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A report on grant number GOO7237-O1 and GOO7253-O1
of the United States Environmental Protection Agency
from the
Iowa Geological Survey

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INTRODUCTION

Previous investigations in northeast and north-central Iowa have identified areas where surficially derived contaminants, particularly nitrates and commonly-used pesticides, have caused degradation of groundwater quality (Hallberg and Hoyer, 1982; Hallberg et al., 1983, 1984; Libra et al., 1984). These studies showed that the depth to bedrock aquifers, and the presence or absence of karst features, have a major influence on the potential for surficial contaminants to reach groundwater. Geologic regions based on these criteria were delineated. In parts of north-central Iowa, where Devonian carbonate strata form a widely used multi-aquifer system, stratigraphic relationships also influence the extent and degree of groundwater contamination (Witzke and Bunker, 1984; Libra et al., 1984). In addition areas with significant numbers of agricultural drainage wells (ADWs) are present in parts of north-central Iowa. The ADWs also must be considered as potential sources of groundwater contamination. ADWs have been shown to deliver tile-drainage water and surfacewaters containing nitrate, pesticides, and microbial contaminants to groundwater (Musterman et al., 1976; Baker and Austin, 1984).

To further the evaluation of ADWs as a groundwater contaminant source in the Floyd-Mitchell County area, a refined understanding of the affect of the Devonian stratigraphy on groundwater flow and quality was needed. Therefore, four core-holes, completely penetrating the Devonian sequence were drilled during the summer of 1984. The coring and subsequent geophysical logging of the coreholes allowed for detailed stratigraphic analysis and correlation of the Devonian strata. Packer tests were run in three of the coreholes to obtain in situ information on aquifer hydraulics, the degree of interconnection of individual aquifers, and to allow for water-quality sampling of individual aquifers. These three holes were then completed as piezometer nests, to allow for continued monitoring of water levels and quality within individual aquifers at each site. In addition, at two of these sites, piezometers were installed in the surficial, unconsolidated glacial materials overlying the Devonian units. This report will summarize the information obtained during the drilling, core analysis, packer testing, and sampling of the test holes, and will also present preliminary monitoring results from the piezometer nests.

Site Locations

Figure 1 gives the location of the test-hole sites with respect to the geologic regions mapped in Floyd and Mitchell counties (see Libra et al., 1984). Site #1 is in a "shallow bedrock" area, just on the north fringe of an open karst area. Site #2 is in a generally "shallow bedrock" area. Site #3 is in a "deep bedrock" area, within which concentrations of ADWs are known to occur; the closest ADW is about 500 feet from Site #3. Site #4 lies in a shallow bedrock region to the west of the mapped area, and was cored for further refinement of stratigraphic interpretations, but it has not been packer tested or completed as a piezometer nest.

HYDROSTRATIGRAPHY

A stratigraphic framework for the Devonian carbonate aquifers in north-central Iowa was presented by Witzke and Bunker (1984). Briefly, their work suggested that the Devonian units form a three-aquifer system. Individual carbonate aquifers are separated by shales or shaly carbonate units that likely have low permeabilities. The regional extent and effectiveness of these confining units was not well known.

Analysis of the four complete core penetrations has supported, and allowed the refinement of, the model suggested by Witzke and Bunker (1984). The stratigraphic terminology of these authors will be used in this report. A further discussion of the stratigraphic framework of the Devonian aquifers is presented in part II of this report.

Geologic logs of the four cores are given in Figures 2 through 5. The "lower" aquifer, the Spillville Formation, is present at all sites. The Spillville is 60-70 feet thick at Sites #1 and #2, and 25 and 45 feet at sites #3 and #4, respectively. Thinning of the Spillville from Sites #1 and #2 towards Sites #3 and #4, to the south and west (see Figure 1), is consistent with the framework of Witzke and Bunker (1984), who showed that the Spillville Formation pinches out to the south and west in the Floyd County area. At all sites, the Spillville Formation is overlain by the Wapsipinicon Formation, a suspected confining bed consisting of 30-40 feet of shale, carbonates, and shaly carbonates. Driller's observations, core analysis, and geophysical logging indicate that at Site #3, the middle member of the Wapsipinicon Formation, the Spring Grove (see Figure 4), is a broken or brecciated, possibly cavernous zone that may change the hydrologic role of the Wapsipinicon Formation.

The "middle" aquifer, lower Unit A (Figure 2-5), is present at all sites, with a thickness of 60-75 feet. The middle aquifer is overlain and confined by the Chickasaw shale, which has a thickness of about 20 feet at all sites (this unit was formerly termed the "Rapid" shale, particularly in reports on the LaBounty waste site, Charles City). The overlying Devonian carbonates, upper Unit A through the Shell Rock Formation, are grouped together as the "upper" aquifer, because no regionally persistent confining bed is present within these strata. However, shales or shaly carbonate horizons are present and may act locally, to subdivide the "upper" aquifer into relatively isolated hydrologic units. Thickness of the "upper" aquifer varies from 120 to 180 feet at the core sites (Figures 2-5).

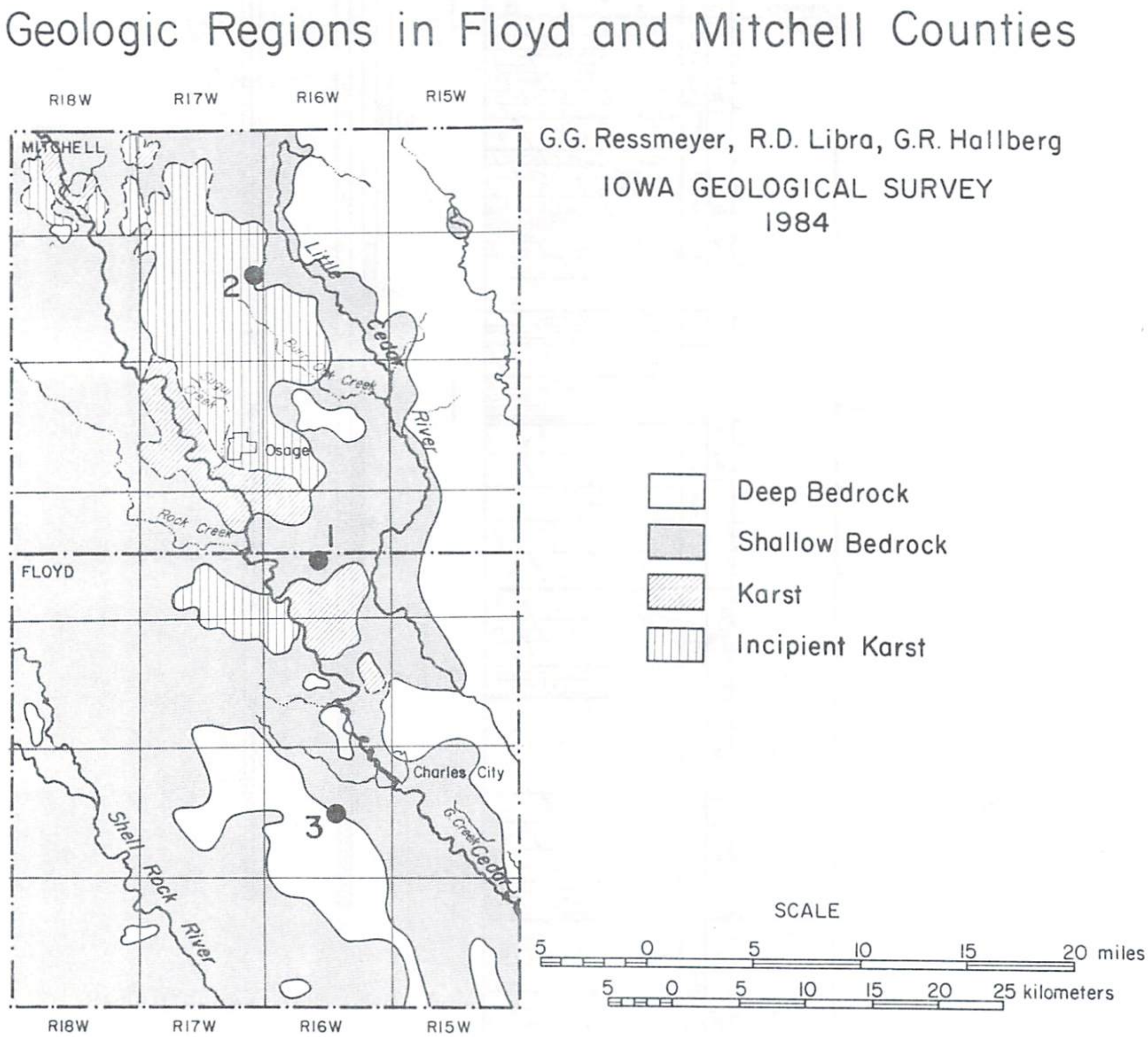

Figure 1. Location of Sites #1 - #3. Geologic regions from Libra et al., 1984.

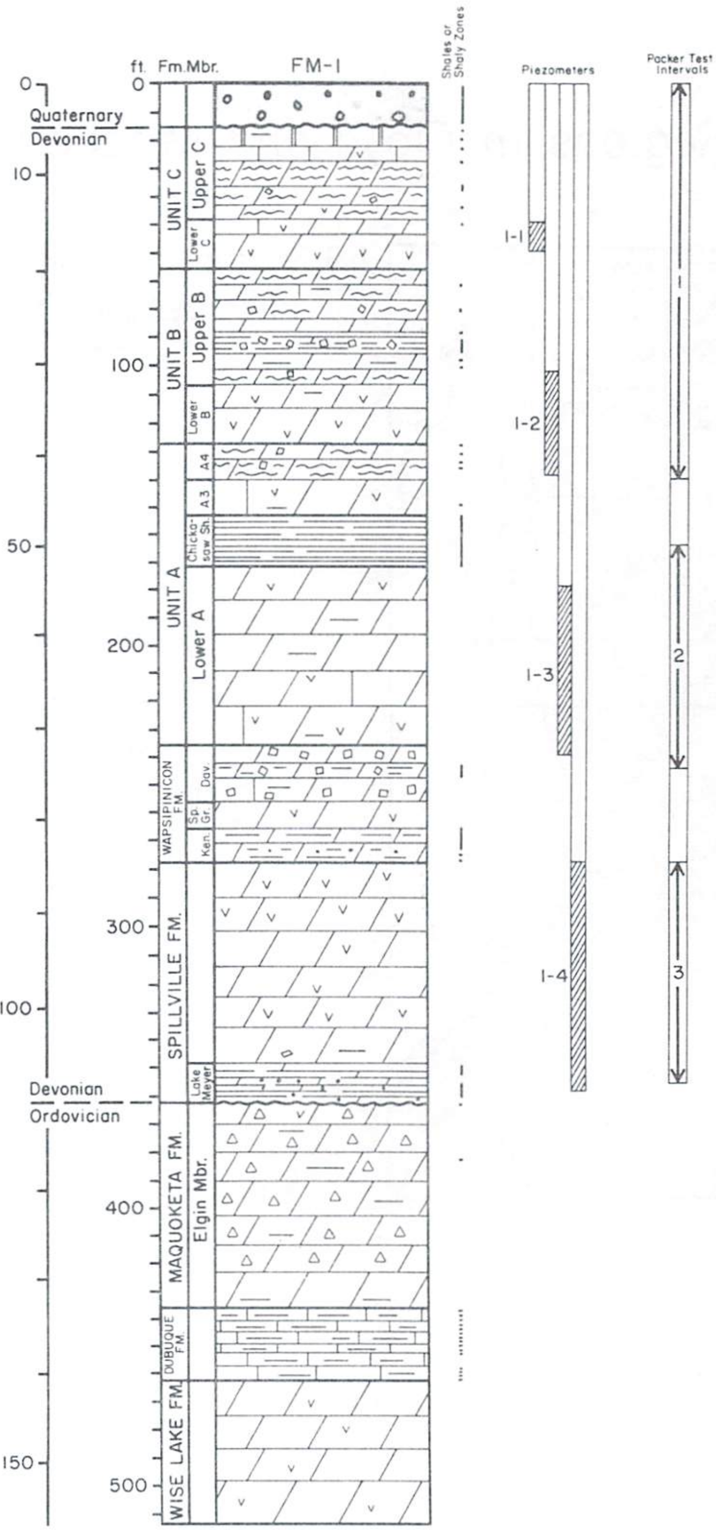

Figure 2. Geologic log, packer-test intervals, and piezometer completions, Site #1.

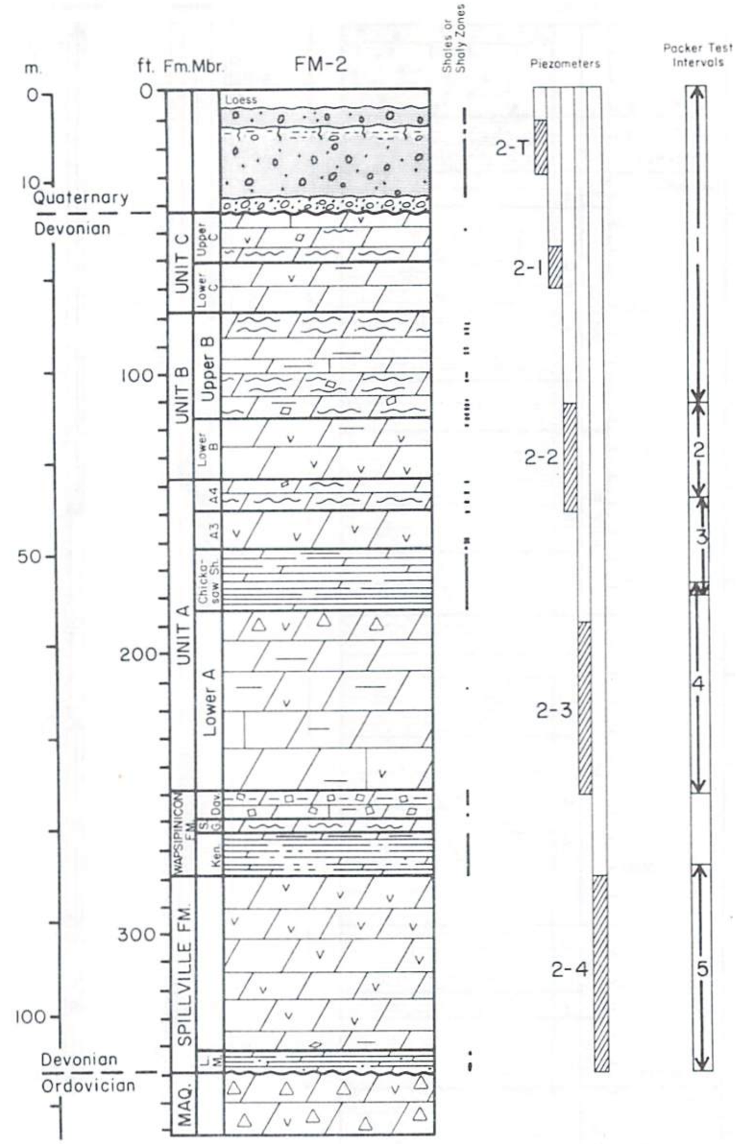

Figure 3. Geologic log, packer-test intervals, and piezometer completions, Site #2.

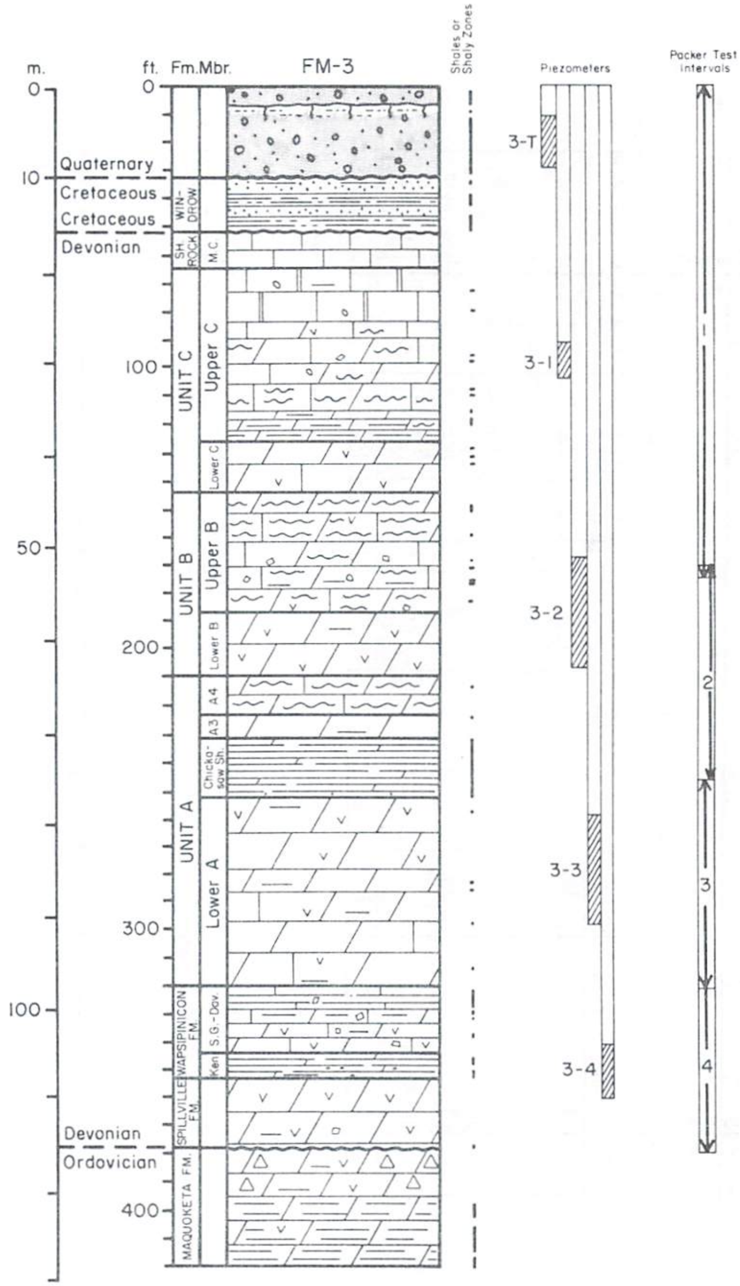

Figure 4. Geologic log, packer-test intervals, and piezometer completions, Site #3.

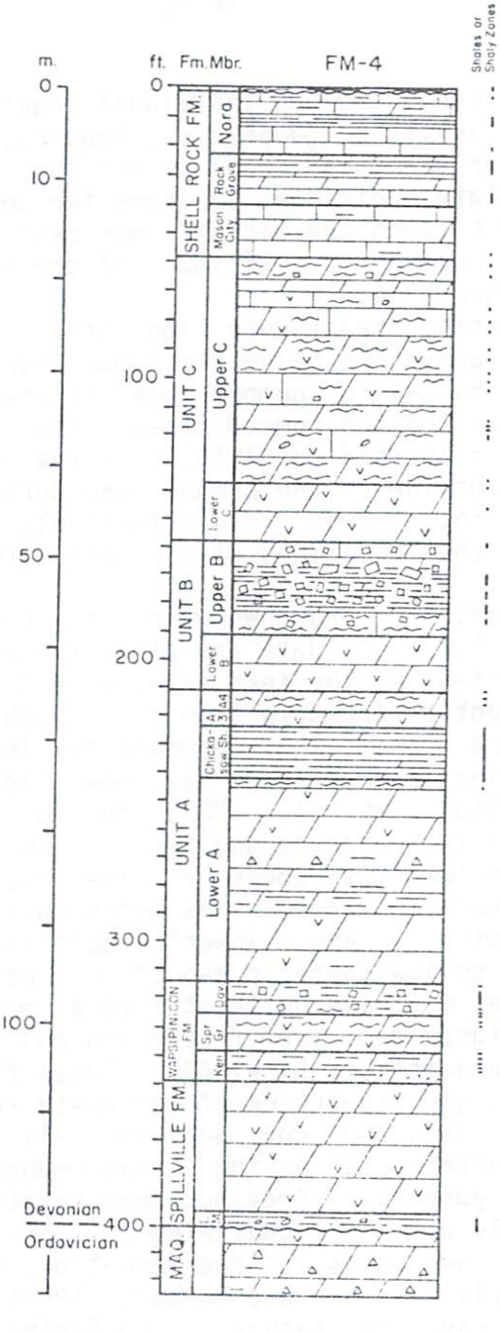

Figure 5. Geologic log, Site #4.

PACKER TESTS

Packer tests were conducted on individual aquifers at each site, as identified from the core analysis, geophysical logging, and driller's observations. The tests were run during the week of 9/10/84. Two rubber, inflatable packers were used to isolate individual aquifers for testing. A 5-horsepower submersible pump, placed between the packers, was used to stress each isolated aquifer. Each zone was pumped for a minimum of one hour. Tested intervals are shown on Figures 2 through 4.

During the packer tests, heads were monitored within the aquifer being pumped, and in the zones above and below the pumped aquifer as well. Monitoring of heads above and below the pumped zone insured that the packers had properly inflated and isolated the pumped zone. This monitoring also allowed for an evaluation of the suspected confining beds that separate the aquifers. No head losses occurred outside of the pumped zone during testing, indicating that the suspected confining beds were effectively isolating the tested aquifers, at least under the conditions of the tests (1-2 hours of pumping at low to moderate rates).

Data from the monitoring of drawdown within the tested zones, and pumping rates are given in Table 1; these data are also expressed as specific capacities. Specific capacities of the test zones varied from less than 0.3 to over 60 gallons/minute/foot of drawdown (gpm/ft). Such variance is typical of carbonate aquifers, where much of the permeability is in the form of fractures, joints, and bedding planes that have been solutionally enlarged to varying degrees (see Hallberg et al., 1983, for further discussion of the permeability distribution in carbonate aquifers). The most productive horizons tested were the two lowermost zones at site #3, intervals 3-3 and 3-4 (see Figures 1 and 2), where no drawdown was noted during testing. These test zones represent the "middle" and "lower" aquifers, respectively. These aquifers showed moderate to low specific capacities at sites #1 and #2. The higher specific capacities of these units at site #3 may result from a number of factors. First, a higher degree of fracturing and solutional activity may be present within these units at Site #3. These factors typically cause variability in the hydrologic properties of carbonate rocks. Second, drillers observations, geophysical logs and core analysis all indicated a very open, broken, cavernous zone within the Spring Grove member of the Wapsipinicon Formation at Site #3 (Figure 4). Previous investigations had suggested that the Wapsipinicon generally acts as a confining bed, because of the presence of shales in the upper and lower parts of the formation, the Davenport and Kenwood Members, respectively (Witzke and Bunker, 1984; Libra et al., 1984). However, at Site #3, the cavernous nature of the Spring Grove Member suggests it is likely a highly productive zone, that the Davenport and Kenwood Members may not be acting as confining units, and that the Spring Grove may have contributed water to the packer tests on intervals 3-3 and 3-4. Therefore, the specific capacity data from these tests may not be strictly applicable to the "middle" and "lower" aquifers. However, the data does indicate that highly productive aquifers occur below the Chickasaw Shale at Site #3.

Moderately high specific capacities, varying from 10 to 40 gpm/ft, also occurred in test intervals 1-2, 2-1, and 3-2 (Table 1). Specific capacities for all other horizons were less than 2.5 gpm/ft.

The specific capacity data were used to estimate tranmissivities and hydraulic conductivities (Walton, 1962). Estimated transmissivities vary from about 200 to over 100,000 gallons per day per foot (gpd/ft). Hydraulic con-

Table 1. Results of packer tests, I.G.S. wells.

INTERVAL	DEPTH (ft.)	PUMPING RATE (gallons/minute)	DRAWDOWN (ft.)	SPECIFIC CAPACITY (gallons/minute/ foot drawdown)	TRANSMISSIVITY (gallons/ day/foot)	HYDRAULIC CONDUCTIVITY (gallons/ day/foot^2)
				Well #1		
1-1	138-and above	17	62.4	0.27	200	---
1-2	165-245	68	9.2	10.65	15,000	190
1-3	275-355	65	27.7	2.35	13,000	40
				Well #2		
2-1	110-and above	73	2.0	36.1	62,000	690
2-2	110-145	55	49.7	1.11	1,400	40
2-3	145-180	64	25.4	2.52	3,500	100
2-4	175-250	41	97	0.42	500	6
2-5	275-350	33	111	0.30	300	4
				Well #3		
3-1	175-and	30	79.7	0.38	300	---
3-2	170-245	65	6.9	9.4	15,000	195
3-3	245-320	60	---*	>60	>105,000	>1,420
3-4	320-380	45	---*	>45	>78,000	>1,300

* No measurable drawdown

ductivities vary from about 5 to 1400 gallons per day per square foot (gpd/ft^2). Note that all measured and estimated hydrologic parameters vary over 3 orders of magnitude.

Existing information from near the test sites were examined to evaluate the applicability of the packer test data to the surrounding area. No wells with reliable production-drawdown data, geologic data, and well-completion information are located in the area around Sites #1 and #2. Of interest are the results from interval 1-1, the uppermost bedrock aquifer tested (units B and C) at Site #1. Packer testing of this interval indicated a very low specific capacity, less than 0.3 gpm/ft. Site #1 lies within a mile of a well developed karst area, with many indicators of extremely high solutional permeability within this upper zone, including large open sinkholes, caves, and springs. Specific capacities of wells intersecting zones of well developed solutional permeability within this upper zone may be very high, easily exceeding 100 gpm/ft. This again serves to illustrate that hydrologic parameters in carbonate aquifers may vary greatly, even over short distances. This is particularly true of carbonate rocks that are near the landsurface, which have been exposed to the most solutional activity.

Existing information is more plentiful in the area around Site #3, primarily because of its proximity to Charles City, the largest city in Floyd and Mitchell counties. Table 2 summarizes estimated transmissivities and hydraulic conductivities from existing municipal, industrial, and monitoring wells completed within the Devonian sequence in the Charles City area. These estimates were derived using the same method that was applied to the packer test data. Results from Site #3 are included for comparison. While these estimates show the typical variability expected for carbonate aquifers, some generalizations can be made. Most data from aquifers lying below the Chickasaw shale suggest that these units have relatively high permeabilities, while overlying units have moderate to low permeabilities. Information from residents living within a few miles of site #3 support this view. Briefly, this information states: 1) many of the ADWs in the area around site #3 were originally drilled to about 150-175 feet (into units C and Upper B, the "upper" aquifer). However, many of these ADWs could not accept all the drainage water directed to them, and were later re-drilled to about 300 feet (into lower unit A, the "middle" aquifer). The re-drilled ADWs were then capable of efficiently accepting drainage water (the ADW located closest to site #3 was plumbed to 305 feet by I.G.S. staff); and 2) most residents utilize wells completed in the uppermost bedrock zones (units C and B) for domestic and stock water. However, those with large livestock operations have had to drill deeper, generally to about 300 feet (lower unit A) to produce quantities of adequate water. While these comments are anecdotal in nature, they agree with the data from the packer tests at Site #3 and existing data on wells in the Charles City area.

INITIAL WATER QUALITY ANALYSIS

Samples for water-quality analysis were collected at the end of each packer-test. Samples were analyzed for all major ions and commonly used pesticides. Results are given in Table 3. Initial samples from the shallow piezometers installed in the till (2T and 3T), collected 11/28/85, are included. In terms of major ion concentrations, all intervals and piezometers produced predominantly Ca-Mg-HCO_3 waters, typical for water from carbonate

Table 2. Estimated hydrologic parameters for Devonian Aquifers, Charles City area.

Well	Location	Open Interval Geologic Unit	Open Interval Elevation	T (GPD/FT)	K (GPD/FT^2)
Charles City #5	NW NE NE 1-16-95	Lower A	858 - 826	67,000	2080
Charles City #7	NW NE NE 1-16-95	Lower A	868 - 828	88,000	2200
Salsbury Labs #2	SW NE SE 11-16-95	Lower A - Spillville	857 - 701	52,000	330
Salsbury Labs #4	? 11-16-95	Lower A - Spillville	?	5,000	30
Sherman Nursery	SW SE NE 11-16-95	Lower B - Upper A	938 - 890	23,000	480
Salsbury LaBounty Site #2	SW SW 7-15-95	Lower C - Upper B	987 - 962	18,000	720
Charles City Creamery	SE NE SE 1-16-95	A	901 - 833	13,000	235
F/M #3-1	SW NE 22-16-95	C - Upper B	1025 - 930	300	--
F/M #3-2	SW NE 22-16-95	Lower B - Upper A	930 - 855	15,000	190
F/M #3-3	SW NE 22-16-95	Lower A - Spring Grove?	855 - 780	>106,000	>1400
F/M #3-4	SW NE 22-16-95	Spring Grove? - Spillville	700 - 720	> 78,000	>1300

rocks and carbonate-rich glacial materials. With the exception of piezometer 2T, major ion concentrations are quite uniform in both magnitude and proportion. Calcium concentrations ranged from 55-98 mg/l; magnesium, 14-22 mg/l; and bicarbonate 253-338 mg/l. Sulfate and chloride concentrations do not exceed 40 and 25 mg/l, respectively. Total dissolved solids varied from 237-354 mg/l. Nitrates and pesticide concentrations indicated significant surficial contamination only within interval 1-1 (NO_3, 16 mg/l; atrazine, 0.20 µg/l). Nitrate and atrazine concentrations in all other samples were less than 2 mg/l and less than detectable (0.1 µg/l), respectively.

Piezometer 2T by contrast, showed high concentrations of many dissolved constituents, particularly nitrate (100 mg/l) and chloride (99 mg/l). Atrazine was also detected at this piezometer. Note that 2T is partially screened above the paleosol indicated on the geologic log of Site #2 (see Figure 2), suggesting that much of the water that collects in this piezometer is shallow groundwater perched above the low permeability paleosol. The nitrate and atrazine levels are similar to that of tile drainage water from fertilized, row-cropped areas in Iowa. Also, similar concentrations of chloride, and similar ratios of chloride to nitrate, have been linked to the application of fertilizers in several parts of the midwest and Canada (Hallberg et al., 1983; Saffinga and Keeny, 1977; Hill, 1982).

PRELIMINARY MONITORING RESULTS

Following the packer testing and sampling of selected intervals, piezometer nests were installed in the three coreholes. Piezometer completion details, along with piezometer designations, are given on Figures 2 through 5. The three lower piezometers were constructed with 1 1/2" O.D. PVC pipe; the uppermost peizometer, with 1" O.D. PVC; the till piezometers, 2" O.D. PVC.

Measured potentiometric elevations from the peizometers are given in Table 4. A number of elevations measured during the first several months monitoring appear anomalous, compared to later measurements. These spurious measurements may indicate that the piezometers had not yet reached equilibrium following construction and air development. Also, equipment problems were occasionally encountered during the cold months of January and February. Subsequent measurements have indicated consistent trends. Potentiometric elevations decrease with depth at all sites, indicating a downward component of groundwater movement, and that all sites are located in recharge areas. Head difference in excess of three feet exist between all peizometers except 2-1 and 2-2, 3-1 and 3-2, and 3-3 and 3-4. Significant head differences between the stratigraphically adjacent aquifers monitored by the peizometers indicates that these aquifers are separated by relatively low permeability confining units. Lesser head differences may indicate less effective confinement.

In general, potentiometric levels rose in response to snowmelt and spring rain recharge during the period February-May. Levels at Sites #1 and #3 have shown the most substantial increases, on the order of 5-10 feet. Levels at Site #2 have risen more moderately, generally about 2 feet. June measurements showed declines of approximately 1 foot at Sites #1 and #2, and 2-4 feet at Site #3.

As previously noted, Site #3 is located near a concentration of ADWs. Preliminary potentiometric monitoring has not detected any anomolous head changes that may have been caused by the adjacent drainage wells. Any such effects will likely be noted with continued monitoring.

Table 3. Initial Water Quality Analyses From Packer Test Intervals and Shallow Peizometers.

INTERVAL	TEMPERATURE[1]	SP COND[2]	pH	Ca[3]	Mg	Na	K	Mn	Fe	HCO_3	SO_4	Cl	NO_3	F	HARDNESS	ALKALINITY	TDS	SiO_2	PESTICIDES[4]
1-1	10°	580	7.4	88	23	5.3	2.6	0.04	0.6	287	25	21.0	16.00	0.2	316	235	354	15	0.20A
1-2	10°	480	7.5	82	18	3.6	2.6	0.08	1.3	253	33	14.0	0.2	0.2	281	207	334	19	ND
1-3	10°	440	7.5	71	14	5.8	1.5	0.03	0.27	248	18	9.0	1.8	0.3	235	203	248	12	ND
2-T	---	1300	7.1	180	48	14	2.0	0.02	0.09	467	66	99.0	100.00	0.1	625	383	976	23	0.12A
2-1	10°	490	7.5	70	22	6.9	0.4	0.06	0.46	282	21	6.5	0.4	0.2	266	231	278	16	ND
2-2	10°	420	7.6	55	19	5.3	0.7	0.08	0.37	254	17	2.5	<0.1	0.15	216	208	239	15	--
2-3	10°	430	7.6	62	20	5.4	0.8	0.07	0.22	256	16	2.5	<0.1	0.15	238	210	237	15	ND
2-4	10°	470	7.5	68	21	6.9	0.6	0.06	0.11	282	19	6.0	0.2	0.2	257	231	268	13	--
2-5	10°	480	7.5	70	22	7.2	0.6	0.06	0.11	285	18	5.5	<0.1	0.2	266	234	269	13	ND
3-T	---	500	7.6	79	20	5.8	1.1	0.05	0.26	338	35	7.5	1.8	0.3	331	277	335	14	ND
3-1	10°	610	7.3	81	22	7.9	2.8	<0.01	0.36	333	35	13.0	0.3	0.2	293	273	350	8.0	ND
3-2	10°	550	7.5	81	20	7.5	2.4	0.07	0.09	305	35	8.0	<0.1	0.3	285	250	301	7.4	--
3-3	10°	580	7.4	81	21	7.6	2.4	<0.01	0.08	312	36	12.0	<0.1	0.2	289	256	331	7.1	ND
3-4	10°	580	7.4	83	21	6.5	2.5	<0.01	0.08	310	37	12.0	<0.1	0.2	294	254	329	7.4	ND

1 - Degrees centigrade
2 - Specific conductance, micromhos/cm
3 - Dissolved constituents in mg/l, unless noted
4 - Pesticides in μg/l; A indicates Atrazine; ND indicates not detected

Table 4. Potentiometric elevations from monitoring of I.G.S. Piezometers[1].

Peizometer	1/1/85	2/12/85	2/27/85	3/25/85	5/6/85	6/19/85
1-1	1099.0	1095.0	1099.9	1108.7	1110.8	1109.4
1-2	1097.5	1100.3	1100.2	1103.5	1107.3	1106.0
1-3	1095.6	1093.1	1095.5	1098.4	1101.1	1100.4
1-4	1095.5	1089.9	1091.6	1093.5	1096.4	1095.7
2-T	---	1203.8	1203.7	1206.7	1207.18	1207.5
2-1	1198.7	1198.2	1099.2	1199.1	1199.7	1198.8
2-2	1197.8	1197.5	1198.0	1198.1	1199.0	1198.0
2-3	1194.6	1183.8	1194.0	1194.4	1196.1	1195.3
2-4	1198.6	1189.1	1188.8	1189.6	1191.2	1190.4
3-T	---	1098.8	1100.7	1103.0	1100.9	1100.7
3-1	---	1021.6	1024.6	1025.3	1031.0	1029.0
3-2	1027.1	1021.0	1021.8	1024.3	1031.0	1028.8
3-3	---	1021.0	1020.6	1024.0	1028.2	1024.6
3-4	---	1017.0	1020.5	1023.8	1028.0	1024.5

1 Elevations in feet above sea level. Estimated ground elevations are - Site #1 - 1120 feet; Site #2 - 1210 feet; Site #3 - 1105 feet. All water levels were made assuming these ground elevations.

Preliminary nitrate and pesticide monitoring data are given in Tables 5 and 6, respectively. A longer period of record will be needed to fully assess the data. Some initial comments can be made however. Nitrate concentrations at piezometer 1-1 have varied between 19-23 mg/l; atrazine and Dual have been detected. These concentrations are consistent with findings in relatively shallow wells (<150 feet deep) in shallow rock areas in Floyd and Mitchell counties (Libra et al., 1984). Nitrates have occasionally been present, at concentrations less than 10 mg/l, in samples from piezometers 1-2 and 1-3. Pesticides have not been detected in peizometers 1-2, 1-3, or 1-4 as of May.

The upper two bedrock zones at Site #2 (piezometers 2-1 and 2-2) have shown low (<10 mg/l) nitrate concentrations during several sampling periods, while the deeper zones (piezometers 2-3 and 2-4) have shown no detectable (<5 mg/l) nitrate. Nitrate levels have fluctuated between 34 and 111 mg/l at peizometer 2-T, with lower values occuring during the March-June period. Pesticides have not been detected in the January-May period of monitoring.

At Site #3, nitrates were detected once in peizometer 3-T, and once in 3-4. Nitrates have not been detected in piezometers 3-2 and 3-3. Piezometer 3-1 has contained detectable nitrates in some samples, with a concentration of 29 mg/l in early February. Atrazine has been present in all samples taken from peizometer 3-1; Bladex and Dual were present in May. May sampling of 3-2 indicated Lasso and Bladex were present. Atrazine was detected once in 3-4.

While detectable levels of nitrates and pesticides have been noted in a few samples from aquifers below the Chickasaw Shale, the preliminary monitoring data indicate that surficially derived contaminants are largely limited to aquifers lying above the shale. At present, the effects of ADWs on water quality at Site #3 is difficult to assess. As Site #3 is in a deep bedrock area (depth to carbonate bedrock is about 50 feet), previous investigations (Hallberg and Hoyer, 1982; Hallberg et al., 1983, 1984; Libra et al, 1984) would suggest that surficially-derived contaminants should probably not be present within the bedrock aquifers. The presence of commonly used pesticides, at concentrations ranging from 0.1 - 0.6 µgl/ (as total pesticides), and nitrates ranging up to 30 mg/l, suggests that the ADWs in the immediate area are affecting groundwater quality. A better assessment of the significance of these preliminary findings will be possible when they can be examined as part of a longer data record. Also, private wells, tiles, and surfacewaters in the Floyd-Mitchell county area are being sampled for nitrates and pesticides. Analysis of this data will also provide a more complete frame of reference for evaluating the effects of ADWs.

PRELIMINARY CONCLUSIONS

Analysis of the cores recovered from Sites #1 through #4 support the stratigraphic framework of the Devonian aquifers described by Witzke and Bunker (1984). Packer testing of individual zones indicates that the hydrologic properties of the Devonian aquifers range over three orders of magnitude, which is typical in carbonate aquifers. Existing data comparable to the packer test data is available in the area around Site #3. Productive, highly permeable aquifers occur below the Chickasaw shale in this area.

Preliminary water-level monitoring data indicate that most of the suspected confining beds are effectively separating individual aquifers. A downward component of groundwater flow exists at all sites, indicating that all sites are located in recharge areas.

Table 5. Nitrate concentrations (mg/l) from I.G.S. Piezometers

Peizometer	1/1/85	2/12/85	2/27/85	3/25/85	5/6/85	6/19/85
1-1	--	19	21	22	33	26
1-2	10	--	6	<5	<5	<5
1-3	<5	<5	7	<5	6	<5
1-4	<5	<5	<5	<5	<5	<5
2-T	109	111	105	92	34	69
2-1	--	<5	<5	<5	<5	9
2-2	6	<5	<5	<5	<5	9
2-3	<5	<5	<5	<5	<5	<5
2-4	<5	<5	<5	<5	<5	<5
3-T	<5	<5	<5	<5	10	<5
3-1	<5	29	7	<5	<5	5
3-2	--	<5	<5	<5	<5	<5
3-3	<5	<5	<5	<5	<5	<5
3-4	<5	<5	<5	<5	6	<5

Table 6. Pesticide concentration (μg/l) from I.G.S. piezometers.

Piezometer	1/1/85	2/12/85	2/27/85	3/25/85	5/6/85
1-1	--	--	0.41A	0.45A 0.20D	N.D. --
1-2	--	--	<0.1A	--	--
1-3	--	--	N.D.	--	--
1-4	--	--	--	--	--
2-T	--	--	--	--	--
2-1	--	--	--	N.D.	N.D.
2-2	--	--	--	--	--
2-3	--	--	--	--	--
2-4	--	--	--	--	--
3-T	--	--	<0.1A	N.D.	--
3-1	--	--	0.51A	0.37A	0.27A 0.16B 0.30D
3-2	--	--	<0.1A	N.D.	0.15A 0.31B
3-3	--	--	<0.1A	--	--
3-4	--	--	0.25A	--	--

-- Not sampled

A - atrazine (AAtrex)

D - metolachlor (Dual)

B - cyanazine (Bladex)

Preliminary water quality monitoring indicates that detectable concentrations of nitrate (>5 mg/l) and pesticides (>0.1 μg/l) mainly occur within the aquifers lying above the Chickasaw shale. Detectable concentrations of nitrate and pesticides occur within relatively deeply buried (>50 feet) bedrock aquifers at Site #3, and suggest that the concentration of ADWs in that area may be impacting groundwater quality.

Continued monitoring of groundwater levels and quality, and analysis of data collected from private wells, surfacewaters and tile lines, will allow for further interpretation of the effects of stratigraphy, hydrology, and ADWs on the distribution of contaminants within the Devonian aquifers.

REFERENCES

Baker, J. L., and Austin, T. A., 1984, Impact of Agricultural Drainage Wells on Groundwater Quality: Project 2450, I.S.U.-E.R.I. - Ames-85183, 239 p.

Hallberg, G. R., Hoyer, B. E., Bettis, E. A. III, and Libra, R. D., 1983, Hydrogeology, Water Quality, and Land Management in the Big Spring Basin, Clayton County, Iowa: Iowa Geo. Surv., O-F Report 83-3, 191 p.

Hallberg, G. R., Libra, R. D., Bettis, E. A. III, and Hoyer, B. E., 1984, Hydrogeologic and Water Quality Investigations in the Big Spring Basin, Clayton County, Iowa -1983 Water-Year: Iowa Geo. Surv. O-F Report 84-4, 231 p.

Hallberg, G. R., and Hoyer, B. E., 1982, Sinkholes, Hydrogeology, and Groundwater Quality in Northeast Iowa: Ia. Geol. Surv., O-F Report 82-3, 120 p.

Hill, A. R., 1982, Nitrate Distribution in the groundwater of the Alliston region of Ontario, Canada: Ground Water, V. 20, No. 6, p. 696-702.

Libra, R. D., Hallberg, G. R., Ressmeyer, G. G., and Hoyer, B. E., 1984, 1. Groundwater Quality and hydrogeology of Devonian-carbonate aquifers in Floyd and Mitchell Counties, Iowa: Ia. Geo. Surv., O-F Report 84-2, p. 1-106.

Musterman, J. L., Fisher, R. A., and Drake L., Underground Injection Control in Iowa, project termination: Office of Drinking Water, Environmental Protection Agency, Department of Environmental Engineering, University of Iowa.

Saffinga, D. G., and Keeney, D. R., 1977, Nitrate and Chloride in groundwater under irrigated agriculture in central Wisconsin: Ground Water, v. 15, No. 2, p. 170-177.

Walton, W. C., 1962, Selected analytical methods for well and aquifer evaluation: Illinois State Water Survey Bull. 49, 81 p.

Witzke, B. J., and Bunker, B. J., 1984, II. Devonian Stratigraphy of North-central Iowa: Iowa Geol. Surv. O-F Report 84-2, p. 107-149.

II. STRATIGRAPHIC FRAMEWORK FOR THE DEVONIAN AQUIFERS IN FLOYD-MITCHELL COUNTIES, IOWA

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INTRODUCTION

Prior to the research drilling program in Floyd and Mitchell counties in northern Iowa, reported in this paper, a general stratigraphic framework for the Devonian aquifers was proposed by Witzke and Bunker (1984). This framework served as a basis for subsequent geohydrologic studies. In particular, the Devonian carbonate rock sequence was subdivided into a three-part aquifer system based on limited, extant data. Continuous rock cores of Devonian strata were drilled at four localities in the Floyd-Mitchell county area during the summer of 1984 to provide more detailed stratigraphic control. Nested piezometers were installed and packer tests were completed in three of these holes to provide critical information on the head relationships and water quality within the Devonian aquifers.

In general, the Devonian stratigraphic framework proposed by Witzke and Bunker (1984) was substantiated by these studies during the past year. Stratigraphic units first recognized in a rock core from Mason City, Cerro Gordo County (Figures 1, 2), and at surface exposures in the Floyd-Mitchell County area were clearly recognizable in the four new core holes. Because of the similarities, most of the details of the stratigraphy need not be reiterated here, and the reader is referred to our earlier report for more information (ibid.). Supplementary data derived from the new rock cores are summarized in the following sections.

ORDOVICIAN STRATA

Devonian strata overlie an eroded surface of Ordovician rocks throughout Floyd-Mitchell counties and much of northern Iowa. Basal Devonian strata rest directly on cherty dolomites of the Upper Ordovician Maquoketa Formation in all four core holes. One-hundred and fifty feet of Ordovician strata were penetrated in the first core hole (FM-1, fig. 3). The upper cherty dolomite interval corresponds to the Elgin Member of the Maquoketa Formation. This interval overlies a limestone and shale unit that probably correlates with the Dubuque Formation (upper Galena Group). The abundance of thin shale beds would serve to impede vertical groundwater flow between the Maquoketa carbonates and the underlying Galena Aquifer. The relatively pure dolomites beneath the Dubuque, containing scattered hardgrounds and receptaculitid algae, are included in the Wise Lake Formation (Galena Group).

At least 20 feet of Ordovician strata were penetrated in each of the remaining three core holes (FM-2, Fig. 4; FM-3, Fig. 5; FM-4, Fig. 6). In cores FM-2 and FM-4 the cherty Maquoketa dolomites (burrowed and fossiliferous)

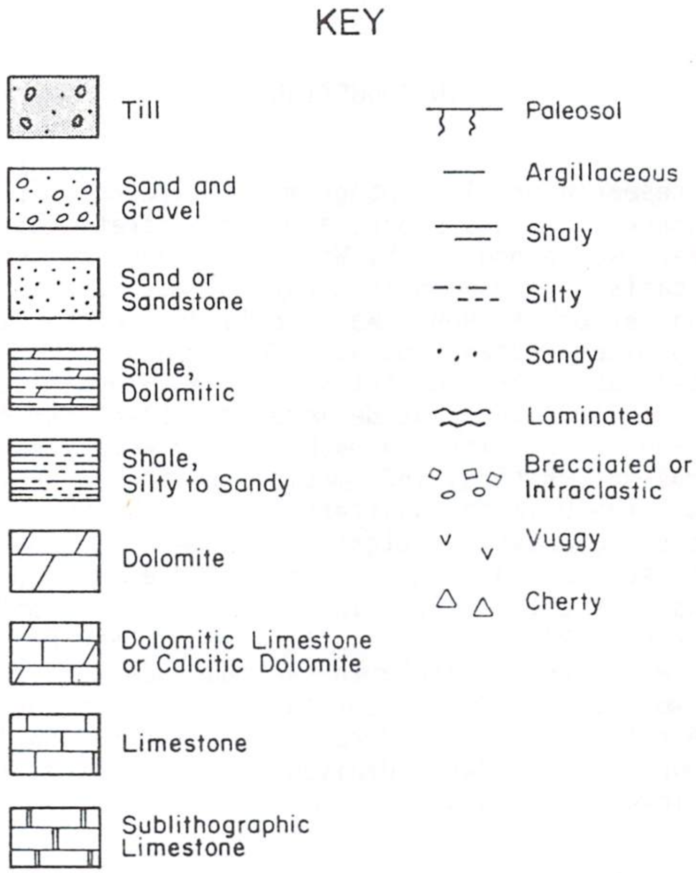

Figure 1. Lithologic key for figures 2 through 6.

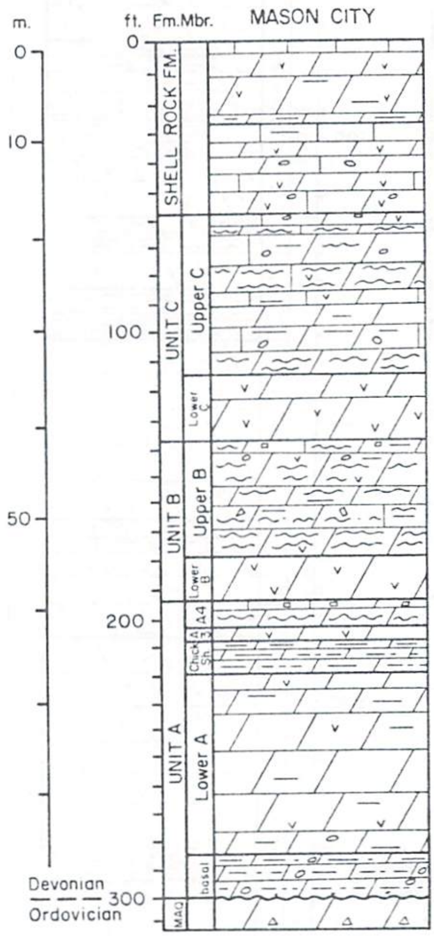

Figure 2. Stratigraphic sequence, Mason City core, Cerro Gordo County (sec. 33, T97N, R20W). Descriptive core log in Witzke and Bunker (1984). See Figure 1 for lithologic key.

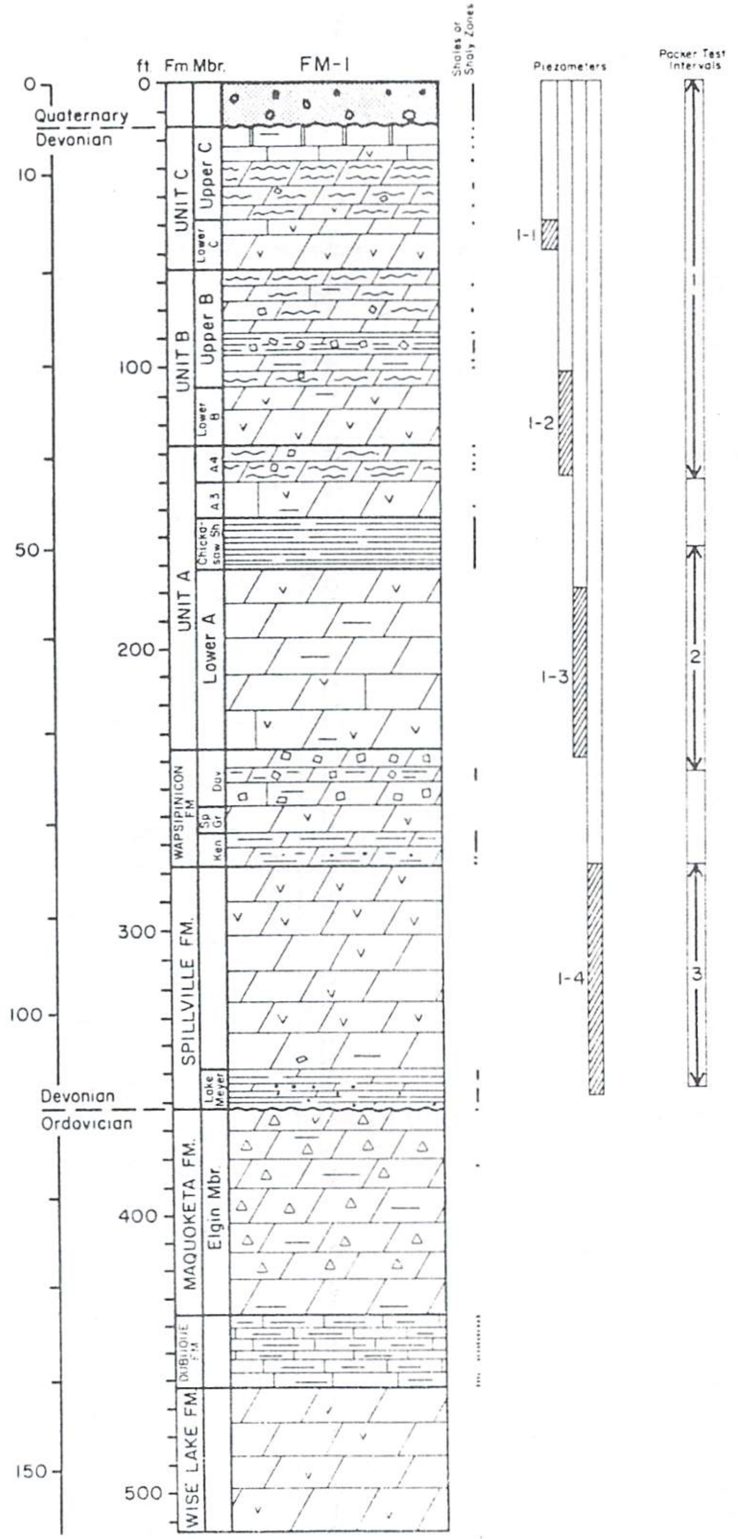

Figure 3. Stratigraphic sequence, FM-1 core, NE SE NE NE sec. 33, T79N, R16W, Floyd County. Top elevation 1120 ft. See figure 1 for lithologic key.

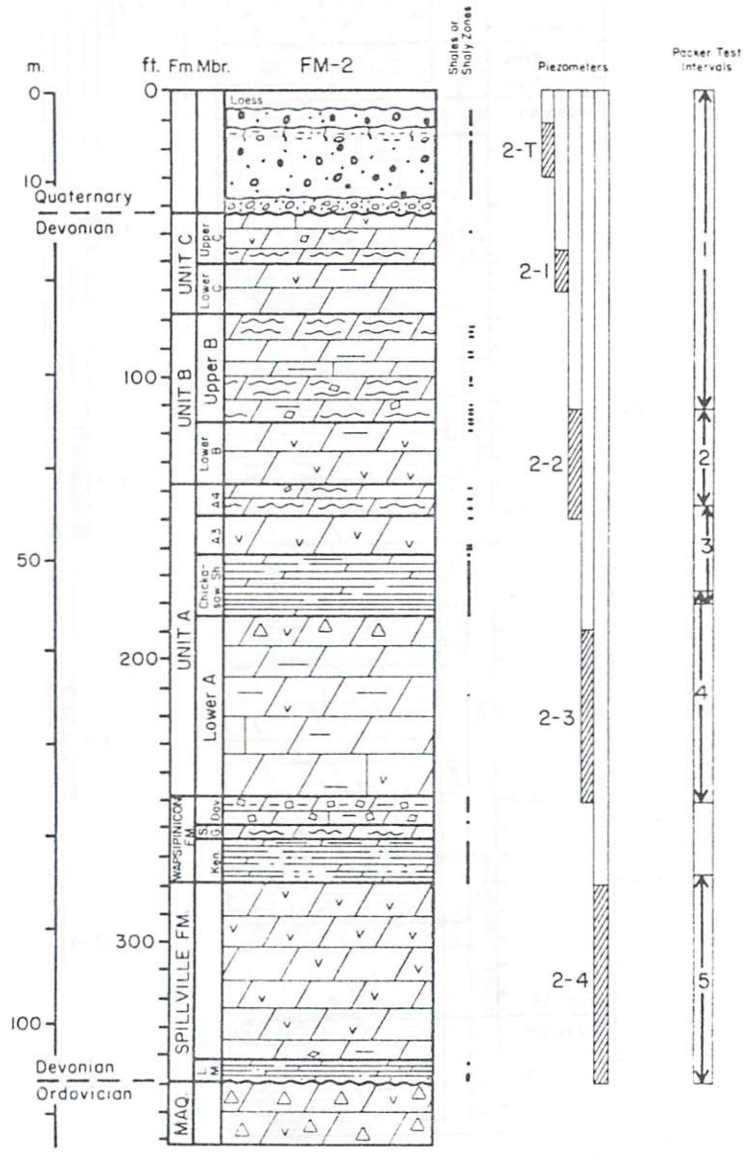

Figure 4. Stratigraphic sequence, FM-2 core, SE NE NE SE sec. 23, T99N, R17W, Mitchell County. Top elevation 1215 ft. See figure 1 for lithologic key.

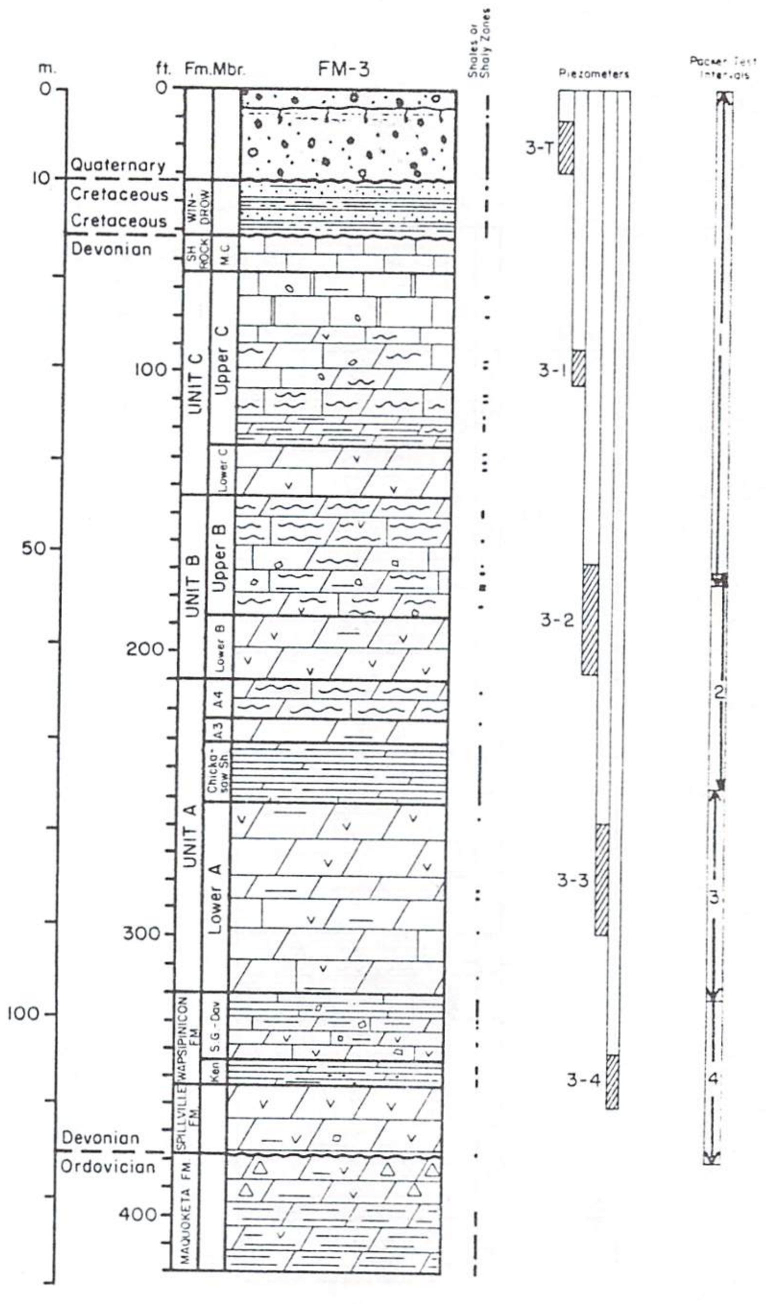

Figure 5. Stratigraphic sequence, FM-3 core, SW NW SW NW sec. 22, T95N, R16W, Floyd County. Top elevation 1102 ft. See figure 1 for lithologic key.

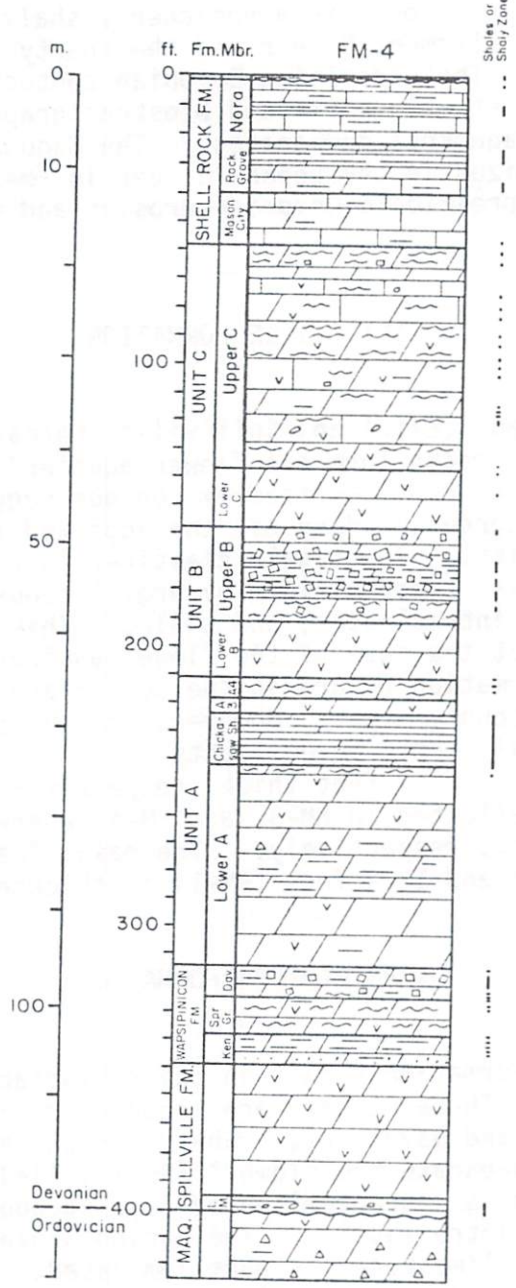

Figure 6. Stratigraphic sequence, FM-4 core, NE SW NW SE sec. 31, T96N, R18W, Floyd County. Top elevation 1050 ft. See figure 1 for lithologic key.

probably correlate with the Elgin Member. However, in FM-3 (Fig. 5) the cherty Maquoketa dolomites overlie a non-cherty shaly unit. The shaly beds may correlate with the Clermont Member and the cherty beds may belong the the Fort Atkinson Member. The Ordovician-Devonian contact in each core hole was determined by physical stratigraphic and biostratigraphic evidence. Conodonts are abundant in the Maquoketa carbonates. The Maquoketa rocks are fractured to brecciated and oxidized in the upper 20 feet in FM-1 (Fig. 3), probably as a result of extensive pre-Middle Devonian erosion and weathering on the Ordovician surface.

SPILLVILLE FORMATION

The Middle Devonian (Eifelian) Spillville Formation is present in all four core holes. These rocks form the "lower aquifer" in the area (Witzke and Bunker, 1984). It is characterized by porous vuggy dolomites which are fractured to varying degrees. Many of the vugs and fractures are filled or lined with sparry clacite. The basal clastic-rich portion of the Spillville ("Lake Meyer member") is characterized by argillaceous to shaly dolomite, in part silty, sandy, or intraclastic, and shale. This shaly interval probably serves as an aquitard at the base of the "lower aquifer."

The Spillville Formation occurs in the subsurface throughout most or all of the Floyd-Mitchell County area. However, it thins to the west and south and is absent in central Cerro Gordo County (Fig. 2). The formation in FM-1 and FM-2 is 84.5 feet and 70.7 feet thick, respectively. Southwestward thinning of the unit is reflected in FM-3 and FM-4 where the formation is 25.2 feet and 49.6 feet thick, respectively. The basal "Lake Meyer member" varies between 1.5 feet (FM-3) and 13.9 feet (FM-1) in thickness.

WAPSIPINICON FORMATION

The Wapsipinicon Formation occurs in the subsurface throughout the Floyd-Mitchell County area. Three members are recognized, in ascending order, the Kenwood, Spring Grove, and Davenport. Shaly strata in the Kenwood and Davenport members serve to separate the "lower" (Spillville) and "middle" (Unit A) aquifers. The Kenwood is characterized by argillaceous to shaly dolomite, in part silty to sandy or intraclastic. The Spring Grove Member is dominated by dolomite and dolomitic limestone, in part laminated. It is vuggy to varying degrees especially in FM-3 where it locally forms a productive aquifer. In FM-1 (Fig. 3) the Spring Grove is non-laminated and contains concentric spherules, probably oolites. The Davenport Member is represented by argillaceous to shaly dolomite and dolomitic limestone, in part prominently brecciated.

The Wapsipinicon Formation is generally unfossiliferous, but the Davenport (FM-1) and Spring Grove (FM-4) members are locally burrowed in part. The formation ranges from 29.7 (FM-2) to 42.2 (FM-1) feet in thickness in the four core holes. Strata tentatively included in the Wapsipinicon at Mason City by Witzke and Bunker (1984) probably represent a basal clastic-rich interval of the Cedar Valley Formation (and are so shown on fig. 2).

CEDAR VALLEY - UNIT A

The Cedar Valley Formation overlies the Wapsipinicon Formation in the Floyd-Mitchell County area, but Cedar Valley strata overstep the Wapsipinicon edge to the west to rest directly on Ordovician units. The lower portion of the Cedar Valley in northern Iowa was informally labelled Unit A by Witzke and Bunker (1984). Unit A will be formally designated as a formation at a future date, and included with an expanded Cedar Valley "Group." In this report Unit A is subdivided into four intervals, in ascending order, lower A, Chickasaw Shale, A3, and A4. The lower A interval comprises over half of the total thickness of unit A, and forms the "middle aquifer." Lower A is dominated by dolomite, but varying quantities of dolomitic limestone occur in the lower half. It contains scattered vugs, especially in the upper part. Lower A is generally non-cherty, but chert nodules are locally developed in the middle to upper parts, and silicified brachiopods are abundant in two of the four cores (FM-3, FM-4). Lower A is typically fossiliferous with silicified or moldic brachiopods, crinoid debris, corals, tentaculites, and trilobites noted. Tabulate corals are prominent in the upper part of lower A in three of the cores (FM-1, 3, 4). However, some sections of lower A are only sparingly fossiliferous (e.g., FM-2). Fossiliferous units noted in some cores are apparently replaced laterally by burrowed facies lacking skeletal fossils. Lower A strata vary between 62 and 72 feet in thickness in the four core holes. The total thickness of Unit A varies between 103 and 111 feet in the cores.

Lower A strata are abruptly overlain by shale and shaly dolomite strata that were informally termed the "Rapid shale" by Witzke and Bunker (1984). The four new core holes and the discovery of a surface exposure of this shale unit enable us to more accurately define the physical characteristics of the interval. The shaly interval separates the "middle" and "upper" aquifers in the area. At present, the only known surface exposure of this shale unit is at Chickasaw County Park (N 1/2, NW 1/4, NE 1/4, sec.21, T95N, R14W, Chickasaw Co.); 13 feet of shale overlie lower A strata, but the upper contact is erosionally truncated. This locality will be designated the type locality of this newly defined Cedar Valley stratigraphic unit; we will informally label it the "Chickasaw Shale" in this report. The Chickasaw Shale varies between 18 and 21.3 feet in thickness in the four core holes in Floyd-Mitchell County. It is prominently burrowed throughout, but skeletal debris is present in the lower 3.5 to 5 feet (brachiopods, bryozoans, small tabulate corals). Some calcite filled vugs are present in the more dolomitic parts of the Chickasaw Shale. The Chickasaw Shale, which is best developed in the Floyd-Mitchell County area, is replaced to the south and west by less shaly and more dolomitic facies. At Mason City it is represented as argillaceous and silty dolomite (Fig. 2).

Strata above the Chickasaw Shale that are included in Unit A can be subdivided into two intervals: 1) a lower vuggy fossiliferous dolomite (A3), and 2) an upper unfossiliferous laminated dolomite, in part intraclastic to brecciated (A4). The A3 interval varies between 4.7 and 13.8 feet in thickness in the four core holes. It thins to the south and west and is apparently absent in parts of Cerro Gordo County. It is commonly vuggy and locally includes an abundance of colonial rugose and tabulate corals (FM-2). Fossil molds are conspicuous (crinoid debris, brachiopods, corals) in two cores, but in the other two (FM-1, FM-2) the A3 interval is only sparsely fossiliferous but is prominently burrowed. The unfossiliferous A4 interval was deposited during the maximum regressive phase of the Unit A depositional cycle. The laminated, brecciated, and intraclastic carbonates were probably deposited in tidal flat and evaporitic environments. Thin shale beds in the interval probably impede vertical groundwater flow within the "upper aquifer." The A4 interval varies between 8.4 and 13.5 feet in thickness in the four core holes.

CEDAR VALLEY - UNIT B

Unit B in northern Iowa was deposited during a second Cedar Valley transgressive-regressive depositional cycle. Unit B can be subdivided into two distinct stratigraphic intervals (Witzke and Bunker, 1984). The lower vuggy and fossiliferous dolomite, if fractured, would provide the best medium for groundwater flow within Unit B. Lower Unit B is commonly stylolitic and locally contains coarsely crystalline calcite masses. Lower Unit B maintains a relatively uniform thickness in the Floyd-Mitchell County area, ranging from 19.3 to 22 feet in the four core holes.

Upper Unit B is dominated by unfossiliferous laminated to brecciated dolomite and dolomitic limestone. Shaly breccias are well developed locally (FM-1, FM-4). These predominantly shaly zones would generally serve to impede groundwater flow. The laminated beds are in part intraclastic. Although upper Unit B is generally unfossiliferous, some beds are burrowed and a few brachiopods are locally noted. Upper Unit B varies between 33 and 43.8 feet in thickness in the four core holes. The complete thickness of Unit B was observed to vary between 52.3 and 61.7 feet.

CEDAR VALLEY - UNIT C

Like Unit B, Unit C was deposited during a major transgressive-regressive depositional cycle. The lower part of Unit C is characterized by vuggy fossiliferous dolomite and dolomitic limestone. It locally contains coarsely crystalline calcite masses. Lower Unit C closely resembles lower Unit B strata; molds of brachiopods and crinoid debris are commonly noted. Stromatoporoids are locally present (FM-3). Lower Unit C strata vary between 16.1 and 20.5 feet in thickness in the four core holes. The porous character of lower Unit C suggests that it would probably form the most productive part of the "upper" aquifer which encompasses Unit C, particularly if fracture or solutional permeability is developed.

Witzke and Bunker (1984) subdivided the interval between the Shell Rock Formation (Unit E) and Unit B into two stratigraphic units, Unit C and D. Subsequent study of the four new core holes in Floyd-Mitchell counties pointed out the general impracticality of consistently recognizing the stratigraphic position of the Unit C - Unit D contact. In order to establish a more usable stratigraphic framework we have decided to include both Units C and D of Witzke and Bunker (1984) in an expanded Unit C (i.e. eliminate the Unit D label). Upper Unit C of this report, therefore, encompasses upper Unit C and all of Unit D of our earlier report (ibid). The base of the Unit D was previously drawn at the base of the first fossiliferous unit above the lower Unit C vuggy and fossiliferous interval. The discovery of some fossiliferous beds within strata apparently equivalent to upper Unit C of our earlier report has obscured this distinction.

Upper Unit C forms the bedrock surface over large areas of Floyd and Mitchell counties. It is dominated by unfossiliferous laminated to intraclastic limestone and dolomite. Mudcracked horizons are common, and thin shales are present. Dense lithographic and sublithographic limestones are locally prominent within Upper Unit C, but these are replaced laterally by dolomites and dolomitic limestones over relatively short distances (a few miles). The dense limestones were quarried and prepared for lithographic engravings from 1915 to 1917 at the former community of Lithograph City in northern Floyd County (secs. 25 and 26, T79N, R17W). Burrowed or fossiliferous beds intercalate with laminated strata in upper Unit C. Brachiopods and crinoid debris are noted in these beds, and stromatoporoid biostromes are locally noteworthy. In general, upper Unit C was deposited in environments which fluctuated between shallow marine, restricted marine, and tidal flat settings. Two core holes (FM-3, FM-4) penetrate the entire thickness of Unit C (80 and 99.3 feet respectively). Upper Unit C in these holes ranges from 63.9 and 78.8 feet in thickness. Fossiliferous strata throughout the entire span of Unit C are characterized by conodonts (microfossils) of the *Pandorinellina insita* Fauna. The Middle-Upper Devonian boundary falls within Unit C.

SHELL ROCK FORMATION

Witzke and Bunker (1984) proposed that strata previously included in the upper part of the Cedar Valley Formation at Mason City (informally termed Unit E) may correlate with the Shell Rock Formation of western Floyd County. FM-4 (Fig. 6) was drilled in western Floyd County in an area known to be underlain by Shell Rock strata. Core FM-4 begins near the top of the Shell Rock Formation, and basal Lime Creek shales with abundant megaspores were sampled with a soil probe at the drill site. Direct stratigraphic comparisons of the Mason City (Fig. 2) and FM-4 (Fig. 6) cores indicate that the Shell Rock Formation and the interval formerly termed Unit E occupy the same relative stratigraphic position and contain a similar faunal and lithologic sequence. Unit E, our prior report, is assigned to the Shell Rock Formation on Figure 2. The Shell Rock overlies upper Unit C strata in both areas. Although the classic Shell Rock section in western Floyd County is dominated by limestone, it is replaced to the west by dolomite-dominated facies which were often included in the Cedar Valley Formation.

The Shell Rock sequence in FM-4 includes all three members of the formation. The Mason City Member contains common stromatoporoids, and hardground surfaces are noted. Similar strata are found at the top of the Devonian section in core FM-3 (Fig. 5), and these are tentatively assigned to the Mason City Member. The Rock Grove Member in FM-4 is notably less fossiliferous and more dolomitic than the Mason City; it is very shaly in the middle to upper part. The Nora Member is characterized by stromatoporoidal limestones with prominent shale beds in the middle and upper part. The Shell Rock Formation is probably more widespread in northern and central Iowa than previously recognized. The classic Shell Rock section in western Floyd County is apparently replaced to the west by more dolomitic and less shaly strata. The Shell Rock Formation is absent in areas east of Floyd County. Its stratigraphic position above Unit C suggests that it forms the upper part of the "upper aquifer." This aquifer becomes confined beneath the Lime Creek shales in western Floyd County.

CONCLUSIONS

Detailed stratigraphic information derived from the four new core holes in Floyd and Mitchell counties has been critical for describing and delimiting the container for the Devonian aquifers in the region. Packer test intervals and the positions of the nested piezometers were determined from the basic stratigraphic sequence so clearly visible in the rock cores. The integration of stratigraphic and groundwater studies is essential in any regional investigation of geohydrologic problems. The Floyd-Mitchell study provided a stratigraphic data base that will be invaluable for future geologic and geohydrologic investigations in the area.

REFERENCES

Witzke, B.J., and Bunker, B.J., 1984, Devonian stratigraphy of north-central Iowa: Iowa Geol. Surv., Open File Report 84-2, P. 107-149 (report on U.S. E.P.A. grant number G007237-01).