MAGNETIC SURVEY OF THE JEFFERSON AREA PARK COUNTY, COLORADO

By

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Abstract

The Jefferson anticline, plunging to the south and extending approximately in a north south direction, is found in the Jefferson area, Park County, Colorado. The west limb of the anticline is cut by the Baker Lake porphyry in Sec. 25, T. 7 S., R. 76 W., while the east limb is overlapped by the upper plate of the Elkhorn thrust fault. The southward extension of the anticline is far beyond the thesis area.

As a result of this work, the previous mapping of the area, published by Washburne (1908), Stark, et al. (1949), and Singewald (1950) has been modified in two respects. The first modification is concerned with the east limb of the Michigan syncline, which was found to parallel the east side of Michigan Hill in Secs. 31, 6, 7, and 18, T. 8 S., R. 75 W. It was found that the limb does not swing westward around the north end of Michigan Hill to combine with the west limb of the syncline, but rather, it parallels the east side of Michigan Hill. The second modification is concerned with the Elkhorn thrust fault which was found to swing northwestward in

Sec. 21, T. 8 S., R. 75 W. to reach Sec. 17, T. 8 S., R. 75 W., where it strikes northward to Sec. 32, T. 8 S., R. 75 W. From there, the fault is believed to change direction again to the northwest to reach the Baker Lake porphyry in Sec. 30, T. 7 S., R. 75 W.

The area was surveyed by magnetic and geological methods. A Varian magnetometer, a nuclear precession device, was used for the magnetic survey. Aerial photographs and topographic maps were used for the geological survey.

A series of magnetic beds were discovered and traced in the area by the magnetic method. The character of the magnetic anomalies, when considered with the data obtained from the geological survey and the shot hole drill logs for seismic work, indicated that the magnetic beds form the basal part of the Denver Formation in the thesis area.

The interpretation that the Jefferson anticline exists was based on the discovery of the basal part of the Denver Formation and was verified by findings from the geological survey and the shot hole drills.

CONTENTS

ILLUSTRATIONS

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INTRODUCTION

The thesis area, Fig. (1), is located in the north end of South Park, Park County, Colorado. The town of Jefferson lies very close to the center of the area. The area extends slightly less than two and one-half miles south of Jefferson to an east-west line running through Portis Ranch (now owned by Mr. D. C. Roth). It extends roughly the same distance to the east and to the north, reaching the crystalline rocks composing the foothills of the Kenosha and Park Ranges, respectively. It is bounded on the west by Michigan Hill. The area can be reached from Denver by U. S. Highway 285.

With the exception of a few small hills, the area is quite flat and is almost barren of trees. The general slope, as indicated by the drainage system, is toward the southeast. Guernsey and Jefferson Creeks, which originate in the mountains to the north, furnish the water for irrigating the hay meadows which cover most of the area. The average elevation above sea level varies from slightly over 9,300 ft. in the south to 9,800 ft. in the north, a distance of

5 miles. The few hills mentioned above rise from 50 to 150 ft. above the surrounding meadows. Michigan Hill, on the west side of the area, reaches an elevation of 10,120 ft. above sea level. The peaks in the Kenosha Mountains to the east and those of the Park Range to the north are in the neighborhood of 12,500 ft. above sea level.

Washburne (1908), Stark, et al. (1949) and Singewald (1950) mapped the area geologically as a part of the work they carried out in South Park. The maps published by Washburne (1908) and Stark, et al. (1949) show the Denver and underlying formations north of U. S. Highway 285, in Sec. 23, T. 8 S., R. 76 W. to continue northward to Sec. 35, T. 7 S., R. 76 W., where the formations swing eastward around the north end of Michigan Hill, and then to turn southeastward to form the east limb of the Michigan syncline. Sabet (1963), however, using a Varian magnetometer, was able to trace the gravel-covered magnetic beds of the Lower Denver Formation from U. S. Highway 285 north to Sec. 35, T. 7 S., R. 76 W. From there, he showed the magnetic beds to swing northwestward to Sec. 27, T. 7 S., R. 76 W. Sabet's results suggested that the magnetic method might be used to resolve the disagreement between Washburne and Stark, et al. in their mapping of the area east of Michigan Hill. Washburne's map shows the Lower Denver Formation to outcrop along the hill in Sec. 32, T. 7 S., R. 75 W.; he extends this outcrop southeastward to Sec. 33, T. 8 S., R. 75 W., where he shows it to be overridden by the upper plate of the Elkhorn thrust fault. The map of Stark, et al. shows the Lower

Denver Formation to pass in a southeastward direction north of the hill in Sec. 32, T. 7 S., R. 75 W., where it is overlapped by the Precambrian granite. Both maps, however, do show the Lower Denver Formation to outcrop in the area east of Michigan Hill.

Using a Schmidt vertical field balance, students in the geophysics option during the summer field course in 1962 found a magnetic anomaly along State Highway 77 southeast of the town of Jefferson. This anomaly was found approximately on a line joining the hill just west of the Wahl Ranch headquarters in the southeast corner of Sec. 32, T. 7 S., R. 75 W. and the small hill in Sec. 8, T. 8 S., R. 75 W. The two hills appear to be connected by an indistinct ridge of very low relief, and this, coupled with the magnetic anomaly noticed on State Highway 77, suggested that the two hills and the connecting ridge might be the surface expression of the magnetic beds of the Lower Denver Formation. During the spring vacation of 1963, the author, using a Varian magnetometer, traced the magnetic anomaly between the two hills. This was accomplished by running east-west profiles in this area. Another anomaly was encountered when one of the profiles was extended westward. Further westward extension of the other profiles showed this second anomaly to continue southward and to merge with the southward extension of the anomaly first observed on State Highway 77, southeast of the town of Jefferson. At this stage it was decided to enlarge the scope of the project to include more detailed mapping of both east and west

branches of the magnetic anomaly and to study the geology of the area and its immediate surroundings so as to interpret, as far as possible, the anomaly in terms of geologic structure.

Work on the magnetic survey began during the spring vacation in April 1963, and continued during the weekends until the end of the spring semester. Eight weeks were spent in the field the following summer, the first week in June and the period between July 24th and September 9th. The magnetic survey was completed during the six weeks of the geophysics summer field session in June and July, 1964. During this period several profiles were surveyed where additional control was needed. The geologic field work was done during the weekends of the fall semester of 1963.

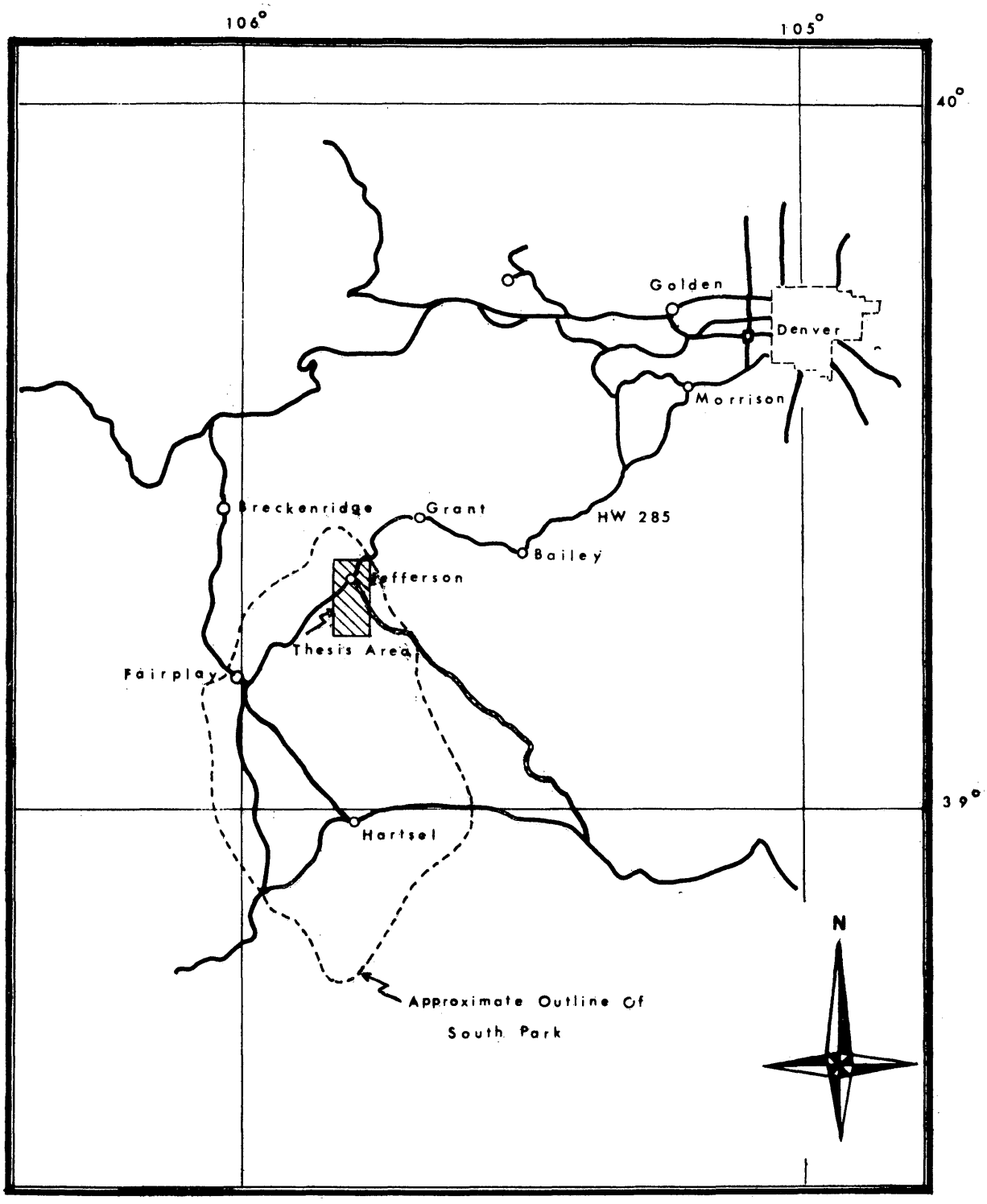

Figure 1

Location Map

STRATIGRAPHY

The sedimentary section in the Jefferson area, South Park, ranges from the Morrison Formation (Jurassic) to the Denver Formation (Paleocene?). There is no evidence suggesting the presence of sediments older than Jurassic. A modification of the generalized stratigraphic section of South Park, by L. R. LeRoy (1960) is shown in Plate (5). The thesis area, as shown in Figure (1), is included in areas mapped by Washburne (1908), Stark, et al. (1949), and Singewald (1950). Their maps show the following formations represented in the area.

Morrison Formation: (Jurassic)

Shales form the most important constituent of the Morrison Formation. Besides shales, there are limestones, siltstones, sandy shales, and sandstones. The lower half consists of slightly calcareous shales which become sandy in the upper beds.

The thickness varies from one locality to another. This may be due either to variation in deposition or to pre-Dakota erosion.

A thickness of 350 ft. is considered to be reasonable in the area, as indicated by Johnson (1935).

The Morrison Formation is considered to overlap the Precambrian in this area. Johnson (1935, p. 1345) pointed out that this is true along the east rim of South Park.

Dakota Formation: (Lower Cretaceous)

The Dakota Formation is formed essentially of sandstone which is highly cemented to an orthoquartzite. A few layers of shale and sandy shale occur near the middle of the portion. The formation characteristically forms prominent hogbacks.

The thickness varies from 250 to 310 ft.

Benton Formation: (Upper Cretaceous)

The Benton Formation is formed mainly of black papery shales and fine-grained limestones. Beds of bentonite occur at intervals throughout the formation.

The thickness of the Benton ranges between 410 and 460 ft. The formation rests conformably over the Dakota (Johnson, 1935, p. 1350).

Niobrara Formation: (Upper Cretaceous)

The Niobrara Formation is formed of two parts: a lower part which consists mainly of limestone with scattered fossils, and an upper part which consists of calcareous shale.

The average thickness of the formation is 540 ft. The

lower part is approximately 40 to 60 ft. thick and the upper part is approximately 500 ft. thick. Johnson (Stark, et al., 1949, p. 53) suggested an unconformity between the Benton and the Niobrara Formations, because of the abrupt change in lithology and the presence of pebbles, phosphate nodules and abundant fish teeth at the contact.

Pierre Formation: (Upper Cretaceous)

The Pierre Formation is formed essentially of black shale with some sandy and calcareous beds.

The thickness of the formation varies between 2200 and 2750 ft. It seems to rest conformably on the Niobrara Formation and to grade upward into the Fox Hills Formation without any stratigraphic break.

Fox Hills Formation: (Upper Cretaceous)

The Fox Hills Formation is formed of fine to medium-grained sandstone, not as well cemented as is the Dakota Formation. The color ranges between yellow and orange brown.

The formation has a maximum thickness of 350 ft. Some variation in thickness is caused by post-Cretaceous and pre-Denver erosion.

Laramie Formation: (Upper Cretaceous)

The Laramie Formation is formed of sandstone, shale,

volcanic tuffs and coal. The coal occurs in three seams. Washburne (1908).

The formation attains a maximum thickness of 375 ft. but in some places it is missing, owing to post-Cretaceous and pre-Denver erosion.

Denver Formation: (Paleocene?)

The Denver Formation is formed of conglomerate, gravel, and sandstone, with interbedded volcanic tuffs, breccias, and agglomerates. In northern South Park, the lower part of the Denver Formation consists of arkosic sandstone and volcanic materials which possess a comparatively high magnetic susceptibility. Granite boulders as large as 4 to 5 ft. in diameter have been observed in the upper part of the Denver Formation.

The greatest thickness of the Denver Formation is 8,000 ft. The lower part is approximately 1,200 to 1,400 ft. thick.

GEOLOGICAL SURVEY

To supplement the magnetic data obtained and to aid in its interpretation, a geological survey was conducted in the area. The survey was facilitated by the use of topographic maps and aerial photographs. The photogeology of the area was studied, using aerial photographs of 1 to 57,600 scale. For the field work, an aerial photograph with a scale of 1 to 16,000 was used. With the aid of a Brunton compass, outcrops were located by the intersection method. U.S.G.S. topographic maps of the Jefferson and Milligan Lakes Quadrangles were used as base maps for the geological map (Plate 3) of the area.

The outcrops found in the area are few, scattered, and lack continuity. This is due to the heavy cover of alluvium and to the outwash from the surrounding mountains to the north and east. For this reason, section measurements were not possible, and the author had to depend entirely on thickness measurements done in the surrounding areas by Johnson (1935), Stark, et al. (1949), and on the

generalized section of South Park by L. W. LeRoy (1960).

RESULTS

The Morrison Formation was found in Secs. 3 and 10, T. 8 S., R. 75 W. east of the Dakota hogback. It is formed of yellowish brown, fine-grained sandstone which is loosely cemented. The outcrop in Sec. 3, T. 8 S., R. 75 W. parallels the contact with the Precambrian, with a strike N 35° E and a dip 25° in a N 55° W direction.

In Sec. 3, T. 8 S., R. 75 W., a Dakota hogback extends southwestward paralleling the Precambrian outcrops to the east. This hogback continues to Sec. 16, T. 8 S., R. 75 W. The outcrop is mainly well-cemented, gray sandstone which is partially transformed into orthoquartzite. It is fragmented and broken into large blocks which obtain sizes greater than 3 feet in diameter. The formation strikes N 35° E and dips 25° in a N 55° W direction.

A fossiliferous limestone was found to outcrop along the road in Sec. 24, T. 7 S., R. 75 W. It forms part of the Niobrara Formation in the area. The outcrop, as can be seen on the aerial photographs, swings from N 35° E to N 30° W. In Sec. 9, T. 8 S., R. 75 W. the same fossiliferous limestone outcrops and changes strike from north-south to N 20° E. The dip varies from 20° to 40° in a N 70° W direction.

Volcanic tuff beds were found to outcrop on top of the hill in Sec. 8, T. 8 S., R. 75 W. The beds strike N 10° E, coinciding

with the strike of the hill, and dip 67° to the west. The same formation outcrops in a cut along U. S. Highway 285 to the north of the town of Jefferson. The formation strikes N 10° E and dips 80° W. Along the eastern foothills of Michigan Hill, two outcrops of arkosic sandstone and volcanic tuff were found in Sec. 7, T. 8 S., R. 75 W. The first outcrop is to the east of Slash 6 Ranch headquarters (now South Park Cattle Co. headquarters) on the crest of a ridge. The outcrop dips 70° to the west and strikes north-south. The second outcrop is found in a cut on U. S. Highway 285, striking N 14° W and dipping 50° in a S 86° W direction. The same formation in the two previously mentioned outcrops was found along the road in Sec. 18, T. 8 S., R. 75 W. to strike N 30° W and to dip 45° in a S 45° W direction. The strike of the three outcrops shows an eastward swing with a flattening of the dip. Samples collected from the outcrop of the basal part of the Denver Formation along the Tarryall water gap in Sec. 26, T. 8 S., R. 76 W. were compared with samples from the previously mentioned outcrops. These samples are alike in grain size, color, amount of dark minerals; and, hence, they are considered to belong to the same map-unit.

In drilling shotholes for seismic shooting along the road in Secs. 18 and 17, T. 8 S., R. 75 W., cuttings of coal were washed up from a bed underlying the volcanic tuffs and the arkosic sandstone. This showed that these beds are in the same relation to each other as the basal part of the Denver and the Laramie Formations, north of the

Tarryall water gap and the King Cole Mine. Consequently, these beds are considered to form the basal part of the Denver Formation and to be the source for the magnetic anomaly found in the magnetic survey.

The upper Denver Formation was found to outcrop in many places along U. S. Highway 285 south of the outcrop of the basal part of the Denver Formation in Sec. 7, T. 8 S., R. 75 W. and also along Packer Road. In Sec. 21, T. 8 S., R. 75 W., along a cut in the hill to the north of Portis Ranch headquarters, the Upper Denver Formation outcrops, striking N 12° E and dipping 40° in a S 78° E direction. This outcrop is very important since the Dakota Formation was found to outcrop at a distance 2500 ft. to the northeast with a different strike and dip. Such relationships do not allow sufficient space for the stratigraphic section as indicated by Johnson (1935) and Stark, et al. (1949); hence, a fault is indicated in the area intervening between the two outcrops.

GEOLOGICAL STRUCTURES AS DESCRIBED IN PREVIOUS WORK

The thesis area is included in areas mapped by Washburne (1908), Stark, et al. (1949) and Singewald (1950). Their maps indicate two major geologic structures, namely the Michigan syncline and the Elkhorn thrust fault.

Michigan Syncline:

Washburne (1908), during his studies of the coal fields in South Park, indicated on his map an unnamed syncline with its axis trending N 10° W and extending along the east side of the Park for about 20 miles. To the north, the west limb of the syncline runs west of Michigan Hill, swings eastward around the north end of Michigan Hill, and combines with the east limb of the syncline east of Michigan Hill. The east limb of the syncline is shown to run parallel to the hill in Sec. 32, T. 7 S., R. 75 W. He extended the east limb southeastward to Sec. 33, T. 8 S., R. 75 W., where he showed it to be overridden by the upper plate of the Elkhorn thrust fault. Naming the syncline the Michigan syncline, Stark, et al.

(1949) mapped the formations on both sides of the syncline with the axis of the syncline trending N 22° W. Their mapping of the east limb of the syncline is not in agreement with Washburne's mapping. They show the east limb to pass in a southeastward direction north of the hill in Sec. 32, T. 8 S., R. 75 W. and to extend to Sec. 10, T. 8 S., R. 75 W., where it is overlapped by the Precambrian. Both maps, however, show the Lower Denver Formation to the east of Michigan Hill, and indicate the west limb of the syncline to swing around the north end of Michigan Hill to combine with the east limb. Sabet (1963), however, using a Varian magnetometer, was able to trace the gravel-covered magnetic beds of the Lower Denver Formation of the west limb of Michigan syncline, from U. S. Highway 285, north to Sec. 35, T. 7 S., R. 76 W. From there, he showed that the basal part of the Denver Formation, a relatively magnetic bed, swings northwestward to Sec. 27, T. 7 S., R. 76 W.

Elkhorn Thrust Fault:

As stated by Stark, et al. (1949), Peak was the first to recognize the Elkhorn thrust fault in 1874. It was studied and mapped by Washburne (1908). A more detailed study was made by Stark, et al. (1949). Their map of the fault shows the Precambrian of the Front Range thrust over the Cretaceous and Tertiary beds of the east side of the Park. A general practice in the previous mapping was to place the fault trace at the contact between the Precambrian and the

Cretaceous or Tertiary beds. In the thesis area this contact is not clear and the fault trace, as mapped previously, is in doubt. Stark, et al. (1949) show the fault, on the basis of their stratigraphic studies, to run northward from Sec. 35, T. 7 S., R. 75 W. up to the valley of Snyder Creek in Sec. 26, T. 7 S., R. 75 W. There is no clear-cut field evidence for such an interpretation. Lovering, in a personal communication with Stark, et al. (1949, p. 121), suggested that the fault passes approximately through Baker Lake, Sec. 29, T. 7 S., R. 75 W., and then to Georgia Gulch, or even further west through Jefferson Hill and then to Georgia Gulch.

MAGNETIC SURVEY

The magnetic survey was carried out by measuring the total intensity of the Earth's magnetic field, using a Varian magnetometer (M49A, Varian Associates), a nuclear precession instrument. No corrections were made for latitude or diurnal variation, since the size of the anomalies being mapped range between 400 and 1000 gammas. Field measurements were made every 10 ft., a spacing found to give a fairly precise picture of the field in the region of the sharply oscillating anomalies. Twenty-six profiles, varying in length, were surveyed, totaling about 44 miles, with about 23,500 stations. The profiles were spaced 700 to 1000 ft. apart, starting from known points on the U.S.G.S. Jefferson and Milligan Lakes quadrangle topographic maps.

Magnetometer stations were located by using a one-thousand-foot cable, rolled on a reel, and marked at spacings of 10 ft. A brunton compass was used to orient the profiles in an east-west direction. After laying out the cable, the magnetometer readings at the marks (stations) on the cable were recorded in the field notebook with

their corresponding station numbers. The process was repeated by pulling the cable forward to the next 1000 ft., and so on to the end of the profile.

The data were plotted first on centimeter paper with the profiles arranged in their relative positions, as shown on Plate (1). Later, by means of a pantograph, these profiles were superimposed on the topographic map of the area, as shown in Plate (4).

RESULTS:

A series of highly magnetic beds was found in the Jefferson area. These beds, consisting of volcanic tuff and arkosic sandstone, form the basal part of the Denver Formation. They are known to rest unconformably over the Laramie and Fox Hills Formations, which are formed of non-magnetic sandstone, and to underlie the Upper Denver Formation, which is formed of very weak magnetic beds of coarse sands, gravels, and clays.

East of Michigan Hill two magnetic beds were discovered which give anomalies in the range of 400 to 1000 gammas wherever they outcrop or come near the surface. Susceptibility measurements on samples from the outcrop on top of the hill in Sec. 8, T. 8 S., R. 75 W., where the anomaly was found to reach a maximum, showed that the formation possesses a magnetic susceptibility of the order of 4000×10^{-6} c.g.s.u.

The magnetic profiles and their locations are shown in Plate (4), where the topographic maps of the area were used as bases.

The profiles with their relative orientations, plotted station by station, are shown on Plate (1).

By mapping the magnetic beds from the magnetic anomalies, it is evident that the beds start in Sec. 25, T. 7 S., R. 76 W. and continue southward, paralleling the east side of Michigan Hill until Sec. 7, T. 8 S., R. 75 W. From there, the beds change direction, more to the southeast. The change in the direction of the anomalies coincides with the strike of the outcrops in this area. On reaching Sec. 17, T. 8 S., R. 75 W., the beds swing eastward and then strike approximately northward. In Sec. 8, T. 8 S., R. 75 W., the beds merge with another magnetic bed and both continue northward to Sec. 5, T. 8 S., R. 75 W. The size and characters of the anomalies in this part is different from the size and characters of the anomalies in the rest of the area. This distortion arises from the overlapping of two beds of the basal Denver Formation by faulting. The beds separate in Sec. 5, T. 8 S., R. 75 W., and disappear in Sec. 32, T. 8 S., R. 75 W.

Although the relatively large magnetic anomalies associated with these beds were similar in shape to the anomalies found by Sabet (1963) at the base of the Denver Formation west of Michigan Hill, it remained to be discovered whether the Denver Formation might include another highly magnetic bed higher in the section. Also, the characteristics and behaviour of the magnetic anomalies due to the basal part of the Denver Formation had to be studied. For these reasons, Profile 26, Plate 2 was laid out, where the basal part of the Denver

Formation outcrops along the Tarryall water gap, Sec. 23, T. 8 S., R. 76 W. The only large anomalies obtained were at the outcrop of the basal part of the Denver Formation at the Tarryall water gap. The anomalies possess a maximum of 1,300 gammas and extend for approximately 1,500 ft., thus giving an estimated 1,400 ft. thickness for the basal part of the Denver Formation in that area. One finds, on examining the character of the anomalies, a small anomaly of 400 gammas at the bottom of the basal part of the Denver Formation. This is followed, up section, by highly oscillating anomalies, with a maximum of 1,300 gammas. This character and succession of the anomalies was noticed on almost all the profiles except those south and north of the town of Jefferson, where the two anomalies mix. The small anomaly always occurs toward the axis of the two branches of the anomalies, as shown by Plates (1) and (4). This observation helped in locating the top and bottom boundaries of the magnetic beds which form the basal part of the Denver Formation.

INTERPRETATION

The results of this work led to the inferrence of the Jefferson anticline and to the modification of the previous geological mapping. The Jefferson anticline, plunging southward, is located to the east of Michigan Hill, with the town of Jefferson on the east limb and Michigan syncline to the west. The east limb of the anticline runs in Secs. 17, 8, and 5, T. 8 S., R. 75 W., and is partially overlapped by the upper plate of the Elkhorn thrust fault, as shown in Plate (3). The west limb of the anticline runs parallel to the east side of Michigan Hill. It is cut by the Baker Lake porphyry intrusion in Sec. 23, T. 7 S., R. 76 W. From there it extends southeastward to Sec. 17, T. 8 S., R. 75 W., where the two limbs merge, indicating the plunge of the anticline. The axial trend of the anticline is about N. 10° W., with the axis approximately located 1000 ft. west of the town of Jefferson.

Differences between Plate (3) and previous geological maps are concerned with the location of the Elkhorn thrust fault. From the

magnetic survey and the geological survey, the east limb of the Michigan syncline was found to parallel the east side of Michigan Hill. The Lower Denver Formation, a part of the east limb of the Michigan syncline, was mapped with the magnetometer between Sec. 25, T. 7 S., R. 76 W., where it is cut by the Baker Lake porphyry, and Sec. 17, T. 8 S., R. 75 W.

Also, from Sabet's work (Sabet, 1963), it is clear that the east limb does not swing westward around the north end of Michigan Hill, as indicated by Washburne (1908) and Stark, et al. (1949). Detailed mapping of the east limb parallel to the east side of Michigan Hill transferred the axis of the syncline more to the west than was indicated by Washburne and Stark, et al. On the basis of this mapping, the axial trend was found to strike approximately N 10° W, with the axis two miles west of Jefferson and coinciding with the axis of Michigan Hill.

The second modification introduced by this work is the location of the Elkhorn thrust fault. The mapping shown in Plate (3) is based on the interpretation of the magnetic data and the results of the geological survey. The author considers the Morrison Formation to rest unconformably on the Precambrian on the east side of the area. This was first pointed out by Johnson (1935).

The fault, as shown in Plate (4), swings northwestward from Sec. 22, T. 8 S., R. 75 W., to Sec. 17, T. 8 S., R. 75 W. It is inferred in this area from the geological survey and supported by the

magnetic data. In Sec. 21, T. 8 S., R. 75 W., the Upper Denver Formation is exposed along a cut in the hill to the north of Portis Ranch headquarters. The formation strikes N. 12° E. and dips 40° S. 78° E. To the northeast, 2,500 ft. from the hill, the Dakota Formation was found to outcrop in Sec. 16, T. 8 S., R. 75 W., striking N. 35° E. and dipping 25° in a N. 45° W. direction. The distance between the two outcrops does not allow for a complete stratigraphic section. One might try to explain this by pre-Denver uplift and erosion. However, in such a case, the magnetic survey should have indicated magnetic anomalies in the area between the two outcrops. Profile 1 shows no anomalies in that area. Furthermore, the two outcrops contradict in strike and dip, thus suggesting faulting between them, with the Dakota Formation in the hanging wall and the Lower Denver Formation in the footwall of the fault. On the geologic sections in Plate (3), the fault is interpreted as a thrust fault, with a horizontal displacement of 2,000 to 3,000 ft. This interpretation is consistent with the characteristics of the Elkhorn thrust fault as mapped to the south. It is partly on this reasoning that the northward extension of the Elkhorn thrust fault is based. The interpretation is supported by Lovering's suggestion to Stark, et al. (1949, p. 121), which is mentioned previously on page 16.

From Sec. 17, T. 8 S., R. 75 W., onward to Sec. 5, T. 8 S., R. 75 W., the fault strikes in a north-south direction. The mapping of the fault in that area is inferred from the magnetic anomalies.

As shown in Plate (4), two anomalies were encountered in this area, one on top of the hill in Sec. 5, T. 8 S., R. 75 W., where an outcrop for the basal part of the Denver Formation was found; and the other to the west of the hill. The two anomalies were interpreted as two different beds of the same formation. The first one is in the upper plate of the Elkhorn thrust fault, and the second one is a member of the east limb of Jefferson anticline. North of that hill, the magnetic anomalies are mixed, losing their character due to overlapping of the basal Denver Formation through the Elkhorn thrust fault.

The mapping of the fault north of Sec. 32, T. 7 S., R. 75 W. is in doubt, and it is possible that the fault changes direction to the west instead of to the northwest. If that is true, the upper plate of the fault will overlap the north ends of Jefferson anticline and Michigan syncline, thus explaining the disappearance of the magnetic anomaly in front of Baker Lake porphyry. Also, there is the possibility that Michigan fault, shown by Sabet (1963), is an extension of the Elkhorn thrust fault.

A second fault is introduced in the area extending between Secs. 16 and 4, T. 8 S., R. 75 W. The fault is a relaxation type fault. It explains the difference in the dip and strike of the Dakota Formation outcrops along the hogback and the dip and strike of the basal Denver Formation outcrops in Secs. 5 and 8, T. 8 S., R. 75 W. The fault is shown in the cross sections in Plate (3). It is consistent with the outcrop of the Niobrara Formation which was found in

Sec. 16, T. 8 S., R. 75 W.

Other interpretations were attempted, but they failed to satisfy either the magnetic data or the geological information. One interpretation assumes that the Denver Formation includes magnetic beds other than its basal part. This assumption was studied by laying out Profile 26 which covers almost the whole sedimentary section in the area. Magnetic anomalies comparable in size to those in the thesis area were encountered only at the Tarryall water gap, where the basal part of the Denver Formation outcrops. Thus, it was concluded that there are no highly magnetic beds other than those in the basal part of the Denver Formation in the sedimentary section. Accordingly, it was thought that the two branches of the magnetic anomalies are due to the repetition of the basal part of the Denver Formation through faulting. When this possibility was examined, it failed to explain the outcrop of the Upper Denver Formation in Sec. 21, T. 8 S., R. 75 W. which has a dip of 40° in a ~~N~~ S. 78° ~~W~~ E. direction and a strike of N. 12° E. It also indicated a reverse movement for the Elkhorn thrust fault.

The interpretation presented in this paper and explained at the beginning of this section is consistent with both the magnetic and geological data. Evidence from the magnetic survey is based essentially on the continuity of the magnetic bed which forms the basal part of the Denver Formation in the area east of Michigan Hill. A study, using Profile 26, of the behavior of the magnetic anomalies over the basal part of the Denver Formation indicates a small anomaly

at the bottom of the formation. The small anomaly is followed by large oscillating anomalies up section. This characteristic was found on almost all the profiles in the thesis area, with the exception of those where the Elkhorn thrust fault is located. It suggested that older beds are in the area between the limbs of the magnetic anomalies. This was confirmed when, in drilling seismic shotholes along the road in Secs. 18 and 17, T. 8 S., R. 75 W., cuttings of coal were washed up. The coal cuttings came from beds underlying the magnetic bed, which has the same position relative to the coal beds as the basal part of the Denver has to the Laramie Formation north of the Tarryall water gap and at the King Cole Mine.

The geological survey showed that the Upper Denver Formation surrounds the magnetic anomalies on the west, the south, and the southeast. In drilling for seismic shotholes along State Highway 77 northwest of the town of Jefferson, dark colored shale cuttings were washed out. This shale is believed to be from the Pierre Formation.

The geological picture can be summarized as follows: Pierre shale exists in the area between the two limbs of the magnetic beds which are considered to form the Basal Denver, while the Upper Denver Formation surrounds the Basal Denver on the west, southwest, south, and southeast. Such relationships suggest an anticline, which is here named the Jefferson anticline as shown in Plate (3). The plunge of the anticline is inferred from the change in the strike and dip along the west limb as well as the swinging of the magnetic anomalies around the nose of the anticline.

CONCLUSIONS

The results of this work are summarized as follows.

A. The Jefferson anticline is inferred in the area from the results of the magnetic and geological surveys.

B. The east limb of the Michigan syncline does not swing westward around the north end of Michigan Hill. Instead, it parallels the east side of Michigan Hill in approximately a north-south direction, and is cut by the Baker Lake porphyry in Sec. 25, T. 7 S., R. 76 W.

C. The Elkhorn thrust fault is not considered as the contact between the Precambrian and the Jurassic or Cretaceous Formations. It takes a different course from that previously mapped by Washburne (1908) and Stark, et al. (1949). It follows approximately a trend suggested by Lovering to

Stark, et al., in a personal communication. (Stark, et al., 1949, p. 121).

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