MAP I-1797-A

DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

CHART SHOWING LITHOLOGY, MINERALOGY, AND PALEONTOLOGY OF THE NONMARINE NORTH HORN FORMATION AND FLAGSTAFF MEMBER OF THE GREEN RIVER FORMATION, PRICE CANYON, CENTRAL UTAH: A PRINCIPAL REFERENCE SECTION

By T. D. Fouch, J. H. Hanley, R. M. Forester, C. W. Keighin, J. K. Pitman, and D. J. Nichols

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TO ACCOMPANY MAP I-1797-A
FOLIO OF THE UINTA AND PICEANCE BASIN AREA

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INTRODUCTION

This chart presents data collected as part of an analysis of sedimentary rocks exposed in Price Canyon between the northeast part of sec. 21 and southwest part of sec. 15, T. 12 S., R. 9 E., and Kyune, Utah (fig. 1). These rocks were assigned to the North Horn Formation and the Flagstaff Limestone by Spieker (1946), but the Flagstaff in Price Canyon is designated a member of the Green River Formation because of its evident continuity with the Green River in the subsurface of the Uinta Basin north of the study area (Fouch, 1976; Fouch and others, 1976; Ryder and others, 1976). The boundary between the underlying North Horn and the Flagstaff in Price Canyon is placed by us at the base of a series of resistant argillaceous and fossiliferous carbonate rocks intercalated with lesser amounts of claystone and sandstone. Collectively these resistant units form a dipslope whose topographic expression can be mapped over much of the western part of the Roan Cliffs. Strata of the North Horn Formation, which generally include fewer laterally extensive carbonate rocks and more sandstone and claystone beds, form a stratigraphic unit less resistant to erosion than the Flagstaff. Lithologies that are typical of the Flagstaff also occur in the North Horn Formation in Price Canyon and may represent tongues of the main body of the Flagstaff, although this relation is uncertain. The North Horn overlies the Price River Formation, and the Flagstaff underlies the Colton Formation.

Exposures of the North Horn and Flagstaff in Price Canyon are generally better than typical exposures of the units in the northern part of the Wasatch Plateau and the western part of the Roan Cliffs. As a result, analysis of lithologic and paleontologic constitutents can be made for most beds. Data derived from our studies are presented in a form relatively free of our interpretations so that they are available to the technical public for its independent assessment. The sequence of rocks is herein designated a principal reference section of the North Horn Formation and of the Flagstaff Member of the Green River Formation because of excellent exposures and their suitability for study.

The section was described and collected by T. D. Fouch and J. H. Hanley using a jacob's staff, Brunton compass, and tape. Sandstone samples for textural and mineralogic analysis were generally taken near the base of individual beds. Petrographic analyses were by C. W. Keighin, and X-ray diffraction studies were by J. K. Pitman. Paleontologic constituents were interpreted by J. H. Hanley (mollusks), R. M. Forester (ostracodes and charophytes), and D. J. Nichols (palynomorphs).

AGE OF ROCKS

Interpretation of the age of the North Horn Formation and Flagstaff Member of the Green River Formation in Price Canyon is based on paleontologic data derived from study of nonmarine fossils. Specifically, palynomorphs, calcareous microfossils (ostracodes and charophytes), and mollusks are used collectively and independently as bases for age interpretations. The time-stratigraphic distribution of these floral and faunal groups is variably understood. For example, the biostratigraphic utility of palynomorphs in nonmarine Upper Cretaceous and Paleogene sedimentary rocks of the western interior is much better documented than for calcareous microfossils and mollusks. However, age interpretations derived independently from each group at a single locality or from a stratigraphic sequence are consistent.

Assignment of the basal part of the North Horn Formation (0-50 m) to the Late Cretaceous (Maestrichtian) is based on palynomorphs, charophytes, and mollusks. Middle and late Paleocene ages of the North Horn are based on palynomorphs. The Flagstaff Member of the Green River Formation in Price Canyon is interpreted to be of late Paleocene age on the basis of nonmarine mollusks. Bases for age interpretations within each major paleontologic group are discussed in detail below. Placement of the Cretaceous-Tertiary boundary and subdivisions of the Paleocene are approximate.

PALEONTOLOGIC CONSTITUENTS

Mollusks

In the stratigraphic sequence exposed in Price Canyon, nonmarine mollusks are common to locally abundant constituents in carbonate units of the North Horn Formation and Flagstaff Member of the Green River Formation and in carbonaceous rocks of the North Horn Formation. Samples from the North Horn

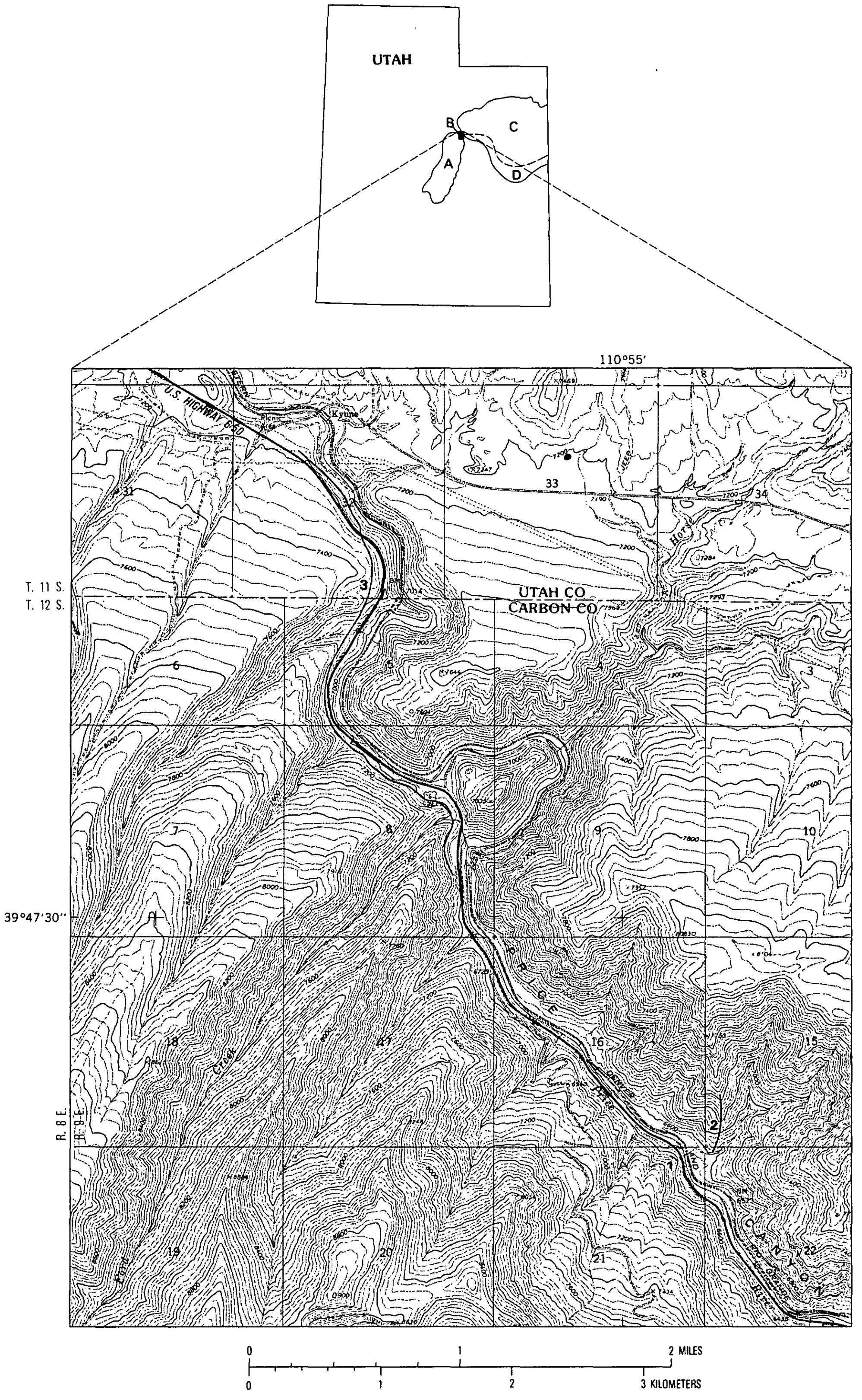

Figure 1.—Map showing location of Price Canyon stratigraphic reference section. Numbers denote locations of measured stratigraphic sections, which correspond to the following intervals on the reference section: 1 (0-30 m), 2 (30-320 m), 3 (320-875 m). State outline map illustrates the location of the following physiographic features discussed in text: Wasatch Plateau; Price Canyon; Uinta Basin; Roan Cliffs = southern margin of Unita Basin. Base map is from U.S. Geological Survey topographic map of the Kyune, Utah, 7.5-minute quadrangle, 1969.

and Flagstaff clearly indicate the presence of diverse molluscan faunas. Because faunal sampling was restricted to relatively unweathered outcrops in order to document details of the stratigraphic sequence, large collections of naturally weathered mollusks could not be obtained. Total faunal diversity is probably well documented by the accompanying faunal list, but a given taxon is typically represented by few specimens. Inadequate documentation of morphologic variability and of morphologically complete, mature specimens of numerous gastropod taxa prompted detailed but conservative interpretation of mollusk taxonomy. Mollusks are assigned to 81 taxonomic categories including 14 genera, 10 species, and 8 new species, some of which are questionably identified. Twenty-one unnamed morphotypes are recognized; the majority of these undoubtedly represent new species. Mollusk samples are deposited in the paleontologic collections of the U. S. Geological Survey (USGS) in Denver, Colo. These collections may be located by reference to the USGS Mesozoic and Cenozoic locality numbers listed in table 1.

Mollusks of the North Horn Formation

The basal 30 m of the North Horn Formation is characterized by interbedded carbonate mudstone, carbonate wackestone, and claystone that contain two molluscan assemblages. The first assemblage is dominated by five new species of unionid bivalves. Four new species are assigned to the genus *Plesielliptio*, and one is provisionally assigned to the genus *Unio*. The unionid-dominated assemblage is best represented by samples D11445, D10227, and D10228. The second assemblage is characterized by notably greater diversity of the gastropod genera *Lioplacodes*, *Pleurolimnaea*, *Reesidella*, *Valvata*, *Physa*, and *Pseudocolumna*; nine distinct, unidentified gastropod morphotypes; sphaeriid bivalves; and rare unionid bivalves. Sample D11447 best represents this assemblage. Mollusk biofabric and preservation and associated lithologies indicate these fossils have been subjected to minimal transportation and reworking. Both assemblages are interpreted to have inhabited a shallow, vegetated, permanent freshwater lake. Greater clastic grain size in the carbonate mudstone characterized by the unionid assemblage indicates a coarser-grained substrate and potentially greater current in that habitat relative to the habitat of the diverse gastropod assemblage. The unionid-dominated assemblage may have inhabited a fluvial-lacustrine setting. Comparison of molluscan faunas in the basal part of the North Horn Formation with those of Late Cretaceous and Paleocene age in the western interior, together with the taxonomic affinities of *Plesielliptio* n. sp. B and *Pleurolimnaea* aff. *P. mclearni* Tozer, tentatively indicate the basal part of the North Horn in Price Canyon is of Late Cretaceous (Maestrichtian) age.

The middle part of the North Horn Formation (between 400 m and 450 m) contains numerous thin, lipid-rich coal beds, which contain as much as 346 liters of oil per metric ton (Fouch and others, 1977), interbedded with laminated ostracode, charophyte, and mollusk skeletal carbonate wackestone rich in organic matter. Coal beds, such as those that contain assemblages D1133NM and D1323NM, are typically grouped with alluvial depositional facies. However, interdisciplinary interpretation of rock types and sedimentary structures, organic geochemistry, and the mollusk, charophyte, and palynomorph content of the coals and associated units indicate nearshore deposition in a fresh, vegetated, quiet-water lake. Biofabric, associated lithologies, and the preservation, composition, and abundance of faunal elements indicate these fossils are virtually untransported. Specimens of one unidentified species of stylommatophoran (terrestrial) gastropod in D1323NM represent transported elements, which are ecologically incompatible with the aquatic mollusks. Organic geochemistry indicates that the coals are composed of a significant amount of organic material derived from land plants. Thus the occurrence of a species of terrestrial gastropod in D1323NM is not unusual. Sample D1133NM is dominated by the sphaeriid bivalve cf. *Sphaerium formosum* (Meek and Hayden) and by the gastropods *Valvata bicincta* Whiteaves and *Physa* sp. Sample D1323NM is dominated by unidentified sphaeriid bivalves, *Physa* sp., and two species of limpets, one of which is assigned to the genus *Acroloxus*. Major faunal differences between these samples include the presence and dominance of *Valvata bicincta* in D1133NM, and the dominance of limpets and the presence of Planorbidae? and Stylommatophora: indeterminate in D1323NM. These faunal differences are tentatively considered to reflect a more restricted (stagnant?) lake setting for D1323NM relative to that of D1133NM.

Lithostratigraphic relations indicate that the middle part of the North Horn Formation (between 400 and 450 m and exposed at the intersection of Ford Creek with U.S. Highway 6-50 in the approximate center NW1/4 sec. 8, T. 12 S., R. 9 E.) that contains interbedded carbonate wackestone and very thin coal beds may be part of a tongue of the Flagstaff Member of the Green River Formation. Comparison of mollusks from coal beds and the molluscan fauna of the lower part of the Flagstaff Formation of the Wasatch Plateau documented by LaRocque (1960) tentatively supports this interpretation. LaRocque used the term Flagstaff Formation rather than Flagstaff Limestone. Specimens assigned to *Valvata bicincta* in D1133NM are interpreted to represent the same taxon as *Carinulorbis utahensis* LaRocque, which is reported only from the lower part (unit 1) of the Flagstaff Formation in central Utah (LaRocque, 1960). In making his identification, LaRocque noted morphologic similarity between his specimens and the genus *Carinulorbis* Yen. Taylor (1975, p. 385-386) ultimately reassigned Yen's type species of *Carinulorbis* to the hydrobiid genus *Clenchiella* Abbott and reassigned *Carinulorbis utahensis* to *Valvata bicincta*. We concur with Taylor that LaRocque's assignment to *Carinulorbis* as defined by Yen (1946) is impractical on the basis of shell morphology and that reassignment of *C. utahensis* to *Valvata bicincta* is warranted. The presence of *V. bicincta* in D1133NM therefore suggests that this interval of the North Horn Formation may be in part temporally equivalent to the lower part of the Flagstaff Formation (unit 1 of LaRocque, 1960).

The part of the North Horn Formation above 425 m is interpreted to be of late Paleocene age on the basis of palynomorph biostratigraphy. A Paleocene age is supported by the occurrence of cf. *Sphaerium formosum* and *Valvata bicincta* in sample D1133NM.

Table 1.--Field locality numbers and corresponding Mesozoic and Cenozoic locality numbers for collections of nonmarine mollusks from Price Canyon principal reference section

[Samples are deposited in the paleontologic collections of the USGS in Denver, Colo. Samples are arranged stratigraphically from youngest to oldest, as on the reference section]

Field locality	USGS locality
UB17-75	D1330NM
U76TF77	D1327NM
U76TF57	D1325NM
UB3-81	D1332NM
U76TF54	D1326NM
U76TF53	D1324NM
U76TF50	D1323NM
UB25-75	D1134NM
UB2-81	D1331NM
UB24-75	D1133NM
UB26-75	D1329NM
U76TF14R	D1322NM
U76TF84	D10219
U76TF41	D10220
U76TF21	D11447
U77TF106	D10228
U76TF18	D10227
U76TF12	D11445

Table 2.--Palynologically productive field locality sample numbers and corresponding paleobotany locality numbers for Price Canyon principal stratigraphic reference section.

[Palynological preparations bearing these numbers are deposited in the paleontological collections of the USGS in Denver, Colo.]

Field locality	USGS Paleobotany locality
U76TF70	D5552
U76TF61	D5551
U76TF52	D5550
U75TF139	D5410
U75TF15	D5473-C
U75TF11	D5473-A
U75TF12	D5473-B
U76TF83	D5553
U76TF40	D5548
U76TF35	D5549
U76TF17	D5545

Overlying lipid-rich coals of the North Horn Formation (between 500 and 550 m) are intercalated sandstone, siltstone, claystone, and clay-rich carbonate mudstone units. Mollusks commonly occur in beds of carbonate mudstone, as represented by samples D1325NM and D1326NM. Preservation, composition, and associated lithology of D1326NM indicate that this sample is an ecologically mixed but relatively untransported assemblage. Hydrobia utahensis? White is the dominant taxon in the sample. Presence of the terrestrial gastropod Carychium? n. sp. in this sample may reflect the proximity of its habitat to the aquatic setting in which it was preserved. The aquatic molluscan fauna and lithology of D1326NM indicate a shallow, muddy substrate, low depositional-energy, nearshore-lacustrine habitat. Composition of D1326NM is similar to that of samples from the lower part of the Flagstaff Formation (unit 1) documented by LaRocque (1960, p. 51-58). However, absent from this sample are unionid bivalves such as Elliptio mendax (White) and the gastropods Goniobasis tenera (Hall), Viviparus meeki (Wenz), and Lioplacodes multistriata (Meek and Hayden) (same taxon as L. mariana Yen of LaRocque, 1960). These species are restricted to the lower part of the Flagstaff (unit 1 of LaRocque, 1960) in central Utah, where they occur together with Hydrobia utahensis, Pleurolimnaea tenuicosta (Meek and Hayden), and sphaeriid bivalves. The latter three taxa are questionably represented in sample D1326NM. The absence of these taxa, which collectively are interpreted to be typical of unrestricted nearshore-lacustrine habitats in the lower part of the Flagstaff, supports the inference that the fauna of D1326NM reflects a lentic nearshore-lacustrine habitat.

Some molluscan taxa of D1325NM and D1326NM tentatively indicate that this part of the North Horn Formation is in part temporally equivalent to the lower part of the Flagstaff Formation (Paleocene) (unit 1 of LaRocque, 1960). The following taxa in these samples are restricted to the lower part of the Flagstaff in central Utah: Hydrobia utahensis?, Pleurolimnaea tenuicosta?, cf. Valvata bicincta (Carinulorbis utahensis of LaRocque, 1960), Carychium? n. sp. (may represent the same taxon as Carychium cf. C. exile H. C. Lea of LaRocque, 1960), Viviparus meeki?, and Physa bridgerensis Meek. This interpretation is supported by Taylor (1975). On the basis of unpublished collections of mollusks from the West Tavaputs Plateau in the Sunnyside area, Utah (equivalent to the westernmost Roan Cliffs), Taylor concluded that the middle and upper parts of the Flagstaff Formation of LaRocque (1960) in central Utah were equivalent to parts of the Colton Formation. Taylor noted that all collections from the Flagstaff in the Sunnyside area contain some of the same fauna as the lower part of the Flagstaff Formation (unit 1 of LaRocque, 1960). Stanley and Collinson (1979) indicate that rocks assigned by LaRocque (1960) to the lower part (unit 1) of the Flagstaff Formation in the Wasatch Plateau are included in their Ferron Mountain Member of the Flagstaff Limestone. We there infer that, on the basis of lithostratigraphy and mollusk biostratigraphy, rocks of the North Horn Formation and Flagstaff Member of the Green River Formation above 400 m in the Price Canyon section are coeval with the lower part of the Flagstaff Formation (unit 1 of LaRocque, 1960) and with much of the Ferron Mountain Member of the Flagstaff Limestone of Stanley and Collinson (1979) in the Wasatch Plateau.

Calcareous Microfossils

Charophytes

Charophytes are distinctive green algae. The gyrogonite or calcareous housing that surrounds the female reproductive parts (oogonia) is common in the fossil record. Charophytes range from the Devonian to Holocene and were most diversified during the Mesozoic and early Cenozoic. Numerous studies of charophytes from various Cretaceous and Paleogene units throughout the world suggest that many taxa are widely distributed and seem to have evolved rapidly, so they are a potentially significant, although untested, biostratigraphic tool.

Charophytes typically live in shallow (less than 10 m, often less than 3 m) water. They occur commonly in the littoral zones of lakes, in marginal lacustrine environments such as marshes, and in the quiet water areas of rivers. Most charophytes live only in freshwater that has salinity below 3,000 (often below 1,000) parts per million of total dissolved solids. The solute composition of these environments is frequently dominated by calcium, magnesium, and bicarbonate-carbonate, and pH values from 7.5 to 9.0. Some living charophyte species are known from saline lakes. The latter occurrences are typified by a limited (low) diversity of taxa and a high density of individuals. Ecology of living charophytes probably represents a good general analog for fossil species, although particular details such as solute compositions may have been different in the past.

The charophytes in the Price Canyon section fall into two very distinctive assemblages. The first and oldest assemblage (assemblage 1) includes Porochara gildmeisteri (Koch and Bliss 1960) Musacchio 1972, Platychara compressa (Peck and Reker 1948) Grambast 1971, Strobilochara n. sp., Microchara sp. cf. M. cristata Grambast 1971, M. sp. cf. M. leiocarpa Grambast 1971, and Retusochara n. sp. These and other charophyte species occur in the lowermost part of the North Horn Formation in sample S84 and in those stratigraphically lower than S84 (0-55 m). Most other charophyte species in this assemblage are poorly preserved, and their taxonomic placement is tentative.

Platychara compressa (Peck and Reker 1948) Grambast 1971 is a very distinctive species that occurs commonly in Upper Cretaceous sedimentary rocks throughout the western United States (Peck and Forester, 1979). To date, P. compressa (Peck and Reker 1948) Grambast 1971 is reported only from North America, but the genus Platychara contains numerous species that have been found in South America, Europe, and Asia(?) (Grambast, 1971; Grambast, 1974; Grambast and Guitierrez, 1977; Peck and Forester, 1979). The majority of occurrences of Platychara spp. have been from Maestrichtian rocks. Some occurrences (for example, see Grambast and Guitierrez, 1977) are from undifferentiated Campanian and Maestrichtian units. Peck and Forester (1979) further suggested that Platychara compressa (Peck and Reker 1948) Grambast 1971 might occur in the early Paleocene. Worldwide occurrences indicate Platychara may have evolved in the Campanian or

Maestrichtian, radiated in the Maestrichtian, and become extinct either in the latest Maestrichtian or earliest Paleocene. The presence of Platychara compressa (Peck and Reker 1948) Grambast 1971 in the lowermost part of the North Horn Formation in Price Canyon suggests a Maestrichtian Age for the rocks.

Strobilochara n. sp. is known from numerous localities throughout North America (R. M. Forester, unpub. data). All of the occurrences of this species are in upper Cretaceous rocks that are probably Maestrichtian but may be in part Campanian in age. As with Platychara spp., most species of Strobilochara are from Maestrichtian units.

Microchara sp. cf. M. cristata Grambast 1971 and M. sp. cf. M. leiocarpa Grambast 1971 may be conspecific with M. cristata Grambast 1971 and M. leiocarpa Grambast 1971, but they are placed in a less certain taxonomic status until North Horn material can be compared with material from Europe. Grambast (1971) described M. cristata Grambast 1971 and M. leiocarpa Grambast 1971 from Maestrichtian rocks.

The North American occurrence of Retusochara n. sp. is thus far restricted to the lower part of the North Horn Formation in the Uinta Basin, but it is reported from Maestrichtian units in Europe (Grambast, 1971).

The occurrence together of Platychara compressa (Peck and Reker 1948) Grambast 1971, Strobilochara n. sp., Microchara sp. cf. M. cristata Grambast 1971, and M. sp. cf. M. leiocarpa Grambast 1971 is interpreted to indicate that the rocks in the basal 30 m of the North Horn Formation in Price Canyon are of Late Cretaceous (probably Maestrichtian) age.

The second charophyte assemblage (assemblage 2) occurs more than 600 m above the base in the uppermost part of the North Horn Formation and in the Flagstaff Member of the stratigraphic section. This assemblage contains Harrisichara bisulcata (Peck and Reker 1948), Peckichara coronata (Peck and Reker 1948), Peckichara sp., and "Chara" inconspicua Peck and Reker 1948. The ranges of these species are not well known. However, their occurrences in the rocks from Price Canyon may prove to be the oldest known if the beds are Paleocene. H. bisulcata (Peck and Reker 1948) and "C." inconspicua Peck and Reker 1948 have tentatively been identified from lower Eocene units in Wyoming and Utah (Forester, unpub. data). The absence of shallow freshwater environments exposed in lower Tertiary rocks in the western interior, which are suitable for study, makes the stratigraphic range of a species difficult to impossible to determine accurately.

Ostracodes

Ostracodes are diverse crustaceans characterized by a bivalved carapace composed of calcite. They are vagile benthic organisms that commonly live in all aquatic habitats in both marine and nonmarine environments. Ostracodes not only occur commonly in all nonacidic, oxic freshwater environments, but they are also common components of saline lakes, often being the only fossil organism found in saline deposits.

As in the case of charophytes, two distinctive ostracode assemblages were found in Price Canyon. The first assemblage (its stratigraphic occurrence coinciding with that of charophyte assemblage 1) includes Bisulcocypridea nyensis? (Swain 1949), Cypridea sp. indet., Timiriasevia sp. 1, and "Cypris" sp. indet.

Bisulcocypridea nyensis? (Swain 1949) has been found only in rocks of undifferentiated Late Cretaceous to early Tertiary age in Nevada. The material from the basal part of the North Horn Formation (basal 20 m) is not well preserved, and hence the identification is tentative. However, each of the specimens has a well-formed bisulcate carapace and a distinctive beak, which are typical of this species.

Cypridea sp. indet. is represented by poorly preserved material that precludes specific identification.

Timiriasevia sp. 1 is present in the basal North Horn (0-55 m) and is reported only from Cretaceous rocks. The genus contains species that occur in both Cretaceous and Tertiary units. Timiriasevia spp. is common in Upper Cretaceous and lower Tertiary rocks from various localities in Asia.

"Cypris" sp. indet. is a large cyprid ostracode that thus far has been recovered only from the basal part of the North Horn Formation.

The second assemblage of ostracodes contain Bisulcocypridea arvadensis (Swain 1949) (various forms) and Timiriasevia sp. 2.

Timiriasevia sp. 2 has been found only in Price Canyon rocks above 675 m. It is readily distinguished from sp. 1 by ornamentation patterns.

Bisulcocypridea arvadensis (Swain 1949) occurs commonly in the North Horn Formation and Flagstaff Member of the Green River Formation in Price Canyon and in Paleocene to middle Eocene rocks throughout major western ancient lake basins. The bisulcate aspect of the carapace is more subdued than in Mesozoic bisulcocyprideids. The beak varies from prominent to absent in specimens from the same sample, and stratigraphically younger populations tend to have a greater percentage of nonbeaked specimens. Also, the overall size of the specimens tends to increase progressively in younger rocks.

Palynomorphs (pollen, spores, and algae)

Biostratigraphy and paleoecology of palynomorphs in the Rocky Mountain region are subjects of ongoing investigation, and palynomorphs have proven useful for determination of age and paleoenvironment. Published studies concerning the Cretaceous-Tertiary boundary and dating of Paleogene rocks that are pertinent to the Price Canyon section include those of Newman (1965, 1974), Leffingwell (1971), Tschudy (1971), Nichols and Ott (1978), and Nichols and others (1983). The palynomorph distribution data shown here are incorporated from several sources, including reports on referred fossils prepared previously by R. H. Tschudy. The sample designated U76TF"0" was analyzed by H. L. Ott, Chevron U.S.A. Inc., who communicated the results to T. D. Fouch. All material has been reevaluated, and the taxonomy and nomenclature have been reinterpreted for consistency.

All palynological analyses are limited by lithofacies, because palynomorphs occur preferentially in certain lithologies. In Price Canyon, lithofacies control of palynomorph distribution is reflected by the fact that samples yielding palynomorphs commonly contain no calcareous microfossils or mollusks, and vice versa. Recovery of palynomorphs from samples collected in Price Canyon ranged from fair to poor, and many samples were barren of palynomorphs. This was the result of a combination of generally unfavorable lithologies exacerbated by the effects of weathering of outcrops. Samples yielding palynomorphs (table 2) generally have relatively sparse assemblages, and some assemblages lack stratigraphically useful taxa. For example, the lowermost palyniferous sample shown on the accompanying chart (U76TF17) is well within the uppermost Cretaceous part of the section, yet it lacks any palynomorph taxa that are restricted to the Cretaceous. Other samples were more productive, however. Biostratigraphic guide species recovered from some samples provided a basis for bracketing the age relations of strata in the Price Canyon section.

Sample U76TF"0" yielded the species Tricolpites interangulus Newman 1965 and Balmeisporites kondinskayae Srivastava & Binda 1969, which are restricted to the Upper Cretaceous. The assemblage in sample U76TF40 includes Zlivisporis sp., which is similarly stratigraphically restricted, along the Balmeisporites kondinskayae. The interval of about 275 m that includes the Cretaceous-Tertiary boundary is predominantly sandstone and has yielded no palynomorphs. The oldest palyniferous sample from the Tertiary in Price Canyon (U76TF83) contains species of Momipites Wodehouse 1933 emend. Nichols 1974. Species in this complex (see notes on nomenclature below) are characteristic of the middle Paleocene in the Rocky Mountain region; they occur in the North Horn Formation (between 340 and 440 m) in the principal reference section. Species of the genus Caryapollenites Potonie´ 1960 emend. Krutzsch 1961 occur in sample U75TF11-12 and above (above 410 m). These forms are regional guides to the upper Paleocene and Eocene. No species restricted to the Eocene were recovered from the Price Canyon section.

Algal palynomorphs that have paleoenvironmental significance occur sporadically throughout the North Horn Formation. The species, all of which are characteristic of nonsaline lacustrine environments, are Pediastrum paleogeneites Wilson & Hoffmeister 1953, Schizosporis spp., Tetraporina sp. cf. T. antiqua Naumova 1950, and Botryococcus sp. Presence of these forms may indicate the presence of lake beds at various levels within the North Horn Formation. Fern spores of the species Laevigatosporites haardtii (Potonie´ & Venitz 1934) Thomson & Pflug 1953 occur in great abundance in samples U75TF11-12, U75TF15, and U75TF139. The great relative abundance of fern spores may suggest that these samples represent deposits from a moist environment, perhaps a lake margin or swamp.

Notes on palynomorph nomenclature

The following notes explain some of the nomenclature used for the palynomorphs identified. In the absence of illustrations of the specimens, author citations and possible synonymies may aid the reader in recognition of taxa. The taxa discussed are listed in ascending stratigraphic order as they appear on the distribution chart.

Ulmipollenites spp. includes forms referable to Ulmipollenites undulosus Wolff 1934 and Ulmoideipites krempii Anderson 1960. The number of apertures varies from three to six. No distinctions have been made on the basis of aperture number, grain diameter, or coarseness of sculpture.

Pandaniidites spp. includes forms that exhibit an annulate pore (in sample U76TF17) and others that have obscure apertures or lack them completely. The porate forms are referable to P. radicus Leffingwell 1971; the others may be referable to Smilacipites Wodehouse 1933.

Zlivisporis sp. includes forms that seem to belong to a single species, but that represent a morphologic continuum from the genus Zlivisporis Pacltova 1961 to the genus Seductisporites Khlonova 1961.

Tricolpites interangulus Newman 1965 includes forms that some authors might assign to Gunnera microreticulata (Belsky, Boltenhagen, & Potonie´ 1965) Leffingwell 1971.

Momipites spp. includes M. coryloides Wodehouse 1933 (present in most samples), M. amplus Leffingwell 1971 (in sample U75TF12), and others not identifiable at the species level due to poor preservation. Momipites anellus Nichols & Ott 1978 includes forms that some authors might assign to M. tenuipolus Anderson 1960. Some authors would assign Momipites anellus, M. leffingwellii Nichols & Ott 1978, and M. triorbicularis Leffingwell 1971 to the genus Macepolipollenites Leffingwell 1971.

Caryapollenites spp. includes one or more species that are fully heteropolar in pore position and are comparable to Carya veripites Wilson & Webster 1946 or Caryapollenites inelegans Nichols & Ott 1978. Some specimens are poorly preserved and difficult to identify with certainty at the species level.

Chenopodipollis sp. includes periporate pollen of uncertain affinity having simple sculpture that differs markedly from Erdtmanipollis pachysandroides Krutzsch 1962.

Specimens identified respectively as Tilia vescipites Wodehouse 1933 and Tilia tetraforaminipites Wodehouse 1933 appear to conform to the original descriptions of those species, but they may not be referable to the modern genus Tilia Linnaeus 1753.

Schizosporis spp. includes forms probably referable to Schizosporis parvus Cookson & Dettman 1959. Some authors might ascribe these forms to the genus Ovoidites Potonie´ 1951 emend. Krutzsch 1959.

MINERAL CONSTITUENTS

Petrology

Petrographic characteristics were determined for 35 samples. Two thin sections were prepared for each sample. One section was impregnated with blue-dyed epoxy to enhance recognition of porosity, and calcite was stained with Alizarin red-S (Friedman, 1959). In the other section (not plastic impregnated) potassium feldspar was stained yellow by sodium cobaltnitrite, and plagioclase was stained pink by amaranth (Norman, 1974). Modal analyses were made by counting 300 points for each section. Average grain size was determined by measuring the minimum cross-section dimension of 25 quartz grains for each section. Angularity and sorting were estimated by visual comparison with published figures (Pettijohn and others, 1972, p. 585-586). A qualitative estimate of porosity was based on the amount of blue-dyed epoxy seen in each section. Classification of the rocks followed the method of Folk (1974, p. 129).

X-ray mineralogy

Whole-rock samples were examined by X-ray diffraction in order to identify the major, minor, and clay mineral constituents. The intensity of the strongest peak of each mineral was measured by recording the number of counts per second above a relative baseline. Clay minerals were noted as present in slight, moderate, and abundant amounts. The principal minerals identified include quartz, orthoclase, and plagioclase feldspar, and a carbonate mineral assemblage composed of calcite, dolomite, and ankerite. Small amounts of pyrite and siderite were identified in several samples. Illite, kaolinite, chlorite, and mixed-layer illite-smectite were identified in small to moderate amounts in most rocks.

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