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LIMESTONE REEFS IN THE LEONARD AND HESS FORMATIONS OF TRANS-PECOS TEXAS.*

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INTRODUCTION.

The Permian section in the Glass Mountains of Trans-Pecos Texas, which comprises some six thousand feet of beds, is one of the standards of reference for the Permian in North America. The simple monoclinal structure of the mountains reveals an unbroken succession of strata of marine facies, extending from the base to the top of the Permian. The section has been divided,[1] in ascending order, into six major units, the Wolfcamp, Hess, Leonard, Word, Capitan, and Bissett formations.

The importance of the section makes desirable a complete elucidation of the relations of the component formations, but these vary greatly in thickness and lithology so that the relations are complicated. Fortunately, however, the structure of the rocks is rather simple, and exposures are sufficient in most places to disclose the stratigraphy, but where there is more alluvial cover and faulting than usual the relations are still very puzzling. The following discussion supplements recently published observations[1] on peculiar relations in the Leonard and Hess formations in the lower part of the section, which have never been satisfactorily explained.

Since the completion of his studies in the Glass Mountains, the writer, as a member of the United States Geological Survey, has had the good fortune to return several times to the mountains, and in 1931 spent several days studying the strata on Leonard Mountain, partly in company with Mr. J. Brookes Knight. There was not time to re-examine all doubtful

* Published by permission of the Director, U. S. Geological Survey.

[1] King, P. B., Geology of the Glass Mountains, Part 1, pp. 57-69, University of Texas Bull. **3038**, 1930.

King, R. E., Geology of the Glass Mountains, Part 2, University of Texas Bull. **3042**, pp. 7-9, 1930.

exposures in the formations, but the observations made are believed sufficient to justify the present contribution. It is now considered probable that the hypothesis of limestone reef barriers accounts in a large part for the anomalous stratigraphic relationships in these rocks. Prof. C. O. Dunbar, who supervised the original work in the area, has made valuable suggestions and criticisms.

THE LEONARD MOUNTAIN REEF MASS.

Leonard Mountain is a bold crag of limestone jutting out from the Glass Mountains escarpment about midway along the range (Fig. 1). From a distance the observer can see that the

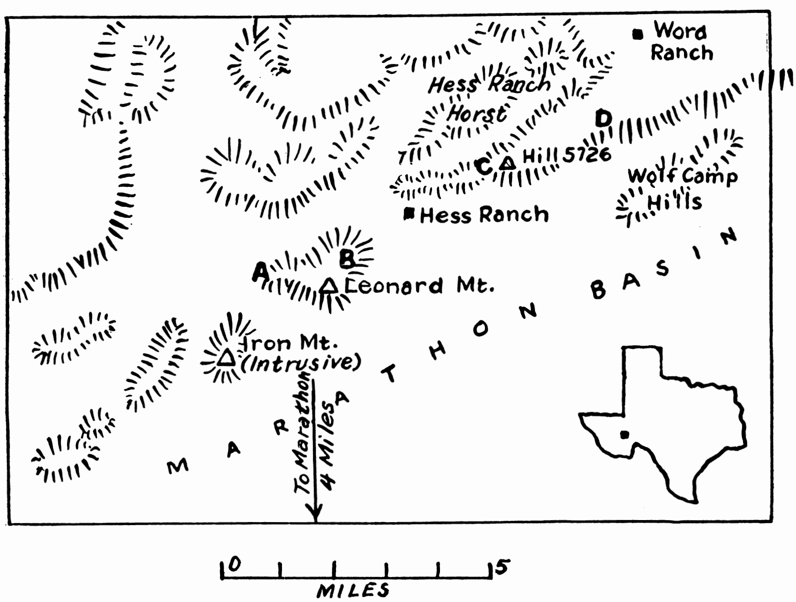

Fig. 1. Index map of the central part of the Glass Mountains north of Marathon to show localities mentioned in text. Letters refer to sections in Fig. 4.

central mass of the mountain, as much as six or seven hundred feet thick, is constructed of great lenticular layers of gray limestone, outcropping in bold cliffs with few descernible bedding planes. The lenses seem to have been piled one on another like a disordered heap of grain bags, so that some have their thickest portions to the east, and others to the west. He can see also that toward the west each cliff-making mem-

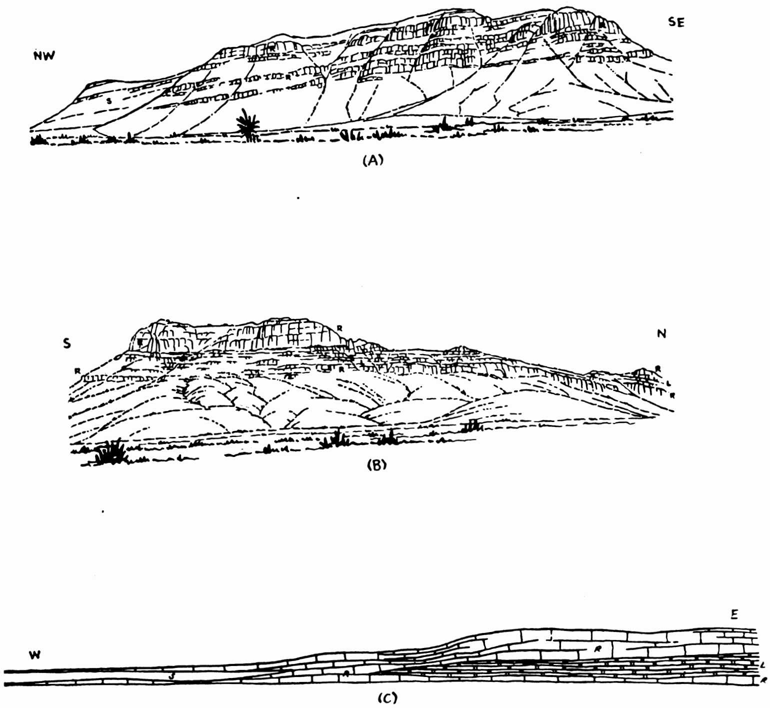

Fig. 2. Views of Leonard Mountain, to show reef structure.

A. Leonard Mountain from the southwest, showing massive reef limestones (*R*) interfingering westward (to left) with slope-making siliceous shales and thin limestones (*S*).

B. Leonard Mountain from the east, showing massive reef limestones (*R*) interfingering eastward (to right) with thin-bedded lagoonal dolomites (*L*). The high point at the left of the view is the same as the high point at the right of the upper figure.

C. Profile, drawn to scale showing stratigraphic relations of lower half of reef beds, as revealed on the face of Leonard Mountain. Symbols as in A and B.

ber merges into thinner ledges, which dip with slight angle away from the massive lenses. If he looks still farther westward, where the mountain terminates in a low but steep escarpment, he sees no cliffs at all, but only smooth slopes, broken here and there by thin ledges that can be traced eastward into cliffs (Fig. 2A).

Even such a distant view, which reveals the peculiar structures and rapid changes just noted, must suggest that the rocks were formed in an unusual manner. A climb up the western end of the mountain confirms impressions gained from the distant view, and shows that the solid succession of limestone so prominent in the middle part of the mountain is wanting there, and that the strata are an alternation of beds of limestone and shale.

The greater thickness of beds at the western end of Leonard Mountain consists of platy brown siliceous shales, with thin layers of dark gray, richly fossiliferous granular limestone. Many of the thin limestone layers are petroliferous, and their fossils are generally silicified and stud the weathered bedding surfaces in great numbers. These rocks are of a facies similar to the Leonard formation as exposed in the western part of the Glass Mountains. The faunal assemblage appears to be of a specialized sort, among which the following types of animals may be noted:

Radiolaria (in the siliceous shales)
Fusulinids (not common)
Crinoids (with small columns)
Ramose and foliaceous bryozoa (such as *Fenestella*)
Small spinose productids
Other brachiopods, mostly thin-shelled
Gastropods and ammonoids (rare)

From collections made in these beds the following species have been identified by C. O. Dunbar: *Cladopora* sp., *Platyceras* sp., *Aulosteges magnicostatus, Aulosteges medlicottianus,* and *Productus ivesi.* The three brachiopods are fairly abundant in both the Leonard and Hess formations.

At intervals of 25 to 50 feet in the shaly beds are ledges as much as 20 feet thick of light gray, granular limestones, full of pebbles and angular blocks of buff dense limestone, and of algal lumps. Much of the limestone is made up of fragments of crinoid columns, many of large size. In places are thinly bedded lenses, and lenses full of abraded fossils. Most of the rock is quite massive, and its beds show a lens-like thickening and thinning. The biota of the ledges is unlike that of the shaly beds between, and indicates specialization to another environment. It includes the following:

Massive calcareous algae
Massive sponges (some as large as one's head)
Colonial corals
Cup corals (sparse)
Crinoids (with massive columns as much as an inch in diameter)
Massive bryozoons
Geyerella, *Scacchinella*, *Prorichthofenia* } (Cemented brachiopods with high cardinal areas)
Leptodus
Large, thick-shelled productids

Eastward these massive limestone ledges are directly traceable into the great hundred foot cliffs of solid limestone at the center of the mountain. The shaly beds between the limestone ledges interfinger and disappear in solid limestone in the space of three or four hundred yards. In these more continuous masses of limestone the imprint of a shell may be seen here and there, but most of the original organic remains are comminuted, recrystallized, or otherwise altered.

Still another change in facies is encountered at the eastern end of the mountain (Fig. 2B). Here, near the middle of the cliff-making beds, is a 150-foot member of thinly and regularly bedded dolomitic, dirty gray limestone, containing scattered tests of fusulinids. Westward, this merges into the massive limestone, but in the hills to the east of Leonard Mountain, rock of this sort attains a thick and prominent development, and the massive gray limestone occurs only in tongues and lenses.

INTERPRETATION OF STRATIGRAPHY ON LEONARD MOUNTAIN.

These observations tend to show that lenticular masses of limestone were built up on the early Permian sea floor, and that the process was continued during the formation of a considerable thickness of strata. The projection of any single stratum along the face of the mountain indicates that the limestone masses rose to a height of about 100 feet above the sea bottom to the west, which received argillaceous sediments (Fig. 2C). The blocks of limestone in the thin edges of the limestone lenses may have been loosened and washed down by waves from the higher standing parts. The rich but specialized biota of the thin edges appears to have been adapted to life in a reef environment, and it is very probable that both the edges and the thicker masses of limestone as well are the result of organic growth. The central part of the mountain appears to be locus of a succession of reefs, whose growing margins interfingered westward into muddy sediments. The thin-bedded dolomitic limestones to the east were deposited on the opposite side of the limestone barrier from the siliceous shales, and may have been laid down in lagoons behind the reefs.

Lower Permian reefs have hitherto not been described in western Texas, though they are well known in the higher Permian (Capitan and related formations). As shown by the descriptions of Lloyd and others[2] in the Guadalupe Mountains, and of the writer[3] in the Glass Mountains, the Capitan reefs are of nearly identical character to that of Leonard Mountain, and exhibit a lateral transition from argillaceous open sea beds to massive reef rock, and on into thin-bedded lagoonal dolomite. Similar structures have also been studied by Knight and the writer in the Lower Permian rocks of the Diablo Plateau farther west, but only a brief abstract has been published.[4] The Leonard Mountain reef is, in some respects, better preserved for study than any of these, since the lateral changes are all exhibited within the space of a single small mountain mass, and since dolomitization has not been as extensive as in other localities.

Not only is the Leonard Mountain reef structure of interest as a new locality and horizon of Permian reefs, but it throws important light on the interpretation of the curious stratigraphic relations in the Leonard and Hess formations in the Glass Mountains. In the previous work in the region the thin-bedded lagoonal dolomite was mapped as the "eastern facies

[2] Lloyd, E. Russell, Capitan limestone and associated formations, Bull. Amer. Assoc. Petrol. Geol., **13**, 645-659, 1929.

Crandall, K. H., Permian stratigraphy of southeastern New Mexico and adjacent parts of western Texas, Bull. Amer. Assoc. Petrol. Geol., **13**, 927-945, 1929.

Blanchard, W. G., Jr., and Morgan J. Davis, Permian stratigraphy and structure of parts of southeastern New Mexico and southwestern Texas, Bull. Amer. Assoc. Petrol. Geol., **13**, 957-997, 1929.

[3] King, P. B., Geology of the Glass Mountains, Part 1, University of Texas Bull. **3038**, pp. 80-84, 1930.

[4] King, P. B., Permian limestone reefs in the Van Horn region of Texas, Bull. Geol. Soc. Amer., Vol. 43, 1932. (Abstract.) In press.

of the Hess formation." The massive reef limestones were called the "western facies." The argillaceous rocks at the western end of Leonard Mountain were mapped with the western facies but it has been shown above that they closely resemble the lithology of the Leonard formation as mapped elsewhere.

STRATIGRAPHY OF THE LEONARD AND HESS FORMATIONS.

The Leonard and Hess formations, as previously distinguished,[5] form a belt of outcrop two or three miles wide for forty miles along the front of the Glass Mountains. Their aggregate thickness is nowhere less than 2000 feet. The dip of the rocks permits the outcrops to run nearly parallel to the strike, thus giving only a two dimensional picture of the stratigraphy.

In the western part of the mountains the Leonard rocks make up most of the combined 2000 feet, and the Hess limestones below are only a few hundred feet thick at most. The Leonard beds are a prevailingly clastic series of interbedded siliceous shale (with radiolaria), clay shale, and sandstone, with thin interbedded layers of limestone and conglomerate. Many of the limestones are of coarsely clastic texture, composed of rolled shells, crinoid columns, and other fossil fragments, in which are imbedded pebbles of limestone and chert. In places in the extreme west part of the mountains there are several limestone members as much as 100 feet thick.

The Hess strata attain their greatest development in the eastern part of the mountains, where more than 2000 feet of limestone underlie a small thickness of Leonard beds. The Hess limestones here belong to the "eastern facies" (of the earlier reports), and consist of dirty gray limestone and dolomite, in thin and regular beds, with few fossils other than fusulinids.

Between the typical areas of Leonard and Hess rocks there is a region of much faulted and disturbed strata, without any complete sections of the lower Permian formations. In this region there are bold but disconnected hills, made up for the most part of massive gray and white limestones, which represent the "western facies" of the Hess. Leonard Mountain, a similar hill in this neighborhood, includes all three facies.

[5] King, P. B., Geology of the Glass Mountains, Part 1, University of Texas Bull. 3038, pp. 57-69, 1930.

There is a well-marked unconformity between the Hess formation and the Wolfcamp formation below. There was sufficient erosion before Hess time to remove considerable thicknesses of Wolfcamp beds in places. At many localities there is also a divergence in dip of five or ten degrees between the two formations. The base of the Hess along the whole mountain front is marked by beds of conglomerate. There is also clear evidence of marked overlaps at the base of the Hess, as on the horst north of the Hess Ranch, where 300 feet of basal Hess strata pass out by overlap in a distance of two miles.

HISTORY OF THE LEONARD-HESS PROBLEM.

The relations between the two formations have been a source of difficulty since the time of the first work in the region. In

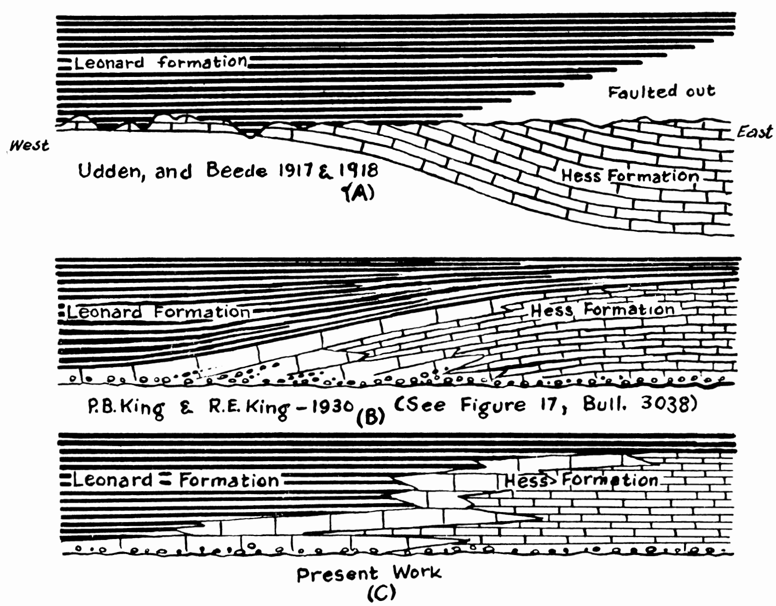

Fig. 3. Three stratigraphic diagrams showing interpretations that have been made on the relation of the Hess and Leonard formations.

1916, when many of the formations in the Marathon region were first described,[6] all the strata discussed here were placed

[6] Udden, J. A., Baker, C. L., and Böse, Emil, Review of the geology of Texas, University of Texas Bull. **44**, pp. 51-52, 1st ed., 1916 (changed in later editions).

in a single formation, the Leonard, which was said to be nearly all calcareous near the Word Ranch (Fig. 1), whereas "toward the west . . . . the shales begin to predominate, while the limestone is reduced in thickness."

In the following year, when more detailed results were published[7] another formation, the Hess, was inserted in the section below the Leonard, to apply particularly to the limestones northeast of the Hess Ranch, which had previously been included in the Leonard formation as first defined. Udden[8] and Beede[9] expressed the opinion that the two were separated by a profound unconformity, so that the Wolfcamp and Hess formations were missing by erosion in the western part of the Glass Mountains except for "small remnants" (Udden, p. 45). Udden saw no great thickness of Leonard beds in the eastern Glass Mountains above the thick succession of Hess limestones, but supposed that a considerable part of the formation was elided by a strike fault (Fig. 3A).[10]

A somewhat different view was expressed by Böse,[11] who was also a member of the first survey party. He described the Leonard in the western part of the mountains as a "mass of shales, alternating with rather thin or medium bedded gray limestones and thinly bedded cherts" (p. 15), and excluded from his definition the limestones and conglomerates beneath it which he called the Hess. The Hess was supposed to rest directly on "a strongly folded member of the Pennsylvanian called the Dimple formation, and on somewhat younger beds, equally much folded" (p. 17). *Prothalassoceras* and some other ammonoids that he collected from the lower conglomerate beds in the western part of the mountains were assigned to the Hess formation, and since these were more primitive than the *Perrinites vidriensis* fauna of the Leonard formation the separation of the Hess was thought to be justified by the fossil evidence.

[7] Udden, J. A., Notes on the Geology of the Glass Mountains, Univ. Tex. Bull. **1753**, 43-46, 1917.

[8] Udden, J. A., op. cit., p. 45.

[9] Beede, J. W., and Bentley, W. P., Geology of Coke County, University of Texas Bull. **1850**, 50, 1918.

Beede, J. W., Notes on the geology of the northern Diablo Plateau in Texas, University of Texas Bull. **1852**, pp. 29-30.

Cheyney, M. G., History of Carboniferous sediments of the Mid-Continent Oil Field, Bull. Amer. Assoc. Petrol. Geol., **13**, 577, 1929; (quotation from conversation).

[10] Udden, J. A., op. cit., p. 32 and p. 46.

[11] Böse, Emil, Ammonoids of the Glass Mountains, University of Texas Bull. **1762**, 15-17, 1917.

Field work by P. B. and R. E. King in 1925-1927 showed that the Wolfcamp formation extended along the entire south base of the mountains, including areas where the oldest beds had previousy been called Hess or younger. *Prothalassoceras* and its associated ammonoids were shown to be upper Wolfcamp and not Hess fossils. The massive limestones of the lower part of Udden's and Beede's western Leonard were shown to be a "western facies" of the typical Hess, with which they merged laterally. No evidence could be found that the thickness of the Leonard in the eastern part of the mountains had been shortened by faulting. The contact between the Leonard and the Hess east of the Word Ranch and west of Iron Mountain was found to have a wide exposure and to show no evidence of unconformity and erosion. It was therefore concluded that the Leonard and Hess were either two distinct but conformable entities, or that they intergraded.

The fact was noted that the units as exposed in their typical areas were each almost mutually exclusive of the other, giving a superficial suggestion of intergradation. However, the distinctive lithologic character of each unit, and the more advanced character of the fossils in the Leonard formation, were thought to be good evidence against such an interpretation. For this reason, it was "concluded that the marked westward thinning of the Hess formation is the result of overlap on uplifted Wolfcamp beds, and is not the result of pre-Leonard erosion, or the intergradation of Hess and Leonard facies."[12] The eastward thinning of the Leonard formation was found to be "accompanied by a convergence of the limestone members, and of the *Perrinites* zones, as though there was a difference in the amount of synchronous deposition in the two areas" (Fig. 3B).[13]

Though no general interpretation of reef origin was made for the beds, Robert E. King[14] pointed out that the fauna of the western facies of the Hess, with its peculiar brachiopods, was suggestive of a specialization to a reef environment. The writer[15] also noted that the interfingering of the massive western facies of the Hess with the thin-bedded eastern facies was of the same sort as the passage from Capitan reef rock into its lagoonal beds.

[12] King, P. B., op. cit., p. 63.
[13] King, P. B., op. cit., p. 66.
[14] King, R. E., Geology of the Glass Mountains, Part 2, Univ. Tex. Bull. 3042, p. 8, 1930.
[15] King, P. B., op. cit., p. 81.

FIELD EVIDENCE FOR INTERGRADATION BETWEEN LEONARD AND HESS FORMATIONS.

As a result of further work in the area, the writer now believes that there is good evidence for a partial lateral intergradation between the Leonard and Hess formations, and even a probability that the whole of one formation is actually the

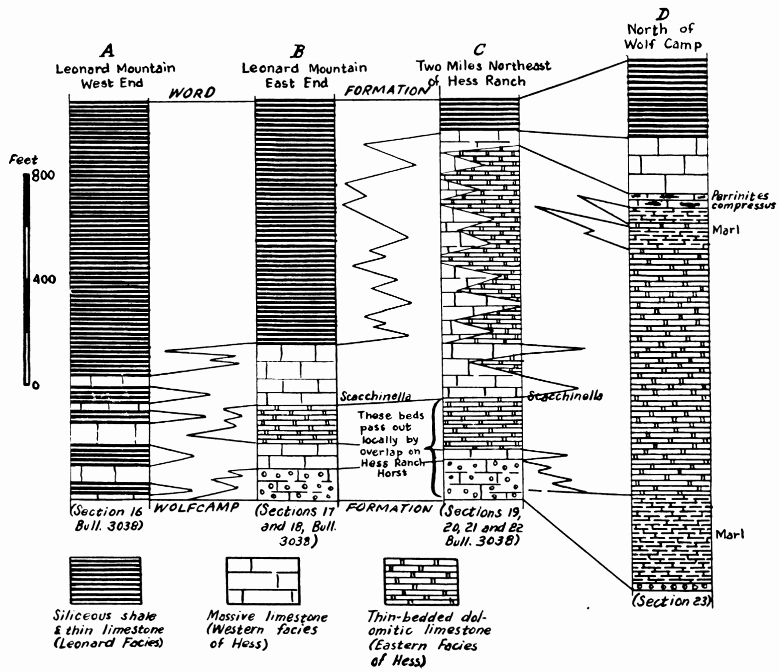

Fig. 4. Four columnar sections in Central Glass Mountains to show probable intergradation of Hess and Leonard formations. Location of sections is given on Fig. 2.

lateral facies of the other. The critical area for the interpretation of the Leonard and Hess formations is between Iron Mountain and Hess Canyon, in the central part of the Glass Mountains, but as noted before, the field relations are difficult to interpret because of faulting and lack of continuous exposures. The relationships seen on Leonard Mountain, in the midst of the critical area, are therefore particularly suggestive, since they show a gradation not only from the thin-bedded eastern facies of the Hess to the western thick-bedded facies, but also a gradation of the thick-bedded Hess into siliceous shales and thin limestones of the Leonard facies. The relations demonstrated for a small part of the section might conceivably apply to the whole thickness.

Evidence for such a transition of the whole series is suggested by the various stratigraphic sections in the critical area. Some of these, generalized from recent and earlier work, are given below, in order from west to east.

(A) At the west end of Leonard Mountain is the following succession:[16]

Word formation at top of section.	
(2) Siliceous shale and thin limestone, with some thicker limestone beds near base	1000′
(1) Interbedded siliceous shales, and massive limestones, the latter in 10-foot to 40-foot members	450′
Wolfcamp formation at base of section.	

(B) In the central and east parts of Leonard Mountain the succession is as follows:[17]

Word formation at top of section.	
(5) Siliceous shales and thin limestones	900′
(4) Massive limestone, with *Scacchinella* at base	200′
(3) Thin-bedded dolomitic limestone, of the aspect of the eastern Hess, which passes into thick-bedded dolomite westward	150′
(2) Massive limestone	100′
(1) Conglomerate	125′
Wolfcamp formation at base of section.	

(C) Northeast of Leonard Mountain the bed rock is mantled by gravel for several miles, and the rocks are seemingly much faulted and intruded by porphyry. In the hills to the northeast, beyond the Hess Ranch, the following general section is exposed.[18]

Top of section faulted and eroded.	
(6) Quartz and chert conglomerate, bituminous limestone, and siliceous shale; exposed at only a few places	100′ plus
(5) Thin-bedded dolomite	600′
(4) Interbedded limestone and dolomite, with sponges and *Scacchinella* at base	400′
(3) Dolomite of eastern facies of Hess	200′
(2) Massive limestone, thickening westward	15′
(1) Conglomerate and marl, with conglomerate replacing the marl to the west	150′
Wolfcamp formation at base of section.	

[16] From recent field work and from section 16, P. B. King, op. cit., p. 139.
[17] From sections 17 and 18, P. B. King, op. cit., pp. 62, 140.
[18] From sections 19, 20, 21, and 22, P. B. King, op. cit., pp. 141-142.

On the Hess Ranch horst, north of the Hess Ranch, the lower beds of this section pass out locally by overlap, so that in places bed 4 lies directly on the Wolfcamp formation.[19] Bed 5 and the upper part of bed 4 are exposed only as far west as hill 5726, a summit two miles northeast of the Hess Ranch, and only the lower beds continue westward to the Hess Ranch. On this hill, both members change westward into massive, reef-like limestone like that on Leonard Mountain, and the hill terminates westward in an abrupt scarp which may be the actual margin of the reef.[20]

(D) Two miles east of hill 5726, northwest of Wolfcamp, and near the head of Hess Canyon, nearly all the strata belong to the thin-bedded eastern facies of the Hess formation, and the following succession is here exposed.[21]

Word formation at top of section.	
(7) Siliceous shale, thin limestone, and beds of chert conglomerate at base	300′
(6) Massive limestone and dolomite, with some beds full of fusulinids, and some with algal nodules	220′
(5) Gray cherty abundantly fossiliferous limestone, in places with small sponge reefs, and in others crowded with brachiopods. *Perrinites compressus* horizon	50′
(4) Marl and thinly bedded dolomitic limestone	175′
(3) Thin-bedded limestone and dolomite, with some marly partings, and numerous fusulinids in places	945′
(2) Thin limestone and varicolored marl, with some sandy beds	348′
(1) Conglomerate	30′
Wolfcamp beds at base of section.	

The sections here described are shown diagrammatically in figure 4, with their suggested correlation. Actual correlations between the two eastern and between the two western sections can be made by walking out the beds, but the two pairs of sections are separated by a belt of alluvium, as above noted, so that correlations between them must depend on other evidence. The two middle sections are dissimilar, for the eastern is composed mostly of limestone, and the western is over half siliceous shale. By earlier correlations the tops of the limestones in each section have been represented as a single contemporaneous layer, with the lowest beds in the east much older than the lowest beds in the west (Fig. 3B). It is now considered probable that the top and base of the Leonard and

[19] Bull. 3038, Fig. 22-upper.
[20] Bull. 3038, Fig. 22-middle.
[21] Section 23, P. B. King, op. cit., pp. 142-143.

Hess formations are approximately contemporaneous in all parts of the area, and that the boundary between the limestones of the Hess and the siliceous shales of the Leonard is a zig-zag line, cutting diagonally across the strike of the rocks (Fig. 3C). Evidence for this is seen in the similarity of the total thickness of all four sections, and in the close resemblance of lithologic sequence and position of the *Scacchinella* zones in the lower part of the two middle sections.

FAUNAL EVIDENCE FOR INTERGRADATION OF THE HESS AND LEONARD FORMATIONS.

Robert E. King[22] has pointed out numerous similarities between the faunas of the Leonard and Hess formations and showed that "a large proportion of the characteristic Leonard brachiopods make their first appearance in the upper Hess." He has, however, noted differences between the two faunas, and cites thirteen Hess brachiopod species that have not been found in the Leonard.

Because of the possibility of intergradation between the Hess and Leonard formations, the fossils in the collections at Peabody Museum were re-examined by Prof. C. O. Dunbar and the writer. The characteristic Hess brachiopods are shown by this study to fall into several groups.

Three species, *Squamularia guadalupensis, Composita mexicana,* and *Composita subtilita* are long ranging fossils, and extend through both Hess and Leonard, the first ranging up into the Capitan.

Six species are more common in the Leonard than in the Hess: *Meekella attenuata, Productus ivesi, Aulosteges medlicottianus, Prorichthofenia likharewi, Camarophoria venusta,* and *Leptodus nobilis americanus.* Five species occur somewhat rarely in the Leonard: *Streptorhynchus lamellatus, Striatifera pinnaformis, Marginifera whitei, Pugnoides elegans,* and *Pugnoides texanus.*

One species, *Enteletes dumblei,* is common in the limestones of the Hess, is absent from the shaly strata of the Leonard, and is again seen in identical form in the Word formation. It is also a common and characteristic shell in the lower Permian limestones of the Diablo Plateau farther west. No species of *Enteletes* is common in the intervening Leonard, and the Leonard form, *Enteletes leonardensis,* is represented by

[22] King, R. E., op. cit., p. 8.

scanty material. The genus *Rhipidomella* has a similar distribution. *R. hessensis,* a fine well-characterized shell, is confined to the Hess, and is found in its limestones west of Iron Mountain, north of the Hess Ranch, and in the *Perrinites compressus* horizon near the Word Ranch. As with *Enteletes, Rhipidomella* is poorly represented in the Leonard, and *R. leonardensis* is known only from scanty material. Possibly these two genera find their best development in limestone deposits.

Two species, *Geyerella americana* and *Scacchinella gigantea,* though confined to the Hess, are obviously adapted to reef environment as shown by R. E. King,[23] and indicate facies rather than horizon. Another species, *Meekella hessensis,* is perhaps of similar nature, as it is known only from the reef rock.

In addition to these, other species of varying abundance are confined to the Hess. *Spiriferina angulata, Hustedia hessensis, Streptorhynchus undulatum,* and *Prorichthofenia teguliferoides* have been found only in the massive Hess limestones of the western Glass Mountains, where these underlie a thick succession of Leonard beds. *Enteletes plummeri,* which also extends up into the overlying Leonard, is associated with them. Possibly all five fossils represent a lower Permian fauna, older and more primitive than any in the overlying Leonard or the upper Hess of the eastern Glass Mountains. Such a supposition finds support in the character of *P. teguliferoides,* which is intermediate in development between the species of the genus *Teguliferina* (found in the Wolfcamp and upper Pennsylvanian) and the more advanced forms such as *P. likharewi* and *P. uddeni* which characterize the higher strata. The species occupies a similar position low in the Permian section, in Sierra Diablo. The specimen reported from the *Perrinites compressus* horizon of the upper Hess in the eastern Glass Mountains is poorly preserved, and *P. likharewi* is abundant in the layer.

The *Perrinites compressus* horizon, at the top of a thick succession of Hess limestones in the eastern Glass Mountains, mostly contains brachiopods like those in the Leonard, but four species, *Chonetes hessensis, Productus hessensis, Pugnoides transversus,* and *Spirifer huecoensis,* are apparently confined to this horizon. The *Productus* and *Spirifer* are abundant in the lower Permian limestones of the Diablo

[23] King, R. E., op. cit., p. 8.

Plateau, presumably of the same facies. Further resemblances in facies in the two regions are suggested by the great abundance, in layers a short distance above the *Perrinites compressus* horizon, of *Composita mexicana* and *Pugnoides texanus*, which are also found in great abundance about 1200 feet above the base of the Permian in the Hueco Mountains, and elsewhere in the Diablo Plateau. The two fossils are long ranging, but their constant association and abundance in the two areas is unusual. *Perrinites compressus*, the ammonoid from which this horizon takes its name, is known from only two specimens collected by Böse. Mr. F. B. Plummer and the writer have recently examined the original material and found it to be poorly preserved, and apparently much more like *P. vidriensis* of the Leonard than Böse supposed.

These observations show that the Hess fauna as such is not well characterized. Many of its typical forms extend up into the Leonard. Most of its unique fossils are confined to a few localities or horizons, and some, particularly in the massive reef limestones, are definitely facies fossils. The more primitive types, such as *Prorichthofenia teguliferoides*, are known only from the lower part of the Leonard and Hess formations. The evidence available, though not entirely conclusive, is therefore not opposed to the supposition of a lateral equivalency between the two formations.

CONDITIONS OF DEPOSITION IN LEONARD AND HESS TIME.

If the interpretation proposed in this paper is correct, there is a remarkable lateral transition in a section 2000 feet thick, in the lower part of the Glass Mountains Permian, from clastic beds into a continuous succession of limestone, within the space of a few miles. These lateral changes, which also appear to have influenced the faunas, are thought to have been brought about by the growth of an intervening reef barrier, such as is postulated for the rocks exposed on Leonard Mountain. It is suggested that this barrier was raised by the growth of algae, sponges, bryozoa, corals, and crinoids, adapted to a specialized environment and apparently rose to a height of 50 or 100 feet above the level of the sea bottom on the west in which siliceous shales, sandstones, fine conglomerates, and thin limestones accumulated.[24] To the east, at approximately the

[24] The occurrence of radiolaria in the siliceous shales of this facies is probably not indicative of deep water; as pointed out in Bull. 3038, p. 69.

same level as the top of the reef, thin-bedded limestones accumulated in which fusulinids were very abundant. The more cosmopolitan character of the Leonard fauna, which lived on the western side of the barrier, the deeper water on that side, and the conglomerates in its western edges which must have been washed down by the force of the waves, suggest that the barrier faced westward toward the open sea, and that the thin-bedded limestones on the opposite side were lagoonal deposits. In many respects the supposed reefs of the Hess resemble the "bioherms" defined and described by Cumings, Shrock, and Stockdale[25] in Indiana.

Observations in the vicinity of Leonard Mountains suggest that the reef front extends in a north-northeasterly direction until it pitches beneath the younger deposits of the Word formation. The thick limestone lenses in the lower part of the Leonard formation southwest of Leonard Mountain are possibly the present limits of a southwestern extension of the postulated Hess reef, now carried away by erosion.

The Marathon Mountains, built by folding and overthrusting in late Pennsylvanian time, and with a northeasterly trend, lay to the south of the area, and the Hess reef may in part have been constructed as a barrier along the shores of these mountains. That this was not entirely true is indicated by the predominantly local source of the pebbles and finer clastics in the Leonard formation, which are largely angular chert fragments identical with the Devonian (?) and Ordovician cherts in the Marathon folded belt to the south.

Though some conflicting features of the stratigraphy of the formations cannot yet be explained by the suggested interpretation, they may perhaps be solved by a wider knowledge of the paleogeography of the time, based on a study of well records and of surface exposures in related areas, which will delimit the outlines of the various far-flung Permian reefs. Further collection of the fossils must also be made before their stratigraphic range and relation to facies can be certainly determined.

CONCLUSION.

The Hess formation, though of quite different lithology from the Leonard formation, is thought to be in the main its

[25] Cumings, E. R., and Shrock, R. R., Niagaran coral reefs of Indiana and adjacent States, Bull. Geol. Soc. America, **39**, 599, 1928.
Stockdale, P. B., Bioherms in the Borden group of Indiana, Bull. Geol. Soc. America, **42**, 711, 1931.

lateral equivalent, and to merge into it through a limestone barrier reef facies. The Hess formation contains a poorly characterized fauna, mostly of fossils found also in the Leonard formation, but in part specialized to an unusual environment. It is herewith suggested that the name Leonard formation be continued in use for the siliceous shales and thin limestones in the western part of the mountains, and the name Hess formation for the massive reef limestones and thin-bedded lagoonal dolomites which replace them toward the east. When the Glass Mountains strata are correlated with other regions, however, it should be remembered that the Hess and Leonard formations both extend across approximately the same span of early Permian time.

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