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Joel A. Degenstein
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GEOLOGY OF THE FLATHEAD FORMATION (MIDDLE CAMBRIAN)
ON THE PERIMETER OF THE BIGHORN BASIN,
BEARTOOTH MOUNTAINS, AND LITTLE
BELT MOUNTAINS IN WYOMING
AND MONTANA

by

Joel A. Degenstein

Bachelor of Science in Geology, University of North Dakota, 1976

A Thesis

Submitted to the Graduate Faculty

of the

University of North Dakota

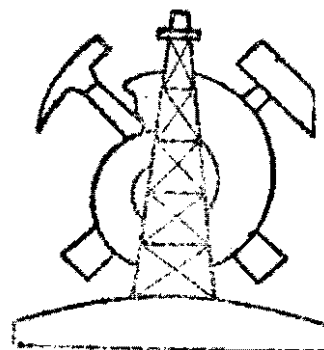
in partial fulfillment of the requirements

for the degree of

Master of Science

Grand Forks, North Dakota

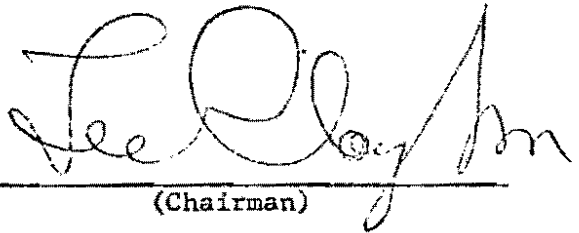
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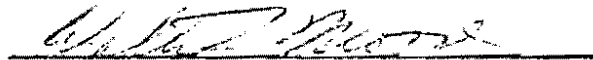



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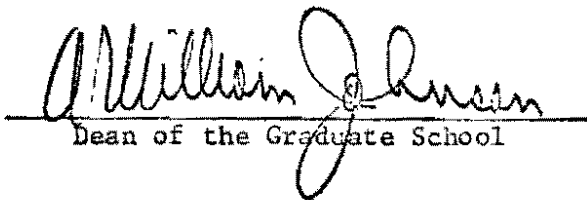
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This Thesis submitted by Joel A. Degenstein in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota is hereby approved by the Faculty Advisory Committee under whom the work has been done.


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ABSTRACT

The Flathead Formation, which is 4 to 60 metres thick in the middle and northern Rocky Mountains of Wyoming and Montana, contains cross-bedded and parallel-bedded, quartz sandstone. The formation contains marginal-marine and shallow-marine sediment that was deposited unconformably on Precambrian crystalline and sedimentary rock by an eastward-transgressing sea during middle Cambrian time.

This field study of the Flathead Formation on the perimeter of the Bighorn Basin, Beartooth Mountains, and Little Belt Mountains reveals that the formation consists of three intervals. The lower interval contains medium to very coarse, pebbly, cross-bedded sandstone and conglomerate. The middle interval contains medium to coarse, cross-bedded, quartz sandstone. Cross beds dip to the west in most places, but some cross beds dipping north, south, and east are present. The upper interval contains fine to coarse, parallel-bedded, quartz sandstone.

Trace fossils are present in the middle and upper intervals. Skolithos, Monocraterion, and Rusophycus have been identified. Horizontal tubes on bedding planes are the most common trace fossils. Large vertical tubes containing smaller Skolithos tubes and bedding deflected downward in a cone-in-cone fashion were formed by anemones moving upwards in their dwelling tubes. Inarticulate brachiopods are

present in the upper interval in some places. The brachiopods, which are the first to be identified in the formation, belong to three genera.

Comparison of the characteristics of the Flathead Formation with modern shallow-marine and marginal-marine environments indicates the sandstone was deposited in a high-energy environment with wave-induced currents. A barrier island was not present in most places.

The sandstone was deposited on a weathered Precambrian surface with 3 metres of relief, but up to 70 metres of relief was present in some places. The thickness of the Flathead Formation varies with the amount of surface relief. Resistant knobs of Precambrian rock existed as islands in the Owl Creek Mountain area.

INTRODUCTION

The middle Cambrian Flathead Formation is the basal Paleozoic rock unit in the middle and northern Rocky Mountains of Montana and Wyoming. It consists predominantly of sandstone, but it does contain some conglomerate and shale. The Flathead unconformably overlies Precambrian sedimentary rock in western Montana and Precambrian crystalline rock in central Montana and Wyoming. The Flathead is overlain by shale and sandstone of the middle Cambrian Wolsey or Gros Ventre Formations.

This study was conducted to determine the stratigraphy, the paleontology, the sedimentary structures, the depositional environment of the Flathead Formation, and the paleotopography of the Precambrian surface before the Flathead was deposited. Because the Flathead does not contain abundant fossils, it has not previously been studied in as much detail as the overlying, more fossiliferous Cambrian formations.

The Flathead Formation and other Paleozoic formations in the thesis area have been described by several geologists. A historical summary of the stratigraphy and terminology of the Cambrian System in Montana and Wyoming was published by Deiss (1936) and Bell (1968). Even though the Flathead had been described previously, only a few geologists have conducted a detailed study of the stratigraphy, paleontology, and the depositional environment of the formation. The Flathead of the Sunlight Basin, Clarks Fork Canyon, Cody, and Beartooth Butte

areas was the topic of a master's thesis by Bell (1968). The study by Bell (1968) dealt primarily with the petrologic aspects of the Flathead Formation. Bell (1968) concluded that the Flathead was primarily deposited in a tidal-flat environment.

The Flathead Formation is exposed at the surface only where tectonic forces have uplifted or deformed the Paleozoic rock. Therefore this study, which was a field-orientated project, had to be conducted on the flanks of structural basins and in the mountainous areas where the Paleozoic rocks have been uplifted and exposed to erosion. The region around the flanks of the Bighorn Basin in northwestern and north-central Wyoming and along the margins of the Beartooth Mountains in south-central Montana and northwestern Wyoming contains numerous, moderately to well-exposed outcrops of the Flathead Formation. This region was selected as the major part of the thesis study area. The Flathead was also studied in the Manhattan area near Three Forks in south-central Montana and in the Little Belt Mountains of central Montana. The Little Belt Mountain area was included because it contains the type section of the Flathead Formation. Figure 1 shows the location of the thesis study areas.

Some preliminary aspects of the study were investigated in the summer of 1976, but most of the fieldwork was done in the summer of 1977. The fieldwork involved measuring, describing, and sampling stratigraphic sections. Samples were collected only of sandstone representing different lithologies and of sandstone containing trace or brachiopod fossils. A metre tape was used to determine the thicknesses of individual beds. Fifty-two sections were measured and 31 outcrops

Fig. 1. Map showing the location of the study areas. The entire thesis study area is shown within bold lines.

were described in the thesis study area. A substantial amount of hiking was required to reach some outcrops. Other outcrops along roadcuts were easily accessible. A four-wheel drive truck was used as a field vehicle. Without it, outcrops in some areas could not have been easily reached. Horses were used to reach distant outcrops in two areas in the Beartooth Mountains.

The Flathead Formation consists of three intervals, which are distinguished from each other mostly on the basis of lithology and paleontology. The lower interval commonly consists of conglomerate and coarse to very coarse sandstone with quartz pebbles. It is parallel or cross bedded. The middle interval commonly contains medium to coarse, cross-bedded sandstone. The upper interval consists of fine to medium, parallel or cross-bedded sandstone. The formation ranges in thickness from 4 to 50 metres. Trace fossils are present, and they form a characteristic assemblage that is common in Cambrian sandstone in other parts of the world. The first inarticulate brachiopods that have been reported from the Flathead were found in three of the study areas. The Flathead Formation has been interpreted to have been deposited in a high-energy nearshore and shore environment with wave-induced currents.

STUDY AREAS

General

An extensive literature search, prior to fieldwork, helped to locate the areas in which the formation had previously been measured or described. Many geologic and topographic maps were used before and during the field season to locate good, reasonably accessible outcrops. Air photos of the Sunlight Basin and of the eastern Beartooth Mountain front from Red Lodge to the Sunlight Basin were also used for mapping and location. The topographic maps and air photos used in the study are listed in Appendix A. In areas where adequate mapping had not been done, a reconnaissance was necessary to determine if the Flathead was present. In some places outcrops of the Flathead were found, but the Flathead was absent because of faulting or nondeposition in many other places.

The thesis study area has been divided into seven smaller study areas. At least two, and as many as fourteen sections, were measured in each study area. In places where sections were not measured, outcrop descriptions were made.

The general geology of the Flathead Formation and the surrounding rock has been described in this chapter for each of the seven areas. Appendix B contains an example of a measured section on the specially-adapted outcrop sheet on which field data was plotted. Tables in

Appendix C contain lists and locations of the measured sections and outcrop descriptions for each of the seven study areas.

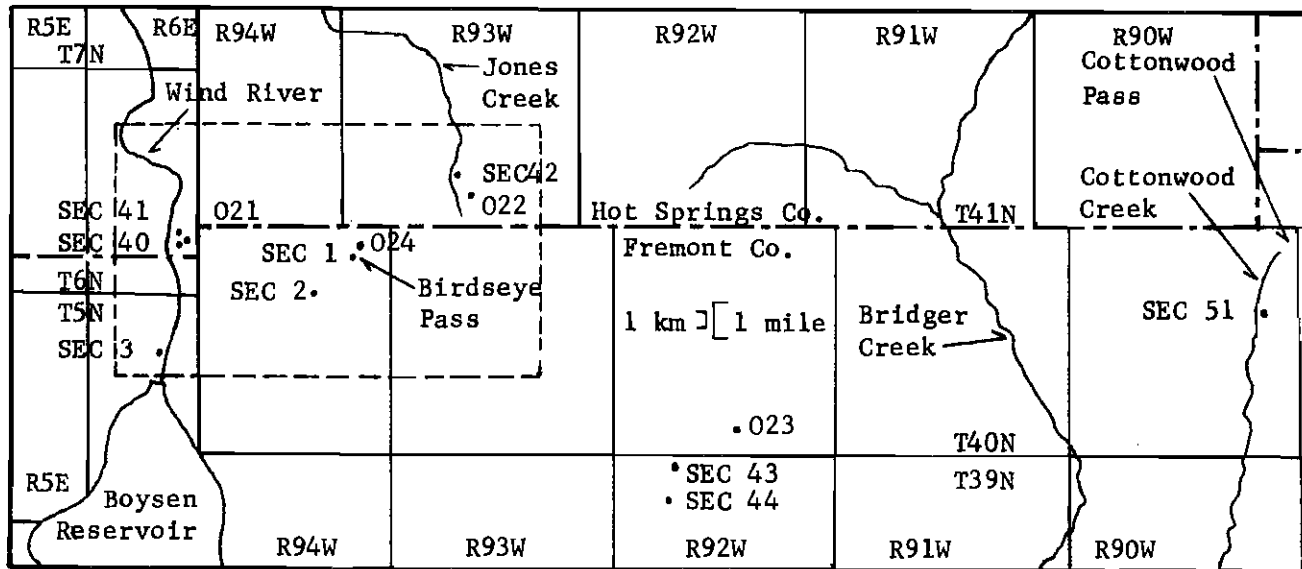
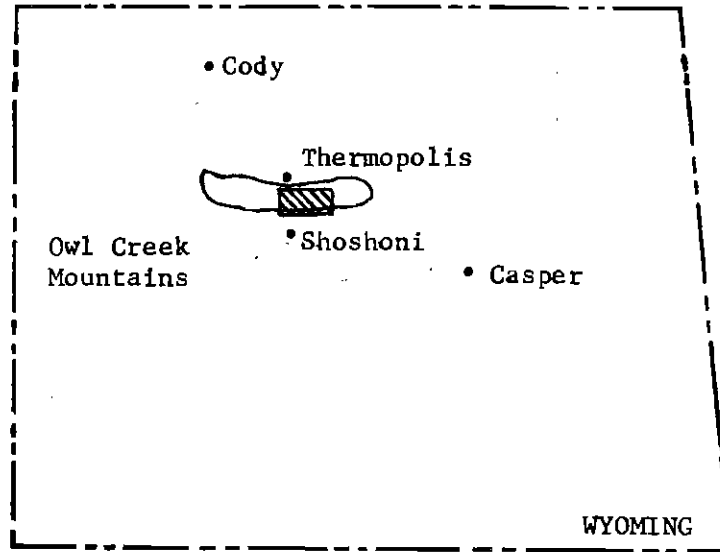
Owl Creek Mountain Area

The Owl Creek Mountain area includes outcrops of the Flathead Formation along the south edge of the mountains from Wind River Canyon on the west to Cottonwood Pass on the east. Paleozoic formations dip gently northward in this area and are bounded on the south by the east-west Boysen Fault. The Flathead Formation and other lower Paleozoic formations are generally well exposed in this area. South of this fault, Precambrian granitic and metamorphic rock are exposed in an east-west band. Further south, complexly folded and faulted Paleozoic formations are exposed. Access is good to all measured sections and all outcrop description localities.

Nine sections were measured and four outcrops were described in the Owl Creek Mountains. Of these nine measured sections, four included the Flathead Formation only, three included the Flathead Formation and part of the overlying Gros Ventre Formation, and two included the Gros Ventre Formation only. The measured sections range in thickness from 10 to 80 metres. Measured sections in this area include Sections 1, 2, 3, 40, 41, 42, 43, 44, and 51. Outcrops described in this area include Outcrops 21, 22, 23, and 24.

Table 1 and Table 2 in Appendix C contain a list and locations of the measured sections and outcrop descriptions in the Owl Creek Mountains. Figure 2 shows the locations of measured sections and outcrop descriptions in this area.

Fig. 2. Location of measured sections and outcrop descriptions in the Owl Creek Mountain area, Wyoming. SEC 3 is a measured section number. 024 is an outcrop description number. The area inside the dashes represents the area of Figs. 19, 20, 21, and 22.



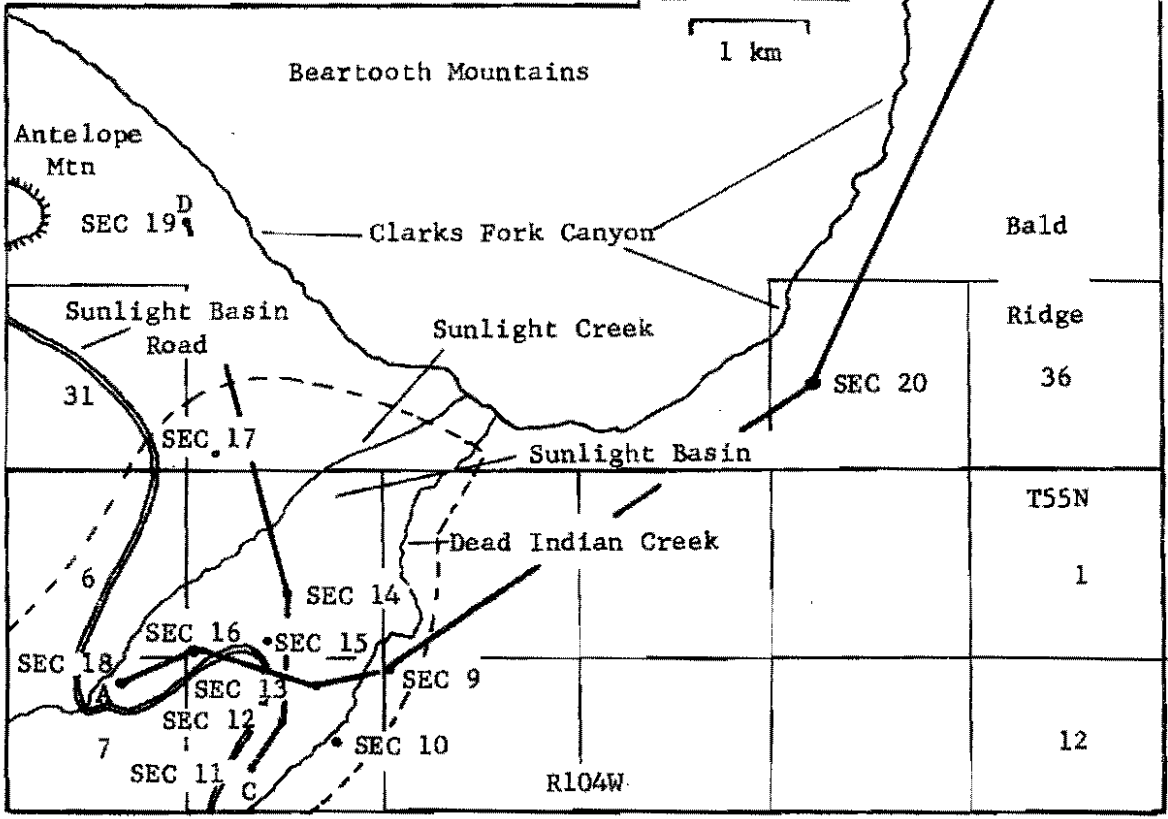
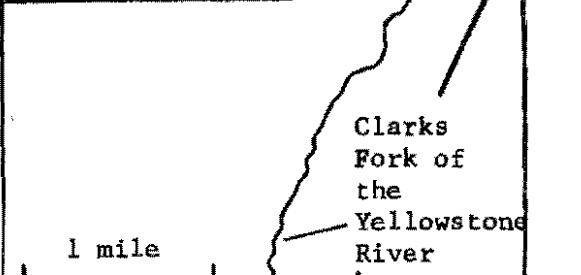
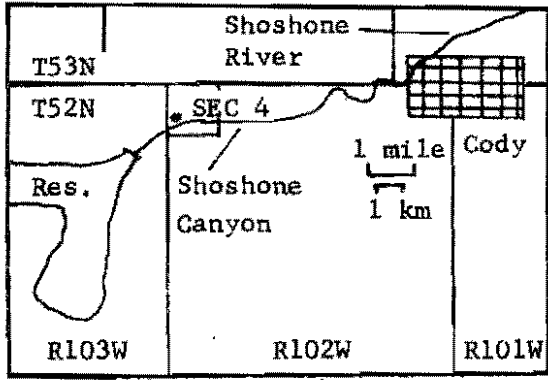
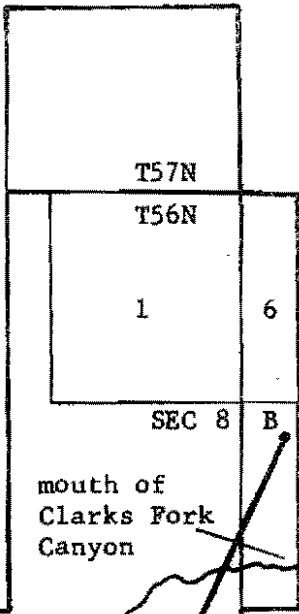
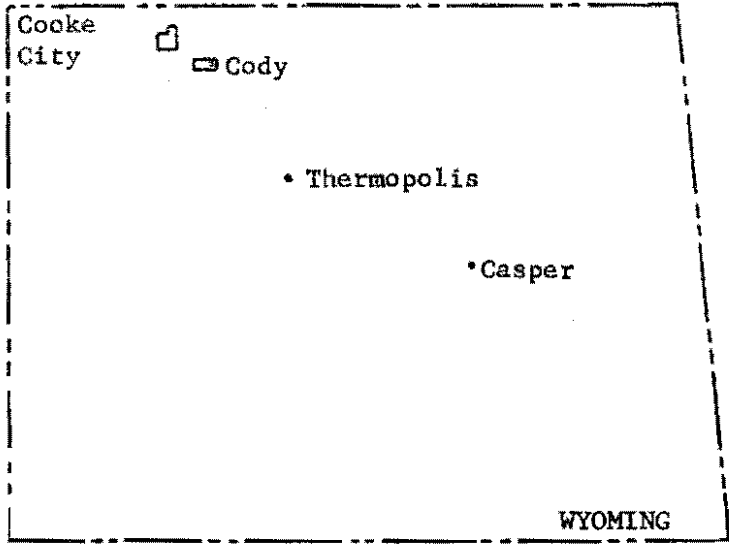
The maps and descriptions of Deiss (1938), Fanshawe (1939), and Lochman-Balk (1972) were used to locate some of the outcrops in the Owl Creek Mountains.

Sunlight Basin, Clarks Fork Canyon, Cody Area

The Sunlight Basin, Clarks Fork Canyon, and Cody area includes outcrops of the Flathead Formation in the Sunlight Basin, along Clarks Fork Canyon from Antelope Mountain in the west to the mouth of the canyon in the east, and in Shoshone Canyon west of Cody. In the Sunlight Basin and most of Clarks Fork Canyon, the Flathead Formation and other lower Paleozoic formations are horizontal or dip less than 10 degrees. At the mouth of Clarks Fork Canyon and in Shoshone Canyon, the Flathead Formation dips eastward from 10 to 90 degrees. In the Sunlight Basin the Flathead Formation is offset by many normal faults. Access is very good in the Sunlight Basin and Shoshone Canyon to all measured sections. In the Clarks Fork Canyon three to four hours of hiking are necessary to reach the measured sections.

Fourteen sections were measured in the Sunlight Basin, Clarks Fork Canyon, and Cody area. All the sections include only the Flathead Formation. The measured sections range in thickness from 7.2 to 36.9 metres. Measured sections in this area include Sections 4, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, and 20. Table 3 in Appendix C contains a list and locations of the measured sections in this area. Figure 3 shows the location of the measured sections in the Sunlight Basin, Clarks Fork Canyon, and Cody area in Park County in northwestern Wyoming.

Fig. 3. Location of measured sections in the Sunlight Basin, Clarks Fork Canyon, and Cody area, Wyoming. SEC 4 is a measured section number. Area inside dashes is the Sunlight Basin. A-B and C-D show the locations of the cross sections in Fig. 12.



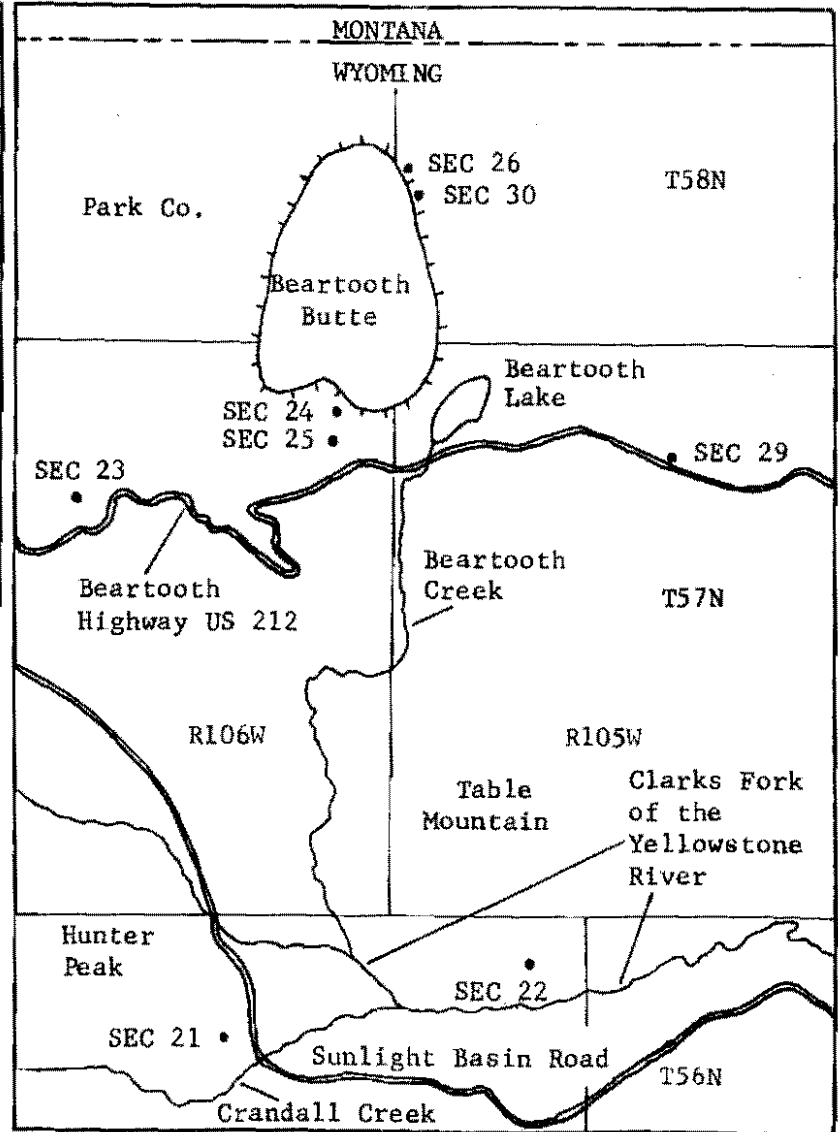
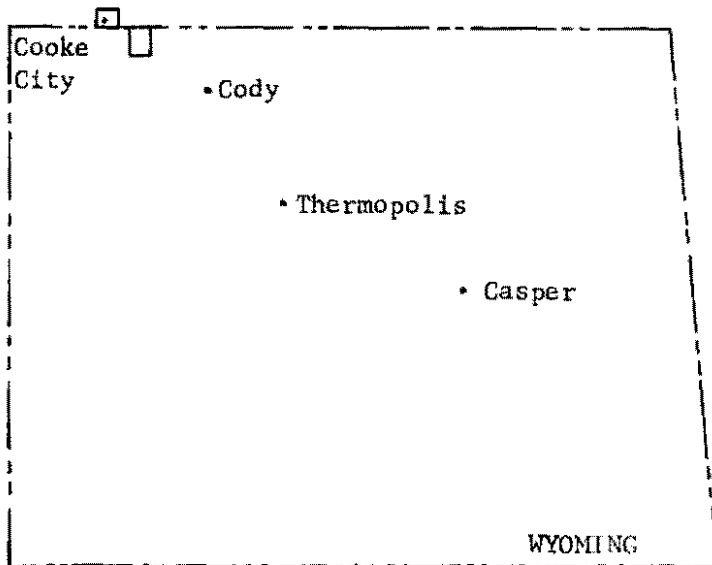
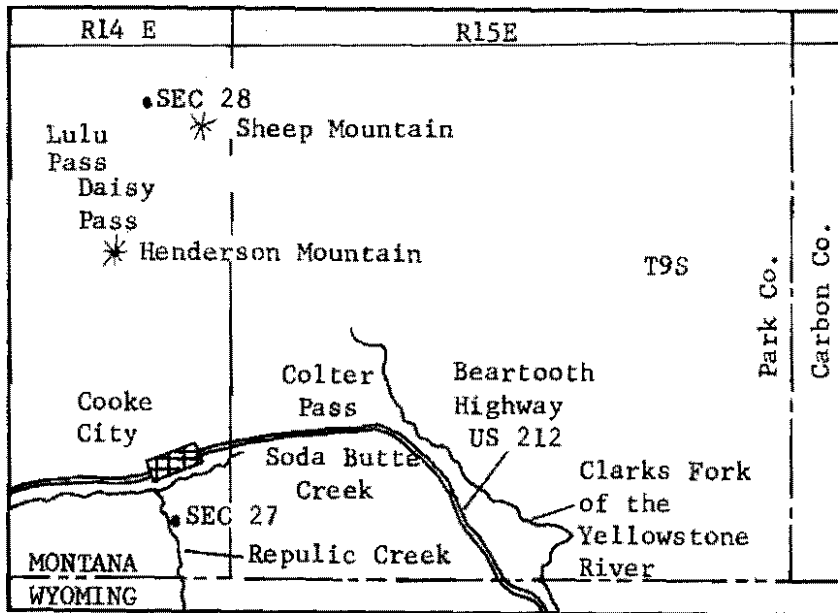
Descriptions by Bell (1968), Stipp (1947), and Johnson (1934) were useful in determining outcrop locations in this area. Geologic maps by the following authors were used in this area: Pierce (1965a), Pierce (1965b), Pierce (1966), Pierce (1970), Pierce and Nelson (1968), and Pierce and Nelson (1969).

Beartooth Butte and Cooke City Area

The Beartooth Butte and Cooke City area includes outcrops of the Flathead Formation along Crandall Creek, at the south end of Table Mountain, along the Beartooth Highway, at the northeast and southwest sides of Beartooth Butte, and north and south of Cooke City. The Flathead Formation and other lower Paleozoic formations are horizontal or dip less than 15 degrees to the south. Hikes of 2 to 4 hours are necessary to reach exposures at Table Mountain, at the northeast corner of Beartooth Butte, and north of Cooke City. A hike of less than 1 hour is required to reach outcrops along the Beartooth Highway, at the southwest end of Beartooth Butte, at Crandall Creek, and south of Cooke City.

Ten sections were measured in the Beartooth Butte and Cooke City area. All sections include only the Flathead Formation. The measured sections range in thickness from 8.8 to 25.3 metres. Measured sections in this area include Sections 21, 22, 23, 24, 25, 26, 27, 28, 29, and 30. Table 4 in Appendix C contains a list and locations of the measured sections in this area. Figure 4 shows the location of measured sections in this area.

Fig. 4. Location of measured sections in the Beartooth Butte and Cooke City area, Wyoming and Montana. SEC 22 is a measured section number.



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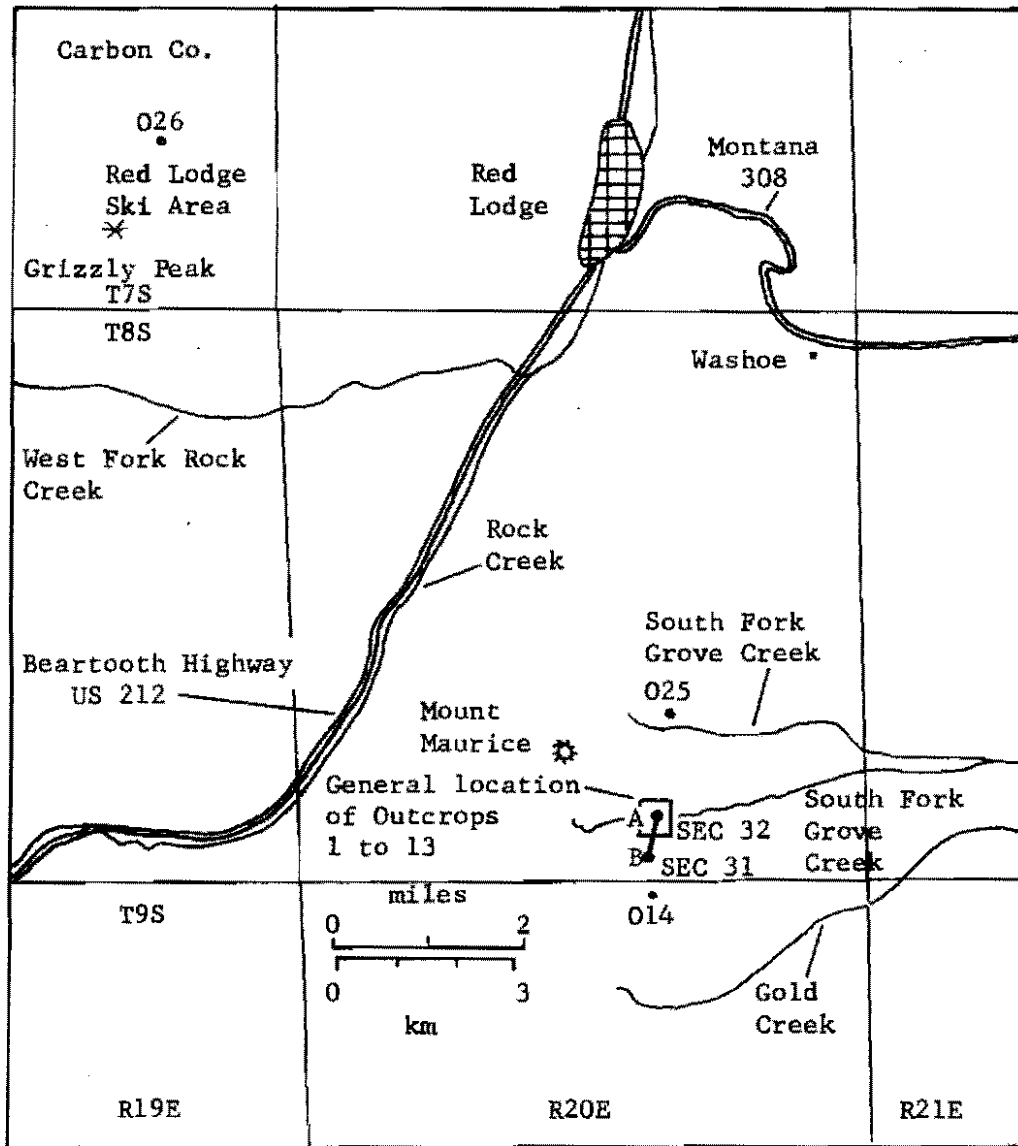
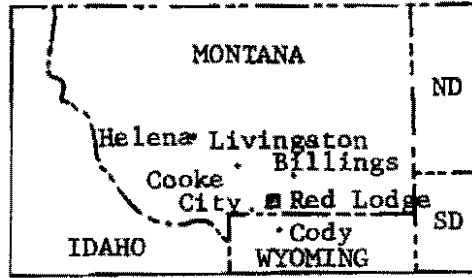
Works by the following geologists were helpful in finding outcrops of the Flathead Formation in this area: Dorf (1934), Lovering (1929), Foose and others (1961), and Hague and others (1899).

Red Lodge Area

The Red Lodge area includes outcrops of the Flathead Formation along the Beartooth Mountain front south of Red Lodge near the north and south forks of Grove Creek and west of Red Lodge near the Red Lodge ski area. The Flathead Formation south of Red Lodge dips east at 25 to 65 degrees. West of Red Lodge the Flathead dips north at 10 to 90 degrees. The Flathead is offset by numerous faults south of Red Lodge. South and west of Red Lodge the Flathead is absent in many places due to complex faulting related to the Beartooth Thrust Fault. Hikes less than 1 hour are necessary to reach most outcrops of the Flathead Formation in the Red Lodge area. Three to 4 hours of hiking are necessary to reach outcrops of the Flathead Formation along the north fork of Grove Creek. To reach Section 31 and Section 32 it is necessary to use the good jeep trail that goes into the area along the south fork of Grove Creek.

Two sections were measured in the Red Lodge area. Both sections include only the Flathead Formation. The measured sections range in thickness from 8.8 to 19.4 metres. Section 31 and Section 32 were measured in the area of the south fork of Grove Creek. Sixteen outcrops were described in this area. They include Outcrops 1 to 14, 25, and 26. Table 4 and Table 5 in Appendix C contain a list and locations of the measured sections and outcrop descriptions. Figure 5 shows the location of measured sections and outcrop descriptions in this area.

Fig. 5. Location of measured sections and outcrop descriptions in the Red Lodge area, Montana. SEC 31 is a measured section number. 025 is an outcrop description number. A and B show the location of the stratigraphic cross section in Fig. 14.



Publications by Field (1932), Foose (1958), and Poldervaart and Bentley (1958) were used to locate some of the outcrops of the Flathead Formation.

Livingston and Manhattan Area

The Livingston area includes outcrops of the Flathead Formation along the Beartooth Mountain front south and southeast of Livingston. The area is bounded on the west by the Yellowstone River and on the east by the East Boulder River. The Flathead dips 10 degrees southeast at Section 50, 45 degrees north and northeast at Section 48 and Section 45, and 34 degrees northwest at Section 49. Complex folding and faulting is present throughout the area.

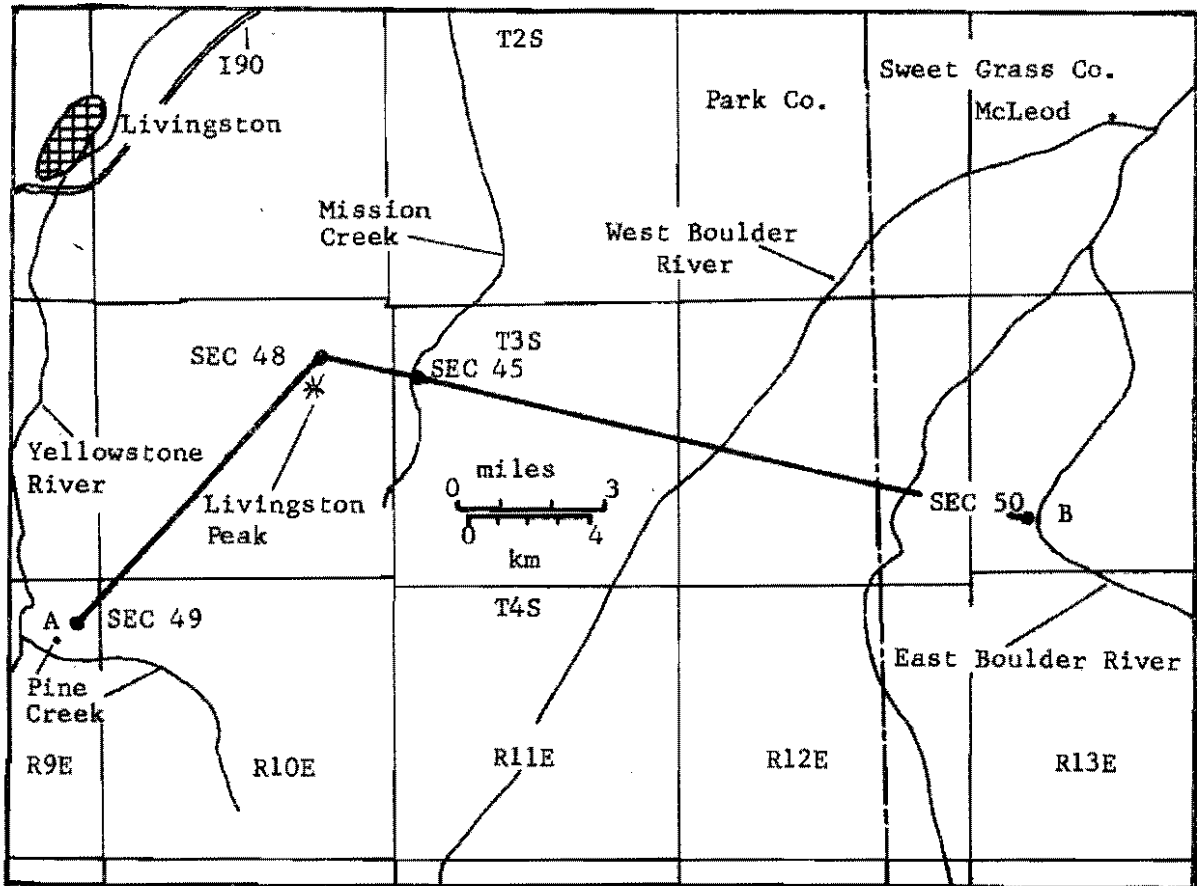
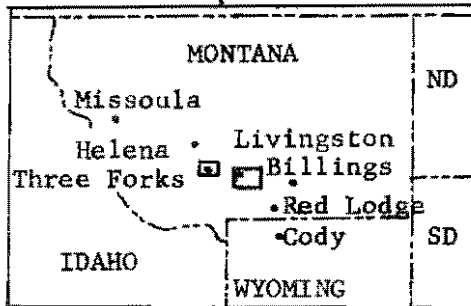
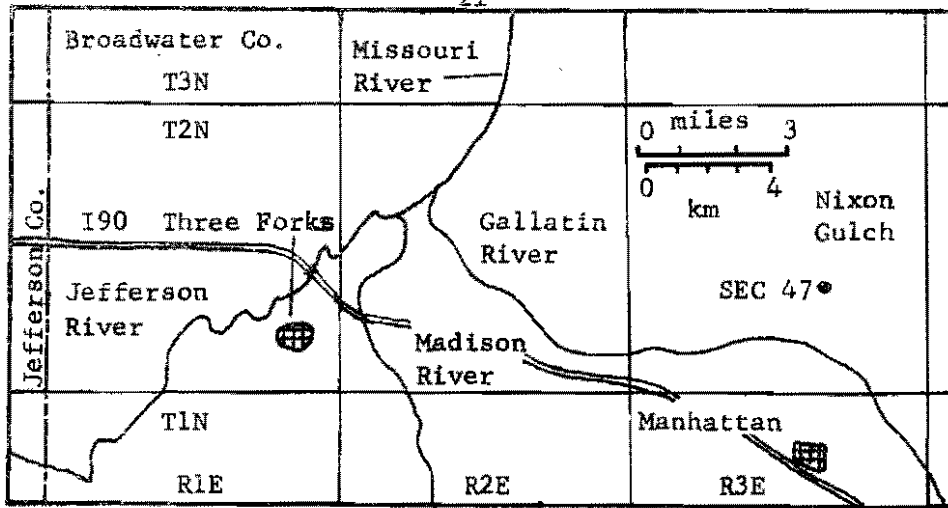
The Manhattan area includes outcrops of the Flathead Formation in Nixon Gulch north of Manhattan. The Flathead dips 26 degrees northwest at Section 47 in Nixon Gulch. The Paleozoic and Mesozoic rock in this area have been folded and intruded by igneous rock.

A 4 hour hike is necessary to reach Section 48, but other sections are easily accessible by jeep trails and 1 hour hikes.

Four sections were measured in the Livingston area. One section was measured in the Manhattan area. The measured sections range in thickness from 11.1 to 40.2 metres. Measured sections in this area include Sections 45, 47, 48, 49, and 50. Table 6 in Appendix C contains a list and locations of the measured sections. Figure 6 shows the location of measured sections in this area.

Maps and articles by the following authors were used in the Livingston area to study the geology and locate Flathead outcrops:

Fig. 6. Location of measured sections in the Livingston and Manhattan area, Montana. SEC 48 is a measured section number. A and B show the location of the stratigraphic cross section in Fig. 15.



Peale (1893), Lammers (1937), Skeels (1939), Hanson (1952), Alexander (1955), Page and others (1973a), and Page and others (1973b).

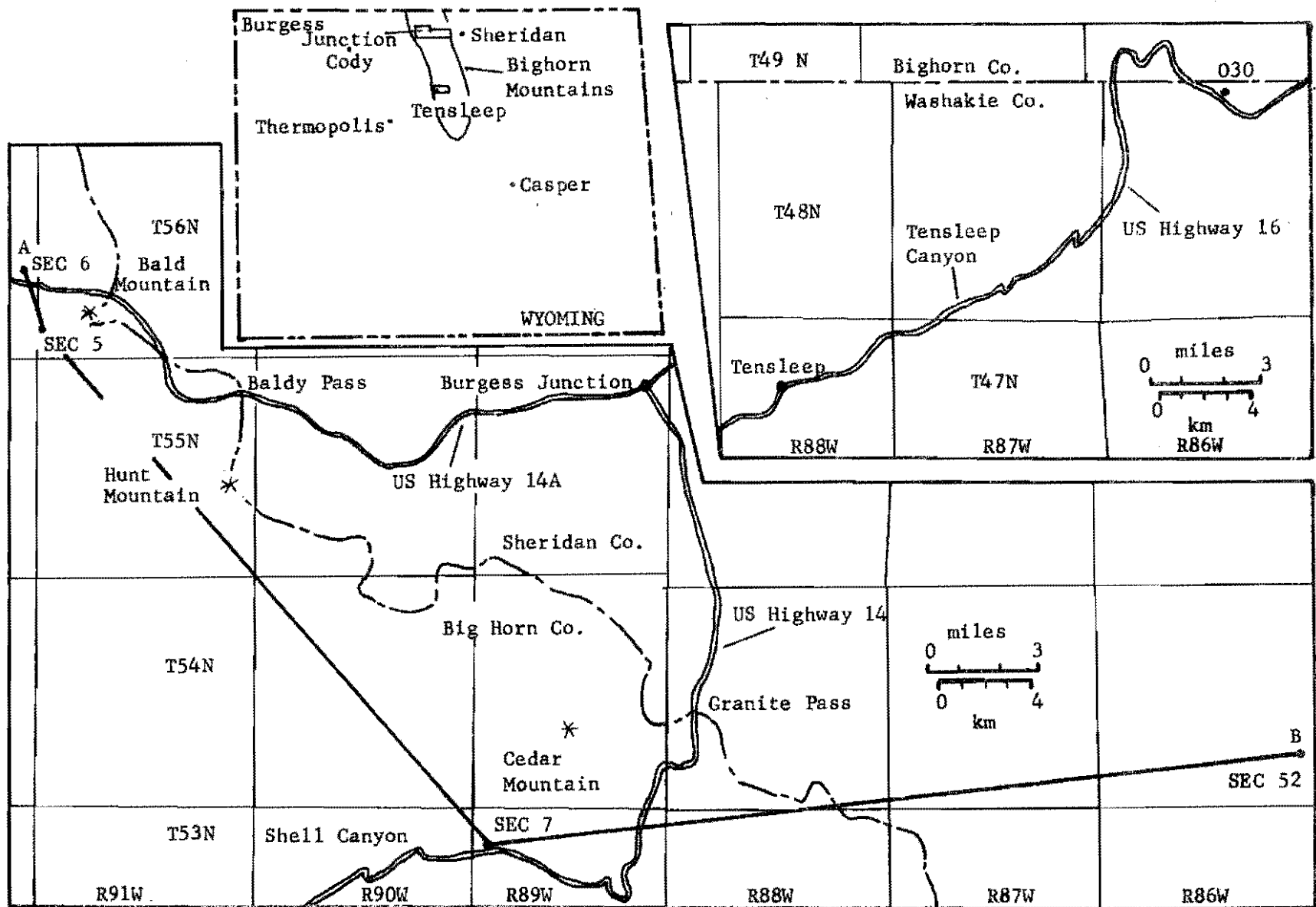
Bighorn Mountain Area

The Bighorn Mountain area includes outcrops of the Flathead Formation along U. S. Highways 14, 14a, and 16 and along the east side of the mountains southwest of Sheridan, Wyoming. The lower Paleozoic rock units have not been extensively folded or faulted in this study area; the Flathead Formation is horizontal or dips very gently east or west. Sections 5, 6, and 7, and Outcrop 30 are easily accessible from U. S. Highways 14, 14a, and 16. Section 52 is reached by a good dirt road that goes west into the Bighorn Mountains southwest of Bighorn, Wyoming.

Four sections were measured in the Bighorn Mountains. One outcrop (Outcrop 30) was described in the area. All include only the Flathead Formation. The measured sections range in thickness from 4.0 to 23.0 metres. Measured sections in this area include Sections 5, 6, 7, and 52. Table 7 in Appendix C contains a list and locations of the measured sections and outcrop descriptions. Figure 7 shows the locations of measured sections and outcrop descriptions in this area.

The publications of the following authors were used in the Bighorn Mountain area to study the geology and locate the Flathead outcrops: Darton (1906), Bucher and others (1934), Shaw (1954), Lochman (1957), and Osterwald (1959).

Fig. 7. Location of measured sections and outcrop descriptions in the Bighorn Mountain area, Wyoming. SEC 6 is a measured section number. 030 is an outcrop description number. A and B show the location of the stratigraphic cross section in Fig. 16.



Little Belt Mountain and Smith River Basin Area

The Little Belt Mountain area includes outcrops of the Flathead Formation along Belt Creek between Niehart and Monarch in the northern part of the mountains. The Flathead Formation in that area dips gently to the northeast at 5 degrees. The formation has not been folded or faulted but has been intruded by a diorite sill or laccolith along part of its exposure along Belt Creek. The diorite in some places occurs in a sill between sandstone beds in the upper member, but in closely adjacent areas the diorite body has more characteristics of a laccolith than a sill.

The Smith River Basin area includes outcrops of the Flathead Formation northwest and south of White Sulphur Springs. At the north end of the basin the Flathead has been folded and faulted and dips 60 degrees to the southeast and the south. A diorite sill is present between the Precambrian rock and the bottom of the formation. At the south end of the basin the Flathead has also been folded and faulted and dips 15 to 30 degrees to the southeast and northeast.

All measured sections in the Little Belt Mountains and the Smith River Basin can be reached easily from highways or maintained dirt roads.

Seven sections were measured in this area. Six sections include only the Flathead Formation. One section (Section 35) was measured of the Precambrian Niehart Quartzite. The measured sections range in thickness from 6.3 to 60.3 metres. Measured sections in this area include Sections 33, 34, 35, 36, 37, 38, and 39. Six outcrops were described in this area. They include Outcrops 15, 16, 17, 18, 19, and

20. Table 8 in Appendix C contains a list and locations of the measured sections and outcrop descriptions. Figure 8 and Figure 9 show the location of the measured sections and outcrop descriptions in this area.

In this area, publications by Weed (1900), Deiss (1936), and Hanson (1957) were used to locate outcrops of the Flathead Formation.

Fig. 8. Location of measured sections and outcrop descriptions in the Little Belt Mountain area, Montana. SEC 33 is a measured section number. 016 is an outcrop description number. A and B show the location of part of the stratigraphic cross section in Fig. 17.

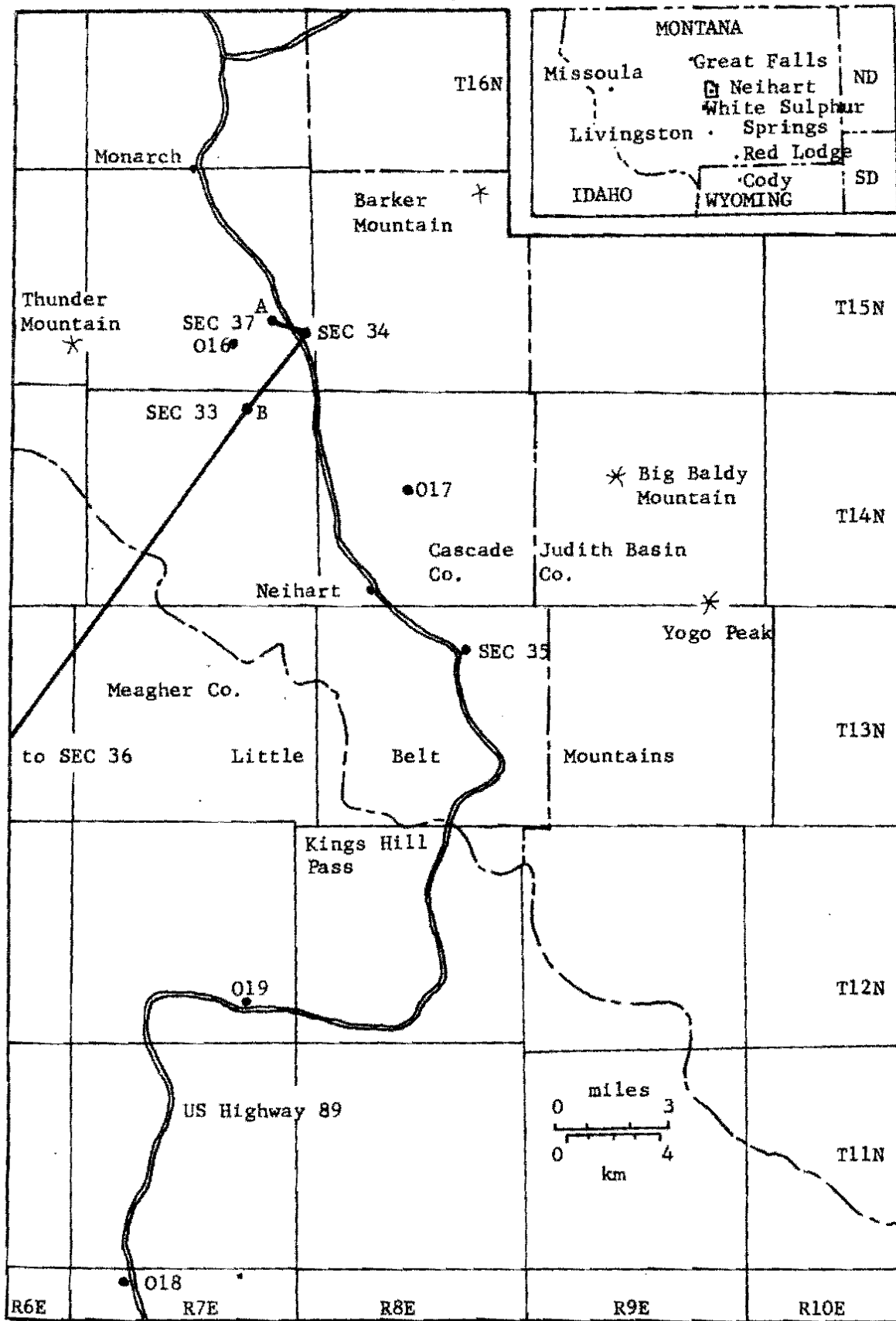
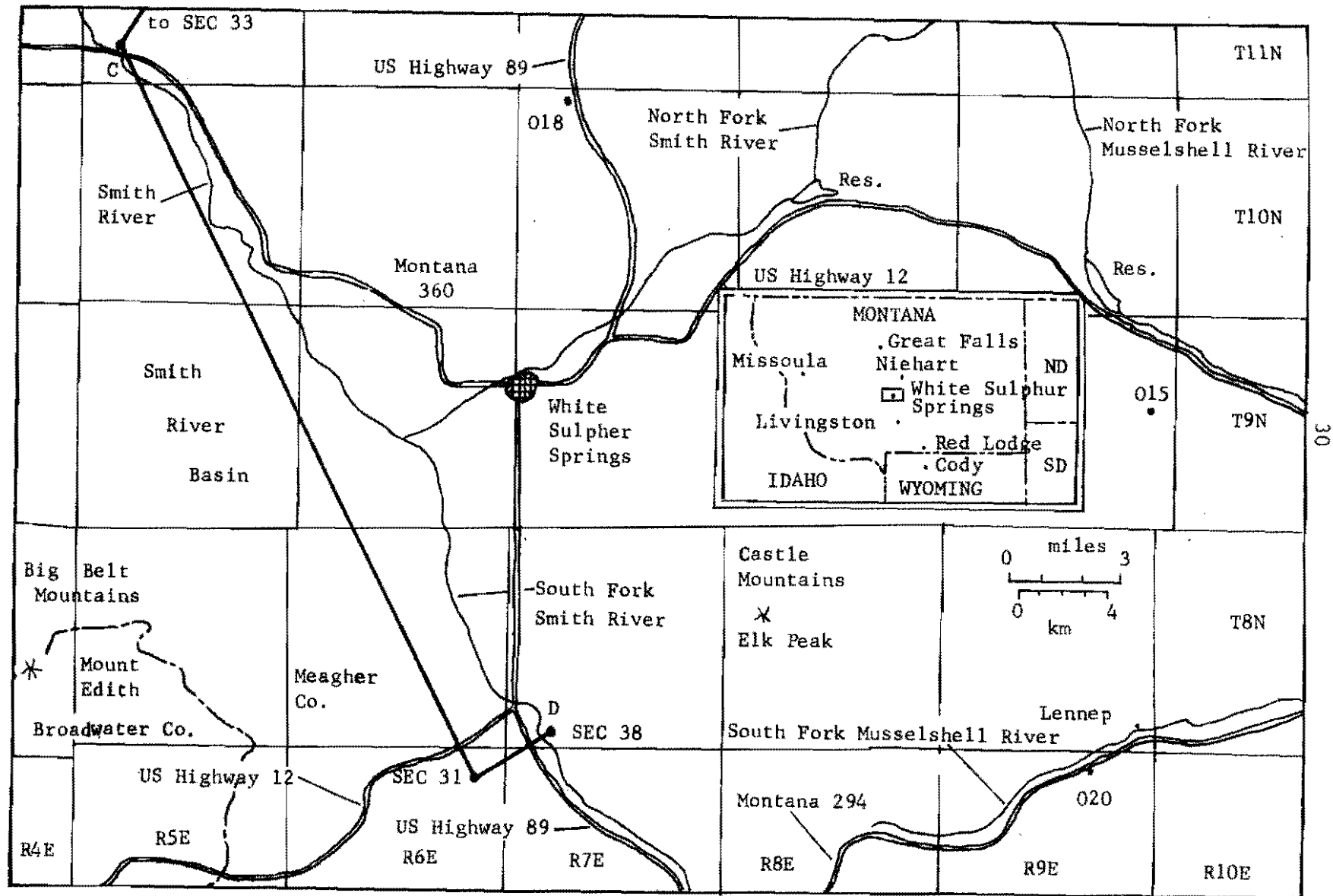


Fig. 9. Location of measured sections and outcrop descriptions in the Smith River Basin area, Montana. SEC 36 is a measured section number. Q18 is an outcrop description number. C and D show the location of part of the stratigraphic cross section in Fig. 17.



11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197 198 199 200 201 202 203 204 205 206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232 233 234 235 236 237 238 239 240 241 242 243 244 245 246 247 248 249 250 251 252 253 254 255 256 257 258 259 260 261 262 263 264 265 266 267 268 269 270 271 272 273 274 275 276 277 278 279 280 281 282 283 284 285 286 287 288 289 290 291 292 293 294 295 296 297 298 299 300 301 302 303 304 305 306 307 308 309 310 311 312 313 314 315 316 317 318 319 320 321 322 323 324 325 326 327 328 329 330 331 332 333 334 335 336 337 338 339 340 341 342 343 344 345 346 347 348 349 350 351 352 353 354 355 356 357 358 359 360 361 362 363 364 365 366 367 368 369 370 371 372 373 374 375 376 377 378 379 380 381 382 383 384 385 386 387 388 389 390 391 392 393 394 395 396 397 398 399 400 401 402 403 404 405 406 407 408 409 410 411 412 413 414 415 416 417 418 419 420 421 422 423 424 425 426 427 428 429 430 431 432 433 434 435 436 437 438 439 440 441 442 443 444 445 446 447 448 449 450 451 452 453 454 455 456 457 458 459 460 461 462 463 464 465 466 467 468 469 470 471 472 473 474 475 476 477 478 479 480 481 482 483 484 485 486 487 488 489 490 491 492 493 494 495 496 497 498 499 500 501 502 503 504 505 506 507 508 509 510 511 512 513 514 515 516 517 518 519 520 521 522 523 524 525 526 527 528 529 530 531 532 533 534 535 536 537 538 539 540 541 542 543 544 545 546 547 548 549 550 551 552 553 554 555 556 557 558 559 560 561 562 563 564 565 566 567 568 569 570 571 572 573 574 575 576 577 578 579 580 581 582 583 584 585 586 587 588 589 590 591 592 593 594 595 596 597 598 599 600 601 602 603 604 605 606 607 608 609 610 611 612 613 614 615 616 617 618 619 620 621 622 623 624 625 626 627 628 629 630 631 632 633 634 635 636 637 638 639 640 641 642 643 644 645 646 647 648 649 650 651 652 653 654 655 656 657 658 659 660 661 662 663 664 665 666 667 668 669 670 671 672 673 674 675 676 677 678 679 680 681 682 683 684 685 686 687 688 689 690 691 692 693 694 695 696 697 698 699 700 701 702 703 704 705 706 707 708 709 710 711 712 713 714 715 716 717 718 719 720 721 722 723 724 725 726 727 728 729 730 731 732 733 734 735 736 737 738 739 740 741 742 743 744 745 746 747 748 749 750 751 752 753 754 755 756 757 758 759 760 761 762 763 764 765 766 767 768 769 770 771 772 773 774 775 776 777 778 779 780 781 782 783 784 785 786 787 788 789 790 791 792 793 794 795 796 797 798 799 800 801 802 803 804 805 806 807 808 809 810 811 812 813 814 815 816 817 818 819 820 821 822 823 824 825 826 827 828 829 830 831 832 833 834 835 836 837 838 839 840 841 842 843 844 845 846 847 848 849 850 851 852 853 854 855 856 857 858 859 860 861 862 863 864 865 866 867 868 869 870 871 872 873 874 875 876 877 878 879 880 881 882 883 884 885 886 887 888 889 890 891 892 893 894 895 896 897 898 899 900 901 902 903 904 905 906 907 908 909 910 911 912 913 914 915 916 917 918 919 920 921 922 923 924 925 926 927 928 929 930 931 932 933 934 935 936 937 938 939 940 941 942 943 944 945 946 947 948 949 950 951 952 953 954 955 956 957 958 959 960 961 962 963 964 965 966 967 968 969 970 971 972 973 974 975 976 977 978 979 980 981 982 983 984 985 986 987 988 989 990 991 992 993 994 995 996 997 998 999 1000

SEDIMENTARY STRUCTURES

Primary Structures

Cross bedding

General

The sandstone in the Flathead Formation is cross bedded in most of the sections in the thesis study area. The sandstone in the lower and middle members is characteristically cross bedded; the sandstone in the upper member is parallel bedded in most places. The cross bedding is well exposed in most of the study areas, but where the sandstone has been well indurated both the grain size and the primary structures are difficult to determine.

The cross-bedding terminology of Reineck and Singh (1975, p. 85) and the bedform terminology of Allen (1970, p. 70) and Reineck and Singh (1975, p. 24) have been used in the following discussion.

Small-scale cross bedding

Small-scale cross bedding occurs in all parts of the Flathead Formation and in association with parallel bedding and large-scale cross bedding. The cross beds dip at high angles, from 15 to 35 degrees, mostly in a westerly to northwesterly direction. The sets of cross bedding are less than 50 millimetres thick. Tabular-shaped sets are most common, but trough-shaped sets also occur. Grouped sets are

most common, but solitary sets are present. The cross beds occur in fine to coarse sandstone.

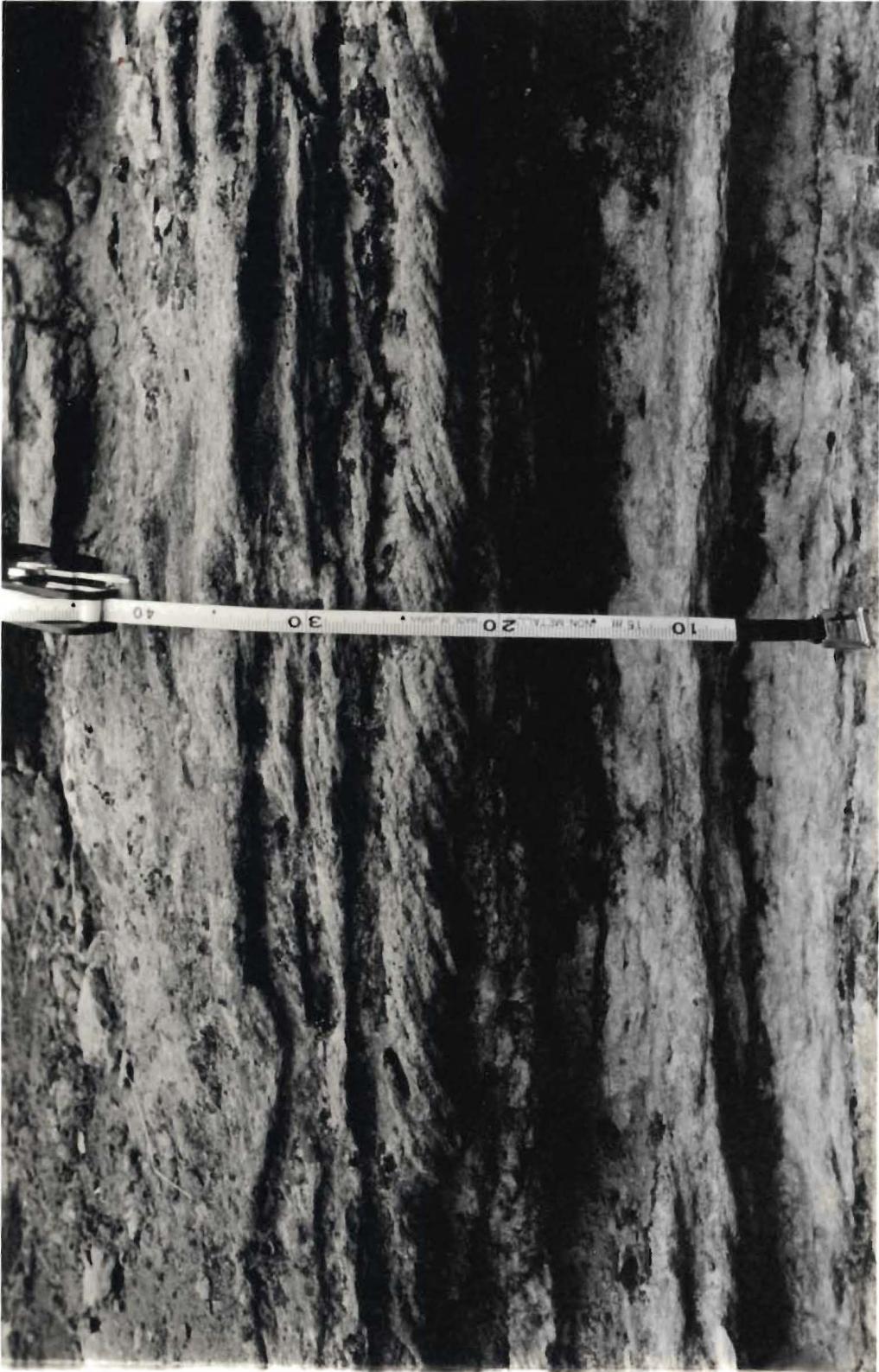
In some of the small-scale cross beds in medium to coarse sandstone, the tops of sets have been truncated. The truncation is usually observed in the coarser sandstone. Figure 10 is a photograph of the small-scale cross bedding that is present at Section 41.

Large-scale cross bedding is the predominant bedding type in the Flathead Formation. This type of bedding occurs more commonly with small-scale cross bedding than with parallel bedding. The foresets dip 15 to 35 degrees, predominantly west to northwest. In the Sunlight Basin, Clarks Fork Canyon, and Cody area, many foresets dip north or south in the middle member. The upper contacts of the foresets in most places are tangential or angular. The shape of the lower contacts of the foresets in most places is tangential or concave, although angular contacts do occur in some cross beds. The sets commonly range in thickness from 0.05 to 0.5 metres. The most common sets size is 0.1 metre, but sets up to 2.0 metres thick are found in the formation. Solitary and grouped, tabular and trough-shaped sets are equally abundant. The cross beds occur in fine to very coarse sandstone. Figure 11 is a photograph of the large-scale cross bedding that is present at Section 24.

Parallel bedding

Parallel bedding is the predominant bedding type in the upper part of the Flathead Formation in most places. Small-scale cross bedding commonly occurs with parallel bedding.

Fig. 10. Photograph of small-scale cross bedding exposed at Section 41. Black numbers on the measuring tape are 0.1 metre apart.



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Fig. 11. Photograph of large-scale cross bedding exposed at Section 24. The set is 0.14 metres thick.



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Parallel bedding, which occurs in fine to coarse sandstone, shaly sandstone, and shale beds, is present in beds less than 10 millimetres to 10 metres thick. This bedding is horizontal in most places but a low angle (less than 15 degrees) dip is present in some places.

Channels

Channels, 2 to 5 metres deep and 10 to 50 metres across, are present in the middle member in the Owl Creek Mountain and the Sunlight Basin area. The channels, which are orientated in an east-west direction, truncate the underlying strata and are internally cross bedded. Some of the bedding at the edges of the channels is draped in relation to the underlying erosional surface. These channels were cut by west-flowing currents that later formed dunes in the channels.

Origin of bedding

The nontruncated, small-scale cross bedding in sandstone beds with grain sizes smaller than 0.65 millimetres (coarse) was formed by the migration of ripples that were produced by unidirectional water currents. The migration of straight and curved-crested ripples formed by the unidirectional currents resulted in tabular and trough-shaped cross beds. The straight-crested ripples were more abundant and were produced by westerly-flowing water currents in most places.

The large-scale cross bedding was produced by the migration of dunes that formed as a result of water currents. Because ripples can not form in sand that is larger than 0.65 millimetres (Allen, 1970, p. 78), the truncated small-scale cross bedding in medium to coarse sandstone probably represents large-scale cross bedding that has been

eroded. The migration of straight and curve-crested dunes resulted in tabular and trough-shaped cross bedding. Many dunes were greater than 0.1 metre high, but in their migration they formed cross-bed sets 0.1 metre thick. The currents flowed predominantly west, but currents flowing north, south, and east were present in some places. The association of small-scale and large-scale cross bedding resulted from changing depositional conditions and was probably produced by dunes migrating over ripples. The tangential and concave upper contacts of the foresets in the large-scale sets indicates that many of the bedforms were probably not extensively eroded before other bedforms migrated over them. Reineck and Singh (1975, p. 21) suggest that a tangential and concave, lower foreset contact becomes more common with increasing current velocity and suspension. This suggests the currents that formed these cross beds probably were fast and contained suspended sediment.

Parallel bedding was produced in the plane-bed phase of either the lower or the upper flow regime. The parallel bedding in the coarser sandstone probably formed in the upper flow regime (Allen, 1970, p. 70).

Secondary Structures

Mudcracks

Mudcracks are found in the lower member of the Flathead Formation at Beartooth Butte. The mudcracks were formed on mud that was exposed to the air. The surface was then covered with sandstone and the cast was preserved on the lower surface.

Biogenic structures

Bedding in the upper members in most study areas has been disturbed or destroyed by the action of burrowing organisms. Evidence, in the form of disturbed or destroyed bedding and the presence of trace fossils, is especially abundant and well exposed in the Owl Creek Mountain, the Beartooth Butte, and the Red Lodge study areas. Vertical tubes, horizontal tubes, and Rusophycus trace fossils are especially well exposed in Sections 3, 30, 31, 32, 37, and 41. The trace fossils will be discussed in greater detail in the chapter on paleontology.

PALEONTOLOGY

Trace Fossils

Horizontal tubes

Horizontal tubes are the most abundant trace fossils in the Flathead Formation in the thesis study area, especially in the middle and upper members. They consist of tubes of cemented sandstone on bedding plans. They are most commonly observed on the undersides of sandstone beds that overlie beds of shale. The tubes stand out in relief because they are more resistant to erosion. They are circular to sub-circular in cross section and are aligned in all directions on the bedding plane. The tubes are 5 to 25 millimetres in diameter and 20 to 150 millimetres long. They are well exposed at Sections 30, 31, 32, and 37. Annelid worms or trilobites are believed to have made these tubes (Banks, 1970). The same type of horizontal tubes have been found in upper Precambrian and lower Cambrian sandstone beds in Norway (Banks, 1970) and East Greenland (Cowie and Spencer, 1970).

Bilobate impressions

Rusophycus, which is a short, bilobate impression 20 to 50 millimetres wide and 30 to 70 millimetres long, is present in the middle and upper members of the Flathead Formation. Rusophycus consists of two subparallel impressions that are joined at one end. In some specimens, the impressions are curved and have their concave side facing another.

Rusophycus in this form looks much like a deer track. This bilobate impression is commonly found with horizontal tubes on the undersides of sandstone beds. Rusophycus has been identified in Sections 21, 27, 30, 31, and 32. Figure 12 is a photograph of Rusophycus that is exposed at Section 32.

Rusophycus was probably formed by a trilobite as it dug a resting burrow (Osgood, 1975) on the ocean floor. However, the sandstone of the Flathead Formation did not provide optimum conditions for the preservation of the trilobites that made Rusophycus.

Cruziana and Diplichnites, other burrows formed by trilobites crawling and walking on the ocean floor, are not found in the Flathead. However, these trace fossils are present in beds of the overlying Gros Ventre Formation at Section 41.

Vertical tubes

Vertical tubes, which are perpendicular to bedding, are present in the middle and upper members of the Flathead Formation in many parts of the thesis study area. Three types of vertical tubes have been identified.

Skolithos is a vertical tube that is 2 to 5 millimetres in diameter and 20 to 100 millimetres in height. The Skolithos tubes are filled with medium to coarse sandstone and are a lighter color and more resistant to erosion than the surrounding sandstone. The tubes are parallel to each other, 10 to 20 millimetres apart, and do not branch. Skolithos has been found only in the upper, medium to coarse sandstone in the Owl Creek Mountain area. Skolithos is abundant at

Fig. 12. Photograph of Rusophycus exposed at Section 32. For scale, the pen is 0.15 metres long.



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Section 41 and is also present at Sections 40 and 42. The bedding in the beds that contain Skolithos has been destroyed. Figure 13 is a photograph of Skolithos at Section 41.

The vertical tubes that are less than 3 millimetres in diameter and 5 to 15 millimetres high are Monocraterion (Häntzschel, 1975, p. 82-83). The tubes, which are funnel-shaped and taper to an apex at their lower ends, are slightly curved to vertical. The Monocraterion tubes are hollow and tend to be darker colored than the surrounding fine to coarse sandstone. These tubes are parallel to each other, 2 to 10 millimetres apart, and do not branch. Small impressions are formed on the top of beds that contain Monocraterion. These pitted surfaces are well exposed at Section 41. In most places, the bedding in the sandstone that contains Monocraterion has not been destroyed. At Section 41, small-scale cross bedding has been partially disturbed in beds that contain Monocraterion. Monocraterion is especially conspicuous at Sections 4, 11, 34, and 41, but it is also present at Sections 31, 32, 42, and 43 and at Outcrop 30. Figure 14 is a photograph of Monocraterion that is exposed at Section 41.

Large vertical tubes, which are 30 to 40 millimetres in diameter and 0.2 to 0.5 metres high, occur only at Section 41 in the upper member of the Flathead. These tubes are 30 to 50 millimetres apart and occur in a resistant bed 0.25 to 0.50 metres thick. The tubes have circular horizontal cross sections. In a vertical section these tubes contain well-preserved, cone-in-cone, downward-deflected bedding. Smaller Skolithos vertical tubes 3 to 5 millimetres in diameter were found in the same bed as the large vertical tubes. The top of the beds

Fig. 13. Photograph of Skolithos exposed at Section 41. Black numbers on the measuring tape are 0.10 metre apart.

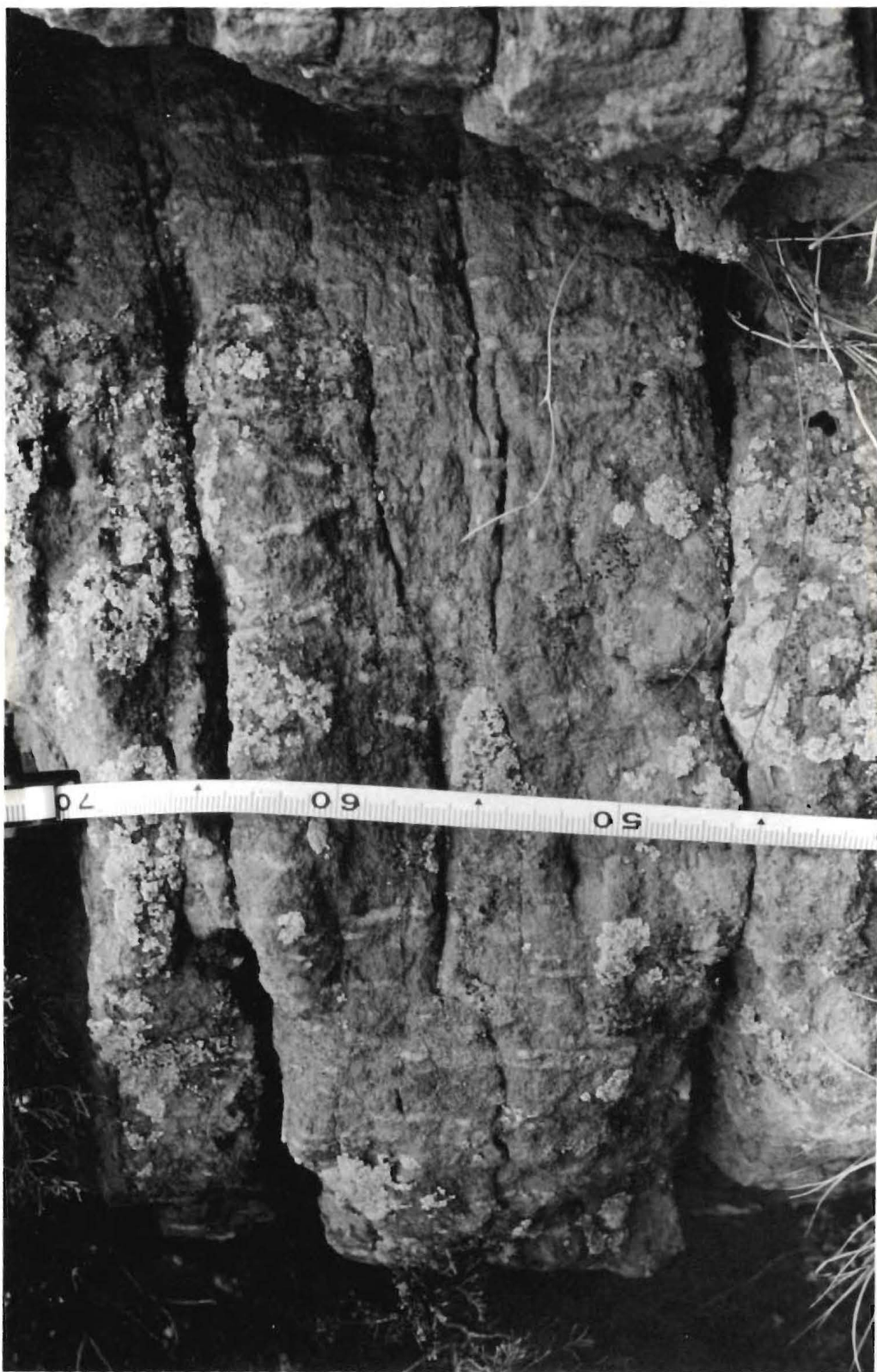
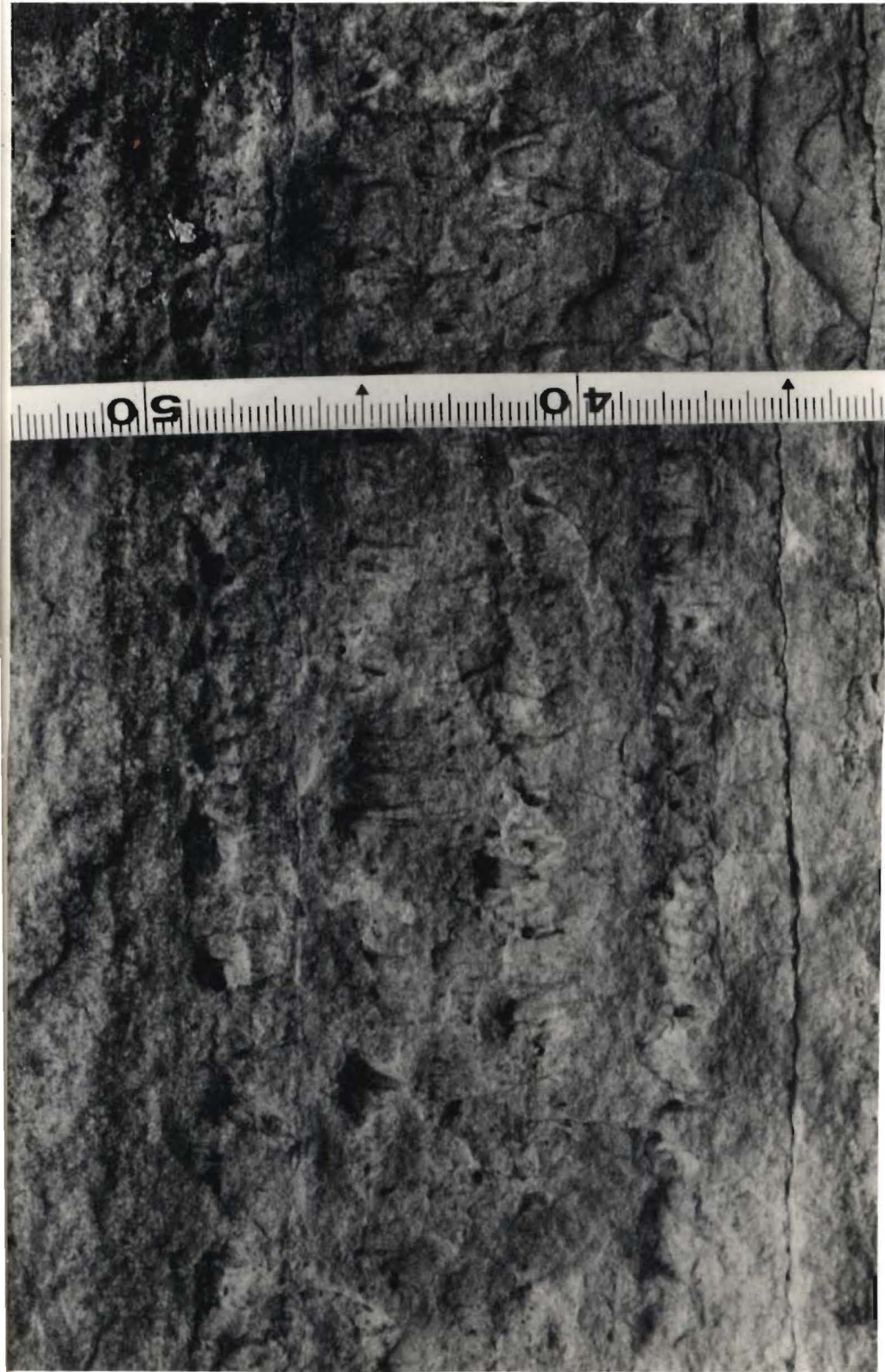


Fig. 14. Photograph of Monocraterion exposed at Section 41.
Black numbers on the measuring tape are 0.10 metre apart.



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containing the large vertical tubes have circular depressions 20 to 30 millimetres in diameter that have been eroded to form a pitted surface. A bed containing only Skolithos vertical tubes overlies the bed containing large vertical tubes in the upper member at Section 41. Figure 15 is a photograph of the large vertical tubes that are exposed at Section 41.

Origin of vertical tubes

Skolithos and Monocraterion vertical tubes are the preserved, resistant, mucous tubes that were secreted by suspension feeding animals (Crimes, 1975). These soft-bodied animals secreted the tubes to protect and stabilize the walls of their dwelling structure. Monocraterion probably represents a mucous tube and dwelling structure of an animal that was smaller than the animal which produced Skolithos. The funnel-shaped end of Monocraterion could represent an escape structure (Hallam, 1975). The apex-down, cone-in-cone bedding structure in the large vertical tubes represents an escape structure (Schinn, 1968) that an animal formed as it moved upwards in its dwelling structure in response to increasing sedimentation (Hallam, 1975).

Animals such as annelid worms, brachiopods, phoronid worms, and sea anemones have been proposed by some authors to have formed the Skolithos and Monocraterion vertical tubes (Häntzschel, 1975, p. 107-108). Boyd (1966) studied the large vertical tubes in the Flathead Formation and concluded that Arenicola, which is an annelid worm that produces U-shaped burrows, could not have formed the vertical tubes. Other annelid worms and burrowing sea anemones secrete mucous tubes and

Fig. 15. Photograph of large vertical tubes that are exposed at Section 41. Black numbers on the measuring tape are 0.1 metre apart.



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live in vertical dwelling structures (Schäfer, 1972, p. 287-299). Both animals have worm-like forms and respond to increasing sedimentation by moving upward. Both animals can form characteristic escape structures in their burrows when they move upward after being buried. The annelid worms do not form escape structures that look like those formed by sea anemones (Schäfer, 1972, p. 287-299). The escape structures of annelid worms are inclined from vertical and do not produce downward-deflected bedding. However, the escape structures formed by a modern burrowing sea anemone, Cerianthus (Schäfer, 1972, p. 288-289), moving upward after being buried, are very similar to the large vertical burrows found in the Flathead Formation. Frey (1970) reported that a sea anemone that lives below the low tide mark in the nearshore zone off the coast of North Carolina builds a durable, mucous tube as lining for its dwelling burrow. The mucous tube of this sea anemone permits preservation of the sediment that fills the burrow as the animal moves upwards. Schinn (1968) describes "nested-cone" structures in the burrows that were produced as the animal moved upwards in its burrow responding to sedimentation. These sea anemones live in cross-bedded oolitic sandstone in the Bahama Banks.

Some burrowing sea anemones produce resistant vertical mucous tubes without escape structures (Frey, 1970). These tubes are very similar to Skolithos and Monocraterion in the Flathead Formation.

The large vertical tubes in the Flathead probably are escape structures that were made by a burrowing sea anemone. Skolithos and Monocraterion probably are resistant mucous tubes that were made by smaller burrowing sea anemones or annelid worms.

Summary

The trace fossils in the Flathead Formation in the thesis area form a characteristic assemblage. The overlying Gros Ventre Formation in the Owl Creek Mountain area contains an abundant assemblage of Cruziana, Rusophycus, and many different kinds of horizontal tubes. This Gros Ventre assemblage together with the assemblage of trace fossils found in the Flathead Formation form two of the assemblages of the bathymetric zonation of trace fossils proposed by Seilacher (1967). In most places, the Flathead contains the Skolithos assemblage and the Gros Ventre contains the Cruziana assemblage. The Skolithos assemblage contains trace fossils formed in high and low-energy shore and nearshore environments. The Cruziana assemblage contains trace fossils formed in quieter nearshore and offshore environments (Seilacher, 1967).

The trace fossils in the Flathead Formation in the thesis area form an assemblage that is common in Cambrian sandstone throughout the world. Hallam and Swett (1965) have described Skolithos and Monocraterion in the lower Cambrian Pipe Rock of northwest Scotland. Banks (1970) has described Cruziana, Rusophycus, horizontal tubes, and vertical tubes from the Precambrian and lower Cambrian marine sandstone of northern Norway. Skolithos and Rusophycus have been described from lower Cambrian sandstone in southern Sweden (Bergström, 1970). In east Greenland, Cowie and Spencer (1970) have described lower Cambrian sandstone containing Skolithos, Diplichnites (trilobite trails), Cruziana, and horizontal tubes. Orłowski, Radwanski, and Roniewicz (1970) have described Rusophycus and Cruziana in the Cambrian sandstone in central Poland. In southern Jordan, Selly (1970) has described Cruziana,

Diplichnites, Rusophycus, Skolithos, and Monocraterion in the lower Ordovician sandstone.

Assemblages of trace fossils in the upper Cretaceous of the western interior of the United States are very similar to those found in the Flathead and Gros Ventre Formations. Frey and Howard (1970) have described trace fossils that belong to the Cruziana and Skolithus assemblages from the marine and marginal-marine sandstone of the upper Cretaceous in Utah. Howard (1972) used the primary structures and trace fossils belonging to the Cruziana and Skolithos assemblages to interpret a marginal-marine environment for the upper Cretaceous Blackhawk Formation in Utah.

Brachiopods

Brachiopods have been found in the upper beds of the upper member of the Flathead Formation in the Red Lodge area, the Clarks Fork Canyon area, and the Livingston area. They form an important correlation horizon in the top sandstone bed in the Red Lodge area at Section 31 and Section 32. Specimens found in other areas were poorly preserved, and therefore no identification was possible, but in the Red Lodge area three genera have been identified. The brachiopods in that area occur in Member M, which is 2 metres thick. However, the greatest concentrations of these fossils occur in a bed 0.1 to 0.2 metres thick.

Three genera of inarticulate brachiopods belonging to two different orders have been identified. Although preservation is good, identification to the species level was not attempted.

Micromitra has rounded or elliptical valves that are wider than they are high. Micromitra is about 7 millimetres high and 12 millimetres wide. Growth lines or rugae may be present on the shell surfaces. Micromitra belongs to the Order Paterinida.

Obolus has a valve with higher vertical dimensions than Micromitra, but it is not as elongate as Lingulella. Obolus has a slightly pointed beak, rugae, and is 10 millimetres high and 10 millimetres wide.

Lingulella is more elongate and has a more pointed beak than Obolus (Walcott, 1912, p. 469-474). Lingulella is teardrop shaped. Lingulella and Obolus belong to the Order Lingulida. Lingulella is 10 millimetres high and 5 millimetres wide.

All three of these brachiopods have been described by other geologists in the lower and middle Cambrian sandstone, shale, and limestone throughout the world (Walcott, 1912, p. 120). However, these are the first brachiopods that have been reported from the Flathead Formation. Brachiopods have been found in the Deadwood Formation, which is a stratigraphic equivalent of the Flathead Formation, in the Black Hills in South Dakota (Walcott, 1912, p. 825). Lochman (1964) identified brachiopods in the Deadwood Formation in the subsurface of the Williston Basin in Montana.

Inarticulate brachiopods such as those found in the Flathead Formation probably lived in burrows on the sandy ocean bottoms of the nearshore zone (Tasch, 1973, p. 294-295).

STRATIGRAPHY

Introduction

The Flathead Formation in each study area has been divided into three or four informal members. The members are distinguished from each other on the basis of grain size, primary structures, paleontology, color, and resistance to erosion.

A cross section has been included for each study area to show the stratigraphy, lithologic, and paleontologic relationships of the Flathead Formation. For each measured section shown in the cross section, the lithology, primary structures, grain size, color, trace fossils, brachiopods, and cross-bed set size have been shown. The location of each cross section in the study area is shown on an index map on the cross-section figure or on the study area location map.

Owl Creek Mountain Area

The Flathead Formation in the Owl Creek Mountain area can be divided into four members. This four-fold stratigraphic division can be applied to most of the Flathead Formation in this area with little difficulty. However, the formation can be quite uniform in some places, making application of this four-fold division difficult.

Figure 16 shows the four members in five sections in the study area. The sections include the overlying Gros Ventre Formation, the Flathead Formation, and the underlying Precambrian rock.

Fig. 16. Stratigraphic cross section of the Flathead Formation and lower Gros Ventre Formation in the Owl Creek Mountain area, Wyoming.

Member A

Member A may overlie the weathered zone or lie directly on Precambrian rock. This member contains poorly sorted, subangular, medium to very coarse, quartz sandstone. Quartz pebbles 5 to 30 millimetres in diameter are present throughout the sandstone. Two beds of conglomerate and some shale are also present in this member. The conglomerate contains potassium feldspar grains 30 millimetres in diameter and quartz grains that average 30 to 50 millimetres in diameter. However, quartz grains as large as 0.2 metres in diameter were found in the conglomerate. At Section 3, one bed of conglomerate 0.5 metres thick directly overlies the weathered zone. A second bed of conglomerate 0.1 metre thick, which contains fragments of Precambrian metasediments, is present 2.5 metres above the first conglomerate. The sandstone and conglomerate are normally brown and tan, but colors may range from white to red. The shale is red.

Large-scale cross bedding, with tabular and trough-shaped sets 0.1 to 0.4 metres thick, is the predominant bedding type in the sandstone of this member. Sets throughout this area are most commonly 0.1 metre thick. The cross beds in these sets dip west. Some cross beds are graded. Conglomerate and thin shale beds 0.1 metre thick are the only beds that show parallel bedding.

Individual beds in this member are 0.1 to 2.2 metres thick. The average thickness of the member is 7.0 metres. No trace fossils are present in this member.

Member B

Member B, which overlies Member A, consists of medium to poorly sorted, subangular, medium to coarse, quartz sandstone. Several beds of shale occur in the middle part of this member. At Section 41, several beds of shale 0.1 to 0.4 metres thick are well exposed between thicker sandstone beds. These shale beds are believed to occur throughout the area but in most outcrops occur in covered intervals. The sandstone is brown or tan, and the shale is red.

This member is either cross bedded or parallel bedded. All three types of bedding are present in varying amounts at each section. For example, at Section 41 this member has mostly large-scale cross bedding with a small amount of the other two types of bedding. At Section 3, this member consists mostly of sandstone with parallel bedding and small-scale cross bedding, with only one bed of sandstone with large-scale cross bedding. At section 43, this member consists of equal amounts of all three types of bedding. Local variations in the sedimentary environment explain these differences. The sets of cross bedding are 0.1 metre thick in most outcrops, but the sets are 1.2 metres thick in some places. The cross beds in the sets dip west to northwest. Channels, 2.0 metres thick, are exposed in a roadcut through the Flathead Formation in Section 41 in Wind River Canyon. The channels, which truncate underlying strata, are believed to have been formed by local erosion during the deposition of the sandstone.

The most common sandstone bed thickness is 2.3 to 3.3 metres. The member is 20 to 25 metres thick.

A horizontal burrow in Section 41 is the only trace fossil that has been found in this member.

Member C

Member C, which overlies Member B, contains medium to poorly sorted, subrounded, medium to coarse, quartz sandstone. Shale beds, 0.6 to 1.0 metres thick are also exposed in this member in Section 41 in Wind River Canyon. The sandstone is tan and brown, and the shale is red.

This member consists predominantly of sandstone with parallel and small-scale cross bedding. Some large-scale sets of cross bedding that range in thickness from 0.1 to 0.4 metres are present at Section 3. The cross beds in these sets dip west. At Section 41, the medium sandstone of this member is mostly parallel bedded. At Section 41, small-scale cross bedding predominates in the medium to coarse sandstone.

Sandstone beds in Member C are characteristically thinner than in adjacent members. The common bed thickness is 0.3 to 0.9 metres. The member is 10.0 to 13.5 metres thick.

Horizontal tubes are present in several sandstone beds at Section 41. The tubes are found on the bottom sides of sandstone beds that lie above shale beds. Monocraterion is present at both Section 41 and Section 3. These vertical tubes are used as a local marker horizon. The bedding generally was not disturbed by the vertical burrowers who made these tubes, and in some places small-scale cross bedding is observed in beds that contain these vertical tubes.

Member D

Member D, which overlies Member C, contains medium-sorted, sub-rounded, coarse, quartz sandstone. Some interbedded shale occurs in the upper part of this member. The sandstone is brown or tan. The interbedded shale is green. A color change from the brown and tans of the Flathead Formation to the greens of the lower Gros Ventre Formation can be easily seen throughout this study area.

This member contains all types of bedding, but large-scale cross bedding is the most common. Well-exposed cross bedding is present at Section 41, where sets from 0.1 to 0.3 metres thick are present. The cross beds in the sets dip both to the east and to the west. Trough-shaped cross bedding is exposed in the lower part of the member at Section 41. Sets of cross bedding up to 0.5 metres thick are present at Section 3. Small-scale cross bedding is commonly present with this large-scale cross bedding at Section 3. At Section 51, tabular and trough-shaped sets of cross bedding as thick as 2.0 metres are exposed. The cross beds in the sets dip south.

Beds in this member are thicker than in the underlying member and range from 0.2 to 5.0 metres in thickness. Member D averages 12.0 metres in thickness.

One of the most characteristic features of this member is the presence of vertical tubes in almost every section throughout the study area. The tubes occur near the top of the Flathead Formation, which is the top of the predominant sandstone section, and just below the interbedded fine sandstone and shale of the Gros Ventre Formation. The beds that contain vertical tubes form a reliable marker horizon.

Skolithos, large vertical tubes, and Monocraterion are present. The bedding has been destroyed by burrowing organisms in some places in this member. Horizontal tubes are found near the top of the Flathead Formation, but large numbers of horizontal tubes are found only in the lower Gros Ventre Formation.

Precambrian rock

The Precambrian granitic and metamorphic rock is unconformably overlain by a weathered zone in some parts of the study area. The weathered zone contains crumbly, intensely-weathered, granitic rock or metasediment. Large blocks of weathered granite up to 1.0 metre in diameter are present at Section 40 in Wind River Canyon. At Section 3, quartz cobbles 0.15 to 0.2 metres in diameter are present in the weathered metasediment. No bedding is present in the weathered zone. When present, this zone is 1.5 to 2.0 metres thick.

Gros Ventre Formation

The interbedded sandstone and shale of the lower Gros Ventre Formation is gradational from the sandstone in the upper part of the Flathead Formation. The lower Gros Ventre Formation is mostly green and contrasts noticeably from the underlying brown or tan Flathead Formation. The formation boundary has been drawn at the point where sandstone and shale are equally abundant and the color changes. The Gros Ventre Formation gradually changes upward into shale.

The lower part of the Gros Ventre Formation contains an abundant assemblage of trace fossils. Cruziana, Rusophycus, Diplichnites, and

horizontal tubes are characteristically well exposed in the Gros Ventre Formation. Vertical tubes were also found in one section.

Lingulid brachiopods occur in some sandstone beds between the shale beds. The brachiopod sandstone is commonly red and forms resistant ledges that crop out in otherwise covered intervals. Some of these sandstones are cross bedded and have trough-shaped sets, showing that these brachiopods may have been mechanically concentrated. Other brachiopod sandstones show no evidence of mechanical concentration. The brachiopod sandstone beds form marker horizons.

Sunlight Basin, Clarks Fork Canyon, and Cody Area

General

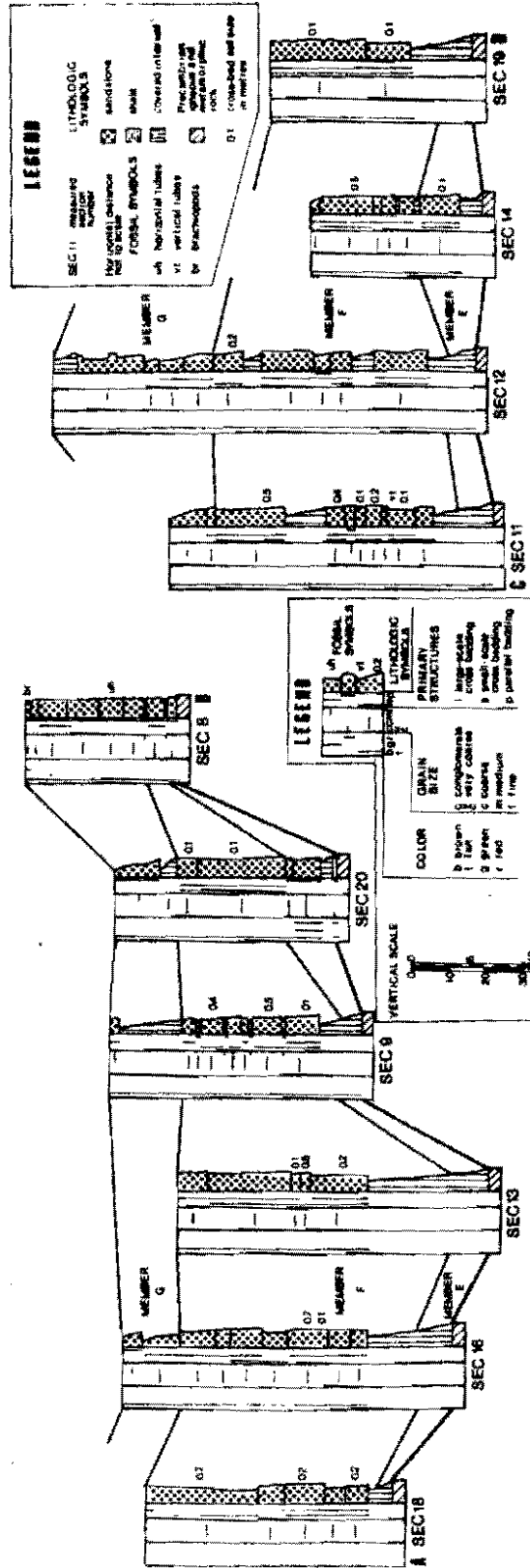
The Flathead Formation in the Sunlight Basin, Clarks Fork Canyon, and Cody area has been divided into three members. In the Sunlight Basin, the middle member has been well indurated to a quartzitic sandstone. The quartzitic nature of the sandstone in many places makes field identification of grain sizes and primary structures difficult.

Figure 17 is a cross section of measured sections in the Sunlight Basin and Clarks Fork Canyon. An east-west and north-south cross section is shown in Figure 17.

Member E

Member E overlies a weathered zone or lies directly on Precambrian rock. This member contains poorly sorted, angular to subangular, medium to very coarse, quartz sandstone. Quartz pebbles 5 to 50 millimetres in diameter are present throughout the member. Conglomerate and shaly sandstone are also present in this member. Beds of shaly sandstone

Fig. 17. Stratigraphic cross section of the Flathead Formation in the Sunlight Basin and Clarks Fork Canyon area, Wyoming. Location of cross sections is shown on Fig. 3.



LEGEND

LITHOLOGIC SYMBOLS

SEC 11: measuring section
 No fossiliferous
 Fossil symbols
 Horizontal tubes
 Vertical tubes
 Brachiopods
 Covered on the left
 Shale
 Fossiliferous sandstone
 Fossiliferous shale
 Fossiliferous limestone
 Covered on the right
 D1: Crinoidal and spongy in texture

LEGEND

GRAIN SIZE

1 conglomerate
 2 sandy coarse
 3 sand
 4 fine medium
 5 fine

COLOR

1 brown
 2 tan
 3 green
 4 red

PRIMARY STRUCTURES

1 inter-scale
 2 cross bedding
 3 wash marks
 4 horizontal bedding
 5 parallel bedding

Fossil Symbols

1 horizontal tubes
 2 vertical tubes
 3 brachiopods

VERTICAL SCALE

0
 100
 200
 300

at Section 4 and Section 20 have quartz and potassium feldspar grains up to 50 millimetres in diameter. This bed contains approximately 60 percent quartz, 30 percent potassium feldspar, and 10 percent mica. The shaly sandstone is poorly sorted; it contains thin beds of shale and large quartz and potassium feldspar grains. At Section 4 in Shoshone Canyon, this bed of shaly sandstone forms a wedge 0.0 to 4.0 metres thick and lies directly on weathered Precambrian rock. At Section 20, a conglomerate bed 0.2 metres thick with rounded quartz pebbles up to 0.15 metres in diameter, lies directly on Precambrian rock. The sandstone and conglomerate are brown or tan, and the shaly sandstone is green, brown, and red.

Parallel bedding is the predominant bedding type of this member. However, small-scale and large-scale cross bedding is present in this member in a few places. The large-scale sets are 0.1 metre thick.

The member ranges in thickness from 0.7 to 8.0 metres. The member is commonly covered, but good outcrops are present at Section 4, 14, 20, and 8.

Member F

Member F, which overlies Member E, consists of medium to poorly sorted, subangular to subrounded, medium to coarse, quartz sandstone. Beds of shale 50 to 150 millimetres thick are present throughout this member. A bed of medium to very coarse sandstone 1.2 metres thick, which has subrounded to rounded quartz grains, was found in two sections in this member. This member is brown and tan.

Cross bedding is the predominant bedding type in this member. Large-scale and small-scale cross bedding occurs in equal amounts. Parallel bedding is uncommon, except in shale beds. Large-scale, tabular and trough-shaped sets are 0.1 to 1.0 metres thick. The most common set size is 0.1 metre thick. Most cross beds in these sets dip west but at Section 16 and Section 4 some cross beds in some sets dip north and south. A channel orientated in an east-west direction was found at Section 16. This channel is 4.6 metres deep and approximately 10 to 15 metres across. The channel is believed to have been formed by local erosion.

The most common sandstone bed thickness is 1.5 to 2.5 metres. Member F is 1.7 to 22.0 metres thick.

The lower part of this member in many places is covered. Good outcrops in Sections 14, 20, 8, and 4 show the contact between the lower part of Member F and the underlying Member E. The upper surface of Member F forms a resistant bench in the Sunlight Basin area. This bench simplifies correlation in that area. In Shoshone Canyon at Section 4, and at Section 20 in Clarks Fork Canyon, this surface is easily recognizable and separates the cross-bedded Member F from the overlying parallel-bedded member. In many places in the Sunlight Basin the strata overlying the resistant bench have been removed by glacial erosion. In all sections, except Section 4 and Section 8, the sandstone has been well indurated. The sandstone in these areas is quartzitic.

Trace fossils in this member have been found in only two places. Vertical tubes were found at Section 4 and Section 11.

Member G

Member G contains medium to poorly sorted, subangular to sub-rounded, fine to coarse, quartz sandstone. The beds of this member become finer grained upwards. The sandstone is brown and tan but is characteristically lighter colored than the underlying member.

Parallel bedding is the predominant bedding type in this member, but small-scale cross bedding is common throughout the member. Large-scale cross bedding is present in the lower part of the member at Section 4. Bedding is hard to distinguish in some beds in this member. It is thought the bedding in these beds has been destroyed or disturbed by burrowing organisms.

Beds in this member are thinner than in the underlying members. A thickness of 0.05 to 0.1 metres is the most common bed thickness. Member G ranges in thickness from 4.0 to 17.0 metres. At Section 4, 17.0 metres of Member G are overlain by sandy shale of the Gros Ventre Formation.

Trace fossils in this member have been found in only two places. Horizontal tubes were found in the middle part of the member at Section 4 and Section 8. Brachiopod fossils were found in the upper bed at Section 8, but the specimens were poorly preserved and no identification was possible.

Precambrian rock

Precambrian granite and granitic gneiss underlie the Flathead Formation. A weathered zone of Precambrian rock overlies the Precambrian at Section 4 in Shoshone Canyon near Cody. This weathered zone is up to

1.0 metre thick and contains weathered and unweathered rock fragments up to 0.2 metre. The weathered zone is variable in thickness and is not present everywhere beneath the Flathead Formation at Section 4. A weathered zone is not present at Section 8 and Section 20 in Clarks Fork Canyon, where the Flathead sandstone and conglomerate lie directly on unweathered Precambrian rock. The Precambrian-Flathead contact is covered in all sections in the Sunlight Basin.

Beartooth Butte and Cooke City Area

General

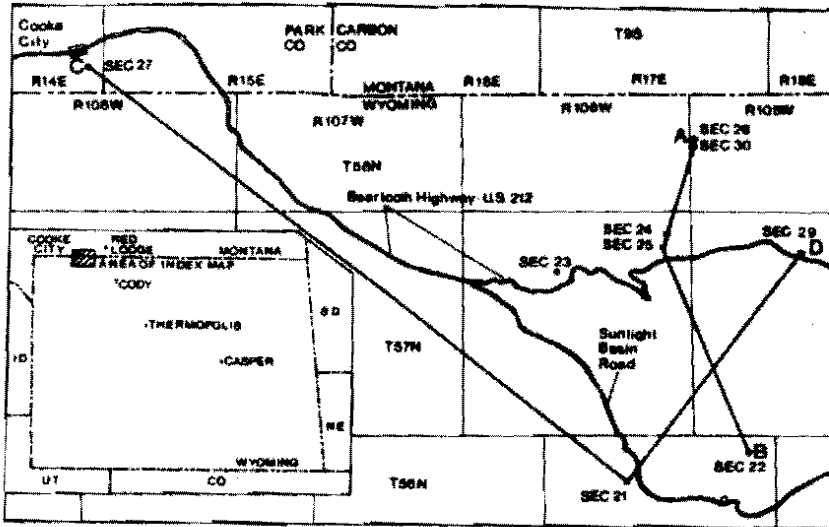
The Flathead Formation in the Beartooth Butte and Cooke City area has been divided into three members. The Flathead Formation at Cooke City has been slightly metamorphosed to quartzitic sandstone near intrusive rocks.

Figure 18 is a cross section of measured sections in the Beartooth Butte and Cooke City area. An east-west and north-south cross section is shown.

Member H

Member H lies directly on Precambrian rock. This member contains conglomerate and poorly sorted, angular, medium to very coarse, quartz sandstone. Quartz pebbles 20 to 70 millimetres in diameter are present throughout this member. A conglomerate bed at Section 30 contains quartz cobbles 0.1 metre in diameter and fragments of Precambrian rock. A sandstone bed at Section 22 contains approximately 10 percent potassium feldspar. The sandstone and conglomerate are brown and red.

Fig. 18. Stratigraphic cross section of the Flathead Formation in the Beartooth Butte and Cooke City area, Wyoming and Montana.



LEGEND

SEC 26 measured section number

Horizontal distance not to scale

FOSSIL SYMBOLS

uh horizontal tubes

ru *Rensselaerella*

LITHOLOGIC SYMBOLS

☒ sandstone

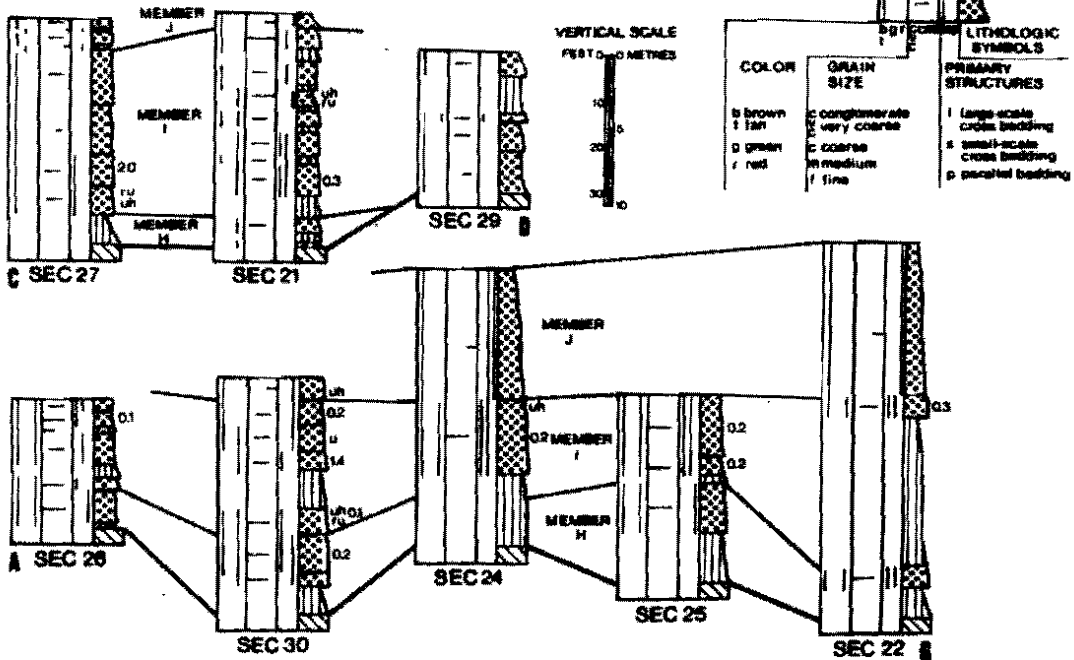
▨ covered shales

▧ Precambrian igneous and metamorphic rock

0.2 cross-bed salt 0.22 in section



INDEX MAP



Parallel bedding is the predominant bedding type in the conglomerate. Large and small-scale cross bedding is the predominant bedding type in sandstone. The large-scale sets are 0.2 metres thick.

The member ranges in thickness from 2.0 to 5.5 metres. The contact with the Precambrian rock is commonly covered but the rest of the member is well exposed in most sections. A conglomerate bed 0.3 to 1.7 metres thick is present in many exposures; especially at Beartooth Butte. No trace fossils were found in this member.

Member I

Member I, which overlies Member H, consists of poorly sorted, angular to subangular, medium to very coarse, quartz sandstone. The sandstone is brown and red.

Cross bedding is the predominant bedding type in this member. Large-scale and small-scale cross bedding occurs in equal amounts. Parallel bedding is uncommon. Large-scale, tabular and trough-shaped sets are 0.1 to 1.4 metres thick. The most common set size is 0.2 metres. Most cross beds in these sets dip west or southwest. Mud-cracks were found in the lowest part of the member at the south and east side of Beartooth Butte.

The member ranges in thickness from 6.0 to 12.5 metres. Sandstone beds 1.4 to 1.7 metres thick are most common. The upper part of Member I is covered by landslide deposits in many places. At Section 27 near Cooke City, Member I has been slightly metamorphosed to quartzitic sandstone by an overlying sill.

Horizontal tubes were found in this member at Sections 21, 23, 24, 27, and 30. Most beds that contain these trace fossils are red. Rusophycus was found with horizontal tubes in Sections 21, 27, and 30.

Member J

Member J contains medium to poorly sorted, subangular to sub-rounded, medium to coarse, quartz sandstone, but most beds contain medium to fine sandstone. The sandstone is brown, red and green.

Parallel bedding is the most common bedding type, but some small-scale cross bedding is present. Bedding has been destroyed by burrowing organisms at Section 22. These beds at Section 22 are the same as Member G in the Sunlight Basin. Ripple marks were found at Section 27 near Cooke City.

The member is 1.3 to 10.5 metres thick. The member is commonly covered by landslide deposits. The horizontal tubes present at Section 30 are the only trace fossils that were found in this member.

Precambrian and younger igneous rock units

The Flathead Formation overlies Precambrian igneous and metamorphic granite, granitic gneiss, and gabbro. The Flathead Formation north and south of Cooke City has been intruded by monzonite sills and dikes of Tertiary age.

A weathered zone of Precambrian rock was not exposed in this area, but may exist because the basal Flathead contact was covered in most sections.

Red Lodge Area

General

The Flathead Formation in the Red Lodge area has been divided into three members. Figure 19 shows the three members in Section 31 and Section 32 south of Red Lodge.

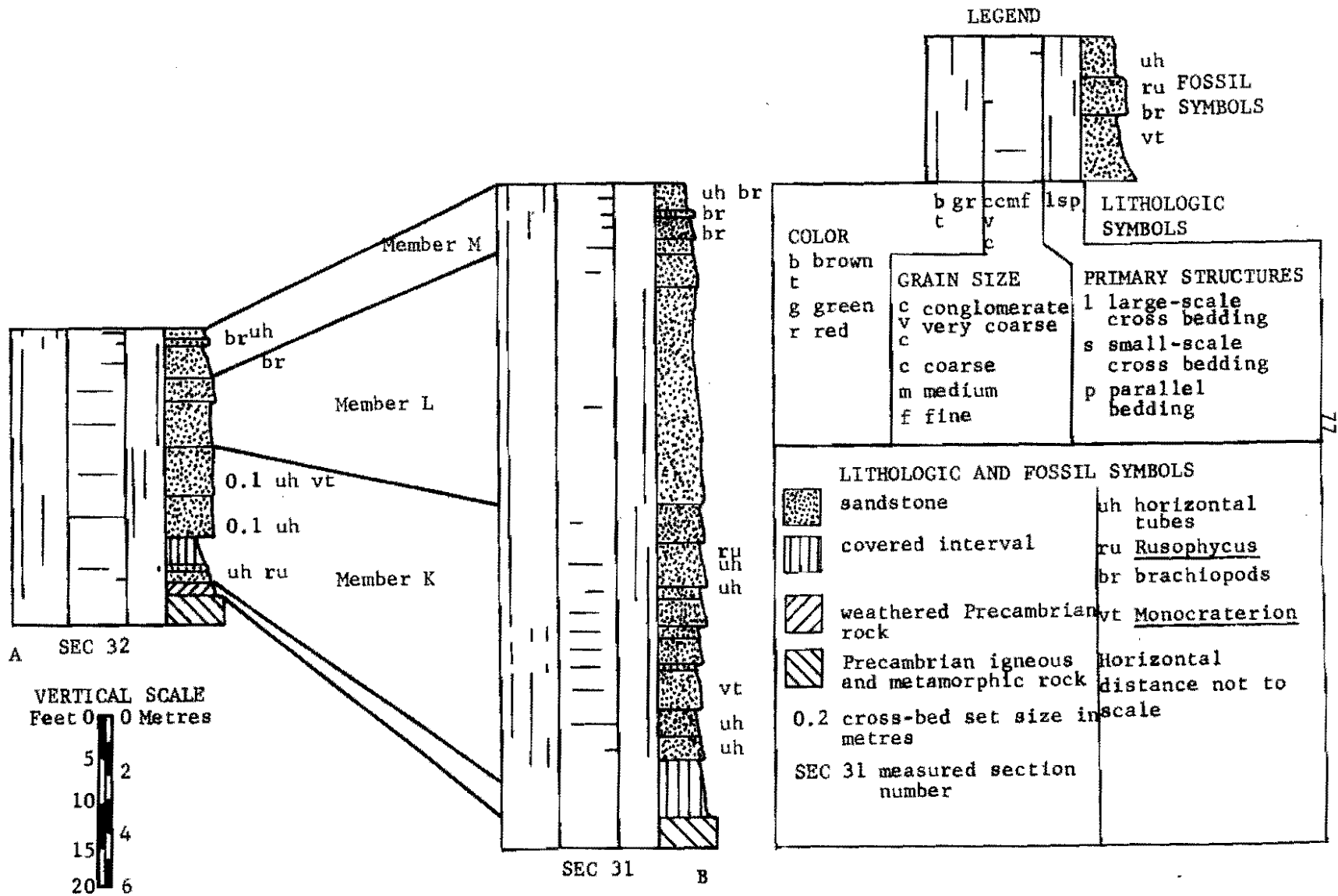
Member K

Member K lies directly on a weathered zone at Section 32, but the contact is covered in other outcrops in the Red Lodge areas. The member contains medium to poorly sorted, angular to subangular, fine to very coarse, quartz sandstone. Quartz pebbles up to 10 millimetres in diameter are present in several beds in this member, but no conglomerate was found. A sandstone bed at Section 32 contains approximately 5 to 10 percent potassium feldspar. Shale beds 10 millimetres thick occur between the beds of sandstone in the lower and middle part of the member. The sandstone is green, red, and brown, and the shale is red.

Parallel bedding is the predominant bedding type at Section 31, but small-scale cross bedding is also present in the upper part of the member. Cross bedding is the predominant bedding type at Section 32. Large-scale cross bedding is most common; the sets are 0.1 metre thick, and cross beds in the set dip south. Some parallel bedding is also present in the lower part of the member at Section 32. Bedding in part of this member at Section 32 has been destroyed by burrowing organisms.

The member ranges in thickness from 4.6 to 9.5 metres. Most beds in this member are 1.0 to 1.4 metres thick and are separated from each other by thin beds of shale. A bed of green, shaly sandstone at

Fig. 19. Stratigraphic cross section of the Flathead Formation in the Red Lodge area, Montana. Location of cross section is shown on Fig. 5.



Section 32 is very similar to a bed of shaly sandstone at the base of Section 4 in Shoshone Canyon and Section 20 in Clarks Fork Canyon.

Trace fossils are abundant and well exposed in this member in the Red Lodge area. Horizontal tubes are present in all parts of the member, and are well exposed in the upper part of the member at Section 31. Rusophycus and Monocraterion were found in the lower and upper part of the member. At Section 32, horizontal tubes and Rusophycus are excellently exposed on the bottom of a sandstone bed that lies on a weathered zone of Precambrian rock.

Member L

Member L, which overlies Member K, consists of medium to poorly sorted, subangular to subrounded, medium to coarse, quartz sandstone. At Section 31 this member consists of medium sandstone. The sandstone is brown to tan.

Parallel bedding is the only bedding type present in this member. The member ranges in thickness from 2.3 metres at Section 32 to 8.4 metres at Section 31. At Section 31, a thick, resistant bed of sandstone 7.3 metres thick is present. This bed forms a steep cliff, which makes thorough description of the sandstone difficult. This bed is not present at Section 32. Local variations in depositional conditions probably explain the presence of this bed at Section 31. The upper part of Member L forms a resistant bench in the study area. No trace fossils or brachiopods were found in Member L.

Member M

Member M contains well to medium sorted, subrounded, fine to medium, quartz sandstone, which is brown, red, or green. Parallel bedding is present in one bed at Section 32, but no bedding was found in the rest of the member at Section 31 and Section 32. The absence of bedding is probably due to the action of burrowing organisms.

The member is 1.5 to 2.4 metres thick. The member forms an important correlation horizon in the Red Lodge Area because of its abundant lingulid brachiopods. The bed containing brachiopods in the Red Lodge area is the same as the top part of Member G at Section 8 in the mouth of Clarks Fork Canyon. Horizontal tubes are present at both Section 31 and Section 32.

The member is made up of three beds. The lowest, fine to medium, brown sandstone bed contains few brachiopods and is 1.0 to 1.4 metres thick. The middle, fine-grained, green sandstone bed contains abundant brachiopods, and is 0.1 metre thick. The upper, fine-grained, red sandstone bed contains horizontal tubes and few brachiopods, and is 0.4 to 0.9 metre thick.

Precambrian rock

The Flathead Formation overlies Precambrian gabbro, granite, and granitic gneiss. The Precambrian rock is well exposed in the area of the south fork of Grove Creek. At Section 32, Precambrian metamorphic rock has been intruded by a younger Precambrian gabbro.

A weathered zone of Precambrian granitic gneiss 0.4 metres thick is present at Section 32. The thickness of the weathered zone varies

along the outcrop. The weathered zone, which varies in thickness along the outcrop, is overlain by lower Flathead sandstone that has abundant, well-exposed horizontal tubes and Rusophycus.

Livingston and Manhattan Area

General

The Flathead Formation in the Manhattan and Livingston area has been divided into three members. Figure 20 shows the three members in Sections 45, 48, 49, and 50 south and southeast of Livingston.

Member N

Member N overlies Precambrian granitic gneiss and amphibolite at Section 48. At Section 47 north of Manhattan, Member N overlies the Precambrian Lahood Formation. The underlying Precambrian rock is covered at all other sections in the Livingston area. This member contains poorly sorted, angular to subangular, medium to coarse, quartz sandstone. Quartz pebbles up to 40 millimetres in diameter are present in the sandstone in some places. Some very coarse sandstone is present at the bottom of Section 47. A conglomerate bed 2.6 metres thick overlies the Precambrian rock at Section 43. This conglomerate bed contains rounded quartz and rock fragments up to 0.4 metres in diameter. The sandstone and conglomerate in this member are red and brown.

Large-scale cross bedding, with sets 0.1 metre thick, is the predominant bedding type at Section 45 and Section 47. Small-scale cross bedding is also present at Section 45. Parallel bedding is also found in the member at Section 45 and Section 47. No bedding is present in the conglomerate at Section 48.

Fig. 20. Stratigraphic cross section of the Flathead Formation in the Livingston area, Montana. Location of cross section is shown on Fig. 6.

The member is 3.9 to 6.3 metres thick. No trace fossils were found in this member.

Member O

Member O overlies Member N at Sections 45, 47, and 48. The lower contact of this member at Section 49 and Section 50 is covered. This member consists of medium to poorly sorted, subrounded to rounded, fine to coarse, quartz sandstone. Quartz pebbles 5 to 30 millimetres are present throughout the member at Section 50 and Section 48. These pebbles occur either dispersed through the sandstone or in layers between sandstone beds. Very coarse sandstone is present in a few places at Section 49 and Section 48. The sandstone is mostly red at Sections 48, 45, and 49, but it is brown at Section 50 and Section 47.

Parallel bedding is the predominant bedding type in this member, but some small-scale cross bedding occurs at Section 45 in the middle of the member.

This member is 9.1 to 12.0 metres thick. The most common bed thickness is 1.4 to 2.0 metres. A covered interval of approximately 15 metres, which is thought to contain a body of intrusive rock, splits the exposures of Member O at Section 47 into two parts. The sandstone is quartzitic where it has been well indurated in Sections 47, 50, and 49.

Member P

Member P, which overlies Member O, consists of medium to poorly sorted, subangular to subrounded, fine to coarse, quartz sandstone. Some very coarse sandstone is present in this member at Sections 47, 48,

and 49. At Sections 45, 47, and 50 fine to medium sandstone occurs in the upper part of this member. Quartz pebbles 10 to 30 millimetres are present in this member at Section 47 and Section 48. Potassium feldspar grains 10 millimetres in diameter are present in this member at Section 47. The predominant colors are brown and tan, but red sandstone is also present.

Small-scale cross bedding is the most common bedding type in this member at Sections 45, 48, and 49. At Section 47, large-scale cross bedding and parallel bedding are present in equal amounts. Cross bed sets are 0.1 metre thick.

The member is 2.0 to 9.3 metres thick. This member has been indurated to a quartzitic sandstone at Sections 47, 49, and 50.

Horizontal tubes were found in two beds in this member at Section 48. The action of the burrowing organisms that created the tubes has destroyed part of the bedding at Section 48. Brachiopods were found in the top beds at Section 45 and Section 50, but the fossils could not be identified because of their poor preservation.

Precambrian rock

The Flathead Formation in the Livingston area overlies Precambrian granitic gneiss, metasediment, and amphibolite. The Precambrian rock is exposed only at Section 48 and near Section 45. In the Manhattan area, the Flathead Formation overlies the Precambrian Lahood Formation. The Lahood Formation, which is part of the Belt Supergroup, contains arkose. A weathered zone was not exposed in the Manhattan area or in the Livingston area.

Bighorn Mountain Area

General

The Flathead Formation in the Bighorn Mountain area has been divided into three members. Figure 21 shows the lower two members in Sections 5, 6, 7, and 52.

Member Q

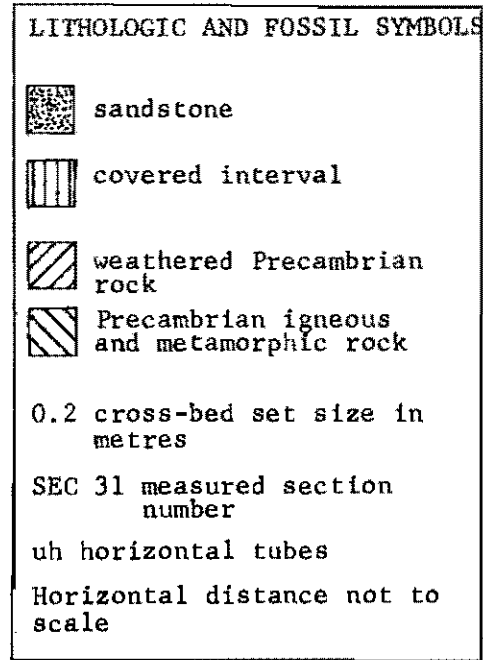
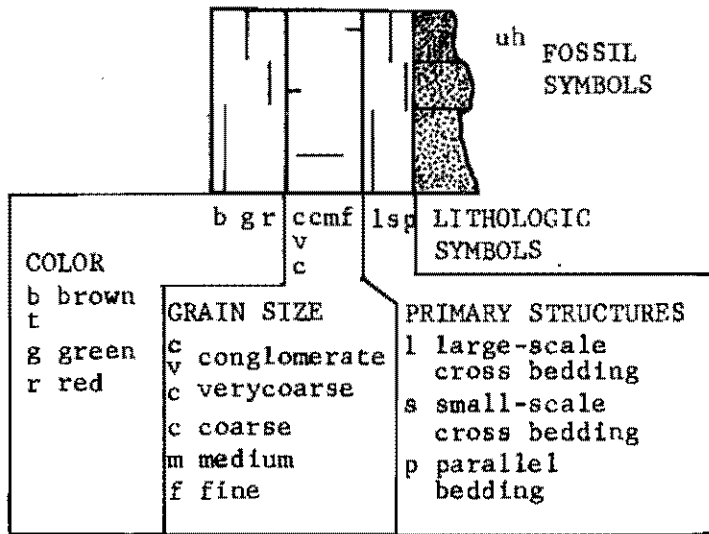
Member Q either overlies the weathered zone or lies directly on Precambrian rock. This member contains poorly sorted, angular to sub-angular, medium to very coarse, quartz sandstone and conglomerate. Quartz pebbles 10 to 100 millimetres are present in the conglomerate beds at Section 5 and Section 6. The pebbles at Section 5, where 4 metres of conglomerate is present, are subrounded. The conglomerate bed at Section 6, which is 2.4 kilometres (1.5 miles) from Section 5, is only 0.1 metre thick. The sandstone is red, brown, and tan, and the conglomerate is red..

Cross bedding is the predominant bedding type of this member. Large-scale cross bedding, with sets 0.1 to 1.0 metre thick, is present at Section 7 and Section 52. At Section 52, cross beds in the sets dip southwest. Small-scale cross bedding is present at Section 6. Conglomerate beds and a few sandstone beds are parallel bedded.

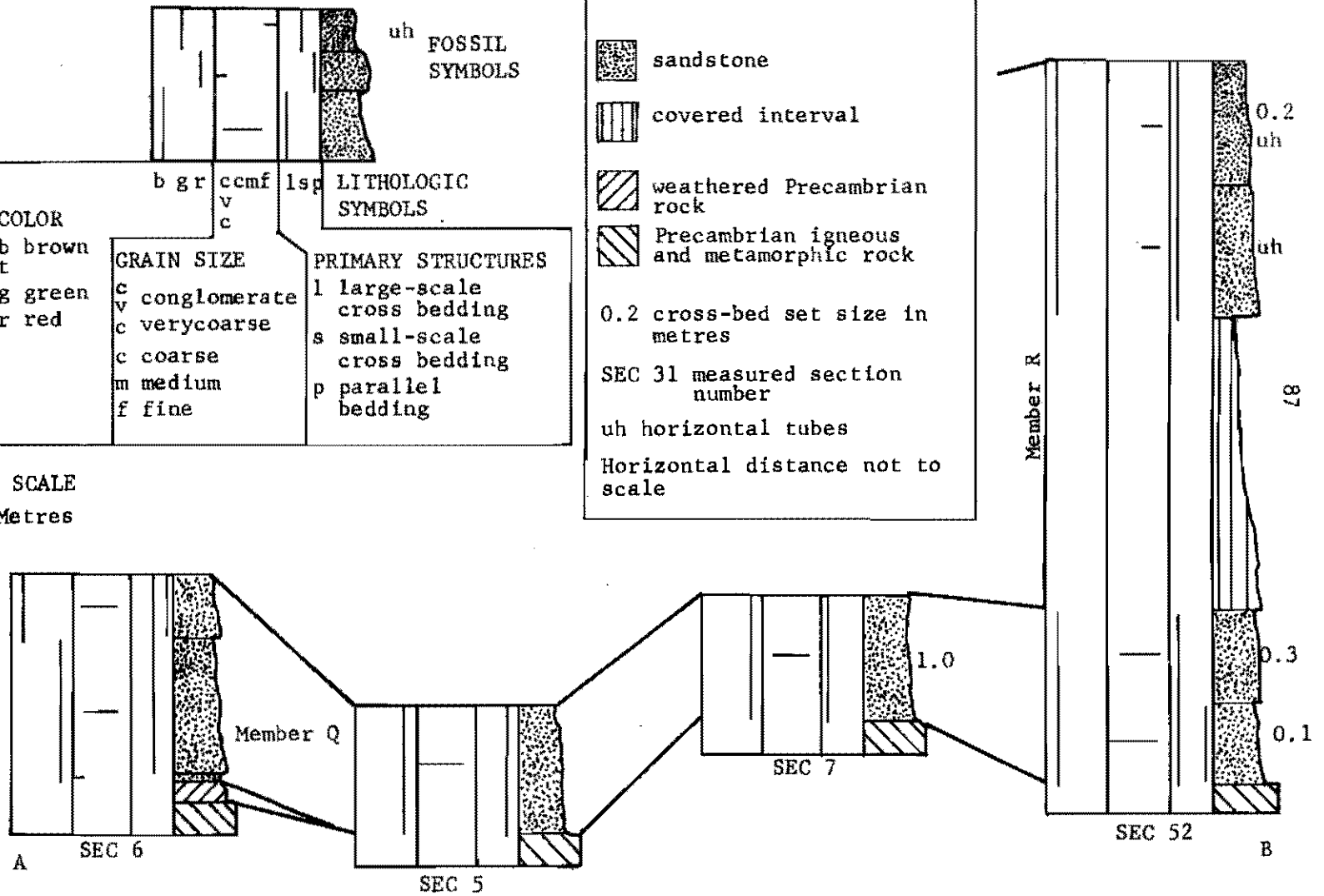
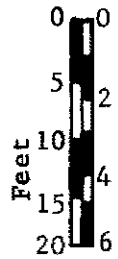
This member is 4.0 to 6.5 metres thick. No trace fossils were found in this member. Member Q is very similar to Member A in the Owl Creek Mountain area.

Fig. 21. Stratigraphic cross section of the Flathead Formation in the Bighorn Mountain area, Wyoming. Location of cross section is shown on Fig. 7.

LEGEND



VERTICAL SCALE



Member R

Member R overlies Member Q at Section 52 and Outcrop 30. The member consists of medium sorted, subangular, medium, quartz sandstone. The sandstone is brown and red.

Large-scale cross bedding, with sets 0.1 to 0.2 metre thick, is the predominant bedding, but some parallel bedding is also present.

The member is 18 metres thick at Section 52, but the lower 10 metres are covered. The strata above the member at Section 52 were also covered. Horizontal tubes, found in two beds at Section 52, were the only trace fossils found. Member R is similar to Member B in the Owl Creek Mountain area.

Member S

Member S, which is red and brown, fine to medium, quartz sandstone, overlies Member R at Outcrop 30. No bedding was noted, but in the top bed some evidence of burrowing was found in a bed that contained vertical tubes. Because of the poor quality of the outcrop no thicknesses were measured. Member S is similar to Member C in the Owl Creek Mountain area.

Precambrian rock

The Flathead Formation overlies Precambrian granite and granitic gneiss. A weathered zone of Precambrian rock 0.6 metres thick is exposed at Section 6, and may exist in other areas, although such a zone was not exposed at the other sections in this study area.

Little Belt Mountain and Smith River Basin Area

General

The Flathead Formation in the Little Belt Mountain and Smith River Basin area has been divided into three members. In the Smith River Basin the Flathead Formation has been well indurated to a quartzitic sandstone. The quartzitic nature of the sandstone in many places makes field identification of grain size and primary structures difficult. Figure 22 is a cross section of the measured sections in the Little Belt Mountain and Smith River Basin area.

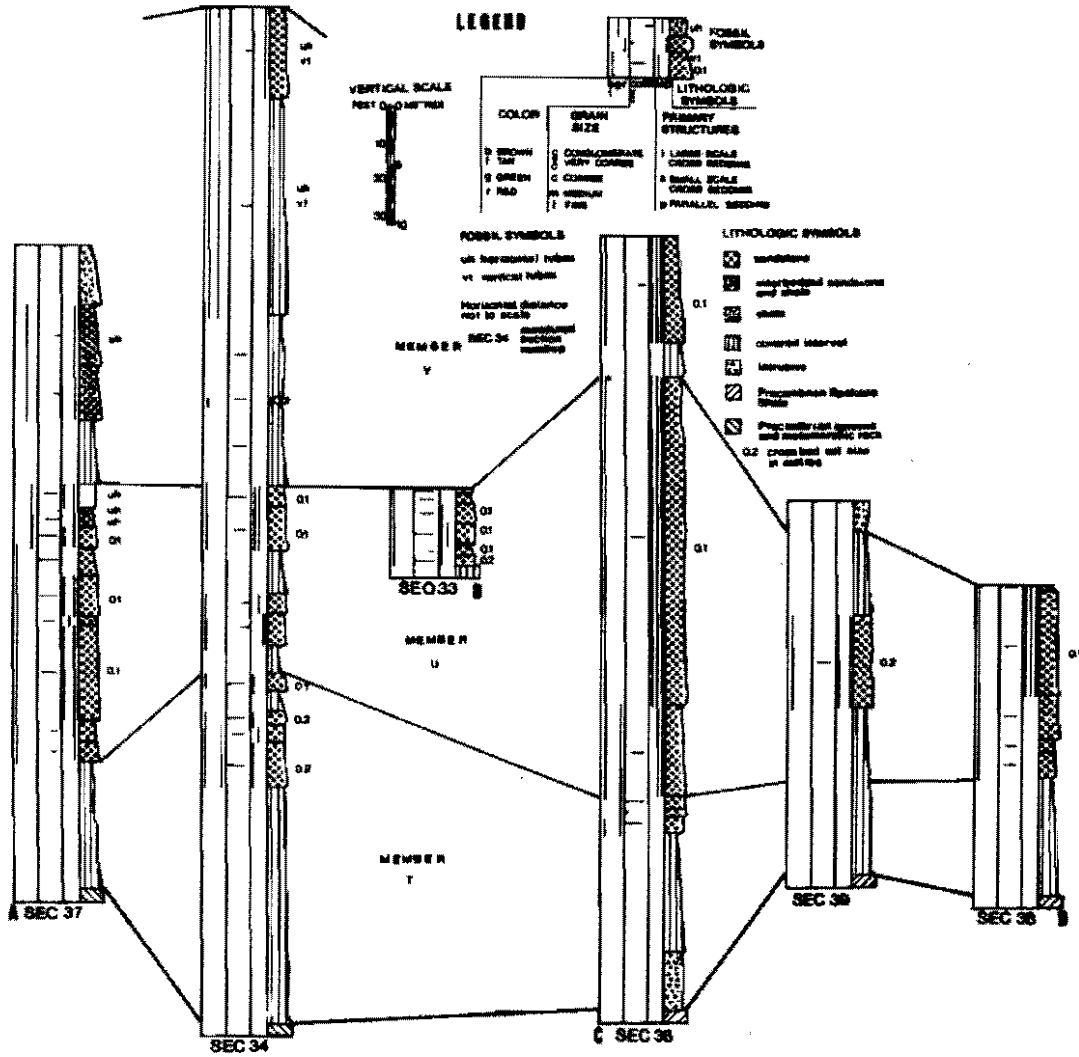
Member T

Member T overlies Precambrian igneous, metamorphic, and sedimentary rock. This member which is exposed only at Section 34 and Section 36, contains poorly sorted, angular to subangular, medium to very coarse quartz sandstone and conglomerate. Quartz pebbles 10 millimetres in diameter and a conglomerate bed 0.5 metres thick, are present in this member at Section 36. The sandstone and conglomerate are red and brown.

Large-scale cross bedding, with sets 0.1 to 0.2 metres thick, is the predominant bedding type observed in this member at Section 34, but one bed with small-scale cross bedding is also present. No bedding was found at Section 36 where the beds have been indurated to quartzitic sandstone.

This member is 12.9 to 32.0 metres thick, but the lower and middle parts of the member are covered in all sections. The thicknesses of the covered intervals is approximate because of the poor quality of

Fig. 22. Stratigraphic cross section of the Flathead Formation in the Little Belt Mountain and Smith River Basin area, Montana. Location of cross section is shown on Fig. 8 and Fig. 9.



the exposures. The outcrops of the upper part of the member at Section 34 and Section 36 are 9.1 and 2.9 metres respectively. No trace fossils were found in this member.

Member U

Member U, which overlies Member T, consists of medium to poorly sorted, subangular to subrounded, medium to very coarse, quartz sandstone. The lower and middle parts of this member consist of medium to coarse, quartz sandstone. The upper part of the member at Sections 33, 34, and 37 consists of 5.3 to 6.4 metres of medium to very coarse, quartz sandstone with thin beds of shale. At Section 37, 3.9 metres of rounded, medium to coarse, quartz sandstone is present in the middle part of the member. At Outcrop 15 potassium feldspar makes up approximately 10 percent of the grains in the lower part of the member. The sandstone is red or brown, and the shale is red.

Large-scale cross bedding is the predominant bedding type in this member. Trough and tabular-shaped sets are 0.05 to 0.2 metres thick, but a set 0.5 metres thick was found in this member at Outcrop 15. The most common set size is 0.1 metre thick. Parallel bedding and small-scale cross bedding are also present in this member.

The member ranges in thickness from 6.3 to 34.5 metres. At Sections 33, 38, and 39, the upper and lower contacts of the member is covered. At Sections 36, 39, and 38, the sandstone is quartzitic where it has been well indurated.

Horizontal tubes in the upper part of the member at Section 37 are the only trace fossils that have been found in this member in the study area.

Member V

Member V, which is present at Sections 34, 36, and 37, overlies Member U. It consists of medium to well sorted, subangular to subrounded, fine to medium, quartz sandstone. At Section 34 the lower part of the member consists of medium to coarse, quartz sandstone. The sandstone of this member is green and brown.

Parallel bedding is the predominant bedding type in this member, but large-scale and small-scale cross bedding is present in this member at Section 36.

This member ranges in thickness from 11.9 to 40.6 metres. The lower part of the member at Section 37 has been intruded by a gray, diorite sill. At Section 34, the member has not been intruded, but 0.3 kilometres (1000 feet) to the north, the lower part of the member has been intruded by a diorite sill.

Horizontal tubes are common in this member at Section 34 and Section 37. In the upper part of the member at Section 34, horizontal and vertical tubes are abundant in the green and brown, fine to medium sandstone. At Outcrop 16, Flathead sandstone with horizontal tubes is present above a diorite sill.

Precambrian rock and younger igneous rock units

The Flathead Formation in the Little Belt Mountain area overlies Precambrian granite and granitic gneiss. The Precambrian rock is well exposed in the valley of Belt Creek south of the measured sections, but an exposed contact with the Flathead is not present at the base of any of the measured sections. In the Smith River Basin the Flathead overlies

the Precambrian Spokane Formation. The Spokane Formation, which is part of the Belt Supergroup, is a red shale and siltstone. A weathered zone was not exposed in this area or in the Little Belt Mountains.

One section, Section 35, was measured of the Precambrian Niehart Quartzite. The Niehart Quartzite, which is the basal part of the Belt Supergroup in the Little Belt Mountains, is very similar in grain size and primary structures to the Flathead Formation. The Niehart Quartzite and the Flathead Formation probably were deposited in similar depositional environments.

The Flathead Formation in the Little Belt Mountain and Smith River Basin area has been intruded by diorite sills and laccoliths. Sills occur at the base and at the top of the formation.

Summary

General

The Flathead Formation has been divided into informal members in each of the seven study areas. These members have been correlated only within their own study area. Generally, these members can be grouped into three intervals that characterize the Flathead Formation. These intervals can be correlated throughout the entire thesis study area.

The lower interval is medium to very coarse, quartz sandstone that contains large-scale cross bedding with sets 0.1 to 0.2 metres thick. Small-scale cross bedding and parallel bedding is present in smaller amounts. Conglomerate beds are found in many places at or near the base of the formation. Shale and shaly sandstone are not uncommon.

Quartz pebbles 5 to 50 millimetres in diameter are common in every study area. Potassium feldspar and mica grains are present in many places in the basal sandstone beds. Quartz and Precambrian rock fragments 0.1 to 0.4 metres in diameter were found in four areas. Fossils are not present in this interval. The interval is 2 to 8 metres thick.

The middle interval is medium to coarse, quartz sandstone that is cross bedded. Small-scale cross bedding is more abundant in this interval than in the lower interval, but large-scale cross bedding is most abundant. Very coarse sandstone is present in about 25 percent of the sections. In several sections some sandstone beds are separated by thin beds of red shale. The sandstone is brown. The interval is 6 to 20 metres thick. A few horizontal and vertical tubes are present in this member. Rusophycus burrows were found in two sections.

The upper interval is fine to coarse, quartz sandstone that is predominantly parallel bedded, but small-scale cross bedding does occur. Burrowing has disturbed or destroyed bedding in many places. In some places the top of this unit contains some interbedded sandstone and shale that gradationally changes upward into the shale of the overlying formation. The interval is 2 to 15 metres thick. Trace fossils are most common in this interval. Horizontal tubes are found in every study area. Vertical tubes are found in most of the study areas. Inarticulate brachiopods in the upper part of this interval were found in three areas.

Correlation

Figure 23 is a fence diagram which shows a correlation of the members in the seven study areas. All members are correlated as stratigraphic equivalents on the basis of their stratigraphic position, grain size, primary structures, and paleontology.

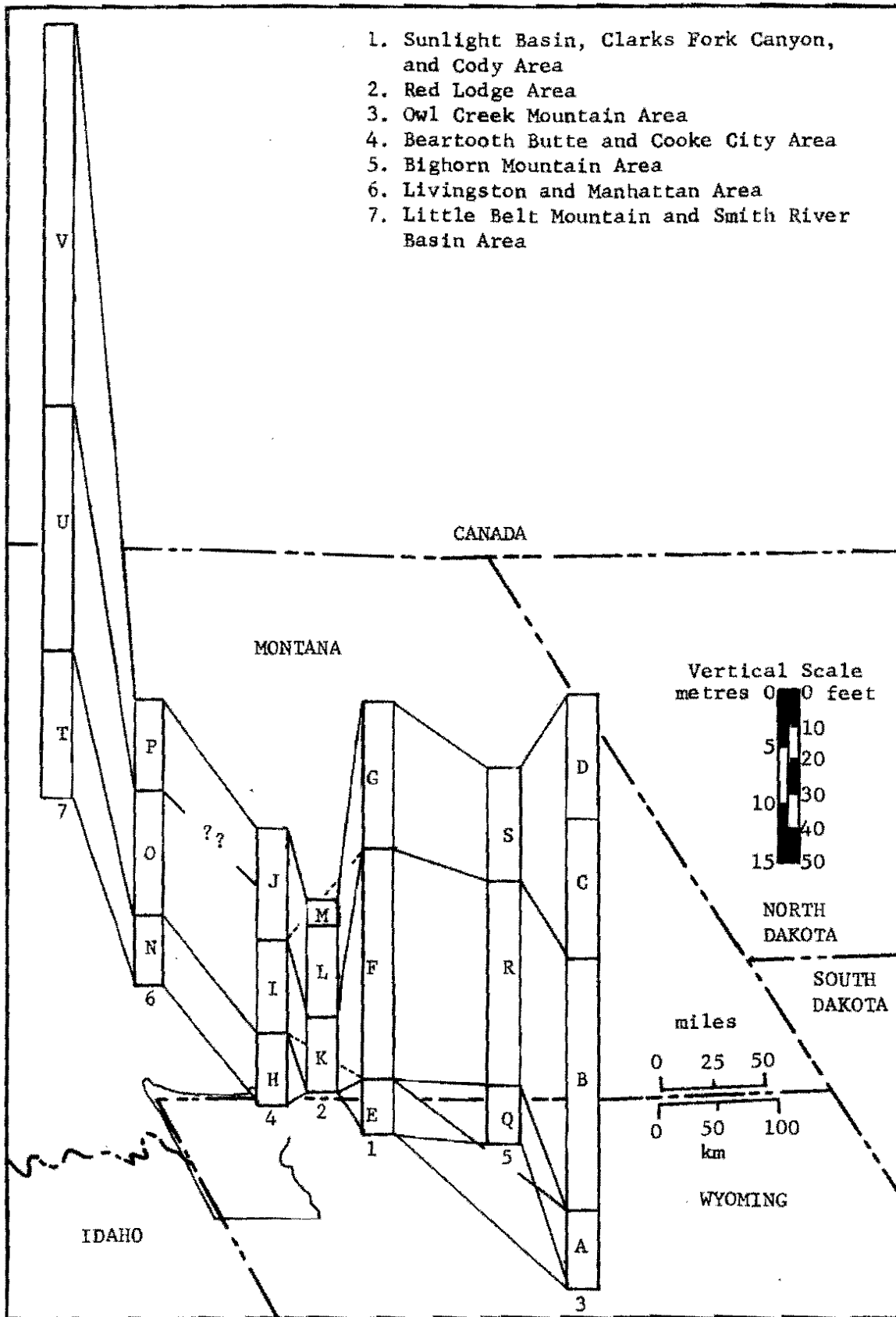
The key criteria used in correlating the lower members are the grain size and the presence of quartz pebbles and conglomerate beds. The key criteria used in correlating the middle members are the cross bedding, the grain size, and its resistance to erosion. The key criteria in the upper member are the parallel bedding, the thin bed size, the evidence of burrowing, the horizontal and vertical tubes, and the brachiopods. The brachiopods in the upper sandstone bed of the upper member provide an important correlation zone in the Clarks Fork Canyon, Red Lodge, and Livingston areas.

The lowest member present in the Beartooth Butte and Sunlight Basin areas is not present in the Red Lodge area. Member K in the Red Lodge area correlates with Members I and F in the Beartooth Butte and Sunlight Basin areas. Member L in the Red Lodge area correlates with Members J and G in the Beartooth Butte and Sunlight Basin areas. Member M in the Red Lodge area correlates with the upper part of Members J and G in the Beartooth Butte and Sunlight Basin areas.

The upper member in some areas is not always equivalent to the upper member in other areas. This is illustrated in the Little Belt Mountain and Livingston areas. The middle and upper members (Members O and P) in the Livingston area correlate with the middle member (Member U) and lower part of the upper member (Member V) in the Little Belt Mountain area.

Fig. 23. Fence diagram showing correlation of members in the thesis study area. Relative thicknesses of the members are shown for each study area. The dashed lines represent a correlation line behind a column.

1. Sunlight Basin, Clarks Fork Canyon, and Cody Area
2. Red Lodge Area
3. Owl Creek Mountain Area
4. Beartooth Butte and Cooke City Area
5. Bighorn Mountain Area
6. Livingston and Manhattan Area
7. Little Belt Mountain and Smith River Basin Area



PALEOTOPOGRAPHY

Owl Creek Mountain Area

Field observations in the Owl Creek Mountains suggest that the Flathead Formation was deposited in most places on a Precambrian surface that was almost flat, but with a relief up to 3 metres. In a few places the surface had maximum relief of 70 metres. The almost-flat Precambrian surface probably had some local, small knobs and pits, but deep channels and high, resistant knobs also existed. Near Outcrop 22, rock relationships suggest that the lower part of the Flathead Formation was deposited in a channel about 10 metres deep. At Outcrop 24 a large knob of Precambrian rock outcrops above the lower Gros Ventre Formation.

Observations at Outcrop 24 suggest that the Precambrian knob existed as an island throughout the deposition of the Flathead and lower Gros Ventre Formations. The granitic Precambrian rock forms an outcrop 0.4 kilometres (0.25 mile) across. The knob stands 15 to 45 metres above the lower Gros Ventre Formation. The Precambrian rock is complexly jointed and has been weathered to form a rounded outcrop. The granitic rock in the lower flanks of the knob is crumbly, indicating intense weathering. Circular and elongate pits 0.2 metre deep and 0.6 metre in diameter are present on some of the Precambrian rock surfaces. The pits on the Precambrian knob might have been scour pits formed as water currents oscillated around the base of the island.

The Paleozoic formations in the area of the knob dip 5 degrees in a northerly direction, but around the margins of the knob the Gros Ventre Formation dips gently away from the Precambrian rock. Rounded quartz pebbles 30 millimetres in diameter were found at the contact between the Precambrian and the lower Gros Ventre Formation. The sandstone is coarser nearer the knob than it is farther away. The lower Gros Ventre sandstone contains large-scale cross bedding with trough-shaped sets 0.5 to 1.0 metre thick. The beds in the set dip southwest, away from the knob. This probably indicates that the cross bedding was formed by currents that flowed outward from the island as the water washed up by waves returned to the sea. Gros Ventre sandstone was also found in cracks on the Precambrian knob. This sandstone was probably deposited as the island slowly became buried beneath Gros Ventre sediments.

The field observations fit with what might be expected of an island and its surrounding sediments. The field observations do not suggest that this large Precambrian knob was pushed up by tectonic forces because the sediments do not dip steeply away from the knob. An igneous contact zone around the knob does not exist; rather the contact relationships of the surrounding rock suggest a sedimentary origin. Furthermore, the lithology and texture of the Precambrian rock is not typical of an igneous intrusive rock. The rock at the knob is a coarse-grained granite; it is not fine grained or of the composition typical of a Tertiary intrusive igneous rock. The Precambrian rock in the knob is the same as other Precambrian granitic rock that is present below the Flathead Formation in other places in the study area.

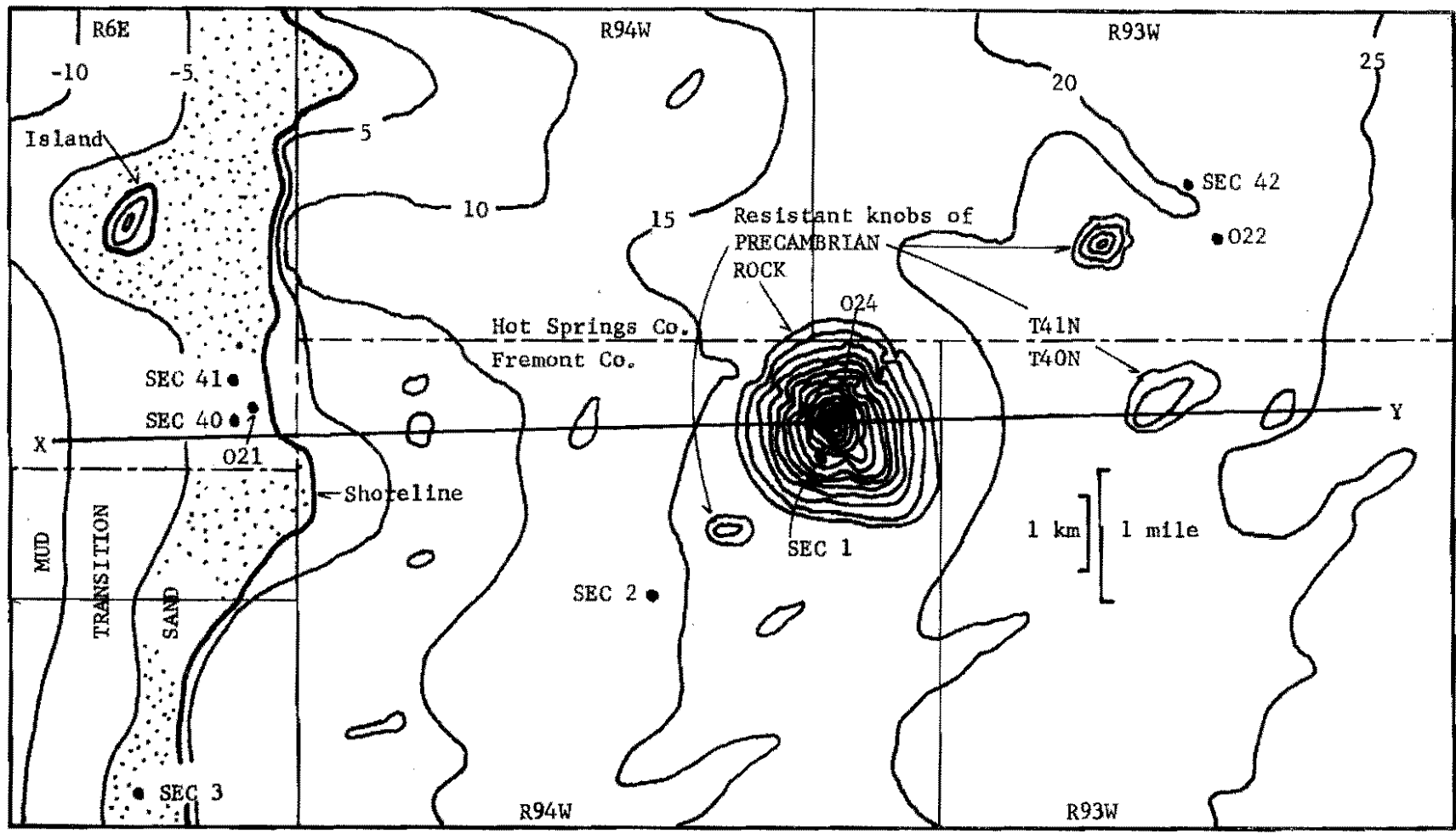
Four figures are included in this discussion to illustrate the relationships between the Precambrian island and the Flathead and Gros Ventre Formations.

Figure 24 is a diagrammatic topographic map and cross section of the Precambrian surface at the beginning of the deposition of the Flathead Formation. The resistant Precambrian knob at Outcrop 24, the channel at Outcrop 22, and other hypothetical knobs and channels on the Precambrian surface are shown. The topography of the knob at Outcrop 24 and the channel at Outcrop 22 are based on observed field data. The configuration of the topography in other places is speculative. A shoreline, a coast with cliffed and non-cliffed areas, an island, and areas of inferred sand and mud deposition are also shown on Figure 24. The area included in Figures 24, 25, 26, and 27 is shown by dashed lines on Figure 2.

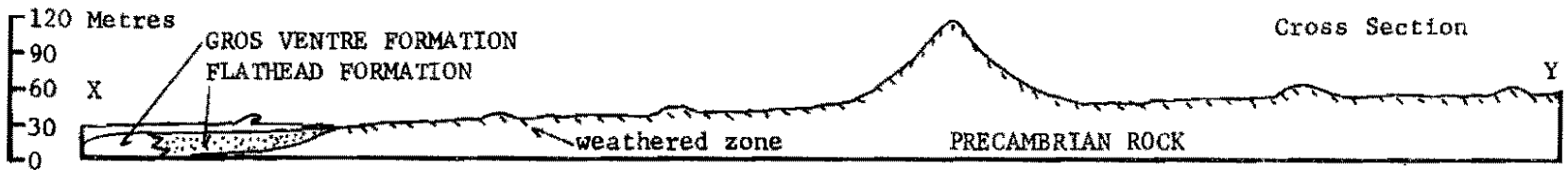
Figure 25 is a map and cross section showing the rock units with the lower Gros Ventre Formation and younger rocks stripped off. It shows the Flathead Formation except in those areas where an island of Precambrian rock was not covered by Flathead sediment. These resistant knobs existed as islands throughout the deposition of the Flathead Formation, and one island existed throughout the time of deposition of the lower Gros Ventre Formation. The area of the map is the same as Figure 24.

Figure 26 is a map and cross section showing the rock units with the upper Gros Ventre Formation and younger rock units stripped off. It shows the lower Gros Ventre Formation except in the area where the

Fig. 24. Paleotopographic map of the Precambrian surface at the beginning of deposition of the Flathead Formation. SEC 3 is a measured section number. 024 is an outcrop description number. Contour interval is 5 metres. Location of Fig. 24 is shown inside dashes on Fig. 2.

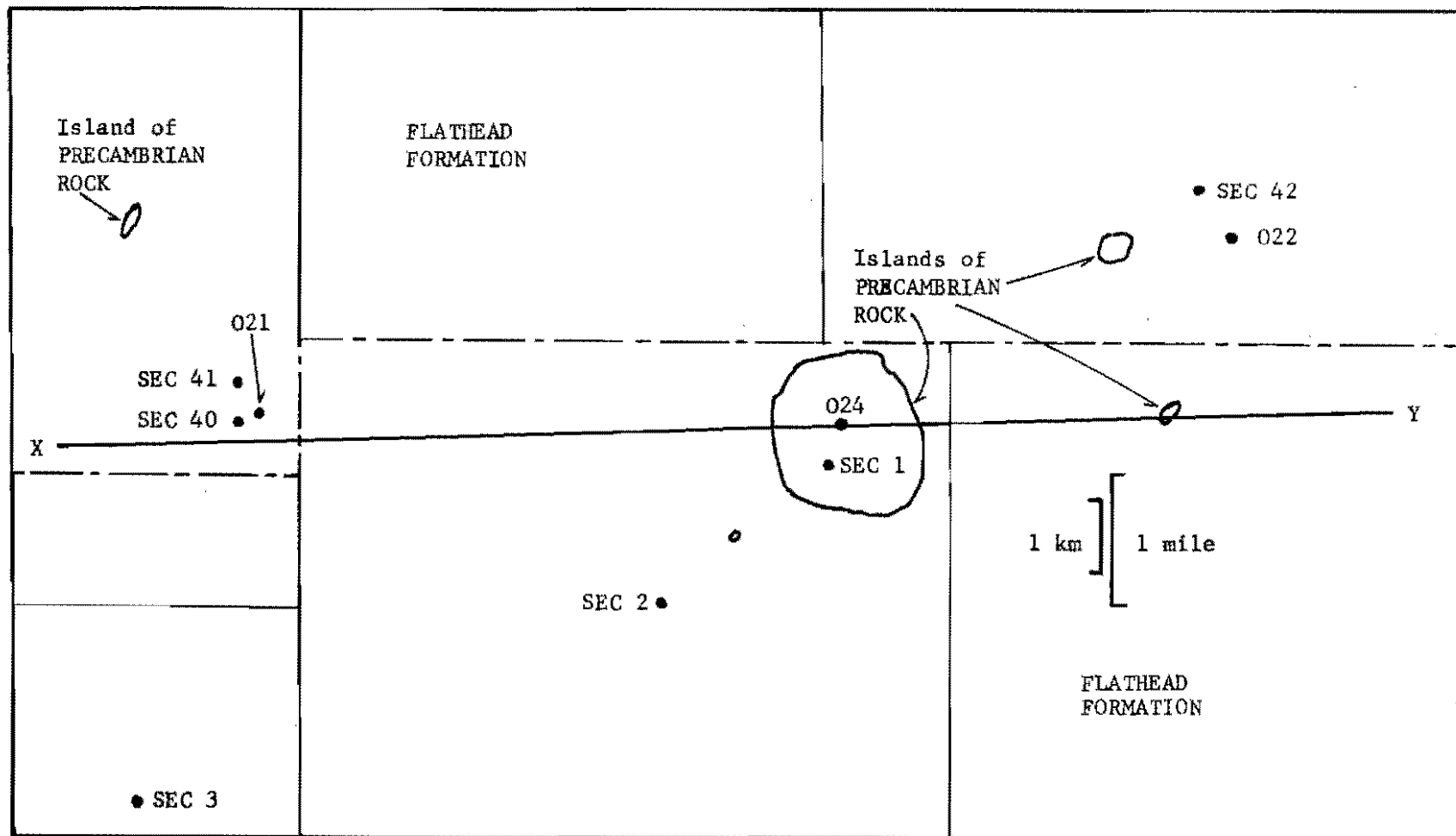


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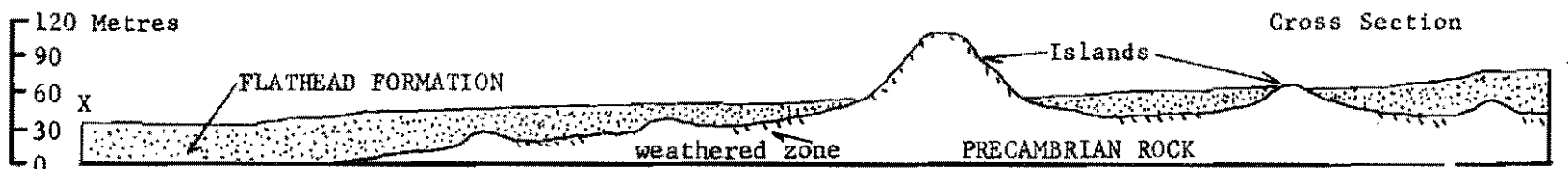


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Fig. 25. Map showing rock units with lower Gros Ventre Formation and younger rock stripped off. SEC 3 is a measured section number. 024 is an outcrop description number. Location of Fig. 25 is shown inside dashes on Fig. 2.

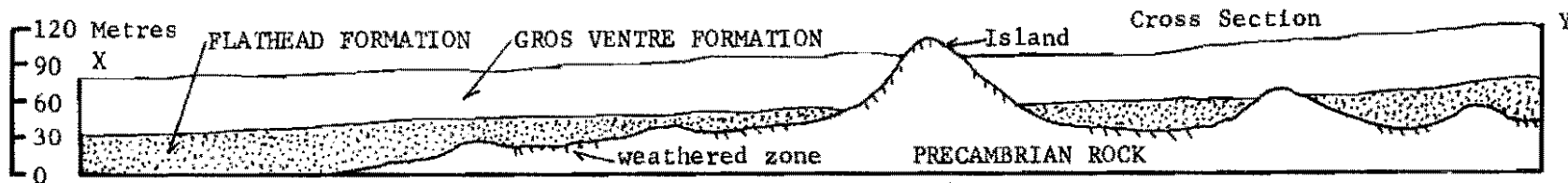
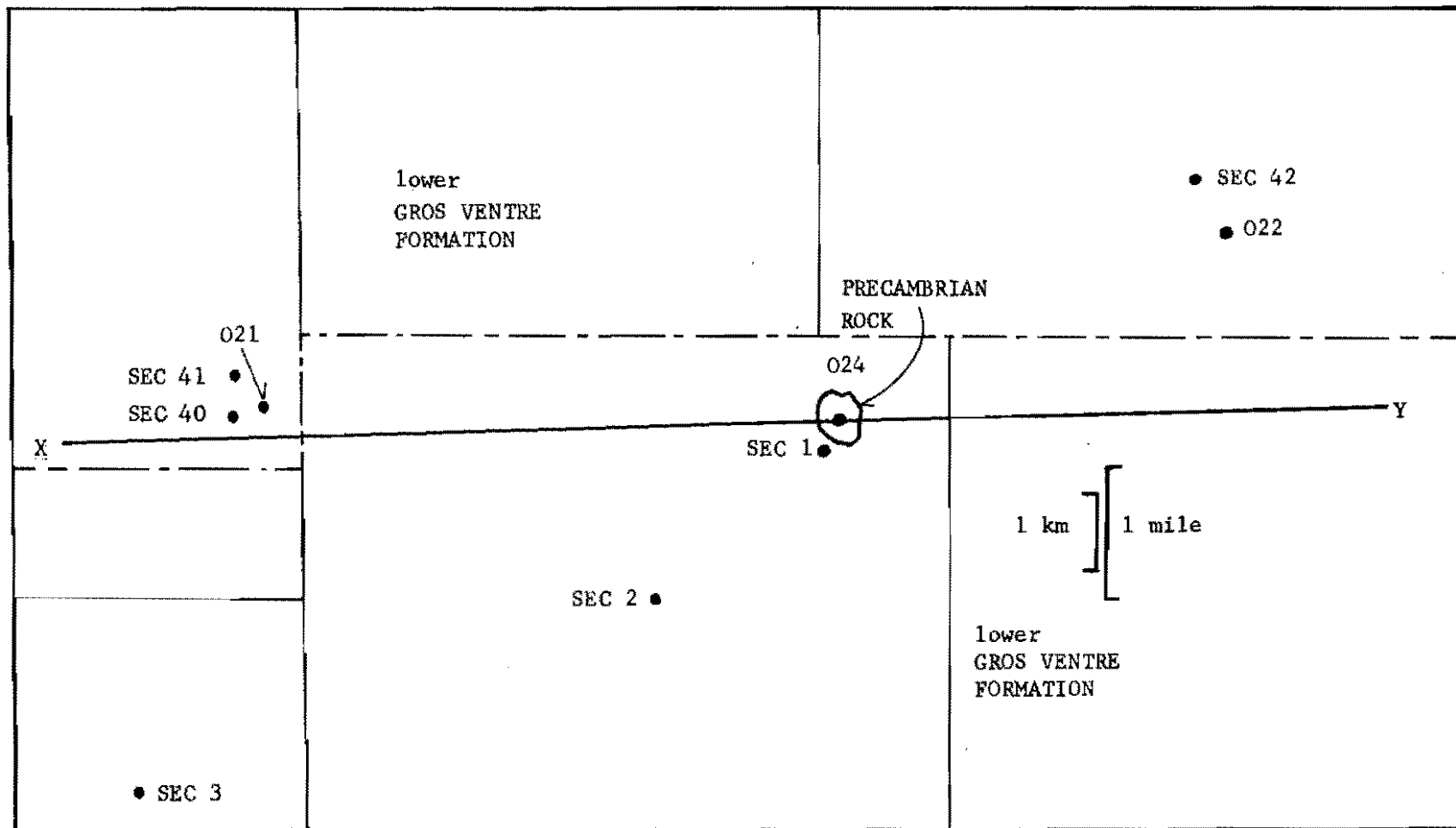


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Fig. 26. Map showing rock units with upper Gros Ventre Formation and younger rock stripped off. SEC 3 is a measured section number. 024 is an outcrop description number. Location of Fig. 26 is shown inside dashes on Fig. 2.



island of Precambrian rock was not covered by lower Gros Ventre deposition.

Figure 27 is a "worm's-eye-view" map of the strata overlying the Precambrian rock. It shows the Flathead Formation except in those areas where the Gros Ventre Formation covered the islands.

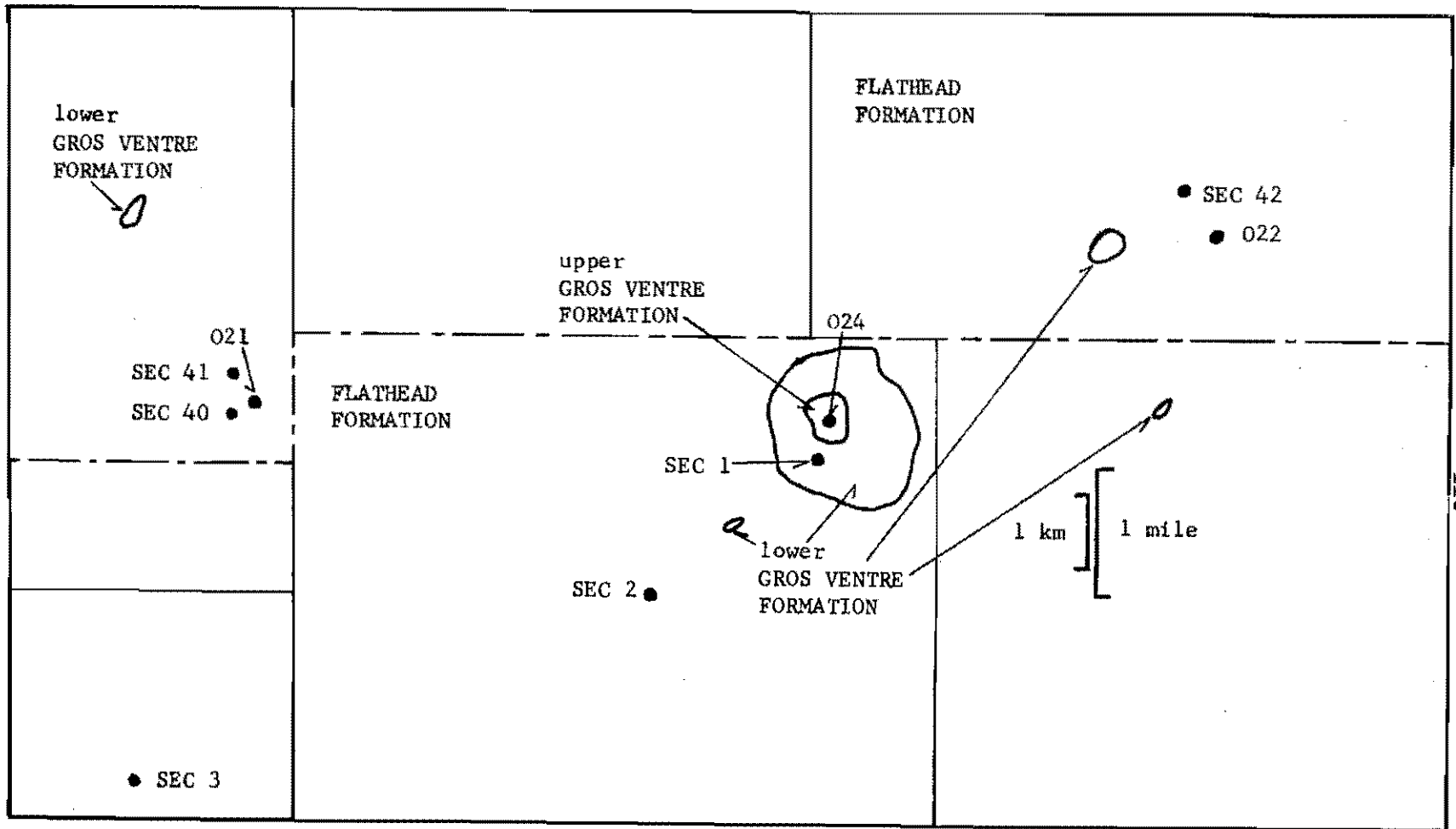
Sunlight Basin, Clarks Fork Canyon, and Cody Area

The Flathead Formation in the Sunlight Basin, Clarks Fork Canyon, and Cody area was deposited in most places on Precambrian surface of low relief. This surface had a relief of approximately 3 metres. A maximum relief of 15 metres was present in a few places.

A good outcrop of the Precambrian surface exists 0.4 kilometres (0.25 miles) west of Section 16. The outcrop of the Precambrian rock is on the east side of Sunlight Creek. Small, shallow depressions give the surface a relief of 1 metre. The existing depressions may be pre-Flathead features, but even if they have been formed by recent erosion, the present surface probably closely resembles what the Precambrian surface was like in most places. The Flathead Formation outcrops east of this surface. The surface is on the same horizontal plane as the bottom of the Flathead. The same type of Precambrian surface is present in the vicinity of Section 20 and Section 8 in Clarks Fork Canyon.

Other outcrops in the Sunlight Basin show the Precambrian surface had up to 15 metres of relief in some places. Along the west side of Dead Indian Creek, near Sections 11, 12, and 13, the Precambrian rock has ridges and troughs oriented northwest-southeast on its surface.

Fig. 27. "Worm's-eye-view" map of strata overlying the Precambrian rock. SEC 3 is a measured section number. 024 is an outcrop description number. Location of Fig. 27 is shown inside dashes on Fig. 2.



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The lower and middle parts of the Flathead Formation (Members E and F) in this area vary in thickness with relief on the Precambrian surface. At Section 4 in Shoshone Canyon, the weathered zone and a bed of shaly sandstone wedge out along the outcrop against the Precambrian rock. Figure 28 shows the relationships at Sections 11, 12, and 13, and at Section 4.

Beartooth Butte and Cooke City Area

The Flathead Formation in the Beartooth Butte and Cooke City area was deposited in most places on a Precambrian surface with 1 to 3 metres of relief. Figure 29 shows the Precambrian and Flathead relationships at the northeast corner of Beartooth Butte. At the northeast corner of Beartooth Butte, up to 20 metres of relief is present on the Precambrian surface. Several troughs orientated northeast-southwest are present on the Precambrian surface. The lower member of the Flathead Formation outcrops in the bottom of these channels. The middle member of the formation lies on the Precambrian rock at the edges of these channels.

At an isolated outcrop of the lower part of the Flathead Formation in the bottom of a channel near Section 30, 0.8 to 1.2 metres of conglomerate overlies the Precambrian rock. The conglomerate contains quartz cobbles 0.1 metre in diameter and fragments of granite. Overlying the conglomerate is 1.6 metres of medium to very coarse sandstone that has quartz grains 10 millimetres in diameter.

The relationships of the channel and the Flathead Formation strongly suggest that the channels were paleodrainage channels that

Fig. 28. Cross sections showing relief and topography of the Precambrian surface in Shoshone Canyon and the Sunlight Basin. A, cross section of the lower part of Section 4 in Shoshone Canyon showing the relief on the Precambrian surface, and the lateral pinchout of the weathered zone and the bed of shaly sandstone against the Precambrian rock. B, cross section showing the topography of the Precambrian surface along the west side of Dead Indian Creek in the Sunlight Basin. A maximum of 15 metres of relief on the Precambrian surface is shown. SEC 11 is a measured section number.

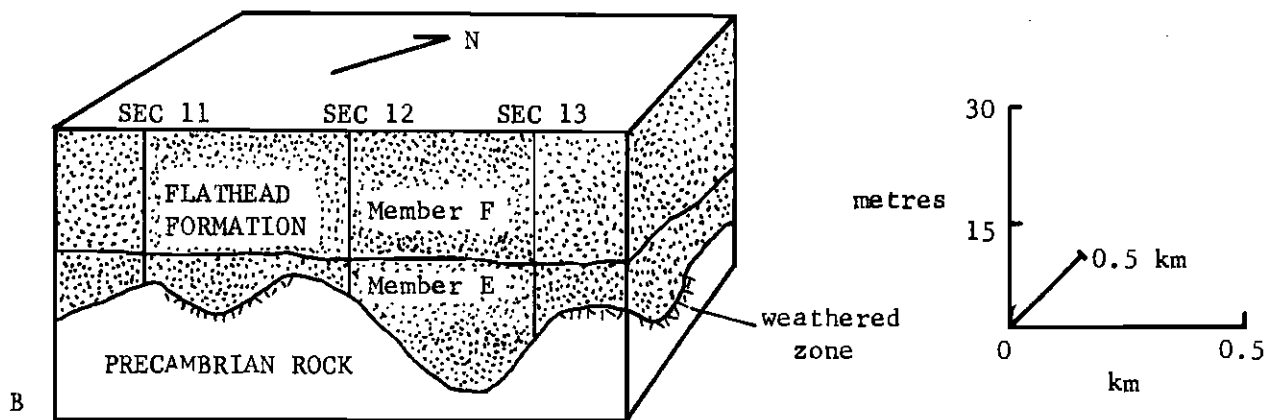
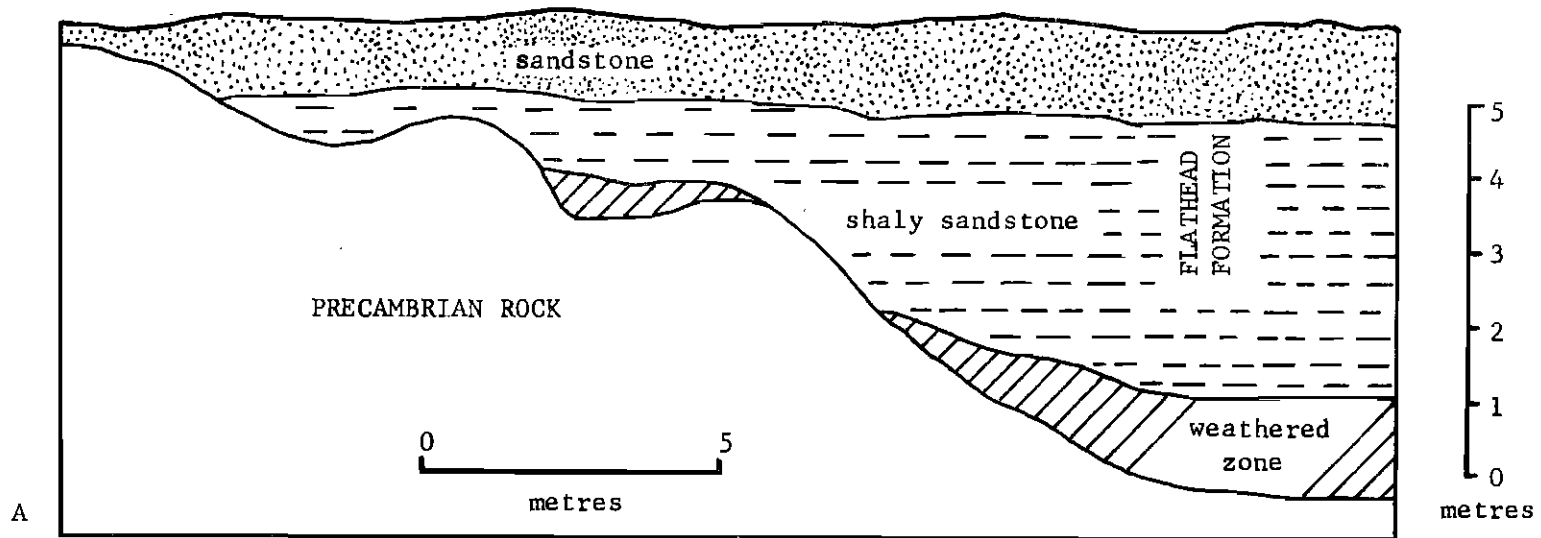


Fig. 29. Block diagram showing northeast-southwest orientated channels on the Precambrian surface at the northeast corner of Beartooth Butte. View looking southwest. Note the isolated outcrop of the lower Flathead Formation in the bottom of a channel. SEC 30 is a measured section number.

carried clastic material to the shoreline from the Precambrian land surface.

Other Study Areas

The Flathead Formation in the Red Lodge area was deposited on a Precambrian surface with 1 to 3 metres of relief. Correlation of Section 31 and Section 32 indicates that there was up to 8 metres of relief. Field relationships between the Flathead and Precambrian rock near Outcrops 9, 10, 11, 12, and 13 suggest that part of the Flathead in that area probably was deposited in a channel on the Precambrian surface that was orientated in a northeast direction. In the area south and west of Red Lodge an interpretation of the Flathead-Precambrian relationship is difficult because faults have altered the original rock relationships.

The Flathead Formation in the Bighorn Mountain area was deposited in most places on a Precambrian surface that had low relief. Areas in which relief was higher did exist in some places. Near Shell Canyon, the Flathead Formation is present in only a few places. At Shell Falls there are 4 metres of sandstone, but in other places in the surrounding area the Gros Ventre Formation lies directly on the Precambrian rock. Knobs of Precambrian rock along U. S. Highway 14 suggest some islands probably existed in some places in the Bighorn Mountain area.

The Flathead Formation is 23 metres thick at Section 52 on the east side of the Bighorn Mountains, but only 4 to 7 metres thick at Sections 5, 6, and 7 on the west side of the Bighorn Mountains. On both the west and east sides, the shale of the Gros Ventre Formation

overlies the sandstone and conglomerate of the Flathead Formation. These relationships suggest that the Flathead was deposited on a relatively higher Precambrian surface in the west than in the east. The relationships also suggest that the depositional conditions were probably different in these two areas.

The Flathead-Precambrian contact is covered in all but one section in the Livingston and Manhattan area; therefore little information on the nature of the Precambrian surface was collected. However, the correlation of Section 48 and Section 45, which are 3.2 kilometres (2 miles) apart, shows that at least 3 metres of relief existed on the Precambrian surface in that area.

Little information is available on the nature of the Precambrian surface in the Little Belt Mountain and Smith River Basin area, because the Precambrian rock is not extensively exposed and the Flathead-Precambrian contact was covered in all sections.

DEPOSITIONAL ENVIRONMENTS

Introduction

Shallow-marine and marginal-marine depositional environments are indicated by the brachiopods and trace fossils in the Flathead Formation. The Flathead sandstone, the overlying marine shale of the Wolsey or Gros Ventre Formation, and the overlying marine limestone of the Meagher or Gallatin Formation, are part of a transgressive marine sequence.

Sandstone can form in many deep-marine, shallow-marine, and marginal-marine environments. Sandstone deposited by turbidity currents or deep-ocean currents would not have the fossils, the shape, the thickness, and the stratigraphic relationships that are characteristic of the sandstone in the Flathead Formation. However, the cross and parallel-bedded sandstone that is formed in shallow and marginal-marine environments does have many of the characteristics of the sandstone in the Flathead Formation.

Shallow and marginal-marine environments include the shore, the nearshore, and the offshore environments. The terminology used in this discussion of shallow-marine and marginal-marine environments is shown in Figure 30. The shore and nearshore environments can be subdivided into environments on the basis of their energy and whether the currents are created by tidal or wave action. Figure 31 shows the combinations

Fig. 30. Terminology used in shallow-marine and marginal-marine environments. A, special terms used in high-energy environments with wave-induced currents. B, special terms used in low-energy environments with wave-induced currents. C, special terms used in high-energy environments with tide-induced currents.

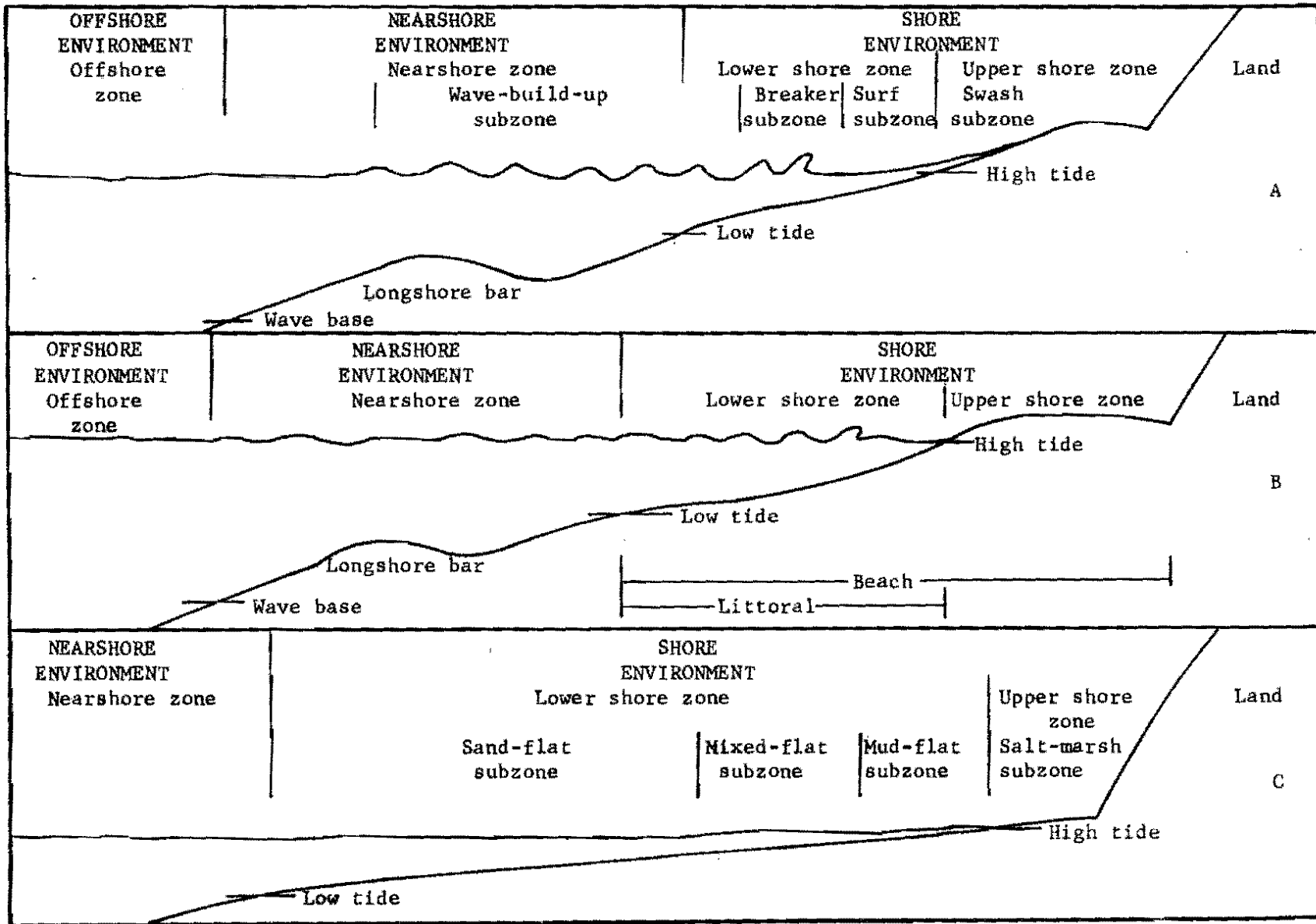


Fig. 31. Classification of shallow-marine and marginal-marine environments. Defining parameters are the energy of the environment and wave or tide-induced currents. I to XII denote different combinations that are referred to in the discussion.

	WAVE-INDUCED CURRENTS		TIDE-INDUCED CURRENTS
LOW-ENERGY ENVIRONMENTS	with barrier islands with longshore bars I	with barrier islands without longshore bars II	with barrier isalnds III
	without barrier islands with longshore bars IV	without barrier islands without longshore bars V	without barrier islands VI
HIGH-ENERGY ENVIRONMENTS	with barrier islands with longshore bars VII	with barrier islands without longshore bars VIII	with barrier islands IX
	without barrier islands with longshore bars X	without barrier islands without longshore bars XI	without barrier islands XII

of these environments. Twelve different combinations are possible if the presence or absence of barrier islands and longshore bars are included in the classification. Because longshore bars are created by wave-induced currents, they are not included in the tide-induced-current category.

Low-energy environments with
wave-induced currents

The following description of a Texas low-energy environment has been summarized from Dickinson and others (1972). Where barrier islands are present in environments with wave-induced currents, a lagoon or marsh environment is commonly present landward of the island. The lagoon or marsh contains mud and peat with some washover-fan sand. The barrier island is commonly covered with eolian sand dunes, but the eolian dunes also can be found on coasts without barrier islands.

Sand and gravel with parallel bedding and landward-dipping cross bedding is deposited in the upper shore zone. Low-angle, seaward-dipping, parallel-bedded sand is deposited in the lower shore zone. In the nearshore zone, small-scale, landward and seaward-dipping, cross-bedded sand is deposited. Where longshore bars are present their migration produces large-scale, landward-dipping, tabular-shaped, cross-bedded sand. Unidirectional dunes and ripples may form in troughs between longshore bars. Sand with low-angle cross bedding and with parallel bedding is also deposited in this zone. In deeper water near the offshore zone, interbedded sand and mud is present. Parallel-bedded mud is deposited in the offshore zone. Bioturbation is common in the nearshore and offshore zones.

The cross-bedded and parallel-bedded sand and mud previously described in the upper shore, lower shore, nearshore, and offshore zones are deposited in environments I, II, IV, and V of Figure 31. A vertical sequence through the sediment deposited in environment I of Figure 31 by a transgressing sea is shown in Figure 32. Deposits left by environments II and V do not have cross bedding produced by migration of long-shore bars. Transgressive deposits left by environments IV and V lack the lower lagoon, marsh, and washover-fan deposits. Environment I is present along the Gulf of Mexico and Atlantic coast, and has been extensively studied along the Texas coast.

Low and high-energy environments
with tide-induced currents

Reineck and Singh (1975, p. 355-372) and Reineck (1972) have described low and high-energy environments with tide-induced currents. The following discussion has been summarized from their work.

Where tide-induced currents are weak, they commonly cannot move medium and coarse sand but carry substantial amounts of suspended material. The low-energy shore environment contains mixed-flat and mud-flat subzones. A salt-marsh subzone can also be present. Where a sand-flat subzone is present, it is not likely to be extensive. Barrier islands may separate these subzones from the open ocean. A transgressing sea with a barrier island (environment III in Figure 31) results in shore and nearshore sand deposits overlying mud deposits of the mixed-flat, mud-flat, and salt-marsh subzones.

Where tide-induced currents are strong they carry medium to coarse sand. The high-energy shore environment contains sand-flat,

Fig. 32. Vertical sequence through sediments deposited in environment I of Fig. 31 by a transgressing sea. Environment I is a low-energy environment with wave-induced currents, barrier islands, and longshore bars.

LITHOLOGY AND PRIMARY STRUCTURES

ZONES AND
SUBZONES OF
DEPOSITION

Parallel-bedded mud

Interbedded mud and sand; bioturbation

Small-scale, landward and seaward-dipping,
cross-bedded sand; low-angle and parallel-bedded
sand; large-scale, landward-dipping, cross-bedded
sand if longshore bars are present; bioturbationLow-angle, seaward-dipping, parallel-bedded sand;
bioturbationParallel-bedded sand; large-scale,
landward-dipping, cross-bedded sand

Large-scale, trough-shaped, cross-bedded sand

Small-scale, landward-dipping, cross-bedded sand;
large-scale, landward-dipping, cross-bedded sand

Parallel-bedded mud; peat; mudcracks; bioturbation

Coastline bedrock

OFFSHORE

NEARSHORE

LOWER
SHOREUPPER
SHOREEOLIAN
DUNEWASHOVER
FANLAGOON
or
MARSH

LAND

mixed-flat, mud-flat, and sand-marsh subzones. The mixed-flat and mud-flat subzones are sandier than under low-energy conditions. The sand-flat subzone contains sand that has been deposited by tidal currents that move in and out of the lower shore zone. Small-scale, trough and tabular, landward and seaward-dipping cross bedding is formed by the migration of ripples. Parallel bedding is also present. Thin beds of mud are deposited in the sand-flat subzone in quiet water during high tide. The mud flat, mixed flat, and sand flat are commonly bioturbated.

The nearshore zone contains tidal channels that commonly have curved, unidirectional dunes in their bottoms. Large-scale, trough-shaped, seaward-dipping cross bedding is produced by dune migration in the tidal channels. Most of these tidal channels are orientated perpendicular to the coastline and they commonly dissect the lower shore zone. Seaward of the nearshore zone is the offshore zone, which contains parallel-bedded mud.

A vertical sequence through sediments deposited in environment XII of Figure 31 is shown in Figure 33 (Reineck, 1972). The sequence could also include shore and nearshore sand deposited in an environment by wave-induced currents if a barrier island was present (environment IX of Figure 31).

Environments in which tide-induced currents are dominant exist along part of the Atlantic coast of North America and along the North Sea coast of the Netherlands, Germany, and Denmark.

Fig. 33. Vertical sequence through sediments deposited in environment XII of Fig. 31 by a transgressing sea. Environment XII is a high-energy environment with tide-induced currents and without a barrier island.

LITHOLOGY AND PRIMARY STRUCTURES

ZONES AND
SUBZONES OF
DEPOSITION

Parallel-bedded mud

OFFSHORE

Large-scale, trough-shaped, seaward-dipping,
cross-bedded sand in channelsNEARSHORE
(tidal
channel)Small-scale, trough and tabular-shaped, landward
or seaward-dipping, cross-bedded sand; parallel-
bedded sand; thin bedded mud; large-scale
trough-shaped, cross-bedded sand in channels
perpendicular to shoreline; bioturbationLOWER
SHORE
(sand-flat)

Thin-bedded sand and mud; bioturbation

(mixed-flat
subzone)Thick-bedded mud; thin bedded sand; mudcracks;
bioturbation(mud-flat
subzone)

Peat and mud

UPPER
ZONE
(salt-marsh)

Coastline bedrock

LAND

High-energy environments with
wave-induced currents

In high-energy environments the waves are strong enough to produce stronger longshore currents, wider surf and swash subzones, stronger shoreward currents, and stronger backwash and rip currents than are present in the low-energy environments. Therefore, larger bedforms and hence larger bedding forms can be formed in this environment. The following description of an Oregon high-energy environment with wave-induced currents has been summarized from Clifton and others (1971). This is environment XI of Figure 31.

The swash subzone consists of horizontal or seaward-dipping parallel-bedded sand and gravel. The surf subzone consists of large-scale, trough-shaped, seaward-dipping, cross-bedded sand. The primary structures in these subzones are formed by seaward-moving backwash currents which predominate in the swash and surf subzones. When longshore currents are present, some of the cross-bedded sand in the surf subzone dips perpendicular or at some angle to the shoreline. Parallel-bedded sand is deposited in the breaker subzone. Large-scale, trough-shaped, landward-dipping, cross-bedded sand is deposited in the wave-build-up subzone by the landward migration of dunes. Seaward of the wave-build-up subzone in the nearshore zone, small-scale, landward-dipping, cross-bedded sand is deposited. Some parallel-bedded sand is also deposited in this zone. In the breaker subzone and in the nearshore zone landward-flowing currents are dominant. The offshore zone consists of parallel-bedded mud and thin beds of parallel and cross-bedded sand.

Depending on the local conditions of waves, tides, shore shape, and many other factors any of the subzones and their deposits could be absent. Where longshore currents and seaward-flowing rip currents are present, they can modify the deposits formed in the lower shore, near-shore, and offshore zones. Both longshore and rip currents form dunes, and the cross bedding formed by their migration can be preserved. Although longshore bars were not present in the Oregon environment studied by Clifton and others (1971), they can exist in the nearshore zone, and their landward migration will result in large-scale, landward-dipping, tabular-shaped, cross-bedded sand.

Storms can have a drastic effect on the deposits of a high-energy environment. During a storm or in the winter, sand is transported seaward and the seaward-dipping bedding forms formed by the seaward migration of bedforms will be preserved.

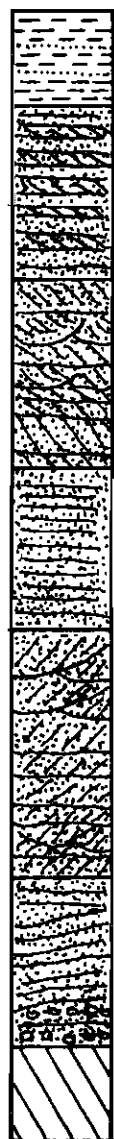
A vertical sequence through deposits formed in an Oregon high-energy environment (environment XI of Figure 31) by a transgressing sea is shown in Figure 34.

If barrier islands are present the vertical sequence in Figure 34 could be underlain by eolian-dune, lagoon, marsh, washover-fan, or tidal deposits. These deposits would result in environments VII and VIII. If longshore bars and their associated cross bedding are present the vertical sequence in Figure 34 would represent environment X of Figure 31.

High-energy environments with wave-induced currents are present along the Pacific coast of California and Oregon. This environment has not been studied extensively because of the strength and size of the

Fig. 34. Vertical sequence through sediments deposited in environment XI of Fig. 31 by a transgressing sea. Environment XI is a high-energy environment with wave-induced currents and without barrier islands and longshore bars.

LITHOLOGY AND PRIMARY STRUCTURES

ZONES AND
SUBZONES OF
DEPOSITION

Parallel-bedded mud and thin, cross-bedded sand

OFFSHORE

Small-scale, landward-dipping, cross-bedded sand;
parallel-bedded sand

NEARSHORE

Large-scale, trough-shaped, landward-dipping,
cross-bedded sand; small-scale, cross-bedded sand(wave-build-up
subzone)

Parallel-bedded sand

LOWER
SHORE
(breaker
subzone)Large-scale, trough-shaped, seaward-dipping,
cross-bedded sand; cross-bedded sand dips at some
angle to shoreline if longshore currents are
present(surf
subzone)Horizontal or seaward-dipping, parallel-bedded
sand and gravelUPPER
SHORE
(swash
subzone)

Coastline bedrock

LAND

wave and the wave-induced currents in the lower shore and nearshore zones.

Depositional Environment of the Flathead Formation

The Flathead Formation appears to have been deposited in a high-energy environment by wave-induced currents at the margin of an eastward-transgressing sea. A north-south shoreline with land on the east and a sea on the west has been assumed in the interpretation of the environment of deposition.

The lower interval of the Flathead Formation contains parallel-bedded conglomerate and coarse to very coarse sandstone with quartz pebbles that formed in the swash subzone in a high-energy environment.

The middle interval of the Flathead in most places consists of large-scale, cross-bedded, medium to coarse sandstone. The sets of cross bedding dip predominantly west, but some sets dipping north or south are present. The north and south-dipping cross bedding represents cross bedding formed by longshore currents. In some places several east-west channels are present with internal west-dipping cross bedding. This cross bedding probably represents the migration of dunes in rip-current channels. The middle interval of the Flathead formed in the surf subzone.

The upper interval of the formation in most places contains fine to medium sandstone with parallel bedding and with small-scale cross bedding. This part of the Flathead was deposited in the offshore and in the outer part of the nearshore zones. The Flathead Formation

is overlain by interbedded shale and sandstone or parallel-bedded shale that was deposited in the offshore zone.

Because eolian-dune, lagoon, marsh, washover-fan, mud-flat, mixed-flat, and salt-marsh deposits are not present in the Flathead, a barrier island was probably not part of the depositional environment. Therefore, the Flathead Formation probably was not deposited in environments I, II, III, VII, and VIII of Figure 31 which contain barrier islands.

The bedding in the Flathead Formation is not the same as the bedding that is formed in the upper and lower shore zones or in the nearshore zone in a low-energy environment with wave-induced currents and without barrier islands. Therefore, the Flathead Formation probably was not deposited in environments IV and V in Figure 31.

The bedding in the sand-flat subzone and in the nearshore zone in a high-energy environment with tide-induced currents is similar in some ways to bedding in the Flathead, but the bedding differences between the Flathead and this environment are more common. Channels with large-scale, seaward-dipping, trough-shaped cross bedding are present in this environment and in the Flathead. The large-scale, seaward-dipping cross bedding in the tidal environment is commonly restricted to tidal-channel bottoms. However, large-scale, seaward-dipping, cross bedding, which is most common in the Flathead, is not restricted to the channels in the Flathead. The small-scale, seaward and landward-dipping cross bedding which is the most common bedding in a tidal environment is not commonly present in the Flathead. The thin layers of mud that are deposited in the sand-flat subzone

between tidal currents in a tidal environment are not commonly present between the beds of sandstone in the Flathead Formation. The energy of tidal currents may not be strong enough to winnow, concentrate, and deposit the cobbles, pebbles, and very coarse sand that is present in the conglomerate and sandstone in the lower part of the Flathead. The Flathead Formation probably was not deposited in a high-energy environment with tide-induced currents with or without barrier islands (environments IX and XII in Figure 31).

The Flathead Formation probably was not deposited in a low-energy environment with tide-induced currents and without barrier islands (environment VI in Figure 31) because mud-flat, mixed-flat, and salt-marsh deposits are not present in the formation.

The bedding, grain size, geometry, and stratigraphic relationships suggest the Flathead Formation was deposited in a high-energy environment with wave-induced currents and without barrier islands. In addition, the comparison of the characteristics of the Flathead Formation with the characteristics of the other high and low-energy environments in Figure 31 has shown that environments X and XI are the most probable depositional environments.

The high-energy environment with wave-induced currents is, like most shoreline systems, a very complex environment that is affected by many variables. The Flathead Formation is an example of this. Not all of the primary structures described in this environment in Oregon by Clifton and others (1971) are represented in the formation. The lower two parts of the Flathead represent deposits of the swash and surf sub-zones and the upper part represents deposits of the outer part of the

nearshore zone, but deposits of the wave-build-up and breaker subzones are not represented in the formation in most places. The slope of the beach, strength of the waves, and the effect of the tides could have been responsible for omission of these two facies, but little information can be derived from the formation to explain these differences. The effect of storms could have had an important effect on the deposits and their primary structures.

History of Deposition

The Precambrian rock in the thesis area had undergone a long period of weathering before a sea transgressed from the west in middle Cambrian time and a thick zone of weathered material accumulated in most areas. Some resistant hills of rock were present on a Precambrian surface that in most places had little relief. As the land slowly subsided the sea transgressed to the east. The shoreline in most places was north-south, but bays existed in some areas. The coastline consisted of a gently seaward-sloping surface, but cliffs did exist in some places. Channels on the Precambrian surface suggest that in some places rivers carried sediment to the shoreline, but because fluvial and deltaic deposits were not found beneath the Flathead, rivers and deltas probably were not widespread. Islands did exist in some places where the Precambrian rock resisted the erosive action of the sea. As the sea transgressed, a sheet sand was deposited in a high-energy environment with wave-induced currents. The weathered zone in most places was eroded and only a relatively thin remnant of it was left before sand and gravel was deposited over it. The energy of the environment allowed

the weathered zone and fresh rock to be eroded and thoroughly winnowed, leaving the deposits of sand free from the fine clastics that were transported into the offshore zone and deposited. The sand was eventually overlain by offshore mud as the shoreline moved slowly eastward.

The conditions were such that the sand deposits of the swash and surf subzones and the outer part of the nearshore zone were preserved. The thickness of the sand from the swash subzone varied in relation to the topography of the Precambrian surface on which it was deposited. The lower shore zone was affected by longshore and rip currents that modified deposits in the surf zone. Storms were common and produced seaward-dipping cross bedding.

Anemones, annelid worms, trilobites, and inarticulate brachiopods thrived in the sandy bottom sediment seaward of the surf zone. Burrows and tubes made by anemones, annelid worms, and trilobites were preserved as trace fossils in the sand. Inarticulate brachiopods were preserved in only a few places.

Ancient and Modern Analogs

One section (Section 35) was measured in the Little Belt Mountains of the Niehart Quartzite, which is the basal formation in the Belt Supergroup in central Montana. One section (Section 46) was measured of the Pilcher Formation in western Montana. The Pilcher Formation is the youngest formation in the Belt Supergroup in western Montana, and is overlain by the Flathead Formation. The primary structures of the sandstone of both the Niehart Quartzite and the Pilcher Formation are very similar to the primary structures of the Flathead Formation and

could also have been deposited in a high-energy environment with wave-induced currents.

The Ironton and Galesville Formations in Illinois and Wisconsin (Emrich, 1966) and the Potsdam Formation in New York (Otvos, 1966) are upper Cambrian transgressive sandstone deposits that exhibit bedding, grain size, geometry, and stratigraphic relationships that are very similar to those characteristics in the Flathead Formation.

Deposits similar to those of the Flathead Formation are presently forming along the Pacific coasts of California and Oregon. Clifton and others (1971) has described Pleistocene and Quarternary marginal-marine sandstone in Oregon with structures similar to those structures found in the Flathead.

However, characteristics of published studies of modern shallow-marine and marginal-marine sandstone environments do not completely account for all the characteristics of the Flathead Formation and other Cambrian transgressive sandstone (Pettijohn and others, 1973, p. 497).

Further study of the high-energy nearshore and shore environments with wave-induced currents may reveal better comparisons with the characteristics of Cambrian transgressive sandstone. However, no analogous modern environment may exist, and the Cambrian transgressive-sandstone depositional environment may not have existed since Cambrian time.

APPENDICES

INTRODUCTION TO APPENDICES

Appendix A contains a list of topographic maps and air photos used before and during fieldwork. The 7 1/2 and 15 minute quadrangles are arranged in groups according to study areas

Appendix B contains a sample measured section on the outcrop data sheets that was specially devised for use in the field. The first sheet contains places for a column and the important characteristics for each measured bed. The second sheet, which was on the back side of the first sheet for field use, contains spaces for location descriptions, weather, topography, sketches, and summaries for the geology field data. Because of space limitations, abbreviations were used on the outcrop data sheets. A key for the abbreviations is listed below:

b	brown
hem	hematitic
mrn	maroon
t	tan
w	white
dk	dark
lt	light
uh	horizontal tubes
ru	<u>Rusophycus</u>
sl	slight
f	fine
m	medium
c	coarse
vc	very coarse
//bdd	parallel bedding
h<lsc	large-scale cross bedding
h<ssc	small-scale cross bedding
sms	shallow-marine shore
ss	sandstone

cgl conglomerate
pbl pebble
Gr Gn granitic gneiss

Appendix C contains locations and thicknesses of the measured sections and outcrop descriptions for each study area. A key for the rock unit abbreviations is listed below:

Pcb Precambrian Belt Supergroup (sedimentary rock)
Pcg Precambrian granite and granitic gneiss
Pcn Precambrian Niehart Quartzite (sedimentary rock--Belt
Supergroup)
Pcp Precambrian Pilcher Formation (sedimentary rock--Belt
Supergroup)
Cf Flathead Formation--Cambrian
Egv Gros Ventre Formation--Cambrian
K Cretaceous sedimentary rock
Tert Tertiary sedimentary rock

APPENDIX A

TOPOGRAPHIC MAPS AND AIR PHOTOS USED

IN THE THESIS STUDY AREA

Topographic Maps of the U. S. Geological Survey

1. Scale: 1:250 000

<u>Name</u>	<u>Serial Number</u>
a. Arminto, Wyo.	NK 13-1
b. Cody, Wyo.	NL 12-12
c. Sheridan, Wyo.	NL 13-10
d. Thermopolis, Wyo.	NK 12-3
e. Billings, Mont.	NL 12-9
f. Boseman, Mont.	NL 12-8
g. Great Falls, Mont.	NL 12-2
h. White Sulphur Springs, Mont.	NL 12-5

2. Owl Creek Mountain Area

<u>Name</u>	<u>Quadrangle size</u>
a. Birdseye Pass, Wyo.	7½ min
b. Boysen, Wyo	7½ min
c. DePass, Wyo.	7½ min
d. Gates Butte, Wyo.	7½ min
e. Guffy Peak, Wyo.	7½ min
f. Picard Ranch, Wyo.	7½ min
g. Wedding of the Waters, Wyo.	7½ min

3. Sunlight Basin, Clarks Fork Canyon, and Cody Area

a. Clark, Wyo.	15 min
b. Cody, Wyo.	15 min
c. Dead Indian Peak, Wyo.	15 min
d. Deep Lake, Wyo.	15 min
e. Devils Tooth, Wyo.	15 min
f. Pat O'Hara Mountain, Wyo.	15 min

4. Beartooth Butte and Cooke City Area

a. Beartooth Butte, Wyo.	15 min
b. Cooke City, Mont.	15 min
c. Pilot Peak, Wyo.	15 min

5. Red Lodge Area

a. Alpine, Mont.	15 min
b. Mount Maurice, Mont.	15 min
c. Red Lodge East, Mont.	7½ min
d. Tolman Flat, Mont.	7½ min

<u>Name</u>	<u>Quadrangle size</u>
6. Livingston and Manhattan Area	
a. Beehive, Mont.	7½ min
b. Brisbin, Mont.	7½ min
c. Emerald Lake, Mont.	7½ min
d. Emigrant, Mont.	15 min
e. McLeod Basin, Mont.	7½ min
f. Manhattan, Mont.	15 min
g. Mission, Mont.	7½ min
h. Mount Rae, Mont.	7½ min
i. Mt. Cowen, Mont.	15 min
j. Mt. Douglas, Mont.	15 min
k. Mt. Wood, Mont.	15 min
l. Sliderock Mountain, Mont.	7½ min
m. Squaw Peak, Mont.	7½ min
7. Bighorn Mountain Area	
a. Bald Mountain, Wyo.	7½ min
b. Burgess Junction, Wyo.	7½ min
c. Granite Pass, Wyo.	7½ min
d. Hidden Teepee Creek, Wyo.	7½ min
e. Medicine Wheel, Wyo.	7½ min
f. Shell Falls, Wyo.	7½ min
8. Little Belt Mountain and Smith River Basin Area	
a. Belt Park Butte, Mont.	7½ min
b. Catlin Spring, Mont.	7½ min
c. Checkerboard, Mont.	7½ min
d. Fort Logan, Mont.	7½ min
e. Monarch, Mont.	7½ min
f. Niehart, Mont.	7½ min

Air Photos

Available from: U. S. Forest Reproduction Lab
 Room 548
 San Francisco, Calif. 94111

1. Sunlight Basin and Clarks Fork Canyon Area

<u>Area</u>	<u>Line</u>	<u>Photo</u>	<u>Area</u>
<u>Number</u>	<u>Number</u>	<u>Numbers</u>	
ECF	12	80-90	east Beartooth Mountain front
ECF	1	195-198	Clarks Fork Canyon
ECF	1	151-160	Clarks Fork Canyon

<u>Area</u> <u>Number</u>	<u>Line</u> <u>Number</u>	<u>Photo</u> <u>Numbers</u>	<u>Area</u>
ECF	1	113-120	Sunlight Basin
ECF	11	148-154	Antelope Mountain
ECF	11	119-122	west Clarks Fork Canyon
ECF	11	17-20	west Clarks Fork Canyon
ECF	10	123-125	west Clarks Fork Canyon
ECF	10	96-100	west Clarks Fork Canyon
ECF	9	131-135	west Clarks Fork Canyon
ECF	8	115-118	west Clarks Fork Canyon

Date flown: August 1, 1958. Photo scale 1:20 000
Shoshone National Forest--Wapiti district

2. Red Lodge Area (all photos are of the eastern and
northern Beartooth Mountain front)

EXX	1	127-135
EXX	2	143-147, 137-141
EXX	3	201-202, 165-172, 208-212
EXX	4	177-179
EXX	5	214-215
EXX	6	221-222
EXX	7	96-98
EXX	8	137-139
EXX	9	38-40
EXX	10	32-33

Date flown: July 15, 1971. Photo scale 1:20 000
Custer National Forest--Red Lodge district

APPENDIX B

SAMPLE MEASURED SECTION ON OUTCROP DATA SHEETS

SECTION NO. 30 UNIT Flathead Fm DATE 7 / 19 / 77 STATE WY
 LOCATION SWNW SEC 30 T 58N R 105W COUNTY Park
 AREA Beartooth Butte STRUCTURE: STRIKE N 80° E DIP 6° S
 GEOLOGIST J. Degenstein SAMPLES 2 (#23, #24) QUAD Beartooth Butte 15
 SCALE: 1 vert. division = 1m TOTAL THICKNESS 15.8 m OUTCROP QUAL good

UNIT NO.	Thickness in meters	Lithologic symbol	% grain size	roundness	sorting	color	induration	fossils	iron stain	minerals	lithologic descr.	primary structures	environ. deposition	COMMENTS
9	1.3			X	X	w/lt+	X	uh	al		m-f	bdd	p.m.n.	top of sandstone outcrop
8	1.7			X	X	lt+/lt	X		al al		c-m	hclsc bdd		set 0.2 m
7	1.7			X	X	lt+/man	X	uh	X		c-m	bdd		set 1.4 m
6	1.4			X	X	red/man	X		X		c-m	hclsc		covered
5	2.5													
4	1.7			X	X	lt/dk to man	X	uh ru	X		vc-m	hclsc		set 0.1 m mudcracks
3	2.7			X	X	red/lt+/lt	X		al X		vc-m	hclsc bdd		set 0.2 m cgl troughs N50°E
2	0.8			X	X	red/man	X		X	#24	vc-m	bdd		cgl quartz pit 0.03 m to 0.10 m covered
1	2.0									#23				Gr Gm

Groa Ventre formation above ↑

SECTION NO. 30 DATE 7 / 19 / 77 TIME 4:30 TIME AT OUTCROP 5 hrs.
 WEATHER cloudy, windy, cool
 LOCATION: STATE WY COUNTY Park QUAD Beartooth Butte 15'
SW 1/2 NW 1/2 SEC 30 T 58N R 105W OTHER INFO, ACCESS,
 SPEC. DIRC., NEAREST TOWN, ROAD COND., Section lies along NE corner of
Beartooth Butte and may be reached by Beartooth trail 169, which
leaves Beartooth Lake campground and heads N. Approximately a 3
mile, 2 hour hike.
 TOPOGRAPHY NE base of Beartooth Butte between butte and glaciated
Pre C land to north. Relief-0 to 60' ELEV. 10,000'
 GEOLOGY: UNIT Flathead Fm AGE middle Cambrian
 LITHOLOGY vc-f grained ss and cgl
 CONGL x size 3-10 cm C.GR. x M.GR. x F.GR. x SH SLT
 DESCR. Basal unit is cgl up to 1.7 m thick. Middle unit is vc-m
grained ss. Upper unit is f-c grained ss.
 THICKNESS 15.8 m
 PRIMARY STRUCTURES PRESENT h<lsc, //bdd
 BEDDING: CROSSBEDS x GROUPED x SOLITARY x GRADED x SORTING poor
 ANGLE: HI x SCALE: LRG x SET SIZE .1 to 1.4 m
 LO SML TROUGH PLANAR UNBEDDED
 PARALLEL STRAT x SET SIZE: LAMINATED (LESS THAN 1cm)
 THIN (1-60cm) x THICK (60-120cm) MASSIVE (GR THAN 120cm)
 DESCR. Parallel bedding is most common in the lower unit. h<lsc is
most common in middle unit. //bdd is most common in upper unit.
 DISTURBED OR BURROWED
 FOSSILS: TRACE: VERTICAL TUBES _____ HORIZ. TUBES x CRUZIANA x
 BRACHIOPODS _____ OTHER _____ DESCR. Present in
both middle and upper units.
 COLOR: FRESH w, lt t, red, b WEATHERED lt t, t, b, dk b, lt mrn
 DESCR. _____ and mrn
 STAINS: HEMATITIC x LIMONITIC sl ALTERED _____
 DESCR. most lower and middle units--mostly hem stained
 NO. OF SAMPLES 2 (#23, #24) PYRITE _____ ORGANICS _____
 STRUCTURES: STRIKE N 80° E DIP 6° S JOINTS _____ FAULTS _____
 DESCR. _____
 RADIOMETRICS: _____ / BG/NORMAL, _____ / BG/ANOM
 DESCR. _____
 SHOWS: GOOD _____ POOR _____ PREC. READING _____ BG
 PREC. LITH. _____ DESCR. _____
 COMMENTS AND SKETCHES:

APPENDIX C

TABLES OF LOCATIONS AND THICKNESSES OF MEASURED
SECTIONS AND OUTCROP DESCRIPTIONS

TABLE 1

LOCATIONS AND THICKNESSES FOR MEASURED SECTIONS IN THE
OWL CREEK MOUNTAIN AREA, WYOMING

Section (SEC)	Rock Units	Thickness (metres)	Quadrangle	County	State	Location			
						T	R	Section	
SEC 1	€gv	12.0	Birdseye Pass 7½ min	Fremont	Wyo.	40N	94W	1	SW
SEC 2	€f	28.6	Birdseye Pass 7½ min	Fremont	Wyo.	40N	94W	11	SWSWSW
SEC 3	€gv	8.5	Boysen 7½ min	Fremont	Wyo.	5N	6E	8	N NESE
	€f	37.2							
SEC 40	€f	43.8	Boysen 7½ min	Hot Springs	Wyo.	6N	6E	28	NENESW
	€gv	5.0							
SEC 41	€f	40.2	Boysen 7½ min	Hot Springs	Wyo.	6N	6E	28	E SENW
	€gv	37.7							
SEC 42	€f	44.2	Birdseye Pass 7½ min	Hot Springs	Wyo.	41N	93W	28	SESE
SEC 43	€f	37.4	Guffy Peak 7½ min	Fremont	Wyo.	39N	92W	5	NWSWNE
SEC 44	€gv	42.6	Picard Ranch 7½ min	Fremont	Wyo.	39N	92W	8	NWSWNE
SEC 51	€f	22.8	Cottonwood Pass 7½ min	Fremont	Wyo.	40N	90W	13	SESWNW

TABLE 2

LOCATIONS OF OUTCROP DESCRIPTIONS IN THE OWL CREEK MOUNTAIN AREA, WYOMING

Outcrop (0)	Rock Units	Quadrangle	County	State	Location		
					T	R	Section
0 21	Egv	Boysen 7½ min	Hot Springs	Wyo.	6N	6E	28 NWNWSE
0 22	Pcg, Cf	Birdseye Pass 7½ min	Hot Springs	Wyo.	41N	93W	34 SWNWNW
0 23a	Pcg	De Pass 7½ min	Fremont	Wyo.	40N	92W	34 SESENW
b	Tert	Gates Butte 7½ min	Fremont	Wyo.	39N	92W	10 NWNE
0 24a	Pcg, Egv	Birdseye Pass 7½ min	Fremont	Wyo.	40N	94W	1 SW
b	Egv	Guffy Peak 7½ min	Hot Springs	Wyo.	41N	93W	26 SW

TABLE 3

LOCATIONS AND THICKNESSES FOR MEASURED SECTIONS IN THE SUNLIGHT
BASIN, CLARKS FORK CANYON, AND CODY AREA, WYOMING

Section (SEC)	Rock Units	Thickness (metres)	Quadrangle	County	State	Location			
						T	R	Section	
SEC 4	cf	36.9	Cody 15 min	Park	Wyo.	52N	102W	6	N SW
SEC 8	cf	12.5	Deep Lake 15 min	Park	Wyo.	56N	103W	6	SW
								7	NW
SEC 9	cf	20.8	Deep Lake 15 min	Park	Wyo.	55N	104W	9	NW
SEC 10	cf	7.2	Deep Lake 15 min	Park	Wyo.	55N	104W	8	S NE
SEC 11	cf	26.9	Deep Lake 15 min	Park	Wyo.	55N	104W	8	NESW
SEC 12	cf	35.2	Deep Lake 15 min	Park	Wyo.	55N	104W	8	SWNW
SEC 13	cf	25.8	Deep Lake 15 min	Park	Wyo.	55N	104W	8	NWNE
SEC 14	cf	14.4	Deep Lake 15 min	Park	Wyo.	55N	104W	5	NWSE
SEC 15	cf	16.7	Deep Lake 15 min	Park	Wyo.	55N	104W	5	SESW
SEC 16	cf	27.7	Deep Lake 15 min	Park	Wyo.	55N	104W	5	SWSW
SEC 17	cf	13.2	Deep Lake 15 min	Park	Wyo.	56N	104W	32	SWSW
SEC 18	cf	20.8	Deep Lake 15 min	Park	Wyo.	55N	104W	7	NWNE
SEC 19	cf	17.0	Deep Lake 15 min	Park	Wyo.	56N	104W	30	NESE
SEC 20	cf	18.1	Deep Lake 15 min	Park	Wyo.	56N	104W	35	NWSW

TABLE 4

LOCATIONS AND THICKNESSES FOR MEASURED SECTIONS IN THE
BEARTOOTH BUTTE AND COOKE CITY AREA AND THE
RED LODGE AREA, WYOMING AND MONTANA

Section (SEC)	Rock Units	Thickness (metres)	Quadrangle	County	State	Location			Section
						T	R		
SEC 21	cf	15.4	Beartooth Butte 15 min	Park	Wyo.	56N	106W	9	NWNW
								4	S SW
SEC 22	cf	25.3	Beartooth Butte 15 min	Park	Wyo.	56N	106W	1	SENW
SEC 23	cf	11.0	Beartooth Butte 15 min	Park	Wyo.	57N	106W	9	SE
SEC 24	cf	18.6	Beartooth Butte 15 min	Park	Wyo.	57N	106W	1	NESW
Sec 25	cf	12.7	Beartooth Butte 15 min	Park	Wyo.	57N	106W	12	NENW
SEC 26	cf	8.8	Beartooth Butte 15 min	Park	Wyo.	58N	105W	30	NWNW
SEC 27	cf	15.0	Cooke City 15 min	Park	Mont.	9S	14E	25	SWSE
SEC 28	cf	15.3	Cooke City 15 min	Park	Mont.	9S	14E	1	NWSW
SEC 29	cf	9.3	Beartooth Butte 15 min	Park	Wyo.	57N	105W	9	NWNW
SEC 30	cf	15.8	Beartooth Butte 15 min	Park	Wyo.	58N	105W	30	SWNW
SEC 31	cf	19.4	Tolman Flat 7½ min	Carbon	Mont.	8S	20E	34	NESWSE
SEC 32	cf	8.8	Tolman Flat 7½ min	Carbon	Mont.	8S	20E	34	SWNE

TABLE 5

LOCATIONS OF OUTCROP DESCRIPTIONS IN THE RED LODGE AREA, MONTANA

Outcrop (0)	Rock Units	Quadrangle	County	State	Location		
					T	R	Section
0 1	Pcg, Ef	Tolman Flat 7½ min	Carbon	Mont.	8S	20E	34 NENWSE
0 2	Ef	Tolman Flat 7½ min	Carbon	Mont.	8S	20E	34 SESWNE
0 3	Ef	Tolman Flat 7½ min	Carbon	Mont.	8S	20E	34 NWNWSE
0 4	Ef	Tolman Flat 7½ min	Carbon	Mont.	8S	20E	34 NWNWSE
0 5	Ef	Tolman Flat 7½ min	Carbon	Mont.	8S	20E	34 NENWSE
0 6	Ef	Tolman Flat 7½ min	Carbon	Mont.	8S	20E	34 NENWSE
0 7	Ef	Tolman Flat 7½ min	Carbon	Mont.	8S	20E	34 SWSENE
0 8	Ef	Tolman Flat 7½ min	Carbon	Mont.	8S	20E	34 NESWNE
0 9	Ef	Tolman Flat 7½ min	Carbon	Mont.	8S	20E	34 SWNWNE
0 10	Pcg	Tolman Flat 7½ min	Carbon	Mont.	8S	20E	34 SENWNE
0 11	Pcg	Tolman Flat 7½ min	Carbon	Mont.	8S	20E	27 SESESE
0 12	Pcg	Tolman Flat 7½ min	Carbon	Mont.	8S	20E	27 NESESE
0 13	Ef	Tolman Flat 7½ min	Carbon	Mont.	8S	20E	27 NESESE
0 14	Ef	Tolman Flat 7½ min	Carbon	Mont.	9S	20E	3 NENWNE
0 25	Ef, Pcg	Tolman Flat 7½ min	Carbon	Mont.	8S	20E	26 NW 27 NE
0 26	Ef	Mount Maurice 15 min	Carbon	Mont.	7S	19E	26 E NE

TABLE 6

LOCATIONS AND THICKNESSES OF MEASURED SECTIONS AND OUTCROP
DESCRIPTIONS IN THE LIVINGSTON AREA AND OTHER
AREAS IN WESTERN MONTANA

Section (SEC)	Rock Units	Thickness (metres)	Quadrangle	County	State	Location			Section
						T	R		
SEC 45	ef	23.0	Livingston Peak 7½ min	Park	Mont.	3S	11E	7	SESE
SEC 46	Pcp (Ef?)	64.3	Alberton 15 min	Missoula	Mont.	15N	22W	26	NW
SEC 47	ef	40.2	Manhattan 15 min	Gallatin	Mont.	2N	3E	27	NENE
SEC 48	ef	21.7	Livingston Peak 7½ min	Park	Mont.	3S	10E	11	NE
SEC 49	ef	14.3	Brisbin 7½ min	Park	Mont.	4S	9E	12	N NE
SEC 50	ef	11.1	McLeod Basin 7½ min	Sweetgrass	Mont.	3S	13E	32	SENW
0 27	ef		Jefferson Island 15 min	Jefferson	Mont.	2N	2W	31	
0 28	Pcp (Ef?)		Fishtrap Lake 7½ min	Sander	Mont.	24N	28W	26	NE
0 29	Pcg		Mount Cowen 15 min	Park	Mont.	6S	12E	4	SE

TABLE 7

LOCATIONS AND THICKNESSES OF MEASURED SECTIONS AND OUTCROP
 DESCRIPTIONS IN THE BIGHORN MOUNTAIN AREA, WYOMING

Section (SEC)	Rock Units	Thickness (metres)	Quadrangle	County	State	Location			
						Outcrop (O)	T	R	Section
SEC 5	cf	4.0	Bald Mountain 7½ min	Bighorn	Wyo.	56N	91W	31	NW
SEC 6	cf	6.5	Bald Mountain 7½ min	Bighorn	Wyo.	56N	92W	24	SE
SEC 7	cf	4.0	Shell Falls 7½ min	Bighorn	Wyo.	53N	89W	7	NW
SEC 52	cf	23.0	Park Reservoir 7½ min	Sheridan	Wyo.	54N	86W	25	NE
0 30	cf		Meadowlark Lake 7½ min	Washakie	Wyo.	48N	86W	3	

TABLE 8

LOCATIONS AND THICKNESSES OF MEASURED SECTIONS AND OUTCROP
DESCRIPTIONS IN THE LITTLE BELT MOUNTAIN AND SMITH
RIVER BASIN AREA, MONTANA

Section (SEC)	Rock Units	Thickness (metres)	Quadrangle	County	State	Location		
						T	R	Section
SEC 33	-ef	6.3	Monarch 7½ min	Cascade	Mont.	14N	7E	2 N SW
SEC 34	-ef	60.3	Monarch 7½ min	Cascade	Mont.	15N	7E	25 SWNE
SEC 35	Pcn	30.5	Niehart 7½ min	Cascade	Mont.	13N	8E	10 NWNE
SEC 36	-ef	59.2	Fort Logan 7½ min	Meagher	Mont.	11N	5E	31 NENE
SEC 37	-ef	49.8	Monarch 7½ min	Cascade	Mont.	15N	7E	24 NWSWSW
SEC 38	-ef	16.1	Catlin Spring 7½ min	Meagher	Mont.	8N	7E	32 SWNW
SEC 39	-ef	14.3	Catlin Spring 7½ min	Meagher	Mont.	7N	6E	1 E SW
0 15	-ef	about 40	Checkerboard 7½ min	Meagher	Mont.	9N	9E	13 E NW
0 16	-ef, Tert		Monarch 7½ min	Cascade	Mont.	15N	7E	27 SENESE
0 17	Tert		Niehart 7½ min	Cascade	Mont.	14N	8E	16 SE
0 18	Pcb		Coxcombe Butte 7½ min	Meagher	Mont.	10N	7E	5 SE
0 19	-ef	about 7	Moose Mountain 7½ min	Meagher	Mont.	12N	7E	25 SW
0 20	K		Unfinished	Meagher	Mont.	7N	9E	4 SE

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