These sediments have been identified on the basis of paleontological and lithological evidence as belonging to the Vaqueros, Temblor and Monterey stages.

Pre-Vaqueros?

The oldest sediments exposed in the area have been termed "Pre-Vaqueros" in that they possess no fossil material and underlie sandstones and conglomerates containing *Turritella inezana*. No evidence of an unconformity has been discovered between this series and the overlying fossiliferous beds. The Pre-Vaqueros sediments are composed of sandstones and conglomerates, these materials occurring in about equal proportions. A peculiar White Bed of arkosic and rather angular sands has been taken as the top of this member. Below this bed lie approximately 100 feet of variegated sandstones and shales with an appearance strikingly similar to that of the Sespe Deposits in the vicinity of the Simi Valley, Ventura County, California. These sediments appear to be in part land-laid on the basis of lithologic evidence. A few red beds occur also above the White Bed. However, their lateral extent is variable and for convenience in mapping, the persistent White Bed is more suitable as a marker horizon. The base of this unit is not exposed.

Vaqueros

Overlying the oldest sediments in the area is a conglomerate member with a thickness of approximately 800 feet. *Turritella inezana* and other typical Vaqueros fossils have been found at several localities in this lithologic unit. The contact of this member with the overlying Vaqueros sandstones is gradational. However, a definite contact above which no large conglomerate lenses are found, can be mapped.

The Vaqueros sandstones, approximately 1100 feet in thickness, comprise a series of medium to fine grained sandstones overlying the conglomerates. Vaqueros fossils have been found at numerous localities throughout the section. Several of the fossiliferous horizons are extremely characteristic and persistent and have proved invaluable in establishing structural relations.

Overlying the sandstones are 200 feet of shales with abundant remains of Turritella inezana. These have been named the Vaqueros Shales. Since shales are rare in the earlier sediments, this horizon affords an excellent mapable unit.

Transitional Beds

What has been arbitrarily called the Vaqueros-Temblor Transitional Zone overlies the Vaqueros Shales. The base of this member has been mapped at the bottom of a bed lying immediately on top of the shales and in which Turritella ocoyana makes its first appearance. This member has an approximate thickness of 725 feet. T. inezana has been found alone or in association with T. ocoyana and T. temblorensis throughout most of this thickness. Numerous beds composed almost entirely of remains of barnacles, a pecten bed, and several echinoid beds make this unit extremely distinctive. A calcareous bed composed almost entirely of remains of barnacles, and above which no barnacles are found, has been mapped as the top of this member. The last appearance of the species T. inezana occurs 50 feet below this bed.

Temblor

The unfossiliferous Lower Reef member of the Temblor, due to its propensity to weather into persistent reefs, is readily mapped. This member has a thickness of 280 feet. Conglomerates are sparsely scattered through this portion of the section. The Lower Reef beds are distinguished from the Upper Reef beds by the absence of fossils and of galucophane and the presence of abundant biotite, whose weathering gives a yellow color to the sediments.

Above the Lower Reef member lies 400 feet of poorly indurated fine grained sandstones, named the "Big Punky" on the basis of this characteristic. The Big Punky is highly fossiliferous, several distinctive mollusc beds occur wherever this member is exposed. A bed near the base containing abundant representatives of the species Pecten bowersi is especially characteristic. A reef bed of coarse sandstones with occasional pebbles affords an excellent marker for the approximate middle portion of this unit.

The Upper Reef beds possess a thickness of 875 feet. In addition to their characteristic ability to weather into reefs of great lateral extent, they possess several characteristics of considerable value in field mapping. The base of this member is in part conglomeratic, which gives it good definition from the underlying Big Punky. Glaucophane makes its first appearance 350 feet above the base, occurring mainly as flakes visible in the hand lens. Glaucophane seems to be here confined to a narrow zone, approximately 20 feet in thickness. Its lateral extent is variable and its value as a mapable unit is not great. Fifty feet higher in the section, a persistent bed containing abundant representatives of the species Turritella temblorensis has served as a datum plane for many of the structural determinations. The top of the Upper Reef member is also conglomeratic and thus affords a ready distinction from the overlying shales of the Glaucophane member.

San Onofre Facies of the Temblor

A 50 foot zone of sandstones and shales, immediately overlying the upper reef member, has been mapped as the base of the San Onofre facies of the Temblor. In this section, glaucophane becomes more and more abundant towards the top, with minerals derived from the west predominating in the upper part. For convenience, the San Onofre facies has been mapped as two units. The upper 600 feet, termed the breccia member, is characterized by the presence of angular schist blocks varying from one to ten feet in diameter. The underlying glaucophane member contains no breccia, and is made up entirely of alternating sandstones and shales. The sandstones occur more frequently toward the top and increase in coarseness in this direction. The contact of the glaucophane member with the breccia is in part gradational and probably does not everywhere represent a contemporaneous level. The San Onofre facies possesses an approximately equal thickness on all sides of the area.

Monterey

The white siliceous shales overlying the San Onofre Breccia have been assigned to the Monterey largely on the basis of their lithologic similarity to rocks in a similar stratigraphic position in adjacent areas. The thickness of these beds was not determined. Woodford reports the finding of white siliceous shales interbedded with the San Onofre. Within the present area mapped, no breccia was found overlying Monterey shales. Furthermore, wherever visible this contact is irregular and is presumably disconformable.

Terrace Deposits

Pleistocene terrace deposits are found at three levels on the south and west sides of the San Joaquin Hills, resting with angular unconformity upon Tertiary sediments. The oldest terrace deposit is found at an elevation of from 500 to 600 feet. The sediments at this level possess a dip of 5 degrees to the northwest, suggesting subsequent tilting of the hills in this direction. The maximum thickness measured is slightly over 50 feet. The oldest terrace deposits are composed of medium-grained arkosic sands and contain no fossil material.

An intermediate terrace is discernible along the western side of the San Joaquin Hills at an elevation of approximately 200 feet. Deposits correlated with this terrace are found at slightly lower levels near the northwestern edge of the hills. Tilting of these deposits seems to be indicated, but not to the degree characteristic of the old deposits. Both the older and the intermediate terraces possess sediments similar in character to those deposited by the Santa Ana River west of Newport Beach. It is possible that they originated in this manner, the area standing at a considerably lower elevation during the period of their accumulation.

The youngest terrace occurs at an elevation of 100 feet along the coast and over the mesa surface north of Newport Beach. Remains of marine Pleistocene invertebrates are abundant. Within the area mapped, the youngest terrace displays no discernible evidence of tilting. However, north of Newport Beach, the contours on the U.S.G.S. map seem to indicate a gentle tilting northward.

Igneous Rocks

A dark-colored lava has intruded the Tertiary section of sediments to form sills and dikes. The composition of the lava has not been determined. Direct evidence as to the time of intrusion has not been found, other than that it is younger than the lower part of the Monterey and older than the Terrace deposits. The chief area of outcrop of these rocks is found in the north-south area, a mile west and parallel to Laguna Canyon. In this region, an interrupted series of dikes extends from near the northeastern edge of the map to the marine terrace deposits north of Laguna.

The lavas are most prominent and have the widest outcrop in the northern region, where they occur in two long continuous and roughly parallel dikes, terminating to the south on or near the Irvine Fault. The dikes exposed south of this fault are less continuous, their pattern on the map displaying a branching appearance. Intrusive lavas are also found to a considerable extent along the Signal Peak fault and the area immediately to the west, where they are associated with numerous minor faults. Most of the sills occur within this area and are, in several instances, displaced by faults. Other intrusions occurring locally as pipes, are found in the southwestern portion of the area. Evidences of slight baking and a pronounced increase in degree of induration of the sediments into which the lavas have been intruded, are usually noticeable along the contacts. Gouge and slickensiding have also been observed along most of the dike contacts.

STRUCTURE:

The structural control within the San Joaquin Hills is dominantly that of vertical faulting. The tilting of beds appears to be due largely to differences of throw on bounding faults. A slight bending of strata on the large blocks seems to indicate the presence of minor horizontally acting forces.

The faults shown on the maps and structure sections have been discovered almost entirely on the basis of stratigraphic evidence. Exposures of fault surfaces and presence of mechanical evidences along faults are rare. The correct determination of the stratigraphic sequence for the units mapped is thus of critical importance. Paleontological evidence as determined for this area by Loel and Corey[3] is

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[3] Univ. Calif. Publ., Bull. Dept. Geol. Sci., vol.22, 31-410, 1932.

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entirely corroborative of the stratigraphic succession presented in the foregoing part of this report. Unless otherwise stated it is believed that the actual existence of faults, their location and relative displacement are all essentially correct.

On the map and structure sections, all unbroken lines represent carefully mapped features, whose existence is certain. Broken lines indicate the presence of contacts and faults, whose existence is likewise certain, but lack of time prohibited careful mapping. Broken lines accompanied with question marks indicate the probable location of a structural feature whose existence is regarded as the most reasonable explanation for an anomalous field relation. On the structure sections the dip on faults, when not shown as vertical, has been actually determined in the field. The majority of the faults shown as vertical are so represented in view of the following considerations: (1) the plan of a fault trace crossing irregular topographic surfaces is almost invariably a straight line; (2) an examination of the fault pattern on the map shows in many cases the impossibility of any appreciable horizontal component of throw; and (3) a representation in the structure sections of most of the minor faults at attitudes other than that close to vertical would result in mechanical relations incompatible with the surface data.

Black lines indicating faults along sides of lava dikes are not intended to suggest age relationships. Their purpose is to indicate the structural lines on which faulting as well as intrusion has taken place, and to distinguish them from dikes not associated with fault lines.

Faults mapped in the San Joaquin Hills may be divided into two classes: (1) major faults possessing, with respect to known stratigraphic points on either side, displacements of not less than 500 feet; (2) minor faults of lesser throw and which may be regarded as related to the major lines of fracture. Most of the faults are oriented in a northwest-southeast direction. A few trend at nearly right angles to this axis. All of the faults appear to be contemporaneous, since neither group displaces the other. Furthermore, minor faults seem to be directly related to forces producing the major displacements.

An individual description for all faults would be both long and tedious. For this reason, the pertinent features of minor faults will be discussed only in connection with the major fault to which they appear to be related.

The accompanying index map shows the areal distribution of major faults. Vertical displacements relative to known points on either side are indicated on the edge of the upthrown block. Regional dips and strikes afford some suggestion of the attitude of sediments.

Irvine Fault

This fault enters the northern edge of the area immediately west of French Hill and runs in a northwest-southeast direction toward Laguna Canyon. Gentle curves in the fault trace seem to indicate a slight dip of the fault plane to the west. The maximum displacement has been found near its northern end where a vertical throw of 4100 feet brings Vaqueros conglomerates on the northeastern block up against beds low in the San Onofre Facies. This displacement diminishes slightly to the southeast. Lava is found intruded along the fault trace at numerous localities. Near its north-central part, several small faults leave the Irvine Fault at high angles. These lines possess displacements varying from 5 to 50 feet and seem to be related to drag effects along the major zone. The lava dikes north and east of the Irvine Fault are also the scene of minor displacements, the block between the two dikes having been dropped nearly 300 feet with reference to bounding blocks. A mile east of the area mapped, a large fault parallels the Irvine Fault and again places San Onofre sediments in juxtaposition to early Vaqueros rocks. The area between this and the Irvine Fault is thus a block, on which the oldest sediments are exposed, standing structurally 4000 feet higher than adjacent blocks. For convenience this block, comprising the northeastern part of the area mapped, will be termed the Highland Block.

Red Bed Faults

These faults are located in the northeastern part of the area. The western member possesses a vertical throw of nearly 1500 feet and the eastern member a similar throw of approximately 1000 feet. The block between these faults has been tilted northward and dropped downward relative to the sediments exposed on the Highland Block. The southern extent of the Red Bed Faults is not well known, since they run through conglomerates, displacements in which are almost impossible to determine.

Laguna Fault

The Laguna Fault branches from the Irvine at a point slightly east of the center of the area and trends southward to a point about two miles north of Laguna, where several cross-faults divert the major displacement in an easterly direction. The position of the upthrown block is similar to that on the Irvine Fault, the eastern side having gone up with reference to the west side. The maximum displacement measured near the center of its trace on the map is 1850 feet. Two similar faults possessing a displacement considerably less, and only one of which has been mapped, parallel the Laguna Fault on the east side of Laguna Canyon. These are likewise branches of the Irvine Fault. The area east of the Laguna Fault, here termed the Laguna Block, duplicates all of the characters of the Highland block with the exception that it has not been carried so high.

San Onofre Fault

The San Onofre Fault enters the western edge of the area with a vertical throw of perhaps 1000 feet and continues southeastward with the displacement rapidly increasing in that direction. At a locality two miles northwest of Abalone Point the maximum vertical throw is over 5000 feet. Farther to the southeast most of the displacement is divided between two branches, the northern and the southern. The northern branch gives a vertical displacement of 2000 feet. This fault joins an east-west cross fault which then connects with the Laguna Fault. The throw on this Southern Cross Fault approximates that on the northern branch of the San Onofre, the sediments to the north standing over 2000 feet structurally above those outcropping in the town of Laguna. The southern branch of the San Onofre is more correctly a continuation of this single line of faulting farther to the northwest. The displacement on this branch is approximately 3000 feet. A mile west of Laguna this line of fracture truncates the Southern Cross Fault and then continues out to sea. Sediments on the block between the San Onofre Faults and the coast exhibit a strike roughly parallel to the fault line. This block stands structurally lower than all other blocks in the San Joaquin Hills. It will be termed the Lowland Block and the area near Laguna south of the Southern Cross Fault the Coastal Block.

Sliver Fault

The Sliver Block, on which upper Vaqueros sediments are exposed, is bounded on the southwest by the San Onofre fault and is separated from adjoining blocks to the northeast by the Sliver Fault. This fault is connected at its northwestern end with the San Onofre by means of a cross-fracture on which a vertical throw of 1000 feet has taken place. Half of this displacement seems to have been transmitted to the Signal Peak Fault, for, southeast of its junction with this fault to a point where the Sliver Fault rejoins the San Onofre, the displacement remains approximately 500 feet. The minor faults within the Sliver Block seem to be related to the bounding faults in that the throw is upward towards the middle of the block from both sides. The trace of the Sliver Fault seems to indicate a slight dip of the fault plane to the northeast. The Sliver Block has been lifted above all the surrounding blocks and, with the exception of the Highland Block, stands structurally higher than all others.

Signal Peak Fault

This line of fracture branches from the Sliver Fault near the center of the area, crosses with a slight westerly trend the peak from which it is named, and then continues until it disappears under the alluvium in the northwestern corner of the map. The Signal Peak Fault possesses a maximum throw of 1200 feet with the uplifted block lying to the west. The V-shaped wedge area lying between this fault and the Sliver Fault has been considerably shattered by a large number of minor faults. This zone of shattering has a width of about one mile and continues along the west side of the Signal Peak Fault. The actual displacement on most of the faults has not been determined. Individual displacements are usually small but the total aggregate measured by projecting the dip of the unfaulted sediments eastward approximates 600 feet. In general all of these faults strike toward the apex of the wedge mentioned above. The region between the Signal Peak Fault and the Sliver Faults will be called the Wedge Block.

Bench Block Faults

The area bounded by the Irvine and Laguna Faults and the Signal Peak and Sliver Faults is named the Bench Block. The term Bench is derived from the fact that this block stands several thousand feet higher than the Lowland Block to the southwest, but is, however, structurally lower than the Highland and Laguna Blocks to the northeast. The Bench Block is structurally lower than the Wedge and Sliver blocks and with the exception of its southern boundary, has all the essential requirements of a graben as well. Neither "Bench" nor "Graben" completes the description, however. As can be seen on the index map, the strata on the Bench Block form a semi-dome truncated on the south by the Sliver Fault. In addition, the entire block seems to have been tilted northward. Fractures within this block may be divided into two groups; those whose trend is parallel to the bounding faults, and those trending at a high angle to this direction. The faults belonging to these two groups intersect, forming on the map a parallelogram pattern. Since the members of one group do not displace those of the other, the attitude of fault planes is thought to be nearly vertical. Displacements are all minor in character, throws rarely exceeding 100 feet. The direction of throw on the parallel faults is downward toward the middle of the block from both bounding sides. The high angle faults possess an upward throw towards the center.

Age of Faulting

With the exception that the faulting cuts early Monterey sediments and does not displace the oldest terrace deposits, no direct evidence indicating the age of these displacements is available within the area mapped. The amount of erosion necessary to expose the old sediments on the Highland Block has been considerable. Assuming an early Pleistocene age for the oldest terrace, the date of faulting can hardly be younger than late Pliocene.

The age relation between the faults and the lava is important. The evidence regarding this relationship is in part contradictory. The dikes appear to have been intruded into zones of weakness which if not faults at the time of intrusion, certainly must have represented incipient lines of displacement. The lava in the vicinity of Abalone point is older than the fault bounding it to the north since the breccia in the fault contains previously cooled pebbles of lava. The displacement of sills in the northwestern corner of the area indicates that here the intrusion antedates at least a part of the faulting. The association of lava with all major faults, the slight baking and induration of sediments along all dikes, irrespective of the presence or absence of faulting, and in general, the uniform confinement of dike lava to the fault traces all seem to indicate that the intrusion followed the faulting. However, the slickensiding and gouge along the sides of dikes could have been produced by post-intrusion faulting as well as by the intrusion itself. It seems to the writer that the most probable relationship places the intrusion as contemporaneous with or later than the early part of the faulting and younger than the last of the movements along fault lines. The age of the lavas thus has a bearing on the solution of the problem. Unfortunately, the answer to this problem must remain indefinite. The fact that most of the lava intruded into Tertiary sediments elsewhere in Southern California is upper Miocene in age, is suggestive. It is possible that the time of faulting and intrusion in the San Joaquin Hills area should be correlated with this regional activity and no evidence opposed to this correlation has been found.

The distribution of post-Monterey sediments in areas adjacent to the San Joaquin Hills furnishes some additional evidence. In the vicinity of Capistrano questionable Pliocene sediments have a considerable thickness and lie unconformably upon the Monterey. Well logs in the Huntington Beach area indicate the presence of over 2000 feet of Pliocene rocks. West of the San Joaquin Hills and in the vicinity of Newport Beach a thin veneer of Pliocene rests, according to Rollin Eckis,[4]

[4] Personal communication

with marked unconformity on the Monterey. Farther inland and to the west the Pliocene thickens in directions away from the San Joaquin Hills. According to W. A. English[5] the contact between

[5] English, W. A., U.S.G.S. Bull., 768, 39, 1926.

Pliocene and Miocene rocks in the Santa Ana Mountains and in the Puente Hills is unconformable. The above relations also suggest a late Miocene or early Pliocene age for the period of diastrophism, deforming the strata now exposed in the San Joaquin Hills.

Cause of Faulting

The absolute direction of movement, whether up or down, of the faults cannot be ascertained within the area studied. The lowest known point structurally is situated southwest of the San Onofre Fault and two miles northwest of Abalone point. Here the top of the Vaqueros has a probable depth of 5800 feet below the surface. Rocks exposed at the surface belong to the Monterey, and with the exception of the Santa Ana Mountains, this formation lies considerably lower in adjacent areas. It seems safe to assume therefore, that the relative movement within the San Joaquin Hills has been upward. Deformation of the strata exposed in the San Joaquin Hills is thought to have taken place in the following manner:

The area was at first domed, the center lying approximately in the middle of the Bench Block. With continuation of forces causing the doming, the elastic limit of the rocks forming the exposed strata was reached and exceeded. Fracturing occurred, the uplift then progressing to varying degrees on different blocks. The Highland block rose highest, with the Laguna and Sliver Blocks following in that order, and the Lowland Block remaining relatively stable. The movement of the wedge block was largely that of tilting from the Signal Peak Fault towards the west. The area in the apex of the wedge being caught between two upward and closely situated faults was lifted 500 feet higher than the rest of the Wedge Block to the northwest. This distribution of movement resulted in the development of a local torque in the vicinity of the apex and of which the minor faults on this block are an expression. The movement of the Bench Block relative to adjoining blocks cannot be exactly determined. Certainly it rose above the Coastal Block around Laguna; whether this central part of the initial dome reached a height above all other blocks and then fell back to its present structural position, or whether following the faulting it merely moved upward more slowly than surrounding blocks, is unknown. It is also possible that this block, remaining relatively stable, was tilted from its south side northward. The writer has not been able to find any evidence definitely disposing of any of these possibilities.

A second method by which this deformation may have been brought about allows the area, after doming occurred, to be dropped downward with the release of the horizontally acting forces. Practically no evidence has been found in opposition to this theory. As indicated by the distribution of the San Onofre Facies on the map and by the description of the large fault to the east, the center of the San Joaquin Hills stands higher than the area surrounding it. To accept this theory one would have to postulate a large area of indefinite extent dropping down on all sides from a relatively small central nucleus. It seems to the writer that the mechanics involved in lifting a small block upward are considerably less complicated and therefore perhaps more reasonable than those involved in allowing a small area to remain high while a very much larger and almost entirely contiguous area is dropped four to five thousand feet.

A third possibility receiving careful consideration in the field regards the faulting as older than the deposition of the San Onofre. Since many determinations of displacement are based on the relations of San Onofre sediments to older Miocene rocks the uplift required would be considerably less than that described in this report. However, none of the older Miocene rocks has contributed to the San Onofre Breccia. Glaucophane appears well down in the Temblor section and unconformities between the top of the San Onofre and the oldest Miocene sediments are entirely lacking. In addition, the dip of glaucophane-bearing sediments indicates that the deformation of these sediments has been as acute as that of any of the older rocks.

Origin of Forces

That the forces immediately responsible for the faulting acted in a vertical direction seems beyond question. The lack of folding unaccompanied by tilting of differentially moving blocks, the absence of horizontal components to the faults, and the type of fault pattern all seem to preclude the possibility of horizontal forces causing the fracturing exhibited in the area. It seems more probable that the origin of the forces producing the faulting was directly below the area. Upwelling of igneous masses, causing faults of large throw and short lateral extent, have been frequently postulated by writers in the study of ore bodies and their origins. That lavas are associated with this type of faulting in the San Joaquin Hills is suggestive. However, the possibility of a domed structure settling after release from horizontal compression should also receive careful consideration. The writer feels that he is not qualified to discuss the more fundamental problems dealing with the origin of tectonic forces.

PRESENT ELEVATION OF THE SAN JOAQUIN HILLS:

The relative earth movements causing the present elevation of the San Joaquin Hills have been determined largely on a physiographic basis. The presence of terrace deposits at an elevation of 600 feet, the flat terrane along the coast at the 900 foot level, and the presence of marine-cut terraces all indicate that at an earlier geological date the elevation of the area was considerably less than at present. The development of the existing drainage pattern seems to be entirely subsequent to the deformation of the hills, in that the structural features have no influence on the direction of flow of the streams.

Several facts are of value in suggesting the nature of the movements causing the present elevation.

1. The Old Terrace deposit dips northwest at an angle of five degrees.

2. Profiles taken from the U. S. G. S. map of the Santa Ana Quadrangle seem to indicate that along the western side of the hills the highest or oldest terrace dips more steeply to the northwest than the intermediate terrace, and that the lowest has no discernible dip at all.

3. The streams flowing northward from the median ridge in the center of the San Joaquin Hills have alluviated their valleys for a distance well up toward the center of the Hills.

4. Streams flowing southward toward the ocean are cutting through the country rock near their mouths and at this point the canyon walls are noticeably steeper than those farther inland.

5. Profiles taken northward across the area seem to indicate that there is a constant slope northward from the 900 foot level on the coast to the level of the Santa Ana Plain north of the San Joaquin Hills.

6. The Mesa country north of Newport Beach shows indisputable evidence of having been tilted northward or inland from a line roughly confluent with the present coast line.

7. The large Inner Bay, north of Balboa, was probably produced on this tilted surface by the antecedent Santa Ana River.

All of the above evidence seems to be in accord with the hypothesis that the San Joaquin Hills have been tilted northward and slightly westward during Quaternary time along a line roughly confluent with the present coast line.

The old terrace deposits afford indisputable evidence of such tilting since their accumulation. The alluviation of the northward flowing streams, while not alone indicative of tilting in that direction, indicate when compared with the alluviation of the southward flowing streams that the uplift has not occurred along the central axis of the hills. In the above case one would expect to find the same conditions obtaining on both sides of the Median Ridge. The steep canyon walls and the active cutting taking place along streams approaching the coast line seem to be clearly indicative of recent uplift.

The surfaces of the ridge summits is everywhere near an elevation of 900 feet along the coast. This upland country has the appearance of an old age surface. As one proceeds northward the characters of this surface are found at lower and lower levels. This circumstance may be interpreted as indicating a tilting of an old age surface.

Profiles of the three terraces taken from the U. S. G. S. map indicates that the 600 foot terrace has the greatest slope and that the youngest or 100 foot terraces hardly possess any slope at all. This is exactly what would be found if tilting has taken place.

That the mesa country has been tilted seems indisputable, as is shown by the contours on the map included with this report. From the map it also seems probable that the Inner Bay was cut by the Santa Ana River as it kept pace in its down-cutting with the tilting of the block.

No evidence within the area itself offers a suggestion as to the fundamental forces causing this tilting. Possibly the Inglewood Fault parallels this strip of the coast at a distance not far from the shore line. If this is the case the tilting may be due to forces operative along this fault.