THE STRATIGRAPHY OF THE INDEPENDENCE SHALE OF IOWA.

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PART II.

DEEP WELL RECORDS.

Another source of information about the stratigraphic position of the Independence shale is found in the deep well records of Iowa. Drilling samples have been taken from many of the wells and are now preserved in the files of the Iowa Geological Survey at Iowa City. During a study of the samples of one of them, W. H. Norton discovered Independence fossils which were submitted to the present writer for identification. The well is a city well of Shellsburg in Benton county, Iowa. The log of this well made from a personal study of the samples is as follows:

Depth	*Material*	*Formation and Age*
0–20	drift	Pleistocene
		Devonian
20–60	limestone, fossiliferous	Cedar Valley
60–80	shale, fossiliferous[37]	Independence
		Wapsipinicon
80–85	lithographic limestone	Davenport
85–100	dolomitic limestone, sugary	Spring Grove
100–125	limestone and blue shale	Kenwood
125–150	limestone, sublithographic	Otis
150–165	limestone, chert, shale at bottom	Coggon
160–200	dolomite	Silurian

Another well at Shellsburg shows the following section:

Depth	*Material*	*Formation and Age*
0–160	drift	Pleistocene
		Devonian
50–60	limestone	Cedar Valley
60–70	shale	Independence
70–180	limestone	Wapsipinicon

Other city wells in Benton county add to the weight of the evidence confirming the presence of shale below the Cedar Valley. The Garrison city well has this record:

[37] Fossils recovered include *Douvillina stookeyi* Stainbrook, *Strophonelloids deeringi* Stainbrook, *Douvillinaria variabilis* (Calvin), *Tentaculites*, and crinoid stem segments.

Depth	*Material*	*Formation and Age*
0–40	drift, etc.	Pleistocene
		Devonian
40–50	limestone	Cedar Valley
50–65	blue shale	Independence
		Wapsipinicon
65–70	limestone	Davenport
70–85	limestone	Spring Grove
85-90	limestone and shale	Kenwood
95–105	limestone	Otis

The well is in a valley in Cedar Valley limestone which is exposed for nearly its full thickness in the valley wall above the well curb. At Vinton, the Vinton Produce Company well yields this log:

Depth	*Material*	*Formation and Age*
0–70	drift	Pleistocene
		Devonian
70–150	limestone, fossiliferous	Cedar Valley
150–170	blue shale	Independence
		Wapsipinicon
170-175	limestone, lithographic	Davenport
175–200	dolomite	Spring Grove
200–220	limestone and shale	Kenwood
220–250	limestone, sublithographic	Otis
250–270	dolomite	Coggon
	dolomite	Silurian

The E. Wallace well is five and a half miles northeast of Vinton.

The samples give this record:

Depth	*Material*	*Formation and Age*
90–150	limestone	Cedar Valley
150–160	blue shale	Independence
160–170	no sample	
170–225	limestone	Wapsipinicon

At Newhall a well has this log:

Depth	*Material*	*Formation and Age*
0–168	drift	Pleistocene
		Devonian
168–295	limestone	Cedar Valley
295–320	shale, crinoid segment	Independence
		Wapsipinicon
320-340	limestone, lithographic	Davenport
340–370	dolomite, sugary	Spring Grove
370–385		Kenwood
375–420		Otis
425–445		Coggon
445–470	dolomite	Silurian

At Atkins is a well yielding this record from a study of the samples:

Depth	*Material*	*Formation and Age*
78–83	drift	Pleistocene
		Devonian
83–200	limestone	Cedar Valley
200-210	shale	Independence
		Wapsipinicon
210–225	limestone, lithographic	Davenport
225–255	limestone	Spring Grove
255–270	limestone, blue shale	Kenwood
270–300	limestone	Otis
300–330	limestone and shale	Coggon
330–	dolomite	Silurian

A well at Watkins from the sample study shows this log:

Depth	*Material*	*Formation and Age*
		Mississippian
250–310	shale	Kinderhook
		Devonian
310–410	limestone	Cedar Valley
410–420	shale	Independence
		Wapsipinicon
420–425	limestone	Davenport
425–445	limestone	Spring Grove
445–455		Kenwood

Deep well at Van Horne:

Depth	*Material*	*Formation and Age*
0–155	drift	Pleistocene
		Devonian
155–247	shale	Unnamed
247–370	limestone, fossiliferous	Cedar Valley
370–420	shale, fossiliferous	Independence
420–460	limestone, dolomite	Wapsipinicon

In Linn county are a number of surface exposures of the shale. Near Center Point two deep wells have been drilled and the suites of samples from them show the presence of the shale below the Cedar Valley limestone.

A well at Center Point gives this section:

Depth	*Material*	*Formation and Age*
		Devonian
60–80	limestone	Cedar Valley
80–100	blue shale and sand	Independence
		Wapsipinicon

Depth	*Material*	*Formation and Age*
100–110	lithographic limestone	Davenport
110–130	limestone, brownish	Spring Grove
130–140	argillaceous limestone, shale	Kenwood
140–165	limestone, sublithographic	Otis
165–185	dolomite and limestone, buff	Coggon
		Silurian

The G. M. Mounce well (W 1028) near Center Point also shows in samples about thirty feet of shale and argillaceous limestone below the Cedar Valley and above Wapsipinicon. Crinoid segments and a fragment of an echinoid spine were recovered from shale at the depth of 98-106. Minute quartz crystals with doubly pyramidal ends are also common.

In Buchanan county the Independence shale was first seen and described. In the B. F. Nabholz farm well east of Brandon, argillaceous beds with sandstone occurs below the Cedar Valley. This well is about a mile east of the exposures of the shale northeast of Brandon.

At Charles City in Floyd county a well whose curb is on Cedar Valley limestone reveals this record:

Depth	*Material*	*Formation and Age*
		Devonian
1–100	limestone	Cedar Valley
100–120	shale	Cedar Valley
120–210	dolomite and limestone	Cedar Valley
210–220	silt, etc.	Independence
220–300	dolomite	Silurian

Farther south in Butler county at Clarkesville, the Henry Woods State Park well shows this log:

Depth	*Material*	*Formation and Age*
0–70	drift	Pleistocene
		Devonian
70–120	limestone	Cedar Valley
120–137	shale	Independence

In Johnson county the W. Fisher well near North Liberty shows:

Depth	*Material*	*Formation and Age*
0–130	loess and drift	Pleistocene
		Devonian
130–140	limestone	Cedar Valley
140–155	blue shale	Independence
		Wapsipinicon
155–170	limestone, white	Davenport
170–195	limestone	Spring Grove
195–205	limestone and shale	Kenwood

In Iowa county several deep well sample suites indicate the presence of shale below Cedar Valley limestone.

A well at Homestead has this log:

Depth	*Material*	*Formation and Age*
0–280	drift	Pleistocene
280–470	shale	Mississippian or Devonian
470–560	limestone, fossiliferous	Devonian Cedar Valley
560–575	shale	Independence
575–595	limestone, white	Wapsipinicon Davenport
595–600	(missing)	
600–620	dolomite	Spring Grove

(well continues)

At South Amana the record is as follows:

Depth	*Material*	*Formation and Age*
0–210	drift	Pleistocene
210–300	shale	Mississippian or Devonian
300–375	limestone, fossiliferous	Devonian Cedar Valley
375–390	blue shale	Independence
390–405	lithographic limestone	Wapsipinicon Davenport
405–430	dolomite	Spring Grove
430–445	shale and limestone	Kenwood
445–460	limestone, lithographic	Otis

(record continues)

The South Amana well is a few miles west of the one at Homestead but the records differ somewhat in the thicknesses of the formations penetrated. These variations are readily accounted for as there is a great unconformity between the Pleistocene and the Kinderhook shale and a large one between the shale and the Cedar Valley limestone. The thicknesses of the Devonian formations also differ slightly, as would be expected. Drilling samples at the tops and bottoms of adjacent formations show considerable mixture and the location of the boundary lines between is subject to an error of a few feet either way.

In the same county but farther west is the Marengo well which shows:

Depth	*Material*	*Formation and Age*
0–280	drift	Pleistocene
		Mississippian or Devonian
280–326	shale	Devonian
326–460	limestone	Cedar Valley
460–480	shale	Independence
480–515	limestone and dolomite	Wapsipinicon

These records, all derived from a study of the drilling samples of wells in the east central part of Iowa in the area of its surface exposures, reinforce the conclusion that the Independence shale occurs below the Cedar Valley limestone and above the Davenport member of the Wapsipinicon.

Southeast of that area in Iowa centering about the counties of Linn, Benton and Buchanan where most of the exposures of the shale occur, the Independence may be traced below the surface by deep well samples into Missouri. Study of the suite of samples from a well at Brighton, Washington county, Iowa, gives this record:

Depth	*Material*	*Formation and Age*
0–90	drift	Pleistocene
		Mississippian
90–370	limestone	Osage
370–650	shale	Kinderhook
		Devonian
650–790	limestone, fossiliferous	Cedar Valley
	sandstone at base of above	Independence
790–890	gypsum, limestone, chert, and dolomite	Wapsipinicon
		Ordovician
890–1000	shale	Maquoketa

At Mt. Pleasant in Henry county, Iowa, a well yields this log:

Depth	*Material*	*Formation and Age*
0–68	drift	Pleistocene
		Mississippian
68–234	limestone	Osage
234–602	shale	Kinderhook
		Devonian
602–729	limestone, fossiliferous	Cedar Valley
729–740	shale	Independence
740–806	limestone, gypsum, dolomite	Wapsipinicon
		Ordovician
806–848	shale	Maquoketa

A well at Letts in Louisa county, Iowa, has this sample record:

Depth	*Material*	*Formation and Age*
0–280	drift	Pleistocene
		Mississippian
280–325	shale	Kinderhook
		Devonian
325–440	limestone	Cedar Valley
440–446	sandstone	Independence
446–578	limestone, etc.	Wapsipinicon
		Ordovician
578–810	shale	Maquoketa

At Keokuk in Lee county, Iowa, the Hubinger well shows this driller's record:

Depth	*Material*	*Formation and Age*
0–20	drift	Pleistocene
		Mississippian
28–290	limestone, etc.	Osage
290–560	shale	Kinderhook
		Devonian
560–625	limestone	Cedar Valley
625–645	sandstone	Cedar Valley
645–700	limestone	Cedar Valley
700–737	sandstone	Independence
		Ordovician
737–800	shale	Maquoketa

From these sections it is noticeable that the Independence changes from shale to sandstone toward the southeast. Apparently this change in lithology indicates the approach to the land mass of the Ozark uplift. Stratigraphically the Independence corresponds to the 15 foot bed of sandstone which outcrops about ten miles south of Hannibal, Missouri. At this locality[38] the Callaway limestone has typical Cedar Valley fossils and the limestone below, the Cooper, is white, lithographic and in every way similar to the Davenport member of the Wapsipinicon. This sandstone[39] appears to be the same one previously designated as the Auxvasse Creek sandstone member of the Callaway and there seems to be little doubt that it is the continuation of the sandstone below Cedar Valley to the north in southeast Iowa and of the Independence shale farther north. In several places in Linn county, Iowa, the Independence has sandy phases or is nearly a sandstone.

[38] Guidebook, Fifteenth Annual Field Conference, Kansas Geol. Soc., 1941, p. 65.

[39] Counselman, F. B.: 1935?, Mo. Acad. Sci. Proc., vol. 1, pp. 105, 108-113, 119.

In northwestern Illinois the Hoing sandstone occupies the same stratigraphic position between the Cedar Valley limestone and the lithographic Davenport member of the Wapsipinicon. The Hoing is stated[40] to overlie unconformably the Wapsipinicon and to be everywhere overlain by Cedar Valley. Later Weller[41] states that the Hoing sand is the basal member of the Cedar Valley in the Colmar-Plymouth field of Illinois and present also in the Centralia-Salem area. The present writer believes that the Hoing sand of Illinois, the Auxvasse Creek sandstone member of Missouri and the sandstone and shale in Iowa are all region equivalents and are near-shore phases of the fossiliferous Independence shale farther northwest in central Iowa.

The Independence shale can also be traced below the surface in deep wells into Nebraska and northwest Missouri. At Nevada, in Story county, Iowa, the section as revealed by a study of drilling samples is as follows:

Depth	*Material*	*Formation and Age*
0–68		Pleistocene
68–260		Pennsylvanian
268–660		Mississippian
570–660	shale	Kinderhook
660–1210		Devonian
660–800	shale and limestone	Lime Creek
800–850	limestone	Shellrock
850–1000	limestone	Cedar Valley
1000-1010	limestone and sandstone	Independence
1010–1330	limestone, dolomite, gypsum	Wapsipinicon
1330–1920		Ordovician (Maquoketa to St. Peter)

At Mitchellville in Polk county, Iowa, the section, summarized is:

Depth	*Material*	*Formation and Age*
0–85		Pleistocene
85–500		Pennsylvanian
500–670		Mississippian
505–670	shale	Kinderhook
670–875		Devonian
670-760	limestone	Cedar Valley
760–785	shale	Independence
785–875	limestone, dolomite, sandy at base	Wapsipinicon

(record continues)

[40] Weller, J. M.: 1935, Personal communication, Guidebook, Kansas Geol. Soc., Ninth Annual Field Conference, p. 259.

[41] Weller, J. M.: 1940, Devonian Correlations in Illinois and Surrounding States: a summary; Symposium on Devonian of Upper Mississippi Valley, Univ. of Illinois. In press.

At Des Moines, in Polk county, Iowa, the section, with beds above and below omitted, is:

Depth	*Material*	*Formation and Age*
		Mississippian
765–770	blue shale	Kinderhook
		Devonian
770–915	limestone, some shale	Cedar Valley
915–930	limestone, shale, sandstone	Independence
935–1025	lithographic limestone. shale, anhydrite, dolomite, etc.	Wapsipinicon
(record continues)		

At Ogden in Boone county, Iowa, the section, with beds above and below omitted, is:

Depth	*Material*	*Formation and Age*
		Mississippian
620–630	shale	Kinderhook
		Devonian
630–750	limestone	Cedar Valley
750–760	shale	Independence
760–980	dolomite, limestone, etc.	Wapsipinicon
(record continues)		

At Woodward in Dallas county, Iowa, a well yields this record of Devonian rocks:

Depth	*Material*	*Formation and Age*
		Mississippian
790–840	shale	Kinderhook
		Devonian
840–970	limestone	Cedar Valley
970–983	shale	Independence
983–1045	limestone, etc.	Wapsipinicon
(record continues)		

At Dexter in Dallas county, Iowa, a similar brief section derived from a study of well samples is:

Depth	*Material*	*Formation and Age*
		Mississippian
1020–1050	shale	Kinderhook
		Devonian
1050–1140	limestone	Cedar Valley
1140–1150	shale	Independence
1150-1230	limestone, dolomite, shale	Wapsipinicon
(record continues)		

At Stuart in Guthrie county, Iowa, a summarized section of a well is as follows:

Depth	*Material*	*Formation and Age*
		Mississippian
1177–1218	shale	Kinderhook
		Devonian
1218–1368	limestone	Cedar Valley
1368–1396	shale and limestone	Independence
1396–1690	limestone, gypsum, dolomite, shale	Wapsipinicon
(record continues)		

At Council Bluffs, in Pottawattomie county, Iowa, the Devonian section of a well is:

Depth	*Material*	*Formation and Age*
		Devonian
1160–1285	limestone	Cedar Valley
1285–1320	blue gray shale	Independence
1320–1500	limestone	Wapsipinicon

At Nebraska City, Nebraska, a shortened record of a well is:

Depth	*Material*	*Formation and Age*
		Mississippian
1220–1440	shale	Kinderhook
		Devonian
1440–1640	limestone, dolomite	Cedar Valley
1640–1665	shale	Independence
1665–1840	limestone, dolomite	Wapsipinicon

In a well in the northeast corner of Missouri in Buchanan county and in one near Tarkio, sandstone appears between the Cedar Valley (Callaway) and Davenport (Cooper) limestone equivalents.[42]

DISTURBED EXPOSURES OF THE INDEPENDENCE SHALE.

In a number of places Independence shale, bearing typical fossils and plainly distorted and disturbed, occurs adjacent to Cedar Valley limestone in evidently abnormal positions. With few exceptions, which are noted in the following paragraphs, all exposures of the shale show these features in common. In the first place the fossils found in most of the exposures of the disturbed shale are typical Independence forms identical with those collected from the formation in place below Cedar Valley limestone; in no place were Lime Creek species observed or collected therein. Secondly the shale generally abuts the Cedar Valley limestone on one side only. The plane between the

[42] Information from F. B. Counselman.

shale and the limestone is always sharp, nearly vertical and never passes beneath the shale. In the fourth place in no locality of the thirty odd known to the writer does the shale lie on Cedar Valley limestone in an erosion channel as an original deposit. Nor is the shale, as far as the writer could determine in the field, "supported" by the limestone as intimated by Cooper,[43] assuming that "support" means that the shale overlies the limestone. The shale has never been seen to lie on the Cedar Valley limestone in normally stratified layers as in the case of the State Quarry limestone. In Johnson county, Iowa, the concave erosional contact between the Cedar Valley and the State Quarry above it is readily apparent in several localities.

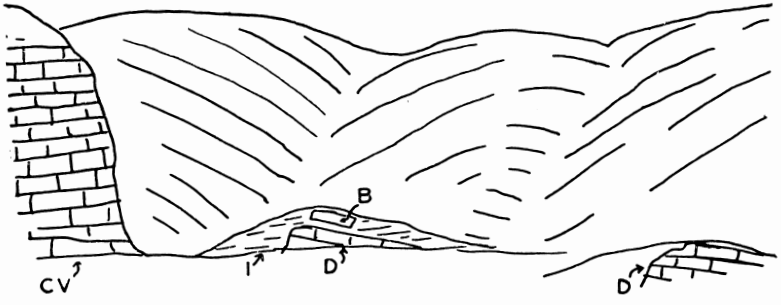

Fig. 5. Diagrammatic view of fault conditions at south end of Lake Minne Estima, Benton county, Iowa. Davenport limestone is present with fossiliferous Independence shale above. Middle Cedar Valley beds are immediately adjacent to the north. I, Independence shale; C V, Cedar Valley limestone; D, Davenport limestone; B, block of basal Cedar Valley limestone.

Faulting, to the writer, best explains the abnormal position of the shale and is in accord with the conditions seen in the various exposures. The separation face between the shale and Cedar Valley limestone is the visible evidence of a fault plane and not of an erosion surface. The Cedar Valley formation where exposed is commonly faulted and buckled and shows considerable disturbance throughout its visible extent. Faults of a few feet throw are not uncommon.[44] The fossiliferous shale in known exposures is everywhere in contact with the lower strata of the Cedar Valley and in no place would the fault movement necessary to bring the shale up from immediately

[43] Cooper, G. A.: 1942, Bull. Geol. Soc. Amer., vol. 53, p. 1766.
[44] Calvin, S.: 1898, Iowa Geol. Surv., vol. 9, p. 238.

below the limestone have been greater than 30 to 40 feet. Careful study by the present writer of the many disturbed exposures brought forth no evidence that faulting had not occurred or that the occurrences could be better explained in any other way.

In Benton county, Iowa, near the south end of lake Minne Estima in Harrison township, is an enlightening exposure of the shale. In the east wall of the valley of Cedar river is a forty foot cliff of Cedar Valley limestone comprising the layers from forty to eighty-five feet above the base of the formation. At the south end of the cliff the limestone ceases abruptly. To the south and perhaps twenty feet away and on the same level at the base of the cliff is a two-foot ledge of lithographic Davenport limestone dipping southward. A few yards farther south an abandoned quarry shows that the Davenport limestone is a few feet thicker. Above the Davenport limestone is Independence shale with its typical fossils. The Davenport beds are stratigraphically fifty feet or so below the limestone forming the base of the adjacent cliff section of Cedar Valley. The relations (see Fig. 5) can only be explained by faulting. Further support for this explanation is given by a large block of fossiliferous limestone lying on the shale and carrying species which are found only in the basalmost layers of the Cedar Valley. In the area there is no known exposure of the basal Cedar Valley beds closer than five or six miles. It seems apparent that this block of basal Cedar Valley limestone must have been moved upward in the movement that has brought the Davenport limestone and the superjacent Independence shale into juxtaposition with the middle layers of the Cedar Valley limestone. Appeal to downward movement into a cavern or sink hole as an explanation of the presence of the shale seems inapplicable here.

Several writers (Cooper, Stookey and Savage)[45] have stated their belief that the abnormal occurrences of the Independence shale described above are to be explained in another way; namely, that the shale occurs in sinkholes and caverns in the Cedar Valley limestone. Sinkholes filled with shale do occur in the Cedar Valley as at Moscow, Iowa, and elsewhere, and the deposits when revealed by quarry operations typically have an upward funnel-shape, which, however, is never seen in the exposures of disturbed Independence shale. The present writer has carefully sampled and sieved the shale in these sinkholes and has

[45] See historical summary above.

never recovered a typical Independence fossil from them. At Moscow conodonts were found in the shale but they have a different aspect from those found in the Independence. The abundant carbonaceous remains, numerous plant fossils and general lack of marine fossils indicate that the shale sinkhole deposits at Moscow and elsewhere are continental and non-marine. The known near occurrences of Pennsylvanian shale and sandstone make it probable that these deposits in true sinkholes in the Cedar Valley are Pennsylvanian in age. This is all the more probable as the Mississippian period would afford sufficient time for sinkholes and channels to be formed by erosion into 100 to 150 feet of Cedar Valley limestone to the base of the formation. It is rather strange that the State Quarry limestone which does lie unconformably on the Cedar Valley does not occur in sinkholes therein. Near North Liberty in a well, shale is found in drilling samples below Cedar Valley in the near vicinity of an outcrop of State Quarry limestone.

Likewise it is difficult for the writer to believe that sinkholes formed during the uplift of a region would not, if open to the surface, be filled wholly or in part, by continental deposits, or that they could remain open until covered by an invading sea and then be filled with shale and limestone containing marine fossils. Probabilities would appear to be against this happening in most cases. How could it occur in dozens of places, widely scattered and distant from each other as are the exposures of disturbed Independence shale? To account for these known exposures the number of sinkholes and caverns must be exceptionally large as it is very probable that only a small fraction would be discovered in wells and quarries in a region so completely and thickly covered by Pleistocene deposits.

Secondly, the disturbed shale is always in contact with the lower layers of the Cedar Valley. If the shale occurred in sinkhole deposits surely some of them should be in the upper half of the formation. Such is not the case as thus far none has been observed.

Lastly, the shale in the exposures under discussion never occurs in continuous layers as originally deposited but is broken and distorted with pieces from several horizons intermingled. This condition could scarcely be the case if the shale were primarily deposited in sinkholes and caverns as indicated by the proponents of the sinkhole hypothesis. It is also inconceivable how the Independence could have been deposited in sinkholes in

the Cedar Valley limestone without debris from the walls and beds above being deposited or washed in simultaneously. The contact between the shale and limestone on fresh exposure is sharp, is not that of erosion and the shale, especially in undisturbed exposures, is remarkably free from erratic blocks of higher layers of the Cedar Valley. What few blocks of limestone are found in the shale are always from the basal layers of the Cedar Valley and not from the upper beds and have fallen onto the shale during erosion rather than having been originally incorporated during deposition. There is little evidence to support the hypothesis that the Independence shale occurs in sinkholes in the Cedar Valley as a primary deposit from above.

Proponents of the hypothesis that the Independence shale is younger than the Cedar Valley should explain whence the shale came downward into the limestone. Several (Stookey, Scobey and Savage)[46] have stated that the parent formation is the Lime Creek. That this is not the case is shown by a comparison of the macro-fossils from the two formations. This evidence is stated at length in another paper and need not be repeated here. It is sufficient to state that the faunas are so different as to be of different ages. Apparently recognizing this fact, Cooper,[47] and after him, Schuchert,[48] have interpolated this missing parent formation in between the Juniper Hill and Cerro Gordo members of the Lime Creek formation. There is no field evidence known to the present writer which supports this contention. The Cerro Gordo shale lies conformably on the Juniper Hill shale and deposition was continuous from the lower into the upper member. The scant fauna of the Juniper Hill shale shows little relationship with that of the Independence and contains no species to indicate its comparative age. The present writer has shown elsewhere that the faunas of the Cerro Gordo and the Independence shale are distinct and he did not find any evidence in them to show that the Cerro Gordo shale was immediately the younger in age. Faunally, then, there is no support for the supposition that there was once a formation, now wholly unknown, between the two lower members of the Lime Creek which was the source of the shale deposits known

[46] See historical résumé above.

[47] Cooper, G. A.: 1942, Bull. Geol. Soc. Amer., vol. 53, p. 1737 and chart.

[48] Schuchert, Charles: 1943, Stratigraphy of the Eastern and Central United States, p. 700.

as the Independence. Cooper[49] justifies this placing of the Independence shale by his assumption that the Independence fauna is of Chemung age. This assignment of the Independence fauna the present writer in his study does not find to be probable because of lack of many Independence species in the Chemung and vice versa. Since the Lime Creek does not appear to have been the source of the shale supposedly washed down into sinkholes near the base of the Cedar Valley, the downward movement of the Independence shale into the Cedar Valley and its younger age, therefore, can be regarded as unproven.

In several localities shale does occur in joints in the basal layers of the Cedar Valley formation. However these joints become narrower and disappear upward. These occurrences of the shale are homologous with the well known sandstone dikes[50, 51] which have been shown to have been formed by the upward movement of the sand. The Independence shale is typically soft and extremely plastic when wet. Since the Cedar Valley limestone is much jointed and occasionally faulted, there is no difficulty in explaining the presence of the shale in vertical crevices and cracks as due to upward movement induced by the weight of the Cedar Valley on a plastic shale directly beneath. The slight movements of ten to thirty feet necessary to account for the shale above its usual position does not appear improbable when one considers the upward thrust of hundreds of feet in salt domes and in the formation of the clastic dikes described by Diller and others. Norton[52] mentions the upward movement of red and green shales into the brecciated superjacent Monroe limestone on Mackinac Island. Trowbridge[53] states that often the Maquoketa shale similarly occurs above its expected situation in many places in the upper Mississippi valley. The peculiar Devonian deposit described by Weller[54] does not appear to have been formed in the same way as the Independence shale joint fillings. The wear suffered by some of the fish teeth in the former suggests also the possibility that they might have been introduced into their present situations as a secondary deposit during a subsequent period of erosion.

In one place evidence was observed that the Independence

[49] Cooper, G. A.: 1942, idem, Chart.
[50] Diller, J. S.: 1890, Bull. Geol. Soc. Amer., vol. 1, pp. 411-442.
[51] Parker, Ben H.: 1933, Jour. Geol., vol. 41, pp. 38-51.
[52] Norton, W. H.: 1920, Iowa Geol. Surv., vol. 27, p. 396.
[53] Trowbridge, A. C.: 1940, personal communication.
[54] Weller, Stuart: 1899, Jour. Geol., vol. 7, pp. 483-488.

shale has moved upward into a large cavern or chamber in the Cedar Valley. On the Close farm two and a half miles southwest of Brandon, in Benton county, Iowa, a quarry, mainly in the Rapid member of the formation, has exposed a mass of blue-gray shale wholly enclosed at the sides and above by limestone. The bottom of the shale is not observable but apparently is below the limestone which surrounds it. The shale mass (Fig. 6) is broader at the base and decreases in diameter upward. In the shale typical macro- and micro-fossils of the Independence are present with numerous scattered and mixed blocks of harder shale and limestone. On fresh exposure, "flow

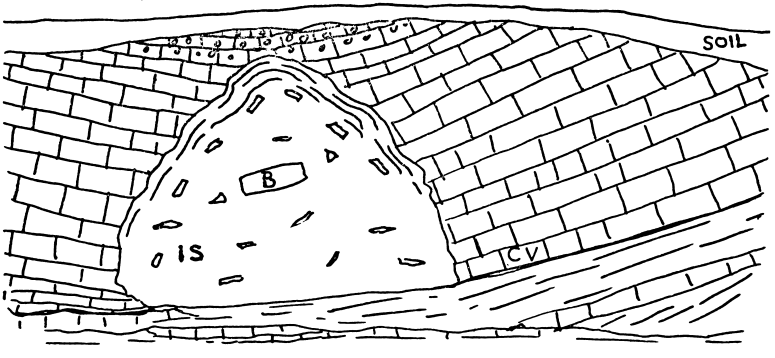

Fig. 6. Diagrammatic section in quarry on Close farm, two and a half miles southwest of Brandon, Iowa. The Independence shale fills a cavern in Cedar Valley limestone. I S, Independence shale; C V, upper Cedar Valley; B, block of basal Cedar Valley limestone, about 30 feet above normal position. The lines near the ceiling represent "flow lines."

lines" are visible in the shale parallel to the enclosing walls. That these lines are not stratification laminae was apparent as the lines curved upward so as to be roughly parallel to the lateral and upper limestone walls. Also blocks of hard shale of variable lithology were roughly aligned similarly but true bedding planes were absent. The mass consisted of thoroughly broken and mixed shale. This deposit of shale is totally at variance with deposits of Pennsylvanian age in caverns in the Cedar Valley near Rock Island, Illinois, and described by Hall.[55] Furthermore, the base of the shale mass on the Close farm is surrounded by the basal beds of the Rapid member which are about

[55] Hall, James: 1858, Geol. of Iowa, vol. 1, part 1, p. 130.

thirty feet above the base of the Cedar Valley. In the shale were several specimens of *Atrypa cf. independensis* Webster, a species typical of the basalmost layers of the Cedar Valley. Also midway in the shale is a block of limestone, 2′ x 3′ x 1′, which also carries examples of the same *Atrypa*. It seems beyond the bounds of probability that any agent could have deposited in a sinkhole from above, a block of limestone from beds stratigraphically thirty feet below and not outcropping within miles of the place. The upward movement of the plastic Independence shale from directly below the Cedar Valley readily explains the features seen in this occurrence of the shale. The chamber now filled with shale could have been formed at any time during the long interval since the close of the Devonian by the solvent action of ground water. The insoluble shale would limit the downward solution of the cavity while the weight of the 150 feet of superjacent limestone would be sufficient to supply the motile force. Exposure No. 3, described by Thomas and Norton,[56] seems to be a similar deposit but in this instance has been exposed to view by the erosive work of the Cedar River.

In summary it is found that in most of the exposures where the shale is not in normal position that all available evidence points to faulting as the true explanation of the abnormality. No deposit of Independence shale has as yet been seen to lie in erosional depressions and channels on the Cedar Valley limestone. The hypothesis that the Independence shale has come down from above into caverns and erosional crevices in the Cedar Valley is untenable: a later shale formation, the Lime Creek, as shown by faunal studies could not have been the parent formation; the Sheffield shale could not have supplied the shale either as its fauna is totally unlike that of the Independence; there is no field evidence of a shale body which could have been the source as supposed by Cooper and Schuchert to have been present between the Juniper Hill and Cerro Gordo members of the Lime Creek. In the one known occurrence of the Independence shale in a cavern in the Cedar Valley, all evidence points to its movement *upward* into its present position. The hypothesis that the Independence shale is a mass of material that has moved downward into the Cedar Valley may well be abandoned. On the other hand the source body of shale is seen in the field to be present below the Cedar Valley.

[56] See historical résumé above.

LITHOLOGY AND THICKNESS.

The Independence is typically a blue-gray calcareous shale. It is highly plastic when wet and breaks down on exposure into a structureless clay. Locally beds of one to two foot thickness may be more strongly impregnated with calcareous material and form layers of argillaceous limestone at Brandon. Often the shale has black layers because of the abundance of carbonaceous material. In some areas the carbon content is high enough that thin beds of impure coal up to an inch in thickness were formed. It is this coal-like substance which, encountered in wells passing through the Cedar Valley limestone, induced futile and expensive attempts to obtain coal in the Devonian by sinking shafts. Pyrite in cubical crystals and twinned masses is also common and locally encrusts many of the fossil shells.

In a few instances the Independence may have sandy layers as at several localities in Linn county, Iowa. This sandy phase is often encountered in wells and when traced southward the Independence changes wholly to a sandstone in northwestern Illinois and in northwest Missouri.

At the type locality near Independence, the shale was about twenty feet thick. It was also penetrated nearly to this depth near Palo, Iowa. As well samples are generally obtained at five or ten foot intervals, well logs rarely give the full thickness correctly. In general the shale varies in thickness from ten to twenty feet, and rarely may be more in some localities.

DISTRIBUTION.

The surface exposures of the Independence shale are chiefly in Buchanan, Benton and Linn counties with one large exposure in Linn county. In these counties the shale occurs but a short way below the surface as the surface slope and the dip of the beds are about the same over a considerable area. Streams, then, do not have to cut deeply to reach the shale. The areas where the shale is exposed are not large and the outcrops are not continuous except for short distances. However continuous outcrops of the shale are hardly to be expected in a region with a heavy drift cover, especially if the formation is thin, easily eroded and quickly overgrown by vegetation. The outcrop, too, coincides in great part with the divide between the Wapsipinicon river and Buffalo creek which is covered with thick Pleistocene deposits. These have not been trenched by streams

deeply enough to reveal the shale below. Consequently no continuous area of the Independence is exposed or mappable. Similarly the eastern border of the Cedar Valley is deeply covered and can only be conjectured in most places and indefinitely indicated on geologic maps of the state.

The Independence shale is shown by deep well samples and shallow well records to be present in much of the area where Cedar Valley limestone is the bed rock. It extends from Osage and Charles City in Iowa southward to Keokuk and thence into Missouri where it appears at the surface near Hannibal as a sandstone. Subsurface in northeastern Illinois the shale appears to be a sandstone also. Locally in Iowa the Independence shale may be absent, as in a small area north of Vinton, Iowa, and the area from Iowa City southeastward to Davenport. Westward the shale may be traced in deep wells to Council Bluffs, Iowa, and then into Nebraska and northwestern Missouri. (See Fig. 5.)

As Cooper and Warthin[57] indicate the surface occurrences of the Independence are "spotty" but these with the well records and artificial exposures are sufficient to demonstrate that the shale has a widespread distribution which precludes any explanation of the shale as a series of cave and crevice filling from above. It appears to the present writer highly improbable that the great number of caves demanded by this hypothesis would be developed over so wide an area in Iowa, eastern Nebraska, northern Missouri and northwest Illinois and all stratigraphically between the Cedar Valley and Wapsipinicon limestones.

CONCLUSIONS.

It has been shown that the Independence shale is a distinct formation and that in a number of exposures it lies in normal position immediately below the Cedar Valley limestone. Artificial excavations, as quarries and exploration shafts, similarly show that the shale occurs in the same stratigraphic position with the same fossils. Records from shallow wells, scattered over a number of counties, also demonstrate that a shale is present below the Cedar Valley in many localities. Numerous suites of drilling samples from deep wells over a wide area add the weight of their evidence in showing that shale is below the

[57] Cooper, G. A., and Warthin, A. S.: 1942, Bull. Geol. Soc. Amer., vol. 53, p. 1766.

Cedra Valley. In the samples from deep wells at Shellsburg, Van Horn, and Center Point, Iowa, typical Independence fossils were recovered from shale immediately below that formation. The occurrence of shale masses in abnormal positions abutting Cedar Valley limestone is best and adequately explained by faulting. No evidence of downward movement of the Independence is seen in the field. On the contrary in at least one exposure, the shale evidently moved upward some thirty feet into a chamber. Shale in joints and crevices from field evidence has been thrust or moved upward.

Surface outcrops, artificial exposures, and deep and shallow well records indicate that the Independence shale is widespread in central Iowa and that it can be traced as a subsurface formation westward to Nebraska and southward into northern Missouri and northwestern Illinois. It has the same position stratigraphically in Iowa as a sandstone that lies between the Cedar Valley and Wapsipinicon in Illinois and one that in Missouri occurs between the Callaway and Cooper limestones.

That the stratigraphic position of the Independence shale is below Cedar Valley and above the Wapsipinicon may be regarded as demonstrated. From this it follows that, as the Independence by its fossils is lower Upper Devonian, the strata which lie above must be younger. The Cedar Valley limestone, the Shellrock formation and the Lime Creek beds are, then, Upper Devonian in age and post-Independence.

ADDENDA.

At Amana, Iowa, occurs a shale discovered by Dr. S. W. Stookey. Fossils collected by him were submitted to the writer who considered them to be closely akin to species in the Independence shale. Extensive collections were made later by the present writer and comparison with the Lime Creek fauna and that of the Independence shale showed that they were more nearly related to the latter although there were varietal differences and many significant absences.

In a paper on the brachiopods of the High Point sandstone of New York,[58] the writer made no distinction between the faunas of the Independence and that of the Amana beds because of their resemblances. It was suggested (p. 889) that the High Point fauna might be intermediate between the Lime

[58] Stainbrook, M. A.: 1942, Amer. Jour. Sci., vol. 240, pp. 879-890.

Creek and the Independence. Faunal comparison showed that there were a number of species in common in the High Point and Amana faunas. Lately (1944) new deep wells in southern Benton county, Iowa, show that the Amana beds lie on Cedar Valley and therefore are younger than the true Independence and probably older than the Lime Creek. The relation of the Amana beds with the Lime Creek and other Devonian formations which lie on the Cedar Valley is yet to be worked out. It must be done wholly by well samples and records. The difficulty of correlating the High Point with either the Independence or the Lime Creek is removed as the Amana beds are its correlative in Iowa.

Thus a fossiliferous shale overlies the Cedar Valley limestone and another lies below it in Benton county. A recent well near Van Horne, Iowa, shows both shales separated by one hundred and twenty-seven feet of Cedar Valley.

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