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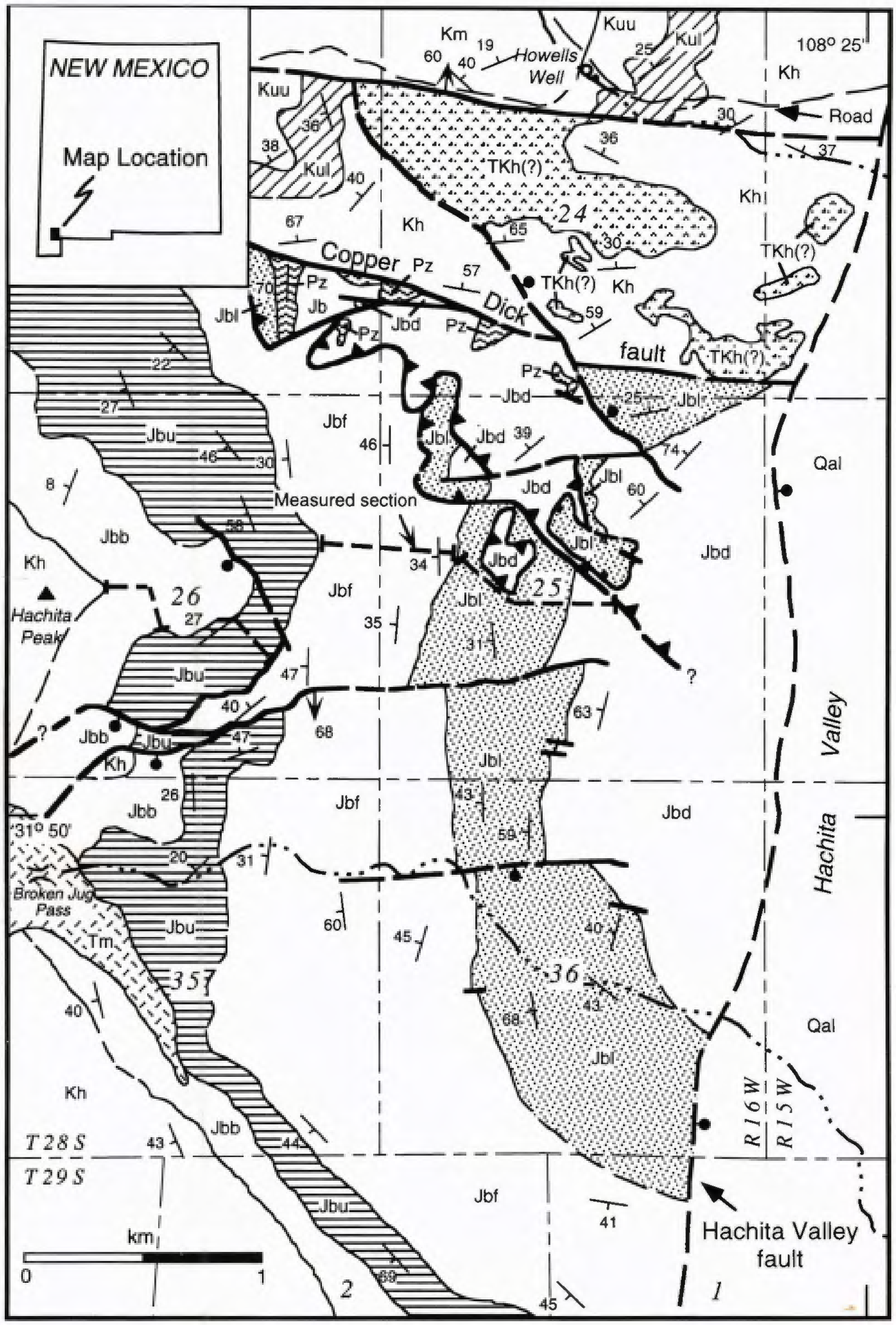

FIGURE 1—Geologic map of east-central part of Little Hatchet Mountains showing distribution of newly defined members of Broken Jug Formation and measured sections of stratotype. Base map is Hachita Peak 7.5-min topographic quadrangle. **Pz**, undifferentiated Paleozoic strata. Broken Jug Formation: **Jb**, undifferentiated strata; **Jbd**, dolostone member; **Jbl**, lower conglomerate member; **Jbf**, fine-grained member; **Jbu**, upper conglomerate member; **Jbb**, basalt member. Cretaceous strata: **Kh**, Hell-to-Finish Formation; **Kul**, lower U-Bar Formation; **Kuu**, upper U-Bar Formation; **Km**, Mojado Formation. Igneous rocks: **TKh(?)**, Hidalgo Formation or igneous rocks in Hell-to-Finish Formation, including fine-grained diorite and dioritic-andesitic breccia; **Tm**, biotite-hornblende monzonite (TKm of Zeller, 1970). **Qal**, surficial alluvial deposits of Hachita Valley. Northern boundary of map is Hidalgo–Grant County Line. Mapping by T. F. Lawton, 1992–98.

Abstract

The Broken Jug Formation, redefined herein, consists of approximately 1,200 m of marine and volcanic strata exposed on the east flank of Hachita Peak in the Little Hatchet Mountains. The Broken Jug Formation rests unconformably on upper Paleozoic strata and conformably underlies Lower Cretaceous red beds of the Hell-to-Finish Formation. Five informal members are defined in the Broken Jug Formation; in ascending order, they are the dolostone, lower conglomerate, fine-grained, upper conglomerate, and basalt members. These

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members record deepening of a marine sedimentary basin, its subsequent infilling by delta-front and fan-deltaic deposits, and final deposition of interbedded lava flows and braided-fluvial deposits. These rocks are not exposed north or south of the Little Hatchet Mountains, but appear to correlate with similar strata in the Chiricahua Mountains of southeast Arizona. Although no biostratigraphic constraints exist in the Little Hatchet Mountains, stratigraphic position and regional correlation suggest a Late Jurassic age for the Broken Jug Formation.

Introduction and historical background

Marine and deltaic sedimentary strata and volcanic flows are exposed on the east flank of Hachita Peak in the Little Hatchet Mountains of southwestern New Mexico, where they lie stratigraphically below the Hell-to-Finish Formation of Early Cretaceous age. This stratigraphic section is at least 1,200 m thick in the Little Hatchet Mountains, but it is not known to be exposed elsewhere in the region. These rocks were included in the Broken Jug Limestone by Lasky (1947) and described briefly by Zeller (1970). Although Zeller (1970) did not formally recommend abandonment of Lasky's term, he included the lower part of the Broken Jug Limestone in an unnamed map unit, to which he assigned a queried Early Cretaceous age. He included the upper part, which contains conglomeratic strata, in the Hell-to-Finish Formation. The rocks were not studied extensively again until Harrigan (1995) measured a stratigraphic section on the east face of Hachita Peak. Harrigan defined six stratigraphic units in the debated interval and recognized that the upper part of the section, considered a diorite intrusion by Zeller (1970), consists of subaerial basalt flows interbedded with conglomerate, sandstone, and siltstone.

The purpose of this report is threefold: (1) to redefine the Broken Jug Limestone of Lasky as the Broken Jug Formation; (2) to establish a type section for the strata on the east side of Hachita Peak; (3) to suggest correlation of the strata with rocks in southeast Arizona and northern Mexico. The strata proposed for redefinition correspond reasonably well with the limits of the Broken Jug Limestone of Lasky (1947). They include all of the unnamed Cretaceous beds of Zeller (1970) and the lower part of the map unit considered as Hell-to-Finish Formation by Zeller (1970). Redefinition is justified by advances in understanding of the lithic character of these strata, which renders the original lithic designation inappropriate (e.g., North American Commission on Stratigraphic Nomenclature, 1983). The proposed redefinition adopts the stratigraphic nomenclature of Lasky (1947) rather than that of Zeller (1970) because the stratigraphic limits proposed by Lasky more clearly distinguish this unique interval of strata that underlies red beds of the Hell-to-Finish Formation, a unit readily identifiable throughout southwestern New Mexico (Mack et al., 1986). These nonmarine red beds lie directly on Paleozoic strata in nearby mountain ranges (Zeller, 1965; Gillerman, 1958; Kottlowski, 1960) and in the subsurface north of the Little Hatchet Mountains (Lawton and Clemons, 1992). The strata of Hachita Peak are dominantly marine and bear no resemblance to rocks of the Hell-to-Finish Formation in other ranges of southwestern New Mexico. The section is therefore critical to improved understanding of the structural geology of the Little Hatchet Mountains and the geologic history of southern New Mexico. Although no direct evidence exists for the age of these strata, stratigraphic position and regional considerations suggest that they are Late Jurassic.

Geologic setting

The Little Hatchet Mountains contain two major geologic domains separated by the high-angle Copper Dick fault. North of the Copper Dick fault, the range contains Lower Cretaceous sedimentary rocks, Upper Cretaceous and Paleogene sedimentary and volcanic rocks deposited in intermontane Laramide basins, and mid-Tertiary pyroclastic rocks (Zeller, 1970; Basabilvazo, 1991; Hodgson, 1991; Lawton et al., 1993a). Reverse faults are common in the north part of the range, but strata are largely unmetamorphosed.

South of the Copper Dick fault, the range is dominated by Mesozoic strata largely equivalent to the Bisbee Group of southeast Arizona (Fig. 1; Zeller, 1965, 1970; Dickinson et al., 1986, 1989). Beds dip dominantly to the southwest, but a broad, faulted asymmetric anticline is present in the north part of the domain. In ascending order, the Mesozoic strata were divided most recently into four map units: (1) an interval of unnamed beds of Cretaceous(?) age; (2) Hell-to-Finish Formation; (3) U-Bar Formation; (4) Mojado Formation (Zeller, 1970). Zeller estimated a total thickness of 5,033 m for the Mesozoic sedimentary rocks of the south part of the range. This is the thickest exposed section of the Bisbee Group in southwest New Mexico. The strata are locally strongly metamorphosed and flattened, commonly with mylonitic fabrics, and they are extensively intruded by microphaneritic gabbro (diorite of Zeller, 1970) and phaneritic monzonite, both of uncertain age. The range is bounded on its east side by a normal fault, named here the Hachita Valley fault, that separates the intruded strata of the mountain block from Quaternary deposits of the Hachita Valley (Fig. 1).

Immediately south of the Copper Dick fault, in a region of abundant and intricate faulting, various Paleozoic formations are exposed, usually closely juxtaposed with the lower two members of the Broken Jug Formation (Fig. 1). The Paleozoic rocks include the following rock types, many separated by exposures of Broken Jug Formation: coarsely crystalline crinoidal grainstone with large gray chert nodules interpreted as Escabrosa or Horquilla Limestone; interbedded limestone-clast conglomerate and fusulinid-bearing limestone interpreted as Horquilla Limestone; white quartz arenite interpreted as Scherrer Formation; gray limestone with silicified productid brachiopods, trochiform gastropods and chert nodules interpreted as Concha Limestone. Unit identifications were made by comparison with descriptions of Paleozoic strata in the Big Hatchet Mountains (Zeller, 1965). These Paleozoic units are inferred to have formed the depositional substrate for the Broken Jug Formation.

Stratigraphy

We propose the name Broken Jug Formation for sedimentary and volcanic

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strata stratigraphically below the Hell-to-Finish Formation on Hachita Peak and extending southeast from Broken Jug Pass on the east side of the range crest. Broken Jug Pass has an elevation of 5,610 ft and is on the range crest in NW¼ sec. 35 T28S R16W (Hachita Peak 1:24,000 topographic quadrangle). Prior to the mapping and stratigraphic work of Zeller (1970), the name Broken Jug Limestone was applied to these rocks (Lasky, 1947) and to rocks now known to be Early Cretaceous (e.g., Zeller, 1965; Mack et al., 1986). We propose to reinstate the name Broken Jug Formation, but to use the general term formation rather than limestone, for three reasons: (1) the rocks are exposed in the vicinity of Broken Jug Pass; (2) limestone is a rare rock type in the section; (3) our redefined unit conforms more closely to the strata designated by Lasky (1947) as Broken Jug Limestone than to subsequent stratigraphic divisions of Zeller (1970).

The type locality of the Broken Jug Formation lies in secs. 25 and 26 T28S R16W, Hidalgo County, New Mexico (Fig 1). The formation is approximately 1,200 m thick on the east flank of Hachita Peak, but this thickness is a minimum because the base of the measured type section is not exposed. The formation rests on Paleozoic limestone north of the type section, but the exposures there are separated from the type locality by a thrust fault (Fig. 1). The formation is divided into five informal members (Fig. 2) that can be mapped at a scale of 1:24,000 throughout the area of exposure (Fig. 1), which constitutes the only known outcrops of the Broken Jug Formation. In ascending order, the members are (1) dolostone member, (2) lower conglomerate member, (3) fine-grained member, (4) upper conglomerate member, and (5) basalt member. The five members are described in the following sections.

Dolostone member

The dolostone member comprises the basal unit of the Broken Jug Formation. It consists of tan-weathering, fine-grained sandy dolostone and dolomitic quartz arenite. It is tan on fresh surfaces. Beds are thin, ranging from 1 to 60 cm thick, and are laterally continuous on a scale of tens to hundreds of meters. Thin beds contain horizontal lamination, ripple cross-lamination, and oscillation ripples with uncommon burrows. Thicker beds contain hummocky cross-stratification that commonly contains angular granules and pebbles of white and gray chert. Convolute lamination is locally present. The uppermost bed of the dolostone member is recrystallized, tan- to white-weathering, 0.5–2-m-thick, fine-grained carbonate litharenite. In outcrop it appears to be limestone but contains relic detrital textures clearly visible in thin section. It comprises about 80% carbonate grains and 20% monocrystalline quartz grains. This bed has

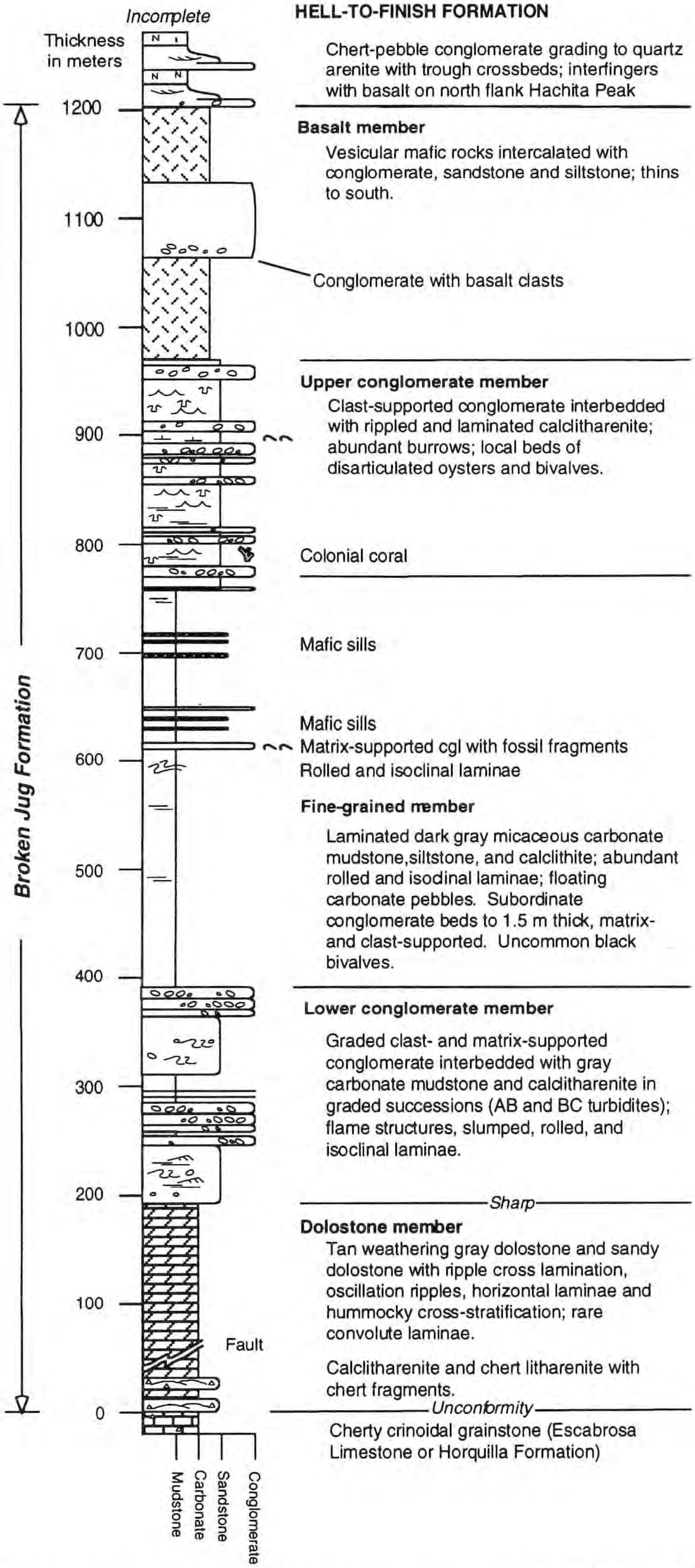

FIGURE 2—Composite stratotype of Broken Jug Formation, east flank of Hachita Peak, Hidalgo County, New Mexico. Lines of measured sections are in Fig. 1.

been interpreted recently as the Permian Scherrer Formation and the underlying strata as Epitaph Dolomite (Lucas et al., 1996). We think this correlation is unlikely, as explained in the section on age and correlation of the Broken Jug Formation.

The dolostone member is 140 m thick at its type section, which begins at elevation 4,960 ft, NW¼SE¼sec. 25 and extends west to elevation 5,120 ft in NW¼SE¼ sec. 25 (Harrigan, 1995). Estimated map thickness in NW¼ sec. 30 (R15W) and NE¼ sec. 25 (R16W) indicates that it may be as much as 360 m thick. Although the base is not exposed at the type section, three exposures of the base are present in secs. 23 and 24 (Fig. 1). The contact is sharp, unconformable, and overlain by a chert-pebble breccia a few cm thick. Beds above the contact are white, recrystallized carbonate litharenite that contains 10–20% angular pebbles and granules of chert. The subjacent unit is thick-bedded crinoidal grainstone with large oblate, light-gray chert nodules. The limestone is exposed only in the axial parts of small anticlines in the hanging wall of the thrust system south of the Copper Dick fault. These strata may be either Mississippian Escabrosa Limestone or cherty limestone of the lower one-half of the Pennsylvanian Horquilla Limestone, both of which are extensively exposed to the west in the north part of the Animas Mountains (Drewes, 1986) and to the south in the Big Hatchet Mountains and are difficult to distinguish but for stratigraphic position (Zeller, 1965). The upper contact of the dolostone member is sharp and concordant.

The dolostone member represents deposits of a shallow-marine shelfal setting. Abundant evidence for wave deposition exists, and although unfossiliferous, the member contains uncommon burrows.

Lower conglomerate member

The lower conglomerate member consists of medium-gray, fine- to medium-grained carbonate litharenite interbedded with brownish-gray calcareous mudstone and limestone pebble to cobble conglomerate. Sandstone dominates the lower 55 m of the member and consists of 20–30 cm tabular beds with sharp bases and tops grading into overlying mudstone beds. Sandstone beds are commonly graded and contain horizontal lamination overlain by small current ripples that indicate sediment transport to the southeast. Harrigan (1995) recognized Bouma sequences in the sandstone beds of this part of the lower conglomerate member. Flame structures are present at the bases of beds, and uncommon rounded pebbles of micrite as much as 5 cm in diameter are present in the lower parts of beds. The sandstone consists of 60–70% rounded, detrital carbonate grains, including micrite and sparry calcite, and 20–40% monocrystalline quartz grains. Argillaceous limestone to calcareous mudstone interbedded with the sandstone beds contains recumbent, isoclinally folded laminae, convolute laminae, rolled-up laminae, and scattered chert clasts.

Conglomerate is a conspicuous rock type beginning 55 m above the base of the unit. Conglomerate beds are 0.5 to 1 m thick, with matrix- to clast-supported textures. Matrix consists of sandy calcareous mudstone and carbonate litharenite. Inverse grading is locally present in the lower few centimeters of the beds. Conglomerate grades upward through beds of carbonate litharenite as much as 20 cm thick into rippled calcareous siltstone that is very dark gray to black but weathers olive gray. Clasts in the conglomerate are rounded and generally less than 20 cm in maximum diameter although clasts up to 40 cm in diameter are present locally. Prolate clasts, many containing unstrained fossils, are extremely common and generally oriented with SE–NW long axes. The clast population consists of 70–80% limestone and dolostone, 0–8% siltstone, 15–20% chert, and a trace of quartz arenite (Harrigan, 1995). Limestone clasts contain echinoids, rugose corals, fusulinids, bryozoans, productids, and a single observed *Omphalotrochus* gastropod. Also present are irregular intraclasts of carbonate litharenite and calcareous siltstone as long as 25 cm, with plastic-deformation features such as isoclinal folds and convolute laminae. The extrabasinal clasts were derived mostly from Mississippian through Permian strata; *Omphalotrochus* is characteristic of the Early Permian Colina Limestone (Bryant, 1968) in southeast Arizona and southwest New Mexico. Clasts of tan-weathering, gray dolomite are interpreted as Epitaph Dolomite. Clasts containing large silicified productids probably were derived from the Concha Limestone. The nearest known source for these upper Paleozoic clasts lies 30 km north of the study area. There Silurian rocks lie depositionally beneath Hell-to-Finish strata (Lawton and Clemons, 1992), indicating pre-Cretaceous erosion of the upper Paleozoic section. Transport directions from ripple cross-lamination, a single measured example of parting lineation in laminated calclithite, and oriented clasts in the member indicate transport of detritus to the southeast.

The lower conglomerate member is approximately 200 m thick at the type section, where its base lies at elevation 5,120 ft in NW¼SE¼ sec. 25. It overlies the dolostone member along a sharp contact. The basal contact is marked by a conspicuous color change from tan to medium gray. The upper part of the member contains a thick interval of olive-weathering dark-gray calclithite with slump folds and beds of matrix-supported conglomerate, but the uppermost 25 m of the section is dominated by clast-supported conglomerate beds. The upper contact is at elevation 5,420 ft in SW¼NW¼ sec. 25. The upper contact is gradational with the overlying Hachita Member and is identified at the first point in the section where dark-gray, almost graphitic, calcareous siltstone is an important component of the section. The contact probably changes stratigraphic position laterally to some degree. This member encompasses units 2 and 3 of Harrigan (1995) as well as the lower 100 m of his unit 4 in order to include the upper 25-m interval of clast-supported conglomerate. The base of the member is about 55 m downsection of the base of the Hell-to-Finish Formation of Zeller (1970), which corresponds to the base of the first conspicuous conglomerate in the section. In SW¼ sec. 23 T28S R16W, conglomerate of this member is depositional on limestone with large silicified fusulinids interbedded with limestone-clast conglomerate (Fig. 1). The beds of the substrate are unique in the region and correlate with Virgilian and lower Wolfcampian beds of the Horquilla Limestone described by Zeller (1965, p. 94) in the Big Hatchet Mountains. This relationship indicates that locally the lower conglomerate member forms the base of the Broken Jug Formation.

The dominant depositional mechanism of the lower conglomerate member was subaqueous sediment-gravity flows, including debris flows and turbidity currents. This mechanism is suggested by matrix-supported textures, local inverse clast grading, and slump structures. The lower conglomerate member therefore represents abrupt deepening relative to the underlying dolostone member.

Fine-grained member

The fine-grained member consists of gray- and tan-weathering calcareous sandstone (carbonate litharenite), siltstone, and mudstone. Carbonate grains in the sandstone consist dominantly of dark-gray to black micrite. The lower one-half of the member is dominantly dark-gray calcareous mudstone and siltstone. Bedding is massive to laminated. Laminated beds contain common recumbent isoclinal, intrastratal folds. Locally siltstone beds are rolled and compacted to form elliptical roll-up structures. These folds are several centimeters to as much as a meter in thickness. Uncommon beds of matrix-supported, chert- and limestone-clast conglomerate are present in the siltstone. Conglomerate beds are 0.8–2 m thick, with clasts mostly 10 cm and less in diameter. The lower part of the member is extensively intruded by dikes and sills of highly altered, orange-weathering, finely crystalline gabbro. The upper one-half of the member consists of tabular beds of tan-weathering, fine- to medium-grained carbonate litharenite mottled with calcareous siltstone and mudstone. The mottles are interpreted as burrows. Oscillation ripples in beds with abundant quartz sand grains are present but uncommon in the upper part. Beds are 20–40 cm thick and alternate with gray-weathering calcareous siltstone.

The fine-grained member is sparsely fossiliferous throughout. Beds as much as 25 cm thick of transported shell fragments near the middle of the member contain thick-shelled pelecypods, high-spired gastropods, and small tests that may be foraminifera. The fossils are supported by gray calcareous siltstone and mudstone. All fossils are recrystallized to coarse calcite spar. Individual thick-shelled pelecypods of black calcite are present in the upper mottled part of the member.

The fine-grained member is 367 m thick on the east flank of Hachita Peak. The base of the type section is at elevation 5,420 ft SW¼NW¼ sec. 25, and the top is at elevation 5,960 ft SE¼NE¼ sec. 26 on a prominent ridge that extends eastward from Hachita Peak. The member is concordant with overlying and underlying units. It rests gradationally upon the lower conglomerate member. The upper contact is sharp and overlain by a white-weathering limestone and chert-pebble conglomerate that is 6 m thick.

The fine-grained member represents dominantly delta-front deposits. The micrite sand grains may be flocculated carbonate mud formed at the delta front. Evidence of slumping indicates depositional instability, and interbedded conglomerate and shell beds with matrix-supported textures indicate intermittent deposition by sediment-gravity flows. The member records continued deepening relative to the underlying lower conglomerate member.

Upper conglomerate member

The upper conglomerate member comprises thick, medium-gray to white-weathering beds of clast-supported conglomerate. Beds range 3–24 m thick, with sharp bases and tops that grade abruptly to very fine to medium-grained carbonate litharenite. Beds are tabular, with planar tops and bases, and may be traced continuously throughout the exposures on the flanks of Hachita Peak. The conglomerate locally lacks visible internal stratification and elsewhere consists of tabular to upward-convex beds 1–1.5 m thick. Clasts are rounded and range in size from 1 cm to 25 cm, with a dominant size of 6–10 cm. The overall clast population consists of about 80% fossiliferous limestone with fusulinids and crinoids, 10–20% gray and white chert, commonly with replaced crinoids, and a few percent of tan quartz arenite. A trace population of quartzite with crossbeds is also present. The matrix of the conglomerate is typically medium- to coarse-grained carbonate litharenite with abundant chert grains. Conglomerate composes 40% of the member (Fig. 3).

Conglomerate is interbedded with intervals of very fine to medium-grained, tan weathering quartz arenite and gray carbonate litharenite. The sandstone beds are 6–20 cm thick; bedding is defined by alternating intervals of mottled, bioturbated sandstone and beds that preserve wispy horizontal laminae, oscillation ripples, trough crossbeds, and hummocky cross-stratification. Fragments of black pelecypods are present in the sandstone. Sandstone and conglomerate beds form upward-coarsening successions 10–36 m thick. Harrigan (1995) reported a colonial coral from a sandstone bed in the lower part of the member (Fig. 2).

The upper conglomerate member is 200 m thick (Fig. 3). This is somewhat thicker than reported by Harrigan (1995) because his section is cut by a normal fault. This thickness includes 19 m of finely crystalline gabbro in both dikes and sills that intrude the member. The type section lies southwest of that of the lower three members, beginning at elevation 5,840 ft in NW¼SE¼ sec. 26 and proceeding northwest to elevation 6,190 ft, also in NW¼SE¼ sec. 26 (Fig. 1). The lowermost conglomerate rests sharply on the underlying fine-grained member, but the interbedded sandstones in both members are similar, suggesting a conformable transition. The upper contact is sharp and marked by the base of the lowermost basalt flow of the basalt member.

The upper conglomerate member represents deposits of alluvial-fan deltas. The clast-supported, tabular to upward-convex conglomerate beds, interbedded sandstone beds with oscillation ripples and hummocky cross-stratification indicate that these conglomerate beds may have been deposited by wave action. Interbedded sandstones are marine with a sparse marine fauna, evidence of bioturbation, and wave-generated structures.

Basalt member

The basalt member is the uppermost member of the Broken Jug Formation. It comprises greenish-gray-weathering, dark-gray vesicular basalt flows 1–30 m thick. Flows have vesicular bases and tops and locally contain angular breccia clasts in a brown-weathering groundmass. Eleven individual flows were identified provisionally in the type section (Fig. 4). Flow tops were identified at transitions to overlying sedimentary rocks or by concentrations of vesicles or breccia fragments in unbroken basalt intervals. Intervening basalt is typically aphanitic to porphyritic but lacks vesicles. Some of the flows indicated in Fig. 4 are likely to be composites of several flows whose tops were not recognized in the section. Chemical analysis of the flows indicates that they are alkali basalts with high TiO_2, high MgO, and trace-element chemistry similar to that of ocean-island basalt (Harrigan, 1995).

Olive-gray to tan-weathering quartzose sandstone and white carbonate litharenite, siltstone, and conglomerate are interbedded with the basalt flows to form non-volcanic intervals 10–65 m thick. Very fine grained sandstone and siltstone locally contain decimeter-scale irregular concretions of white micrite. In the upper one-third of the member, a thick interval of clast-supported chert- and limestone-pebble conglomerate is present. Conglomerate bases are sharp and erosive on basalt or sandstone and grade abruptly to overlying beds of fine-grained sandstone with horizontal lamination. Uncommon clasts of vesicular basalt are present in the conglomerate. The carbonate clasts in the conglomerate are commonly altered to white marble and locally stretched and flattened whereas chert pebbles retain their original shapes.

The basalt member is 234 m thick on the southeast flank of Hachita Peak. The type section is in NE¼SW¼ sec. 26; it begins at elevation 6,000 ft and runs north to the ridge east of Hachita Peak, turning west at elevation 6,330 ft and ending at elevation 6,400 ft. The base of the member is the base of the lowermost basalt flow, which rests abruptly on fine- to medium-grained sandstone with trough crossbeds. The uppermost flow top is vesicular and overlain by brown sandy siltstone of the Hell-to-Finish Formation. The map distribution of this member (Fig. 1) corresponds reasonably well to that of a diorite sill mapped by Zeller (1970).

The basalt member is interpreted as subaerial lava flows, represented by the basalt, and as braided-fluvial deposits, represented by the graded conglomerate-sandstone intervals. Erosion of older basalt flows by the fluvial system incorporated basalt pebbles into the conglomerate. These pebbles may have been derived from river banks or uplifted fault blocks adjacent to the basin.

Hell-to-Finish Formation

The Hell-to-Finish Formation overlying the Broken Jug Formation consists dominantly of brown sandy siltstone in its lower part. The brown color of these Lower Cretaceous(?) beds contrasts with the gray colors of the underlying Broken Jug Formation. Irregular concretions and nodules of white to light-gray micrite are present in the siltstone. These are probably the result of pedogenic processes (Mack et al., 1986). Subordinate limestone- and chert-pebble conglomerate beds as thick as 3 m are interbedded with the siltstone. The Hell-to-Finish Formation was deposited in nonmarine environments that included alluvial-fan and braided-river settings (Mack et al., 1986). Sandstone of the Hell-to-Finish Formation is arkosic and was derived from exposed Precambrian basement to the north (Mack et al., 1986) and probably to the northwest as well.

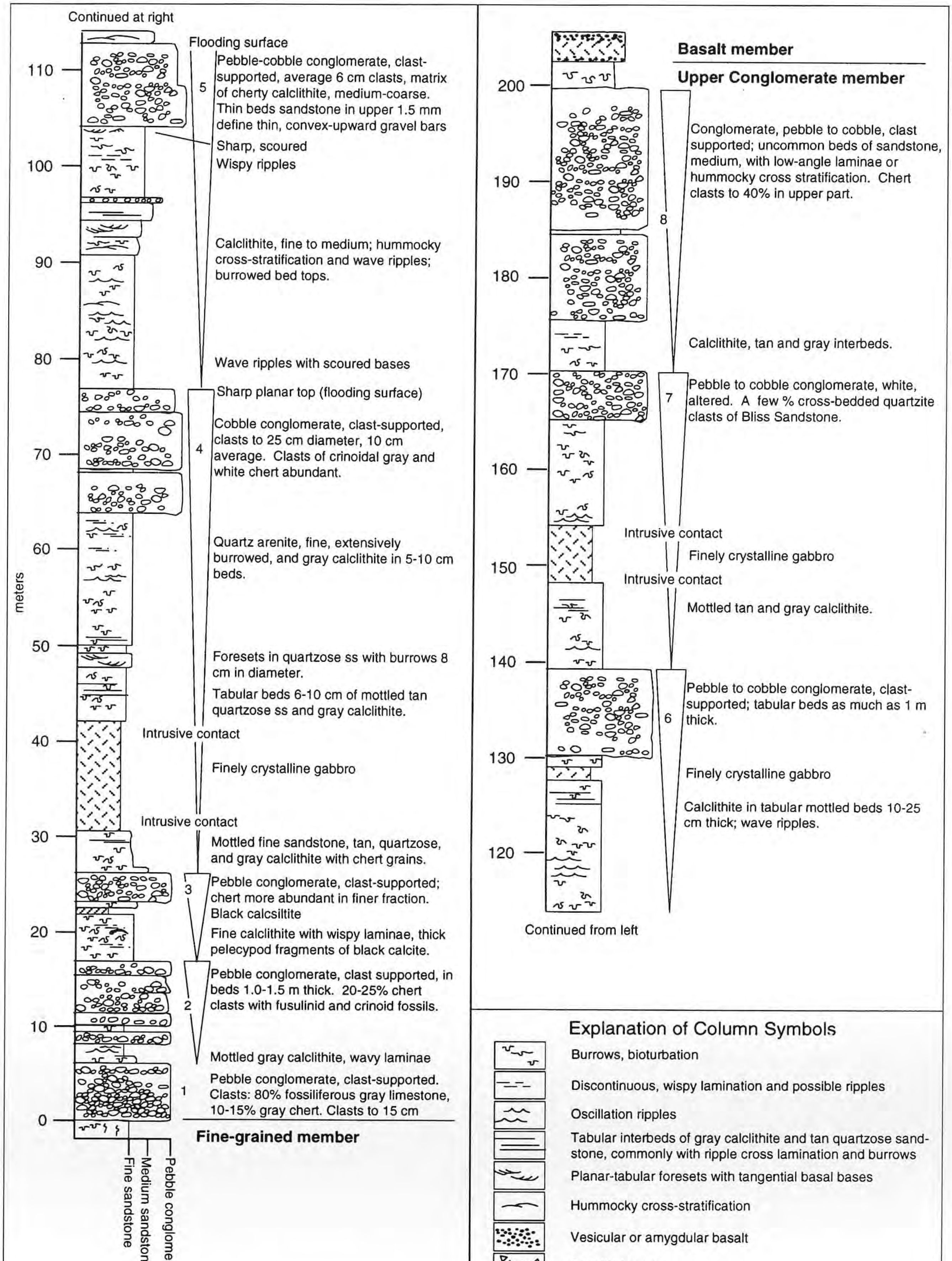

FIGURE 3—Measured section of upper conglomerate member of Broken Jug Formation. Wedges at right of column indicate upward-coarsening successions. Conglomerate beds are numbered sequentially from base. Line of measured section is in Fig. 1.

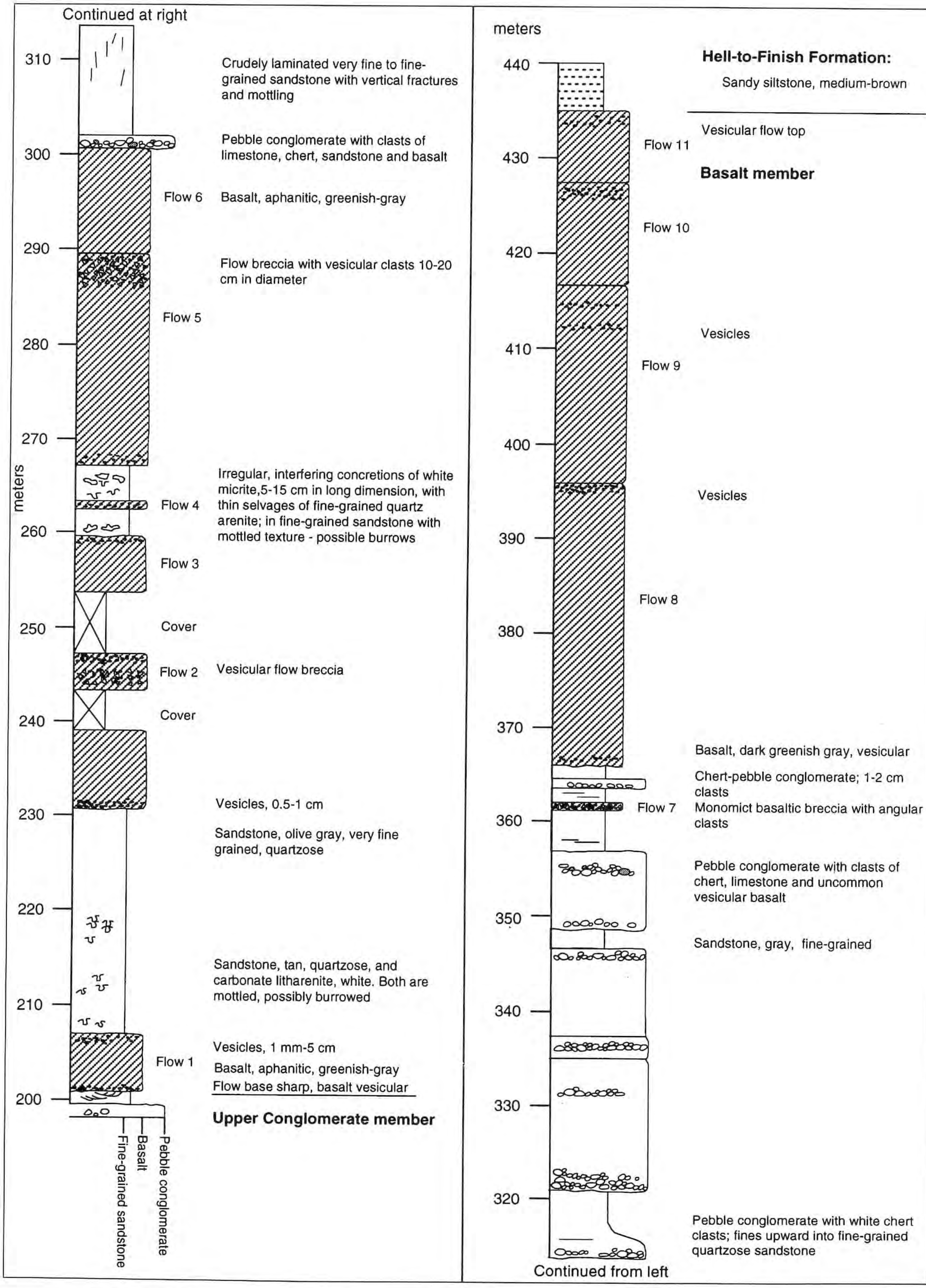

FIGURE 4—Measured section of basalt member of Broken Jug Formation. Line of measured section is in Fig. 1.

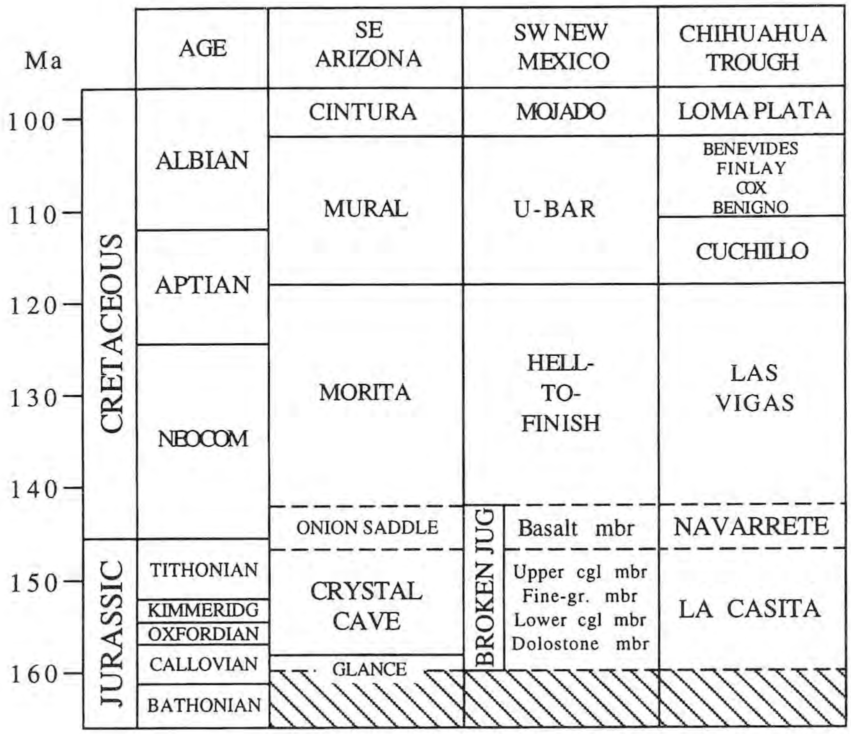

FIGURE 5—Correlation of Bisbee Group strata in Chiricahua Mountains of southeast Arizona and Little Hatchet Mountains of southwest New Mexico and their equivalents in Chihuahua trough of northern Mexico. Formations are capitalized; dashed lines signify approximate age boundaries. Nomenclature and ages of formations in Mexico after Monreal (in press).

Age and correlation

No definitive biostratigraphic age control presently exists for the Broken Jug Formation. Physical evidence brackets the age as post-Permian and pre-Neocomian. The formation must post-date the Leonardian Concha Limestone, whose clasts are present in the lower conglomerate member. The overlying Hell-to-Finish is interpreted as Neocomian to Aptian in age on the basis of regional relations (Zeller, 1965; Mack et al., 1986; Dickinson et al., 1989; Monreal, in press).

Comparison with strata recently described in the Chiricahua Mountains of southeast Arizona suggests that the Broken Jug Formation is Late Jurassic (Fig. 5). In the Chiricahua Mountains, marine and volcanic strata of the Crystal Cave and Onion Saddle Formations overlie the Glance Conglomerate, which rests directly on Concha Limestone (Lawton and Olmstead, 1995). The Crystal Cave Formation contains latest Middle Jurassic and Late Jurassic ammonites and microfossils (Lawton and Olmstead, 1995; Olmstead et al., 1996; Olmstead, 1998) and the overlying Onion Saddle Formation contains Late Jurassic pollen (Lawton and Olmstead, 1995). Like the lower four members of the Broken Jug Formation, the Crystal Cave Formation represents deepening and subsequent shallowing of a marine basin; like the basalt member at the top of the Broken Jug Formation, the Onion Saddle Formation is a succession of subaerial basalt flows and fluvial deposits. The minor-element chemistries of the Onion Saddle and Broken Jug basalts are indistinguishable and indicate mantle derivation during crustal extension (Lawton et al., 1993b). In the Chiricahua Mountains, Upper Jurassic strata are thrust over Lower Cretaceous strata equivalent to the Hell-to-Finish and U-Bar Formations, and the depositional contact between Jurassic and Cretaceous strata is not exposed; however, the normal stratigraphic succession is preserved in the Little Hatchet Mountains. It is important to note that existing data do not preclude an Early Cretaceous age for the Broken Jug Formation, but regional relations (Fig. 5) render the possibility unlikely. Our ongoing investigations in the Little Hatchet Mountains may ultimately resolve this problem.

A recently postulated correlation of the dolostone member with the Permian Epitaph Dolomite (Lucas et al., 1996) raises the possibility that the lowermost part of the Broken Jug Formation is of Paleozoic age and requires discussion. The geologic map of the area (Fig. 1) discloses geologic relations unknown to those authors and suggests a closer affinity of the dolostone member with the overlying section than with the underlying Paleozoic strata. Two observations suggest that the Epitaph correlation is incorrect. First, the dolostone member rests unconformably on Escabrosa or Horquilla Limestone and contains chert fragments derived from it. If the dolostone member were equivalent to the Epitaph Dolomite, this observation would require a local and previously undescribed Horquilla–Epitaph unconformity with attendant erosion of some 480 m of intervening strata at the beginning of the Leonardian stage. In addition, the above observation demands local erosion and subsequent resumption of deposition at specific sites in Early Permian time. We recognize that such patterns are to be expected in extensional settings where local horsts and grabens may create local erosion. Indeed, variable amounts of erosion of the Paleozoic section are observed at the base of the Bisbee Group elsewhere in southwest New Mexico (Lawton, 1996; Bayona and Lawton, 1998). On the other hand, some authors (e.g., Zeller, 1965; Bryant, 1968), citing the gradational nature of the basal Epitaph contact in the region, have regarded the contact as a dolomitization front between the Epitaph and underlying Colina Limestone rather than an unconformity. A second observation is that the Epitaph Dolomite of southern Arizona and New Mexico does not resemble the dolostone member, which contains thin sandy beds, chert-pebble conglomerate and well-preserved wave-generated sedimentary structures, none of which are present in the Epitaph (e.g., Zeller, 1965). Moreover, conspicuous quartz blebs and geodes distinguish the Epitaph Dolomite in the region (Zeller, 1965; Bryant, 1968), but these were not observed in the dolostone member.

Conclusions

1. At least 1,200 m of marine and volcanic strata are present beneath the Lower Cretaceous series in the central part of the Little Hatchet Mountains.
2. These strata are herein defined as the Broken Jug Formation and divided into five informal members that include the dolostone, lower conglomerate, fine-grained, upper conglomerate, and basalt members.
3. The strata record deepening of a marine basin, subsequent infilling by delta-front and fan-delta deposits, and late mafic volcanism.
4. Conglomerate clasts were dominantly derived from upper Paleozoic limestones, dolostones, and cherty limestones and represent erosional unroofing of the Paleozoic sedimentary section prior to the appearance of arkosic detritus in the Hell-to-Finish Formation.
5. Dominant clastic transport was to the southeast by sediment-gravity flows along the axis of the basin, rather than directly from uplifted rocks to the north.
6. Subaerial basalt flows at the top of the Broken Jug Formation have the trace-element chemistry of ocean-island basalt, compatible with derivation from the man-

tle and emplacement in an extensional tectonic setting.

7. Regional relations and stratigraphic position indicate that these strata are likely Late Jurassic.

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