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**THE LIMNOLOGY OF THREE LIMESTONE ROCK QUARRIES
IN EAST-CENTRAL NEBRASKA AND WESTERN IOWA**

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ABSTRACT

Rock-quarry lakes provide a unique environment. The aim of this study was to obtain baseline limnological data on quarries, one in Iowa and two in Nebraska, which have not been previously investigated. The results show the general limnological trends of the quarries' productivity. The mean oxygen, nutrient, pH, and phytoplankton-biomass values indicate the quarries are oligotrophic; however, one quarry has a profound depletion of oxygen in the summer and a large seasonal variation in alkalinity. A higher nitrogen concentration as well as more littoral plants suggests it to have more eutrophic potential than the other two quarries. Metal-ion analysis shows that the Ashland quarry had high levels of aluminum, and the North quarry had a moderate level of lead. The Logan quarry showed great concentrations of many elements, including lithium and uranium, which could account for its high specific conductivity. Further investigations should be carried out to provide a more detailed picture of these quarries.

† † †

Open-pit mining of limestone occurs in eastern Nebraska and western Iowa. Depending on the geology of the quarry, a range of interactions can occur between the quarry lake and the groundwater, which may become a drinking-water source.

This study was undertaken to provide baseline data on the primary production in these lakes for assessing their water quality now and in the future. It should be emphasized that this is a survey and does not include investigations of any unusual phenomena that may be present.

DESCRIPTION OF QUARRIES

The North quarry (Fig. 1) is located in Washington County, Nebraska, just north of Omaha (41° 24' 35" N

and 95° 56' 59" W). This is the oldest of the three quarries. It was last quarried in 1967 by the Ervin Clark Construction Company of Logan, Iowa (R. Burchett, personal communication). No historical account exists, other than rock analysis for testing the quality of rock. The North quarry is the smallest and shallowest of the three studied (Table 1). It is located at the foot of a treed valley that is open to the floodplain leading to the Missouri River. The littoral zone, not more than 5 meters from any shore, contains primarily cattails and scouring rush. Snow-covered ice was continually present during the winter months. The lake sustains a population of bass and crappie since being stocked in the late 1960s. Currently, the new lake owners are renovating the area to exclude trespassers and to connect the lake's northeast end to a small brown stagnant pond just a few meters from the lake. Water from the pond enters the lake at the northwest end when waters rise, at the largest concentration of cattails.

The Ashland quarry is located in the Platte River basin (41° 02' 32" N, 96° 21' 02" W) bordering the Saunders-Cass county line (Fig. 2). This quarry was mined last in 1984 and some debris left from the quarrying has been surpassed by the water level. This

Table 1. Physical parameters of the three quarries.

	Ashland	Logan	North
Elevation (m)	335.3	310.9	304.8
Surface area (m ²)	88,056	50,004	20,272
Wetted perimeter (m)	1903	1511	1086
Maximum length (m)	516	294	204
Maximum width (m)	264	219	109
Maximum depth (m)	23.2	10.4	7
Relative depth (m)	6.2	3.8	4.4

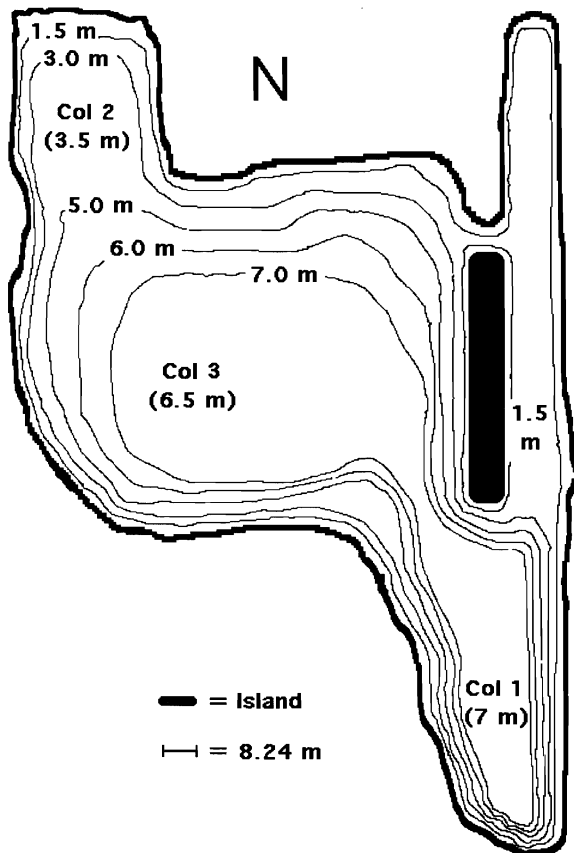


Figure 1. Bathymetric map of the North quarry.

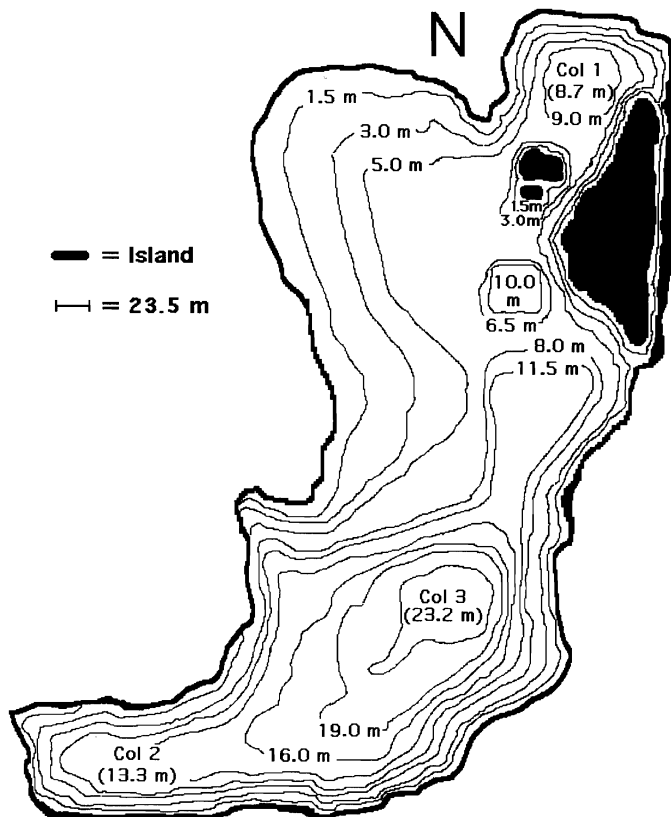


Figure 2. Bathymetric map of the Ashland quarry.

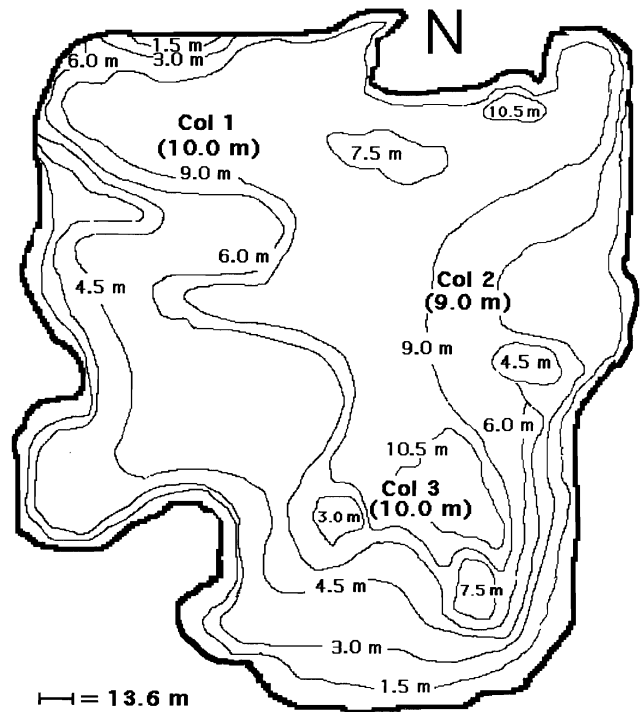


Figure 3. Bathymetric map of the Logan quarry.

quarry is the deepest and largest of the three lakes studied.

The quarry is located in a valley surrounded by loess hills scarred with limestone deposits and ruts due to water erosion. The quarry has cliff faces up to 18 meters that enter the water around the southern shoreline. Ice covers the lake during the winter months. The only aquatic vegetation in the quarry is a green alga that usually stays near the benthic region, and small amounts of scouring rush. The major fish present are sunfish and bass.

The Logan quarry (Fig. 3) is located in Jefferson County, Iowa (41° 39' 05" N, 95° 45' 56" W). The Boyer River is the main tributary, eventually entering the Missouri River. Nearby water from another quarry is pumped into the lake, adding to the volume and characteristics of the Logan quarry.

The quarry is surrounded by both flat land and loess hills, which are covered with grass. Ice covers the surface in the winter except where the water is pumped in by Column Site 2 (Fig. 3). Again, the only aquatic vegetation is a green alga and sparse patches of scouring rush. Few fish were observed. The northern end of the quarry has eroded cliffs up to 12 meters high.

EXPERIMENTAL DESIGN AND METHODS

The design of this survey was done in accordance with the Environmental Protection Agency (E.P.A.) Clean Lakes Act sampling guidelines and as outlined in A.P.H.A. (1989). Sampling occurred from September 1992 through June 1993. Three sites were chosen in each quarry, one near the deepest hole and the other two representing other sites in the lake. At each site, water samples were taken at the surface, middle depth, and bottom, plus a replicate randomly chosen sample at one of the depths. A Van Dorn bottle was used to collect samples, which were emptied into acid-washed, one-gallon milk jugs. Due to ice cover, samples collected in January and March were all surface samples. Analyses of these samples were done at the Creighton University Ecological Wet Lab within 12 h.

An oxygen meter, Y.S.I 51B, with a polarographic electrode was used to measure dissolved oxygen and temperature, while conductivity was measured using a Y.S.I. 3000 T-L-C meter. Light attenuation and transparency were measured with a LI-COR quantum sensor model LI-185A and a Secchi disk (Z_{sd}), respectively. Benthic contour maps were made by using a fish finder (Hummingbird). All measurements were taken at meter intervals.

In the laboratory, a volume of water was filtered through a 0.45 μm membrane filter to determine chlorophyll *a* concentrations by the spectrophotometric method and chlorophylls *b* and *c* concentrations by the trichromatic method (A.P.H.A., 1989). Total suspended solids (TSS) was determined by filtering a volume of sample through a pre-weighed 0.45 μm membrane filter and drying the filter at 10° C for at least 24 h before reweighing (A.P.H.A., 1989). Turbidity was determined using the nephelometric method with a Hach Turbidimeter (Walters et al., 1989).

Total phosphorus, determined using the Hach method (Hach Chemical Company, Loveland, Colorado), orthophosphate, and nitrate+/nitrite samples were read on a spectrometer (Bausch and Lomb Spectronic 20). A Hach One meter was used to measure alkalinity, pH, calcium hardness, total hardness, and magnesium hardness (via subtraction) (Walters et al., 1989).

Metal-ion concentrations were determined using an I.C.P. mass spectrometer. Four mL of nitric acid were added to 300 mL B.O.D. bottles before obtaining a water sample in March. Two samples were taken from the surface of each quarry from the same location. Along with the lake samples, two blanks of ultrapure water with four mL of nitric acid were analyzed to account for any nitric acid impurities that may have

Table 2. Physicochemical parameters for each quarry during the sampling period. Note that in November, the North quarry was the only quarry to be sampled. — = data not available.

	Quarry	Z_{sd} (m)	Turbidity (NTU)	TSS (mg/L)	Conductivity ($\mu\text{s}/\text{cm}$)	Temperature max/min (°C)
September	Ashland	4.3	3.29	3.8	409	21.8/8.4
	Logan	1.7	3.26	4.2	1767	20.5/13.4
	North	1.8	2.14	3.7	476	22.4/16.7
October	Ashland	1.9	—	18.3	416	13.8/10.3
	Logan	1.5	2.00	2.8	1715	13.9/13.1
	North	1.2	4.30	6.9	459	13.5/13.1
November	North	2.5	2.00	2.7	472	4.7/4.1
January	Ashland	—	2.00	0.7	449	4.6/0.2
	Logan	—	2.00	6.9	—	—
	North	—	1.90	1.5	519	4.1/1.5
March	Ashland	—	3.00	3.1	437	3.4/0.9
	Logan	—	1.30	0.5	1929	1.3/1.0
	North	—	1.00	1.6	550	3.8/0.08
June	Ashland	2.1	7.29	3.6	417	24.1/7.7
	Logan	1.6	6.49	19.0	1710	21.3/8.2
	North	1.8	4.96	3.0	477	25.8/9.2

Dissolved Oxygen Profile for Sampling Dates

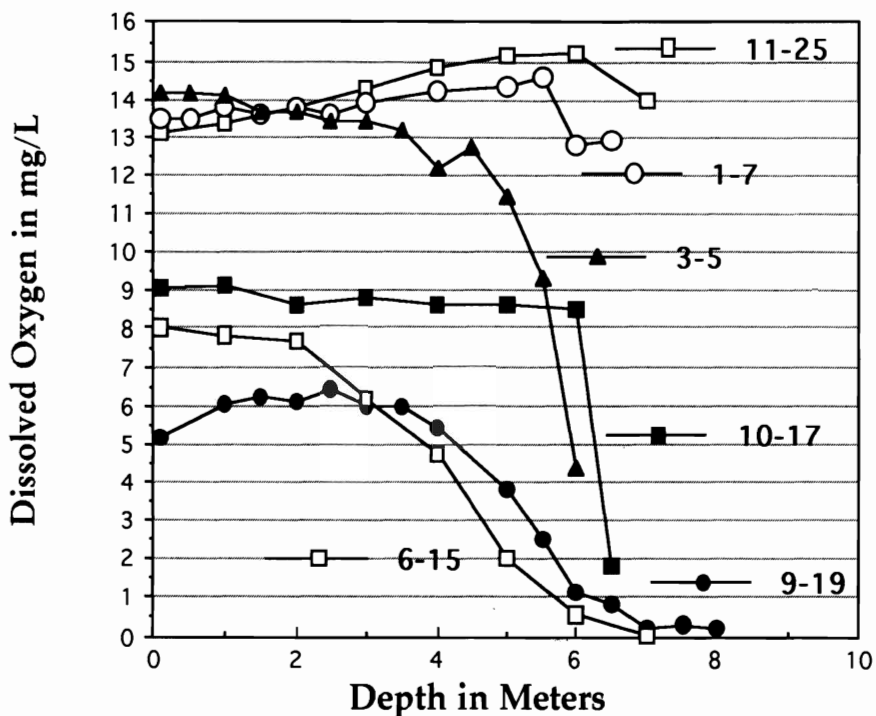


Figure 4. Oxygen profile for the North quarry, showing summer depletion of oxygen in the benthic regions, destratification in the winter, and the beginning of restratification in June. The North quarry could be described as a dimictic lake.

Oxygen Profile Comparison for September

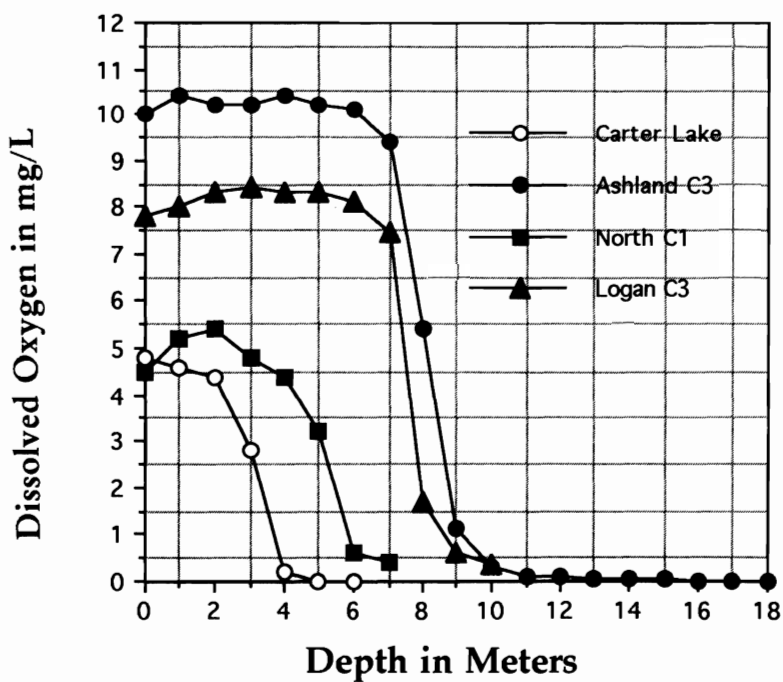


Figure 5. Oxygen concentrations for the deepest columns of water for the lakes in the month of September.

introduced to the water samples.

RESULTS AND DISCUSSION

Tables 2 and 3 summarize the mean test values for each quarry over the sampling period. Note that the North quarry was the only quarry sampled in November.

Light-attenuation data show a euphotic zone down to 5.5 m for both North and Logan quarries, while Ashland's reached 8 m in September. By October the euphotic zone was reduced to 2.5 m for North and 2 m for Logan. In Table 2, the Secchi disk values show a similar trend. In conjunction with the above pattern, the results indicate that the lakes had relatively low concentrations of TSS and low turbidities (Table 2).

An estimate of phytoplankton biomass is obtained by multiplying chlorophyll *a* values by 67 (A.P.H.A., 1989). Mean ranges of 35.2 to 133.9 mg/m³ for North, 49.9 to 110.9 for Ashland, and 16.5 to 105.9 for Logan indicate low to moderate biomass levels. Chlorophyll *a* samples from September through March were too dilute to fall in the 0.1–1.0 absorption range for wavelength 664. A doubling of the filtration volume overcame this limitation for June's samples, but this did not raise the algal concentration values when the raw data were used in the formula determining chlorophyll *a*

concentration. The results indicate that the North quarry had the highest phytoplankton density and may help explain the rich green color of the lake.

The North quarry displayed a typical dimictic-lake oxygen profile (Fig. 4). The temperature readings also revealed a dimictic pattern for the quarries (Table 2). Fall turnover increased oxygen levels until the concentration became uniform in November. This lasted until March, when the spring turnover began to reestablish oxygen stratification. The Ashland and Logan quarries were also dimictic, but a marked difference in oxygen profiles between the North quarry and the other two existed (Fig. 5).

In September, the dissolved oxygen ranged from 10.4 to 0.0 mg DO₂/L for Ashland and 8.9 to 0.5 for Logan. By January the range was 15 to 6.4 mg DO₂/L for Ashland and 11.1 to 12.4 for Logan in February. The range was 9.4 to 3.7 mg DO₂/L for Ashland and 8.8 to 1.4 for Logan in June. Thus enough dissolved oxygen was present in lakes to sustain the biota, except for the benthic region of Ashland in September.

The average total phosphorus for Ashland was 0.093 mg/L, 0.078 for Logan, and 0.05 for North. Average orthophosphate was 0.162 mg/L for Ashland, 0.089 for Logan, and 0.131 for North. The average nitrogen for Ashland was 0.174 mg/L, 0.028 for Logan, and 0.185 for

Table 3. Mean alkalinity, hardness, and pH for the quarries. — = data not available.

	Quarry	pH	Alkalinity (CaCO ₃ mg/L)	Ca Hardness (CaCO ₃ mg/L)	Mg Hardness (MgCO ₃ mg/L)
September	Ashland	8.33	63.6	35.0	40.6
	Logan	7.62	97.1	401.0	228.5
	North	8.10	185.5	62.1	78.6
October	Ashland	8.33	—	—	—
	Logan	7.58	228.0	403.0	239.8
	North	8.23	422.4	75.0	75.0
November	North	8.14	857.8	73.0	88.0
January	Ashland	8.04	322.2	55.0	25.0
	Logan	9.74	228.0	410.0	220.0
	North	7.64	356.7	81.7	86.7
March	Ashland	7.98	244.0	42.5	57.5
	Logan	7.65	222.0	576.5	370.0
	North	7.37	350.0	72.5	115.0
June	Ashland	8.13	311.8	57.5	38.8
	Logan	7.67	212.8	445.8	351.3
	North	8.32	404.5	75.0	113.8

Table 4. Ionic concentrations found on an ICP-MS for the three quarries during the sampling period. Values are given in parts per billion.

	Atomic mass	Ashland	Logan	North
Lithium	7	55.4	255.6	55.8
Boron	11	40.7	59.9	17.3
Magnesium	24	53334.9	46332.9	13852.0
Aluminum	27	113.6	10.3	19.0
Calcium	44	16060.1	104501.5	29226.9
Manganese	55	15.4	96.1	7.6
Iron	57	194.1	502.7	138.0
Zinc	66	13.3	4.6	8.1
Strontium	88	118.9	1245.3	191.5
Molybdenum	98	2.6	253.8	2.4
Barium	138	62.1	67.0	96.3
Lead	208	5.3	0.1	55.8
Uranium	238	4.3	51.7	5.9

the North quarry. Nitrogen is usually present in greater concentrations than phosphorus because sediments can trap phosphorus more easily (Otsuki and Wetzel, 1972). Levels of total inorganic nitrogen ($\text{NO}_3 + \text{NH}_4$) under 0.100 mg/L could induce a limiting situation where 0.400 mg/L would not (Goldman and Horne, 1983), thus all three quarries seem to be in an oligotrophic state.

pH ranged between 7.25 and 8.33 (Table 3) for all three quarries except Logan, where the pH increased to 9.74 in January. These values are within the normal range of most lakes (Goldman and Horne, 1983). The North quarry displayed the highest alkalinity values throughout the sampling period (Table 3). The productivity of primary producers can be represented by a broad seasonal variation of alkalinity (Wetzel, 1975). Hence, the North quarry indicated a higher productivity from its primary producers, with a seasonal variation of 672.3 mg CaCO_3/L , and Logan the least, with a variation of 130.9 mg CaCO_3/L .

Fluctuations in carbonate levels can influence lake metabolism (Wetzel, 1975), affecting certain compounds such as phosphate, which can regulate algal production by competing for organic substrates and sinking into the benthic region out of algal circulation (Otsuki and Wetzel, 1972). The Logan quarry was the hardest of the three (Table 3). According to Hossner's (1988) classification, Ashland was soft, North was moderate, and Logan was very hard.

Conductivity results reveal a trend similar to that seen for the hardness data, with Ashland having the lowest concentration and Logan the highest.

Evaluation of metal-ion concentration is necessary to determine if adequate amounts of biologically impor-

tant metals are present or if ion levels generate a nuisance/toxic state. The Logan quarry had a high level of many ions, including lithium and uranium (Table 4). Ashland had high aluminum and North had a moderate concentration of lead. Whether these ions presented problems for the biota was undetermined. The surrounding rock formations are assumed to be responsible for the metal-ion concentrations found in the quarries (Table 5). The metal ions can form complexes, making dissolved organic compounds available for consumption through chelation or they can take nutrients out of circulation, depending on lake conditions (Wetzel, 1968).

CONCLUSION

This survey was designed to find baseline data on three rock quarry lakes which have never been analyzed. The quarries have a rock basin rather than a sand/silt basin, have steep cliff faces compared to gradual sloping banks, and are younger and deeper than natural lakes. Thus, anthropogenic lakes, common in the region, provide a unique environment for investigation.

Many of the variables tested suggest that the North quarry had the highest eutrophication potential. A seasonal alkalinity range variation of 672.3 mg CaCO_3/L indicates that North had the highest primary production of the three. Nutrient levels were not growth-limiting and mean pH and conductivity values were in the normal range for most lakes. The banks were more suitable for supporting littoral zone vegetation than in the other two lakes.

The Ashland quarry data revealed productivity but the depth and size dilute eutrophication processes.

Table 5. Characteristic concentrations of selected elements found in shale and limestone rock. Adapted from Drever, 1982. Values are in mg/L.

Element	Shale	Limestone
Lithium	66.0	5.0
Boron	100.0	20.0
Aluminum	Major	4200.0
Chromium	90.0	11.0
Manganese	850.0	1100.0
Iron	Major	Major
Nickel	68.0	20.0
Copper	45.0	4.0
Zinc	95.0	20.0
Gallium	19.0	4.0
Selenium	0.6	0.9
Strontium	300.0	600.0
Molybdenum	2.6	0.4
Cadmium	0.3	0.0
Barium	580.0	10.0
Lead	20.0	9.0
Uranium	4.0	2.0

Ashland, only five years old at the time of sampling, has not had as much time to develop as the North quarry. The low seasonal alkalinity variation, high specific conductivity levels, and very hard water may have caused the low phytoplankton biomass. High levels of many ions contribute to Logan's oligotrophic state. High conductivity is probably due to water pumped into Logan from a nearby active quarry. Quarries only a few feet apart have been found to assume different properties (Burgis and Morris, 1987), so it should not be surprising that the quarries studied here are evolving at different rates.

The above analysis presents a general picture of the internal structure of the ecosystems of three previously unexamined Nebraska quarries. More analysis, especially biological, could be conducted to enhance

understanding of the quarries.

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