Proceedings of the Iowa Academy of Science

Volume 86 | Number Article 6

1979

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Proc. Iowa Acad. Sci. 86(2):57-65, 1979

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The Dubuque Formation of Upper Ordovician age crops out in the Upper Mississippi Valley. It comprises interbedded carbonate and argillaceous rocks that are approximately 35 feet thick in Iowa and Illinois, but thicken to a maximum of approximately 45 feet in southern Minnesota. Three proposed informal subdivisions: Frankville, Luana, and Littleport beds, are differentiated on the basis of bed surface topography ranging upward from nearly planar beds in the Frankville to prominently undulose surfaces in the Littleport beds. The Frankville beds represent a transition from the massive dolomite of the underlying Stewartville Member of the Wise Lake Formation to the overlying interbedded carbonate rocks and shale of the upper Dubuque. The base of the Dubuque Formation in Iowa and Minnesota is placed at a prominent, approximately 8 inch thick, carbonate bed at the base of the Frankville beds. This "marker bed" provides a more precise datum for lithostratigraphic correlation than the lowest prominent shale parting employed by previous workers to identify the base of the Dubuque.
INDEX DESCRIPTORS: Ordovician, Lithostratigraphy, Paleontology, Dubuque Formation, Iowa, Upper Mississippi Valley.

Prior to its naming by Sardeson (1907), rocks of the Dubuque Formation were considered by Hall (1854, p. 189), Calvin & Bain (1900), Calvin (1906), and others to be the upper thin-bedded shaly strata of the Galena Formation. Sardeson (1907) identified the Dubuque as the equivalent of the "Triplecia [sic] bed" of Sardeson (1897), but included it in the Maquoketa "series" as did Stauffer & Theil (1941). Kay (1935, p. 571) restricted the Dubuque to bed 15 of Calvin & Bain (1900, p. 429) (i.e., the upper 30 feet of the Galena at Dubuque, Iowa). At Elkader, Iowa, Kay (1935, p. 572) recognized 24 feet of Dubuque strata, while in southern Minnesota he restricted the Dubuque to the *Oxoplecia* Zone (*Triplecia* [sic] bed of Sardeson, 1897) which he believed to be 15 feet thick. The same thickness was also noted by Kay (1935, p. 78) in northern Iowa, west of Waukon. This reduction in thickness to half that of the type locality at Dubuque approximates the usage of the lowest shale parting in thinly interbedded carbonate and shale as the base of the Dubuque. Agnew *et al.* (1956) described the contact of the Dubuque and Stewartville as "gradational from massive honeycombed dolomite below to medium-bedded dolomite and interbedded shale above," and reported fairly uniform thickness for the Dubuque ranging from 35 to 45 feet (p. 298). However, Agnew, (1955, 1720-1721) stated that the Stewartville and Dubuque are largely inseparable in the subsurface.

The Dubuque of Weiss (1957, p. 1040) "conforms closely to that of Kay at the type section," but was elevated by Weiss to formation status. He distinguished the Dubuque from the Stewartville "by the presence of shale partings and beds" in the Dubuque and by slightly differing lithotype. Weiss placed the contact at the lowermost shale parting of the alternating beds of carbonate and shale, resulting in a thickness of approximately 34 feet (p. 1041). Ethington (1959, p. 259) also placed the base of the Dubuque at the lowest shale bed in the section, noting that crinoid "columnals are particularly prominent in the 10 feet of strata immediately underlying the Dubuque and serve to identify the upper Stewartville," Past usage of the lowest shale bed as the base of the Dubuque, however, has not proven satisfactory because of lack of broad lateral continuity of most shale partings within the lower 15 feet of the Dubuque. With the aid of additional easily correlated beds, a higher degree of stratigraphic control can be maintained.

Templeton & Willman (1963, p. 129) recognized a transition zone 20 to 30 feet thick, from the pure massive dolomite of the Stewartville to impure dolomite with shaly interbeds in the Dubuque. They preferred the contact originally selected by Sardeson (1907) resulting in a thickness of 40 to 45 feet. Their locality 32 (p. 239), the type section of the Wise Lake Formation, included an exposure, the "Ravine Section", where they placed the Stewartville-Dubuque contact at the "lowest shaly reentrant." This exposure is now largely covered, although a similar sequence has been exposed for a ski run only 100 feet to the north (Loc. 56-A). They also noted a four inch thick "dolomite, slightly argillaceous; prominent bed set off by shaly partings; a widely traceable marker bed" 8′ 1″ above the lowest shaly reentrant.

In a preliminary study of the Galena Group in Winneshiek County, Iowa, Levorson & Gerk (1972) placed the Stewartville-Dubuque contact at a prominent 2½ inch shale bed 19′ 6″ below the Dubuque-Maquoketa contact because in Winneshiek County, lithic characteristics below this bed more closely resembled the Stewartville than the Dubuque. This 2½″ widely traceable shale parting is known to extend from just north of Spring Valley, Minnesota, to just south of Galena, Illinois.

At the type section of the Dubuque, in Dubuque, Iowa the lower beds are now concealed by a parking lot. The present floor level at the type section is at the 2½″ shale parting which Levorson & Gerk (1972) selected as the Stewartville-Dubuque contact. They chose the top of the transition zone as the contact in Winneshiek County, whereas Templeton & Willman (1963) chose the base, or slightly lower than the base of the transition zone in northwestern Illinois.

As long as the Stewartville-Dubuque contact is chosen within the transition zone or at the "lowest shaly parting" of the alternating carbonate and shale beds, there will be confusion and a lack of stratigraphic uniformity. We therefore propose that the base of the Dubuque Formation in Iowa be redefined at a horizon commonly recognizable in surface exposure, namely at the base of the "marker bed" of Templeton & Willman (1963). This horizon is that accepted by Willman & Kolata (1978, p. 53) for the base of the Dubuque in Illinois.

LITHOLOGY AND CORRELATIVE FEATURES

In northwestern Illinois, the lithology of the Dubuque is that of the type locality: grey to buff, coarse to finely crystalline dolomite and dolomitic limestone, pure at the base and becoming more argillaceous upward at a rate of about 1% per foot (H. B. Willman, personal communication, 1973) to about 10% insoluble clay content. Weiss (1957, p. 1041) also noted the 10% insoluble clay content within the Minnesota Dubuque. This increase in the argillaceous component occurs in the lower ⅓ of the formation (i.e., Frankville beds herein). Separating these carbonate beds are soft, silty, buff to reddish brown dolomitic and calcareous shales that weather readily to form reentrants.

The primarily dolomitic Dubuque of the type locality extends to the

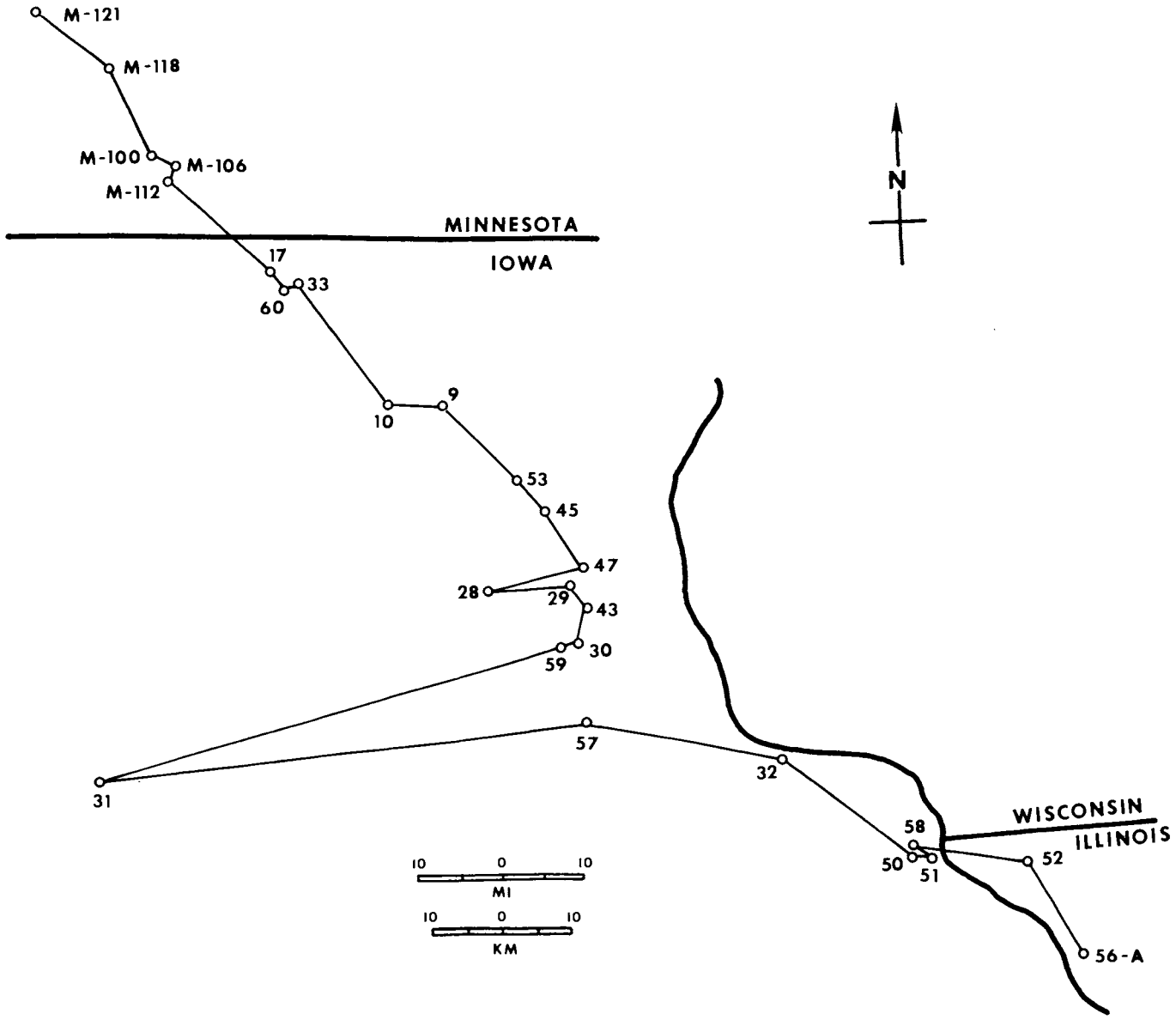

Figure 1. *Map of localities examined for this study. Line connecting locality points indicates order of localities in composite section (Figure 2).*

northern boundary of Clayton County, but becomes progressively more calcareous to the north within the county. The change from predominantly dolomite to limestone occurs between Loc. 45 and Loc. 9 (Figure 1, 2). At Loc. 9 Dubuque carbonates are virtually entirely limestone except for the Lower 14′ 2″ which resembles the Stewartville by its prominent dolomitic mottling. From Loc. 9 into Fillmore County, Minnesota, the limestone is slightly dolomitic at the top and bottom of the formation. Shale partings in northwestern Winneshiek County and in Minnesota become more abundant, thicker, and lose the characteristic reddish-brown color noted to the southeast. Instead, the shales are light to dark olive-grey and are very fossiliferous in the uppper part of the formation. In Minnesota the Dubuque is predominantly shale and limestone; nearly 50% of the unit is shale.

The transition from the Stewartville to the Dubuque is evident both lithologically and faunally; Webers (1972, p. 34) noted a marked change from the restricted fauna dominated by gastropods and cephalopods in the Stewartville, to one dominated by suspension feeders (e.g., brachiopods) in the Dubuque. The upper 10 feet of Webers' (1972) Stewartville (Frankville beds of this study) are extremely crinoidal as is the entire Dubuque. Generally, the lower Dubuque is sparsely fossiliferous, but upward becomes very fossiliferous, dominated by brachiopods and crinoid remains.

The Marker Bed

Prominent shale partings locally present in the upper Stewartville below "the lowest shaly parting" of Templeton & Willman (1963, p. 129) have made early attempts at correlation difficult. However, a prominent, widely traceable 4″ to 6″ carbonate bed set off by 1″ shale partings is present several feet below what is apparently the lowest shale parting of Templeton & Willman referred to as a "marker bed" in Illinois. It has been traced throughout the limits of this study. At the Becker Quarry (Loc. 58), here designated as a reference section for the Dubuque, the "marker bed" is 7′ 7″ above the floor of the quarry and 34′ 8″ below the Dubuque-Maquoketa contact. In Iowa and northwest

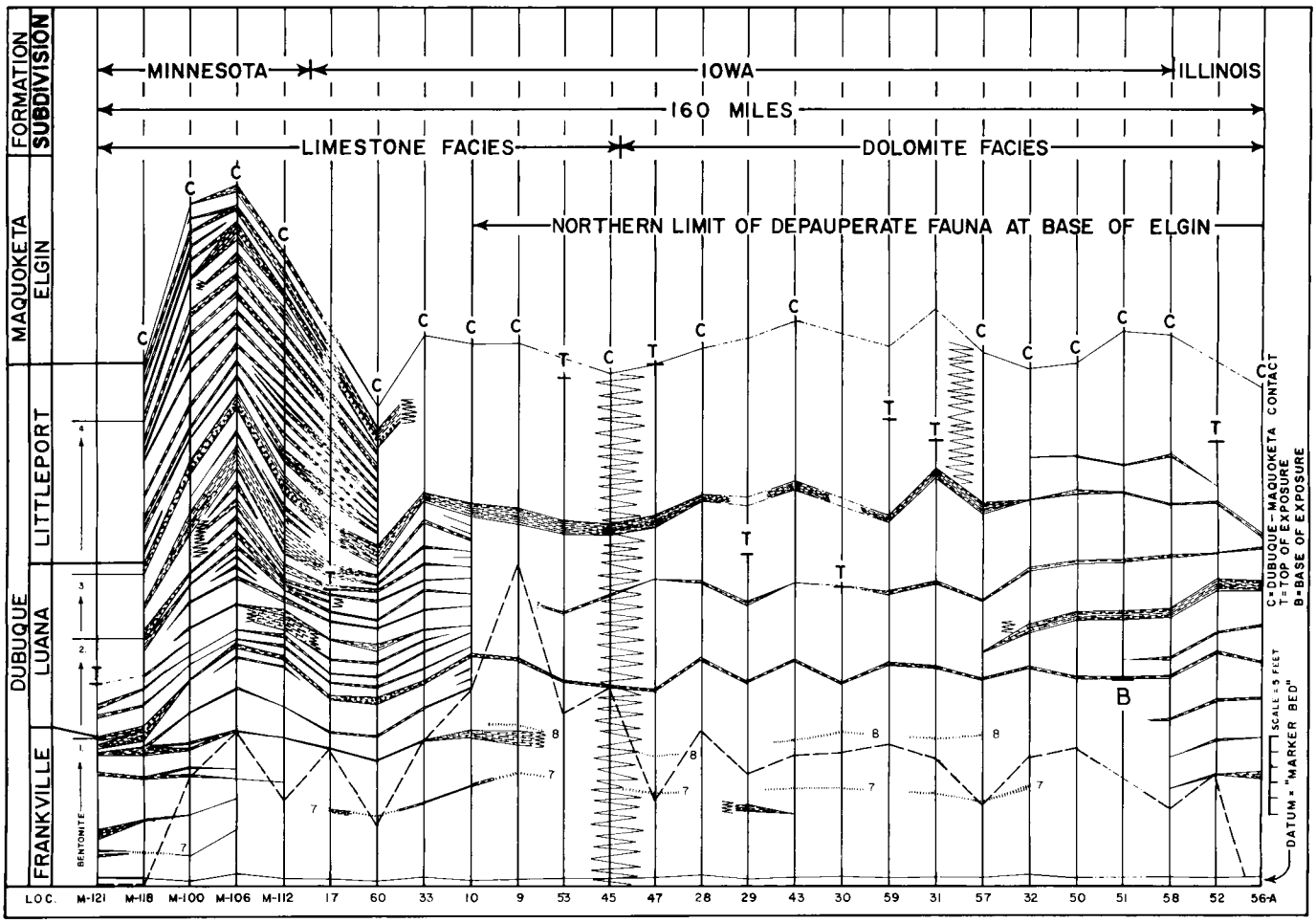

Figure 2. *Composite cross section of Dubuque Formation (see Figure 1 for locality distribution); base line conforms to base of the "marker bed". Symbols: XXX – bentonite beds; vertical hatchures numbers 7 and 8 – sparry calcarenite bands; heavy dashed line – lowest shale parting in alternating carbonate and shale beds used as datum for base of the Dubuque Formation by previous authors. (Note that prominent shale beds occur below this datum (e.g. loc. 9) but are not within the alternating carbonate and shale unit).*

Illinois, this bed is commonly 33′ 8″ below the contact. North of Kendallville, Iowa, the stratigraphic position of the "marker bed" is not always distinct in fresh outcrops, but is commonly enhanced by weathering as at localities M-106, M-118, and M-121. Similarly, the "marker bed" would not be expected to be so distinct in the subsurface. Because the marker bed is commonly recognizable in surface exposure and is a more reliable marker than the "lowest shaly parting," it has been used as a datum for this study. The base of the "marker bed" (See Figure 3-C) is herein proposed as the contact of the Dubuque Formation and the underlying Stewartville Member of the Wise Lake Formation in Iowa.

Shale Beds

Although some of the shale beds between carbonate beds of the Dubuque show wide lateral distribution, their discontinuous nature necessitates use only as local correlatives. However, within the Dubuque there are three shale beds that appear to be laterally continuous throughout the area of investigation, and two of these correspond to contacts between the informal subdivisions of the Dubuque proposed in this report (Figure 2).

The lowermost shale bed commonly includes two shale partings at the top and bottom of the "marker bed". Rarely the "marker bed" is so argillaceous that weathering reduces it to a prominent reentrant such as at Loc. 17 where the "marker bed" is nodular and shaly. Other characteristics commonly observed in the "marker bed" are typified at Loc. 10 (with nodular shaly interbeds), Loc. 9 (1″ shale overlain by a 4″ dolomitic limestone with a weak parting at top), and Loc. 43 (nodular 7″ thick, dolomitic shale bed).

The middle shale bed is approximately 11 feet above the "marker bed", or at the top of the transition zone (top of Frankville beds). This shale generally is 2½″ to 4″ thick, but at Loc. M-118 is 12″ thick (maximum thickness seen) and has a 2″ bentonite (Frankville bentonite) at the top also seen at Loc. 60. This is the lowest shale parting presently exposed [at floor level of the parking lot] at the Dubuque type section (Loc. 51), and is the 2½″ parting formerly used by Levorson & Gerk (1972) as the Stewartville-Dubuque contact in Winneshiek County.

The third, or upper shale bed occurs approximately 10 to 12 feet below the Dubuque-Maquoketa contact except in Fillmore County, Minnesota, where it may be as much as 19 feet below the contact. This bed ranges from 12″ to 14″ thick between Loc. M-118 and Loc. 57 (See Figure 2). To the southeast it thins to an average of 3″ and can be

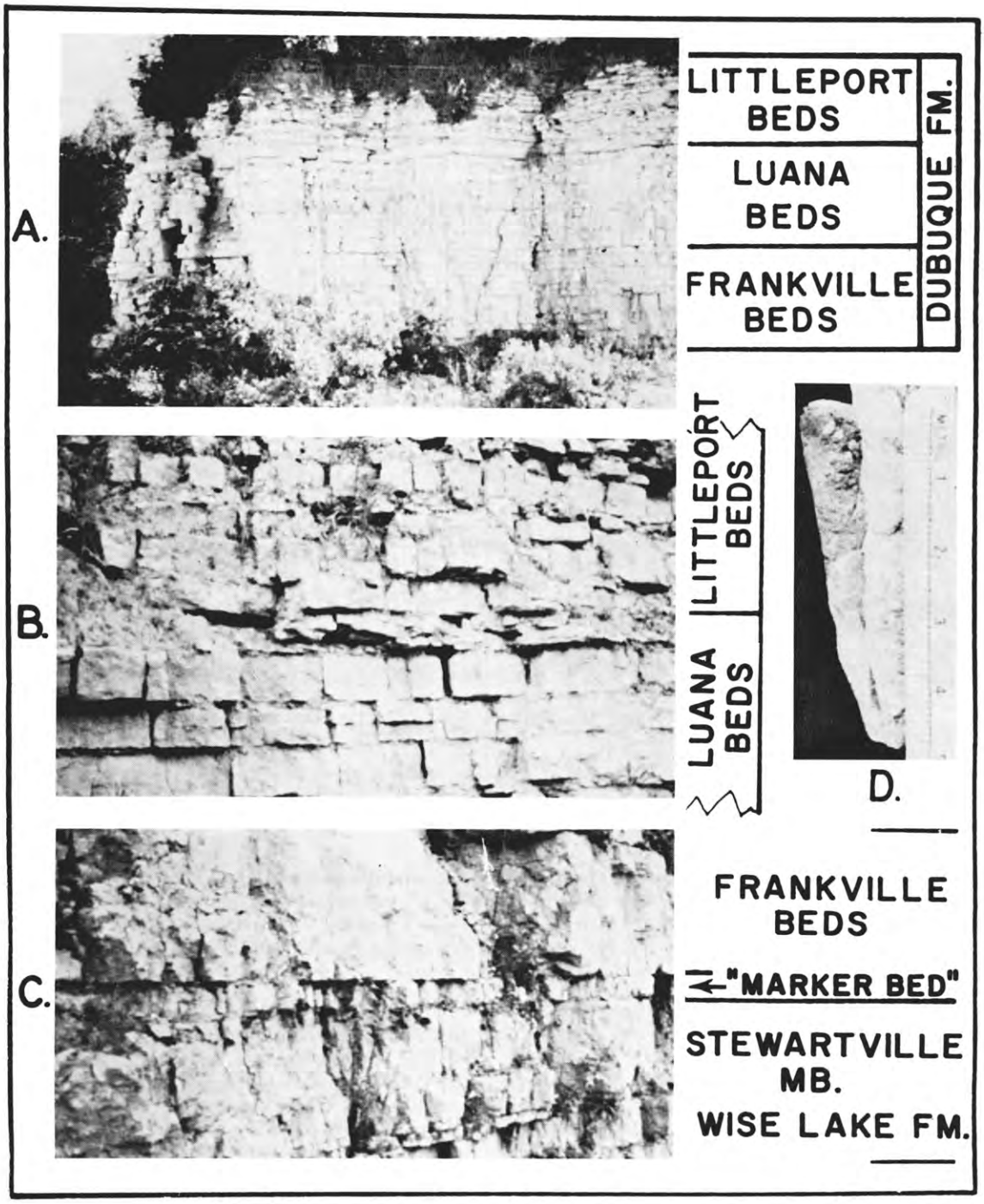

Figure 3. A. *Three part subdivision of the Dubuque Formation east of St. Olaf, Iowa (Loc. 43). B. Contact of Luana and Littleport beds at the Ski Life Section (Loc. 56-A). C. Contact of Stewartville and Dubuque formations at the Ski Lift Section (Loc. 56-A) showing the "marker bed". D.* Paleosynapta flaccida *Weiss, a supposed holothurian common in parts of the upper Stewartville and lower Dubuque. Approximate thicknesses shown: A – 34 ft., 9 in.; B – 8 ft. 3 in.; C – 7 ft. 4 in.*

confused with a 7″ shale bed that occurs approximately 7 feet below the upper shale bed. The 7″ shale bed grades into a highly argillaceous dolomite bed at Loc. 32, and is stratigraphically higher to the south (Loc. 56-A).

Stylolitic Beds

The upper 10 to 14 feet of the Stewartville Member, Wise Lake Formation, as defined herein, comprises thin, stylolitic beds and thick, massive beds with stylolites parallel to bedding. These thick beds

commonly weather to 4'' to 10'' beds along stylolitic surfaces.

Sparry Calcarenite Bands

Levorson & Gerk (1972) employed sparry calcarenite beds (abbreviated SCB) for correlation because of their considerable lateral extent and stratigraphic recurrence. These beds were numbered in ascending order; beds 1-6 are confined to the Wise Lake Formation and the upper two (7 and 8) are between the ''marker bed'' and the 2½'' shale parting formerly used as the Stewartville-Dubuque contact (Levorson & Gerk, 1972, p. 119). With the presently proposed base of the Dubuque Formation, SCB's 7 and 8 lie within the lower subdivision of the Dubuque (i.e., the transitional Frankville beds). At Loc. 9, these SCB's are 34'' apart, with the lower one 6' 8'' above the ''marker bed.'' Where present (principally in Winneshiek and Clayton Counties, Iowa), these SCB's maintain a relatively constant stratigraphic position.

Bentonite beds

In Minnesota, as many as four presumed bentonite beds occur within the Dubuque. Although samples have not been x-rayed, their general physical character is like bentonite from the Dunleith Formation (Levorson & Gerk, 1972, P. 112-113). These bentonite beds are not widespread and may be laterally discontinuous, but often recur in the same stratigraphic position. Two bentonites are quite persistent. The uppermost (well exposed at localities M-118, M-100, M-106, and 60) is 2 to 5 feet below the Dubuque-Maquoketa contact. This bentonite was described by Weiss (1954b, p. 271; 1957, p. 1040) as the ''upper Dubuque feldspathized shale.'' Locality 7 of Ethington (1959, p. 150: our Loc. 60) includes a layer of grey to yellow clay 2 feet below the top of the Dubuque. This is similar to bentonites observed elsewhere; we believe it to be equivalent to the ''upper'' bentonite of Weiss, which he saw only at his Mystery Cave locality F-143 (Weiss, 1954b).

Weiss (1954b, p. 270; 1957, p. 1040) also noted a bentonite bed 16 feet below his upper bentonite, or 20 feet above the base of the Dubuque. Although we do not follow his correlations (1957, pl. 5), we believe Weiss' ''lower'' bentonite (bentonite I-8 of Mossler & Hayes, 1966) to be equivalent to that within the shale at the top of the Luana beds (Figure 2, Bentonite 3) at localities M-118, M-100, M-106, and M-112. Our disagreement with some of Weiss' correlations is based upon his utilization of the ''lowest shale parting'' as the Stewartville-Dubuque contact. As indicated above this thereby lends a considerable range of stratigraphic thickness due to variability in stratigraphic position of the lowest shale parting. The relationship of Weiss' ''upper'' and ''lower'' bentonites to other strata are further discussed in the description of the Littleport beds elsewhere in this report.

Of the remaining two bentonites one occurs at M-118 as the upper 2'' of a 12'' shale bed at the top of the Frankville beds, 9'3'' above the base of the ''marker bed.'' It probably recurs at Loc. 60 as thin (⅛'') seams of bentonite scattered throughout a 3½'' to 5'' shale bed, 12' 4'' above the base of the ''marker bed,'' but has not been seen elsewhere. The other is noted at M-118 near the middle of the Luana beds, within a shale unit 16'' thick and 14' 4'' above the base of the ''marker bed''. This 1'' bentonite is probably the same as one at Loc. M-100 in the middle of the Luana beds in a 2'' shale bed 20' 2'' above the base of the ''marker bed''. Differences in stratigraphic position of these bentonites above the marker bed at different localities may be due to variable thickness of the strata within the respective subdivisions.

Locality M-118 is the only place where all 4 bentonites were observed. At this locality, the bentonite beds occur as follows (measurements from ''marker bed'' 48' 7'' above quarry floor):

1. Frankville bentonite, 10' 1''
2. middle Luana bentonite, 15' 0''
3. upper Luana bentonite (I-8 of Mossler & Hayes, 1966; ''Lower'' bentonite of Weiss, 1957) 19' 6''
4. Littleport bentonite (''Upper'' bentonite of Weiss, 1957) 29' 0''

At Loc. M-100, the Frankville bentonite is absent but the remaining 3 occur as follows: middle Luana bentonite 38' 6'', upper Luana bentonite, 45' 1'', and Littleport bentonite, 58' 2'' above the quarry floor. The Dubuque-Maquoketa contact is 5' 1'' above the Littleport bentonite. Other than in the Kendallville, Winneshiek County, Iowa area, we have observed no Dubuque bentonites in Iowa or Illinois.

Distinctive Bedding

Bedding of three distinctive types characterizes the Dubuque Formation: planar beds with weak or no shale partings in the lower third of the formation (Frankville beds); planar to slightly undulose beds separated by 1'' to 1½'' shale partings in the middle third (Luana beds); and undulose beds separated by 1'' to 5'' shale partings (the greater thickness being more common in Minnesota) in the upper third (Littleport beds). From Minnesota southeast to Littleport (Loc. 57) the upper undulose beds are relatively pure limestone, and individually range from 7'' to 10'' in thickness. From Littleport southeast to 6 miles south of Galena, Illinois (Loc. 56-A), these beds are dolomitic and when freshly exposed are thicker (average 3 feet), but weather to thin undulose beds and laminae. These thin layers show the highly wavy surfaces also evident at the Dubuque type locality (Loc. 51). In Minnesota and Iowa north of Decorah these general bedding characteristics of the Dubuque are most similar within the upper ⅓ of the formation. Throughout the lower ⅔ of the formation, however, 2 to 4 foot thick undulose beds occur sporadically.

Fossils

The presence of *Amorphognathus ordovicicus* and other conodonts of the *A. ordovicicus* zone in the Dubuque Formation confirms a Late Ordovician (probably Maysvillian) age assignment (Sweet, Ethington, & Barnes, 1971; Sweet & Bergström, 1976). Most fossils that have been regarded as indices for the Dubuque have been found to be of little value. For example, *Oxoplecia* is rare even in the most fossiliferous Dubuque strata; we have collected only 1 fragmental specimen. Weiss (1957, p. 1041) stated ''*Oxoplecia* is so rare that it is worthless as a zone marker.'' *Pseudolingula iowensis,* although common in the upper beds of the Dubuque, is scarcer in the lower beds, and also occurs in the upper Stewartville. It is, however, more common above the ''marker bed,'' and seemingly more prevalent in the dolomitic facies of the Dubuque.

Weiss (1954a) described the supposed holothurian trace *Paleosynapta flaccida,* reportedly restricted to a 5 foot zone in the upper Stewartville in Fillmore County, Minnesota. An intensive search yielded a single specimen from 35 feet below the top of the Stewartville and a more concentrated assemblage in a zone 4 feet thick 21'' below the ''marker bed'' at Loc. M-106. *P. flaccida,* while not especially common, is by no means rare, and we have observed the range of the species through a zone only 2 to 8 feet thick at any single locality. However, this zone may be found at levels from four feet above to sixteen feet below the ''marker bed'' (see Figure 3-D).

Ethington (1959) reported the distribution of conodonts within the Galena. Ethington's (p. 262, loc. 7 = our Loc. 60) upper 10 feet of crinoidal Stewartville is the approximate equivalent to the 13 feet thick transition zone (i.e., Frankville beds). From the top of the Frankville beds to the contact with the Maquoketa, the Luana and Littleport beds combined are 18'' 4'' thick, the total thickness Ethington measured for the Dubuque.

Three shifts occur in conodont faunas of the upper Stewartville and Dubuque. At his Loc. 7, (our Loc. 60), Ethington reported few specimens from the lower 20 feet of the Stewartville, but a more abundant fauna in the upper crinoidal horizon (i.e., near the base of our Frankville beds). With the top of the Frankville at this locality equivalent to Ethington's base of the Dubuque (at the lowest shale parting), the

second faunal shift (Ethington, 1959, Table 1) thus occurs at the base of the Luana beds. The third faunal shift is approximately in the middle of his Dubuque, which approximates the contact of the Luana and Littleport beds. Thus, Ethington's (1959) faunal shifts appear to approximately coincide with the contacts of our proposed subdivisions at Loc. 60.

CONTACT OF THE DUBUQUE WITH THE MAQUOKETA

The Dubuque is generally believed to be conformable with the superjacent Maquoketa (Kay, 1935; Agnew, 1955; Templeton & Willman, 1963). The last believed an important unconformity exists to the south (1963, p. 131) where the Galena Group is deeply truncated by the "Depauperate Zone" of the Maquoketa. In Iowa and northwest Illinois, the contact is sharp and easily distinguished by the small fossils and phosphatic pellets of the "Depauperate Zone" in the shaly base of the Maquoketa. A ferruginous surface commonly is also present. Examples of the phosphatic zone are exposed at Locs. 45 and 57.

In northwest Winneshiek County, Iowa, and Fillmore County, Minnesota, the Dubuque-Maquoketa contact is not as obvious as elsewhere. For several miles northwest of Loc. 9, the transition from the Dubuque to the Maquoketa, although distinct lithologically, lacks a phosphatic zone, phosphatic pellets, a concentration of pyrite in the overlying shale, and "depauperate" fossiles. At Rifle Hill (Loc. M-106), alternating carbonate and shale beds at the top of the Dubuque resemble those in the base of the Maquoketa, suggesting a conformable relationship. However, the change in lithology is distinct; relatively pure dolomitic limestone beds interbedded with calcareous to slightly dolomitic shales are overlain by alternating beds of dolomite and dolomitic shale with a larger detrital fraction. At Loc. M-106 the contact includes a thin (⅛") ferruginous layer. Also present is a thin (½") brachiopod coquina containing abundant dalmanellids, *Sowerbyella,* and a few *Strophomena*. At Loc. M-112, about 1 mile south of M-106, the same ferruginous layer occurs at the contact, but the coquina is absent. Neither the ferruginous layer nor the coquina have been observed further to the north.

SUBDIVISION OF THE DUBUQUE

Frankville beds

The Frankville beds are named for Frankville Township, Winneshiek County, Iowa, where Loc. 9 is designated a reference section. This locality shows the least shaly appearance of the Frankville within Iowa. Although the Frankville becomes more argillaceous upward, it lacks alternating beds of carbonate and shale. Strata have planar bedding surfaces and resemble the underlying Stewartville. A second reference section, Loc. 57 (also the type locality for the upper subdivision, the Littleport beds), shows the lowest alternating shale and carbonate beds of the Dubuque in Iowa. At Loc. 57, the upper ⅔ of the Frankville is alternating carbonate and shale, and is comparable to that at localities 60, 47, 29. We have designated no type locality for the Frankville because of it lithologic variability. It constitutes the zone of transition from typical Stewartville to typical Dubuque strata.

The "marker bed" is the base of the Frankville beds — the contact of the Wise Lake and Dubuque formations (Figure 3-C). Sparry Calcarenite Bands 7 and 8 (Levorson & Gerk, 1972) are respectively at an average position of 6′ 8″ and 9′ 6″ above this contact. The top of the Frankville is a 2½″ laminated, silty, reddish-brown shale bed, formerly considered to be the Wise Lake-Dubuque contact by Levorson & Gerk (1972).

The Frankville beds comprise 6″ to 30″ beds, generally thinner and more argillaceous upward. At Loc. 9, the Frankville beds show only planar bedding surfaces, while at other localities they are planar to slightly undulose and have prominent to weak shale partings.

At the Dubuque type locality (Loc. 51), the Frankville beds are not exposed except for the 2½″ shale parting at the top (floor level of the parking lot now occupying the quarry). A reference section here designated for the Dubuque Formation (Loc. 58) shows a typical dolomitic lithotype with the base of the "marker bed" 7′ 7″ above the floor of the quarry. A 3″ shale parting that marks the top of the Frankville beds is 13′ 3″ above the base of the "marker bed". It is equivalent to the 2½″ shale bed 14′ 2″ above the base of the "marker bed" at Loc. 9.

In Fillmore County, Minnesota, the Frankville contacts can be distinguished as elsewhere, but are not as distinct. At Rifle Hill (Loc. M-106) the "marker bed" is 10″ thick, in fresh exposure shows no shale partings, but is argillaceous at the top and bottom. With extensive weathering, it becomes more prominent with weak partings and iron staining at the top and base. At Loc. M-106, the "marker bed" overlies 9 feet of stylolitic Stewartville containing *Paleosynapta flaccida*. The characteristic bedding of the Frankville in Iowa and Illinois, i.e., planar beds with weak or no shale partings, is not maintained in Minnesota. At Loc. M-106, the upper 2′ 9″ bears undulose surfaces; at Loc. M-118, the entire Frankville shows planar to undulose bedding; and at Loc. M-100, the upper 6′ 3″ shows slightly undulose surfaces.

The Frankville beds at all localities are sparsely fossilferous, but may contain much crinoid debris. Although not abundant, *Pseudolingula iowensis* can be collected through the Frankville. Rarely, where the lower Frankville resembles the Stewartville, *Maclurites* was noted (total of 3 specimens from all localities).

Principal characteristics of the Frankville beds are: (1) planar bedding surfaces, with weak or no shale partings, except in Minnesota; (2) lack of stylolites; (3) presence of sparry calcarenite bands 7 and 8, approximately 6′ 8″ and 9′ 6″ respectively above the base from Decorah southeast at least to Littleport, Iowa (SCB 7 at Loc. M-118 is in the lower 2 feet); (4) a 2½″ shale at the top, which weathers to form a prominent reentrant (Figure 3-A); (5) the bentonite bed in the shale at the top (Loc. 60, M-118, and M-121); and (6) general upward increase of insoluble residues at a rate of about 1% per foot.

Luana beds

The Luana beds of the Dubuque Formation are named for their typical development at Lea's Quarry, Loc. 45, north of Luana, Clayton County, Iowa. There the unit is 9′ 6″ thick and ranges upward from 29′ 10″ above the floor of the quarry. Loc. 43 is a reference section showing typical development of the Luana beds 10′ 9″ thick. At Loc. 31, the Luana is 12′ 3″ thick, but thins to the southeast at the Dubuque type locality (Loc. 51) to 11′ 6″.

The top of the Luana beds is marked by a 7 to 12 inch shale bed, (Figure 3-B), which is traceable from several miles north of Spring Valley, Minnesota (Loc. M-118) to North Buena Vista, Iowa (Loc. 32). From there to several miles south of Galena, Illinois, the shale thins to 1″ to 4″ and is difficult to distinguish from other shale partings. Where the identity of the shale bed is lost, however, the distinctive bedding of the overlying Littleport beds, (i.e., very strongly undulose) affords identification of the top of the Luana.

Within the shale bed at the top of the Luana beds in Minnesota, is a bentonite 4″ to 6″ above its base (localities M-118, M-100, M-106, and M-112). At some of these localities the bentonite and overlying shale are fossilferous (e.g., *Megamyonia, Sowerbyella, Tetraphalerella, Calymene,* and *Diplograptus).* At Loc. 45, the shale at the top of the Luana beds is very fossiliferous in the lower half and sparsely so in the upper half (including crinoid debris, *Dalmanella, Sowerbyella,* fragments of *Calymene* and *Isotelus,* and a small *"Orthoceras"*). Commonly in Iowa, this bed is a reddish-brown, laminated, silty shale, with fossils preserved as molds and casts. In fresh exposure, the shale is characteristically reddish-brown, but weathers to a light gray with a reentrant at the top.

One of the most distinctive features of the Luana beds is the planar to

only slightly undulose bedding. Beds are 6'' to 24'' thick, but more commonly range 8'' to 10'' with 1'' shale partings between beds with few exceptions (e.g., Loc. 9, lower ½ has no shale partings). The Luana is considerably more argillaceous than the underlying Frankville. In Iowa and Illinois, the upper 5 to 6 feet of the Luana frequently contain small (¾'') calcite-filled vugs. Also common within the upper 5 to 6 feet are pyritic concretions and small (¼'' to ½'') disseminated clusters of pyrite crystals.

In Minnesota, the Luana beds increase in thickness to as much as 19 feet (Loc. M-106), compared to a relatively uniform 12 feet in Iowa (Figure 2). Other differences include: an additional bentonite in the middle of the Luana at M-118 and M-100 (4' 10'' and 6' 10'' respectively above the base), an increase in thickness of shale beds, and additional shale as well as carbonate beds that do not correlate with strata southeast of Loc. 60.

Littleport beds

The Littleport beds are named after the community of Littleport in Clayton County, Iowa. At Loc. 57, the type locality, the unit is 9' 6'' thick. Reference localities showing different aspects of the Littleport are: Loc. 45, Loc. 9, and the Dubuque type Locality (Loc. 51). The thickness of the unit ranges in Iowa from 9' 4'' (Loc. 28) to 12' 7'' (Loc. 32). The greatest thickness observed (17' 6'') is at Loc. M-100, where several transitional, planar beds overlie the bentonite near the top of the Littleport. At Loc. M-106, 3½ miles southeast of Loc. M-100, the Littleport is only 13' 3'' thick.

The principal characteristic of the Littleport beds is strongly undulose bedding surfaces. These undulations may be up to 3 feet long, and have a maximum relief of 5 inches. In dolomitic rocks, beds tend to fracture to form rectangular blocks in outcrop (Figure 3-B); however, in the limestone facies, they tend to be continuous. When the section at the Littleport type locality (Loc. 57) was freshly cut, it showed the unit to comprise 3 prominent beds, in ascending order 3' 3'', 2' 5'', and 3' 10'' thick. These beds now show weathering of argillaceous horizons within each so that with extended weathering they will resemble those of the Dubuque type locality (Loc. 51), where thick, massive beds have weathered to highly undulose laminae and thin beds. Northwest of Loc. 57 bedding is more massive with 6'' to 17'' beds that do not weather to sequences of thin beds, but still show the characteristic undulose bedding surfaces separated by ½'' to 1½'' shale partings. At Loc. 60, shales between relatively pure carbonate beds are 2'' to 4'' thick and continue to thicken as well as showing additional shale and carbonate beds to Loc. M-106. From Loc. M-106 northwest to Loc. M-118, the additional shale and carbonate beds pinch out, but other beds still retain the thicker shale partings.

Shale partings in Iowa are reddish-brown, but in Minnesota are light grey, and in Illinois are buff to tan and dolomitic. Small pyrite concretions common throughout the Littleport weather to a dark ocherous red-brown stain. The Littleport resembles the remainder of the Dubuque: dolomitic to the south, limestone in the central part, and limestone and shale to the north. It characteristically bears large (up to 3'' diameter) calcite filled vugs, which also occur in the lower Maquoketa at Locs. M-112, M-106, and M-100.

The Littleport beds are most fossiliferous in Fillmore County, Minnesota. The common fossil at most localities is *Pseudolingula iowensis*, but locally, the following are more common: *Rafinesquina, Sowerbyella, Strophomena,* and *Megamyonia; Oxoplecia* is very rare (only 1 fragmental specimen). Fragments of trilobites (e.g., *Isotelus, Calymene*) are common, and the Littleport also bears large amounts of echinoderm debris.

Features characterizing the Littleport beds are: highly undulose bedding (except for the planar beds at the top of the exposure at Loc. M-100), with prominent shale partings from the northern limits of the area of investigation to Loc. 57 at Littleport, Iowa. From Loc. 57 to the southeast to Illinois, bedding is undulose but thicker and weathers to thin laminae. The ''upper bentonite'' of Weiss (1957, p. 1040) is 2 to 5 feet below the top of the Littleport in Minnesota. The unit bears 3'' calcite filled vugs, and relatively small pyrite concretions that oxidize to rusty stains. Except in northwest Winneshiek County and Minnesota, there is a prominent lithologic break between the Dubuque and Maquoketa. Where the ''depauperate fauna'' of the Maquoketa is absent, the contact is slightly less distinct. The Littleport beds range in thickness from 10 to 12 feet in Iowa and Illinois and thicken northwest of Loc. 60 to Loc. M-100, thinning again, sharply, to Loc. M-118.

Increased thickness of the Luana and Littleport beds from Loc. 60 to Loc. M-106, and subsequent reduction to Loc. M-118 (Figure 2), probably represents syngenetic filling of a subsiding trough. The downwarp began in southeastern Minnesota during the early Middle Ordovician (Austin, 1972). Loc. 60 is probably near the southern margin of downwarping during Dubuque deposition, because the thickness is uniform to the south. Following Frankville deposition, subsidence between Loc. 60 and Loc. M-118 with its greatest depth near Loc. M-106, M-100, and Mystery Cave, resulted in increased thickness of the Luana and Littleport beds. Sporadic argillaceous influx during Frankville deposition occurred at several locations from north to south.

CONCLUSIONS

The basal boundary of the Dubuque Formation in Iowa, previously placed at the lowest shale bed in alternating carbonate and argillaceous rocks has not proven consistently applicable because of considerable lithologic variability in the lower ⅓ of the formation. The base of the Dubuque proposed here is at the ''marker bed'', a 6 to 8 inch predominantly carbonate bed bounded by thin shale seams that is easily recognized in outcrop from northwestern Illinois through northeastern Iowa into southern Minnesota.

The proposed tripartite informal subdivision of the Dubuque (Frankville beds, Luana beds, Littleport beds) is based primarily upon bedding surface characteristics. These subdivisions are easily recognized in Iowa and Illinois but less so in Minnesota where the Dubuque is considerably thicker, more argillaceous, and less dolomitic. Lateral facies changes in the Dubuque offer no particular problem in recognition of subdivisions, except in Minnesota. In Minnesota four bentonites assist in recognition of stratigraphic position of units, but are commonly not laterally widespread; care must be exercised in their identification or correlation. Further study of the Dubuque conodont fauna may show that faunal shifts noted by Ethington (1959) correspond to the tripartite subdivisions, possibly facilitating their recognition in the subsurface.

The Dubuque-Maquoketa contact is transitional at most localities in Minnesota, except for the lithologic contrast between relatively pure limestone and shale of the Dubuque and dolomitic limestone with a high clay fraction. In Minnesota and the Kendallville, Iowa area, bedding in the basal Maquoketa commonly resembles that of the Dubuque where it is interbedded carbonate and shale. Across Iowa, the contact is distinct with the phosphatic and ''depauperate zone'' in the base of the Maquoketa, but these have not been seen in Minnesota, or north of Decorah, Iowa.

ACKNOWLEDGEMENTS

Throughout the period of field investigation of the Dubuque, which forms a part of the extensive study of the Galena Group by Levorson and Gerk, the following have been instrumental in the completion of this project. We are grateful to all for their many kindnesses.

Dr. W. M. Furnish and H. L. Strimple, University of Iowa; Drs. H. B. Willman and T. C. Buschbach, Illinois State Geological Survey; Dr. G. F. Webers, Macalester College; and James Meyers, Iowa State Highway Commission have provided useful consultation and accompanied Levorson and Gerk in the field on several occasions. Useful criticism of the manuscript has been provided by B. J. Witzke, D. L. Koch and F. H. Dorheim of the Iowa Geological Survey and by T. J. Frest of the University of Iowa. The library facilities of the University of Tennessee and the University of Iowa have contributed significantly to the preparation of this manuscript.

We are particularly indebted to the generosity of quarry owners and operators who have permitted visits to their facilities. These include: Roverud Const. Co., Decorah, Iowa; Bruenning Const. Co., Decorah, Iowa; Quarve & Anderson Const. Co., Rochester, Minnesota; Kapper Const. Co., Spring Valley, Minnesota; Pederson Bros. Const. Co., Harmony, Minnesota; Pavlovec Rock Co., Calmar, Iowa; Becker Bros. Stone Co., Dubuque, Iowa; Kuhlman Const. Co., Colesburg, Iowa; Wilfred Schmidt, North Buena Vista, Iowa; Vernon Rovang, Decorah, Iowa.

Various county engineering departments have been helpful in the provision of maps and in the location of exposed strata, as have offices of the Iowa and Minnesota State Highway Commissions. Glenn Crossman, Riceville, Iowa frequently assisted in section measurement and also in the search for fossils. To those whom we may have forgotton due to the length of time involved in this project we also express our gratitude, as finally we do to our wives and children who have spent many weekends and evenings alone or sitting in a quarry while work was progressing.

REFERENCES

AGNEW, A.F., 1955. Facies of Middle and Upper Ordovician rocks of Iowa: Amer. Assoc. Petrol. Geol. Bull. *39:* 1703-1752.

AGNEW, A.F., A.V. HEYL, JR., C.H. BEHRE, and R.J. LYONS, 1956. Stratigraphy of Middle Ordovician rocks in the zinc-lead district of Wisconsin, Illinois, and Iowa: U.S. Geol. Surv. Prof. Paper 274K: 251-312.

AUSTIN, G.S., 1972. Paleozoic lithostratigraphy of southeastern Minnesota: Minnesota Geol. Surv. Guidebook ser. No. *4*: 1-24.

CALVIN, S., 1906 (1905). Geology of Winneshiek County: Iowa Geol. Surv. *16:* 37-146.

CALVIN, S., and H.E. BAIN, 1900 (1899). Geology of Dubuque County: Iowa Geol. Surv. *10:* 379-622.

ETHINGTON, R.L., 1959. Conodonts of the Ordovician Galena Formation: Jour. Paleontol. *32:* 257-292.

HALL, J., 1854. On the Silurian System of the Lake Superior Region: Amer. Jour. Sci., ser. 2, *17:* 181-194.

KAY, G.M., 1935. Ordovician Stewartville-Dubuque problems: Jour. Geology *43:* 561-590.

LEVORSON, C.O. and A.J. GERK, 1972. A preliminary stratigraphic study of the Galena Group of Winneshiek County, Iowa: Proc. Iowa Acad. Sci. *79:* 111-122.

MOSSLER, J.H. and J.B. HAYES, 1966. Ordovician bentonites of Iowa: Jour. Sed. Pet. *36:* 414-427.

SARDESON, F.W., 1897. The Galena and Maquoketa series: Amer. Geol. *19:* 21-35.

SARDESON, F.W., 1907. The Galena series: Geol. Soc. Amer. Bull. *18:* 179-194.

STAUFFER, C.R. and G.A. THEIL, 1941. The Paleozoic and related rocks of southeastern Minnesota: Minnesota Geol. Surv. Bull. *29:* 1-261.

SWEET, W.C. and S.M. BERGSTRÖM, 1976. Conodant biostratigraphy of the Middle and Upper Ordovician of the United States midcontinent: The Ordovician System (M.G. Bassett, ed.), 121-151.

SWEET, W.C., R.L. ETHINGTON, and C.R. BARNES, 1971. North American Middle and Upper Ordovician conodont faunas: Symposium on Conodont *Biostratigraphy* (W.C. Sweet and S.M. Bergström, eds.) Geol. Soc. Amer. Mem. *127:* 163-193.

TEMPLETON, J.S. and H.B. WILLMAN, 1963. Champlainian Series (Middle Ordovician) in Illinois: Illinois St. Geol. Surv. Bull. *89:* 1-260.

WEBERS, G.F., 1972. Paleoecology of the Ordovician strata of southeastern Minnesota: Minnesota Geol. Surv. Guidebook ser. No. *4:* 25-41.

WEISS, M.P., 1954a. Notes on some Middle Ordovician fossils from Minnesota: Jour. Paleontol. *28:* 427-429.

WEISS, M.P., 1954b. Feldspathized shales from Minnesota: Jour. Sed. Pet. *24:* 270-274.

WEISS, M.P., 1957. Upper Middle Ordovician stratigraphy of Fillmore County, Minnesota: Geol. Soc. Amer. Bull. *68:* 1027-1062.

WILLMAN, H.B. and D.R. KOLATA, 1978. The Platteville and Galena Groups in northern Illinois: Illinois St. Geol Surv. Circ. *502:* 1-75.

APPENDIX — LOCALITIES

Loc. 9: Road cuts Iowa Highway 9, 7 miles Southeast of Decorah, Ia., SW ¼, SW ¼, Sec. 4, and NW ¼, NW ¼, Sec. 9, T 97N, R 7W; Stewartville, 4′ 2″, Dubuque, 34′ 4″, Maquoketa contact.

Loc. 10: Rovang Quarry, 3½ miles south, ¾ mile east of Decorah, Ia., NE ¼, SE ¼, Sec. 9, T 97N, R 8W; Stewartville, 17′ 10″, Dubuque, 34′ 7″, Maquoketa contact.

Loc. 17: Pavlovec Quarry, north bank of Upper Iowa River at Kendallville, Ia., SW¼, NE ¼, Sec. 33, T 100N, R 10W, Sinsinawa, 6′ 10″, Stewartville, 35′ 10″, Dubuque, 19′ 1″.

Loc. 28: Blockhus Quarry, 4 miles east of Elgin, Ia., SE ¼, NW ¼, Sec. 21, T 94N, R 6W; Stewartville, 1′ 11″, Dubuque, 34′ 2″, Maquoketa contact.

Loc. 29: Houg Quarry, 2 miles west of Farmersburg, Ia., NW ¼, Sec. 14, T 94N, R 5W; Stewartville, 34′ 5″, Dubuque, 21′ 3″. Top of exposure probably 3 feet below top of Luana beds.

Loc. 30: Roverud's Elkader Quarry, 1½ miles northeast of Elkader, Ia., NE ¼, SW ¼, Sec. 12, T 93N, R 5W; Wyota, 7′ 11″, Sinsinawa, 27′ 6″, Stewartville, 46′ 11″, Dubuque, 18′ 11″.

Loc. 31: South Osterdock Quarry, ½ mile south of Osterdock, Ia., NW ¼, SE ¼, Sec. 33, T 91N, R 14W; Sinsinawa, 7′ 0″, Stewartville, 42′ 8″, Dubuque, 27′ 9″. (Since being measured on 9/12/72, additional Dubuque has been exposed, probably in contact with the Maquoketa.)

Loc. 32: Schmidt Quarry, 1½ miles southwest of North Buena Vista, Ia., SW ¼, SE ¼, Sec. 21, T 91N, R 1W; Sinsinawa, 6′ 5″, Stewartville 41′ 7″, Dubuque, 32′ 7″, Maquoketa contact.

Loc. 33: Quarry 3 miles southeast of Kendallville, Ia., SW ¼, SE ¼, Sec. 1, T 99N, R-10W; Stewartville, 16′ 11″, Dubuque, 34′ 5″, Maquoketa, 17′ 3″.

Loc. 43: Gilman Johnson Quarry, ½ mile east of St. Olaf, Ia., NE ¼, SE ¼, Sec. 25, T 94N, R 5W; Stewartville, 5′ 8″, Dubuque, 34′ 9″, Maquoketa contact.

Loc. 45: Lea's Quarry, ½ mile north of Luana, Ia., NW ¼, SE¼, Sec. 5, T 95N, R 5W; Stewartville, 17′ 2″, Dubuque, 32′ 4″, Maquoketa, 31′ 6″.

Loc. 47: Zurcher Quarry, 1½ miles north and ¼ mile west of Farmersburg, Ia., NW¼, SE ¼, Sec. 1, T 94N, R 5W; Stewartville, 25′ 1″, Dubuque, 33′ 0″.

Loc. 50: Roadcut on north side of U.S. Highway 20, Dubuque, Ia., 1/10 mile west of junction of U.S 20 and Devon Drive, SE ¼, NE ¼, Sec. 28, T 89N, R 2E; Stewartville, 8′ 2″, Dubuque, 33′ 11″, contact with Depauperate Zone residuum at base of Maquoketa.

Loc. 51: Dubuque Type Locality, abandoned quarry north side of Loras Blvd., at Cox St. intersection, SW ¼, Sec. 24, T 89N, R 3E; Upper 21′ 9″ of Dubuque with Maquoketa contact. Quarry has been partly filled for a parking lot.

Loc. 52: Roadcut on U.S. Highway 20, 1.2 miles west of junction with Illinois Hwy. 80, SE ¼, NE ¼, Sec. 3, T 28N, R 1W; (Only Dubuque strata measured from "marker bed" to top of exposure.) Dubuque, 27′ 4″.

Loc. 53: Quarry 4½ miles northeast of Postville, Ia., NW ¼, SE ¼, Sec. 19, T 96N, R 5W; Stewartville, 18′ 5″, Dubuque, 32′ 3″.

Loc. 56-A: Ski Lift section, 100 yards north of "Ravine Section" of Templeton & Willman (1963, p. 239, Loc. 32), 6 miles south of Galena, Ill., W. line, NE ¼, SE ¼, Sec. 21, T 27N, R 1E; Stewartville, 28′ 9″, Dubuque, 33′ 7″, Maquoketa contact.

Loc. 57: Littleport Roadcut, roadcut ½ mile south of Littleport, Ia., SE¼, Sec. 25, and NE¼, Sec. 36, T 92N, R 5W; Dubuque, 33′ 7″, with Maquoketa and Stewartville contacts. The lowest shale parting of Templeton & Willman (1963) is 7′ 3″ below the base of the marker bed.

Loc. 58: Becker Quarry, (Dubuque reference locality) north side of Kaufmann Avenue, 0.3 mile west of intersection with Grandview Drive, Dubuque, Ia., NW ¼, SE ¼, Sec. 15, T 89N, R 2E; Stewartville, 7′ 7″, Dubuque, 34′ 9″, Maquoketa contact.

Loc. 59: Quarry 1 mile northwest of Elkader, Iowa. SW ¼, SE ¼, Sec. 16, T 93N, R 5W; Stewartville, 3′ 0″, Dubuque, 29′ 4″.
Loc. 60: Quarry (Ethington, 1959, Locality 7) at fork in road 1½ miles southeast of Kendallville, Ia., SE ¼, NW ¼, Sec. 2, T 99N, R 10W; Stewartville, 15′ 6″, Dubuque, 31′ 8″, Maquoketa contact.
Loc. M-100: "Grabau Quarry", 4 miles east and 3½ miles south of Spring Valley, Mn., SE ¼, SE ¼, Sec. 17, T 102N, R 12W; Stewartville, 18′ 8″, Dubuque, 39′ 10″, Maquoketa, 25′ 3″.
Loc. M-106: "Rifle Hill Quarry," 1 mile north and 2½ miles east of Cherry Grove, Mn., NE ¼, NW ¼, Sec. 35, T 102N, R 12W; Sherwood, 12′ 5″, Wall, 8′ 3″, Wyota, 16′ 6″, Sinsinawa, 31′ 10″, Stewartville, 37′ 11″, Dubuque, 44′ 10″, Maquoketa, 23′ 6″. (Weiss 1957, Locality F-171).
Loc. M-112: "Wubbel's Ravine," 2½ miles east of Cherry Grove, Mn., N ½, Sec. 2, T 101N, R 12W; Stewartville 6′ 9″, Dubuque, 43′ 2″, Maquoketa, 58′ 9″. (Weiss, 1957 Locality F-168).
Loc. M-118: "Kapper Quarry," 4½ miles north of Spring Valley, Mn., NW ¼, SW ¼, Sec. 3, T 103N, R 13W; Sinsinawa, 9′ 10″, Stewartville, 39′ 3″, Dubuque, 32′ 3″, Maquoketa, 3′ 10″.
Loc. M-121: Quarry 2¼ miles west of Stewartville, Mn., NW ¼, NE ¼, NE ¼, Sec. 5, T 104N, R 14W; Stewartville, 17′ 1″, Dubuque, 12′ 4″.

At the 26 localities listed above, either the Stewartville-Dubuque, or the Dubuque-Maquoketa contact is present, and at 16 the entire Dubuque is present. Locality numbers prefixed with the letter M are within southern Minnesota; all others are within Iowa except 52 and 56-A, which are in northwest Illinois.