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FEATURES

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ON THE COVER:
Geologist Fred Anderson at the Crown Butte Creek glacial erratic, one of North Dakota's largest, west of Mandan in Morton County. Drone photograph by geologist Christopher Maike.

Lee C. Gerhard
ND State Geologist
1977-1981

BY ED MURPHY

Lee Gerhard passed away on April 12, 2025. Lee was the North Dakota Geological Survey's Assistant State Geologist from 1975 – 1977 and the State Geologist and Chair of the Geology Department at the University of North Dakota from 1977 – 1981.

Lee was a native of Albion, New York, and earned a bachelor's degree in geology from Syracuse University and his master's and doctorate degrees from the University of Kansas. He began his career in geology as a party chief with Amerada Petroleum and then worked as an exploration geologist and stratigrapher for Sinclair Oil and Gas. Before coming to the North Dakota Geological Survey, Lee was an associate professor of geology at the University of Southern Colorado and then assistant director at Fairleigh Dickinson University's West Indies Laboratory. Upon leaving the Geological Survey, Lee was the western region exploration manager for Supron Energy and then a professor at the Colorado School of Mines from 1982 – 1987. In 1987, he became Kansas State Geologist and remained in that position until 1999. Lee authored more than 200 scientific publications throughout his long career (modified from AAPG Explorer, September 1999).

In 1979, Lee created a Carbonate Study Program, a successful joint venture between the Geological Survey and the Geology Department. Graduate students in this program received technical and financial support from the Survey. An example of the quality of work that came out of that program, beyond the Master's and PhD theses, was a presentation at the 1982 annual meeting of the American Association of Petroleum Geologists authored by Randy Burke, Robert Lindsay, and graduate students Diane Catt, Fred Lobdell, Peter Loeffler, Tom Obelenus, Nancy Perrin, and Rick Webster that received the General Chairman's Award for best poster. In recognition of Lee's life-long interest in carbonate research, the AAPG is in the process of establishing the Dr. Lee Gerhard Memorial Fund for Carbonate Studies, https://donate.aapg.org/Core/eDonation.aspx

Although Lee's time with the Geological Survey was relatively short, he was responsible for hiring several geologists that worked for the Survey for decades: Ken Harris (1977-1989, 2013-2014) Randy Burke (1979 – 2005), Ed Murphy (1980 – current), John Hoganson (1981-2015), and Julie LeFever (1981-2016). As a result, his contributions to the North Dakota Geological Survey extended long after he had left the agency.

Left: Lee Gerhard is interviewed by a reporter in front of the recently constructed Wilson M. Laird Core and Sample Library in the fall of 1980. Right: Three ND State Geologists, from left to right, Ned Noble (1969-1977), Wilson Laird (1941-1969), and Lee Gerhard (1977-1981) at the dedication of the Wilson M. Laird Core and Sample Library on October 3, 1980.

BOULDERS FROM THE FIELD:

GLACIAL ERRATICS AS LANDSCAPING MATERIALS IN NORTH DAKOTA

BY FRED J. ANDERSON

INTRODUCTION

While driving into a shopping complex in north Bismarck recently, I couldn't help but admire the exceptionally large granitic gneiss (sounds like "nice") boulder placed in a decorative rockscape arrangement separating the access roads from the parking areas (fig. 1).

So, I started to wonder how big is the largest glacial erratic boulder in North Dakota and where is it located? As many NDGS geologists over the years have noted, there are several examples of "very large" glacial erratics in various parts of the state that could be the largest. To my knowledge, no one has ever attempted to claim this title or even given a name to any erratic at any specific location. Here, I will highlight what glacial erratics are, where they are commonly found in North Dakota, and what they tell us about our geologic past. I will also show examples of the larger glacial erratics that have been found in North Dakota and North America and look at how old the largest erratic found in the state may be. I will also formally give a name to what is considered the largest glacial erratic in the state; the Crown Butte Creek Erratic, which is located at the southwestern edge of the glaciated terrain of North Dakota just west of Mandan (Clayton and others, 1980).

GLACIAL ERRATICS DEFINED

The word erratic is derived from the Latin errare which means "to wander." Very early on, Sir Charles Lyell, considered by some to be one of the fathers of modern geology, described in his 1830s Principles of Geology, a glacial geologic process that helps to explain the origins of sediment removed from their original locations and transported by glacial ice (Lyell, 1830), like erratic boulders. That early description by Lyell is quite consistent with today's understanding of the entrainment and transport of large boulders in glacial ice.

> ***Erratic (Glacial)*** *- A rock fragment carried by glacial ice, or by floating ice, deposited at some distance from the outcrop from which it was derived, and generally though not necessarily resting on bedrock of different lithology. Size ranges from pebbles to field stones to boulders to house-sized blocks (AGI Glossary of Geology)*

USAGE OF ERRATICS IN LANDSCAPING

With the recent surge in residential and commercial construction activity in North Dakota, particularly in north Bismarck, south Fargo, and Grand Forks, many sand and gravel and landscaping companies have been finding a growing market for the sale of large glacial erratics for decorative landscaping purposes. Some companies charge around forty dollars per ton to have these large remnants of our glacial geologic past placed on residential or commercial properties. Also, stockpiling of erratics when clearing new residential land tracts is becoming commonplace for later landscaping use around the housing development.

FIGURE 1. A very large (for North Dakota) glacial erratic gneissic boulder used as decorative landscaping at the LaSalle Drive shopping complex in north Bismarck. Boulders like these were transported great distances by glacial ice from far north in the Canadian Shield.

FIGURE 2. This large glacial erratic granite located at Bismarck Fire Station 3 is estimated to weigh over seventeen tons. Placement value is estimated at around $700-$800. Hammer length in the left foreground is 1.5ft. on the handle.

According to industry sources, a large granite boulder, like the one located at the Bismarck Fire Station (fig. 2), could cost $700-$800 or more for acquisition and placement.

Consider for a moment that it is estimated there are around 375,000 homes in North Dakota (U.S. Census, 2020). If just one homeowner in ten purchased an erratic for landscaping, this would result in potential market value in the aggregates and landscaping industries easily reaching into the millions. Most often though, since many of these erratics are quite massive, they will commonly be used as landscape boulders in the housing developments where they are found.

The use of glacial erratics for landscaping and decorative rock purposes has greatly expanded in the last twenty years corresponding with the increase in residential and commercial construction. For example, the recent urban expansion, particularly in north Bismarck, has increased the desire for natural landscaping projects that utilize glacial erratics (fig. 3).

Even in longstanding locations, such as the old Bismarck bowling alley, which is now home to the West Central Human Service center, there is an exceptionally large glacial erratic that adorns the entrance to the parking area as you enter from just east of Schafer Street (fig. 4).

NORTH DAKOTA'S LARGEST GLACIAL ERRATIC

One of the largest glacial erratics ever found in North Dakota can be seen about ten miles west of Mandan along Old Highway 10 (fig. 5). This likely was a much larger erratic that has since fragmented over thousands of years of weathering (fig. 6). Since this is likely the largest erratic ever to be identified in North Dakota, its tourism potential as a roadside attraction would be interesting to consider.

The Crown Butte Creek erratic is of metamorphic origin and is called an augen gneiss (fig. 7) due to its porphyroclastic metamorphic rock texture (fig. 8). Erratics like these were most likely scoured and picked up by glaciers, originating in the Canadian Shield of North America and may be some of the oldest representations of Earth's crust from Precambrian time.

FIGURE 3. Large igneous and metamorphic boulders harvested from local glacial deposits in soon-to-be developed residential tracts along North Washington Street in Bismarck. These erratics will likely find homes in front of new residences or within common areas within the housing development.

FIGURE 4. This large red granite erratic is at the entrance to the parking area at West-Central Human Services in Bismarck. This may be the largest single intact erratic in the state at seven feet tall and nearly 11 feet wide (Hammer handle length is 1.5 feet). View is to the west.

FIGURE 5. One of North Dakota's largest glacial erratics is located west of Mandan on the north side of Old Highway 10. View is to the east with the silhouette of the N.D. State Capitol building in the background at right.

FIGURE 6. Possibly the largest glacial erratic found in North Dakota, the Crown Butte Creek Erratic may have once been one large boulder that has since broken into several fragments, perhaps as the glacial ice it was entrained in slowly melted away and receded back to the north.

FIGURE 7. Close-up view of the Crown Butte Creek erratic boulder. The gneissic texture and augen (German for eyes) porphyroclasts, along with granitic veining cross-cutting and invading the orthogneissic country rock, is evident in this large metamorphic boulder.

FIGURE 8. Hand specimen of a fragment of the Crown Butte Creek Erratic exhibiting the characteristic metamorphic petrology of a granitic augen gneiss, which is a blastomylonitic rock containing large "eye like" augen porphyroclasts (commonly feldspar) and gneissic banding.

FIGURE 9. The Madison Boulder in New Hampshire is one of the largest erratics in North America. This granitic erratic is 83 feet long, 23 feet tall, and 37 feet wide. Image courtesy of the NHGS, 2023.

FIGURE 10. The Okotoks Erratic A.K.A. "Big Rock" is located in Alberta, Canada and is 134 feet long and 59 feet high. Note the individual on top of the boulder to the left for a sense of scale. Image courtesy of the Alberta Geological Survey.

FIGURE 11. Sampling the Crown Butte Creek erratic west of Mandan for cosmogenic dating. A well exposed surface, oriented perpendicular to the path of incoming cosmic radiation, is best for sample collection.

Several other states and provinces across northern North America also showcase their largest erratics, such as the Madison Boulder in New Hampshire. The granite behemoth weighs a reported 5,000 tons (fig. 9) and resides in the Madison Boulder Natural Area in east central New Hampshire.

The Province of Alberta, Canada also claims the world's largest glacial erratic near Okotoks, just 20 miles south of Calgary. It is an exceptionally large, fragmented quartzite erratic estimated at over 18,000 tons (fig. 10). Quartzite is a metamorphic rock that originated as a quartz sandstone, a sedimentary rock that was later changed (metamorphosed) by heat and pressure.

To better quantify the geologic history of the Crown Butte Creek Erratic, cosmogenic dating of Beryllium 13 in quartz was performed by Professor Ben Laabs (NDSU) in the fall of 2023 (fig. 11). The dating work gives an exposure age of 8,600 ± 200 years before present, which would unfortunately be too young for its current location at the end of the Napolean ice-advance, which would have been around 15,000 years ago (Clayton and others, 1980). Most likely it broke up during final melt out and collapse of the end moraine, suggesting the surface has not seen consistent exposure over time (Laabs, 2024). Laboratory preparation work for Be-13 dating of this erratic was performed by the cosmogenic laboratory at NDSU. Analysis was completed at Lawrence Livermore National Laboratory in Livermore, California.

The presence of these large boulders on the prairie, along with the rolling surface expression of the glaciated landscape, reminds us of the enormous power that glacial ice had to move large amounts of material far from its place of origin.

A NEW GEOLOGIC RESOURCE?

In the end, it could very well be that the large stockpiles of glacial erratic boulders laying in the middle of one's farm field that is constantly having to be tilled and harvested around could have some meaningful monetary value for those in the landscaping and decorative stone industries. We have recently started to include the locations of these large erratics and rockpiles created by farmers on our geologic maps, to better identify this potentially emerging geological resource.

Please contact our offices directly if you think that you may have an even bigger candidate for North Dakota's largest glacial erratic. We would enjoy hearing from you.

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Pinpointing Enrichment:
Using New Data from Exploratory Drilling to Characterize the Distribution of Rare Earth Elements and Other Critical Minerals in North Dakota

BY LEVI MOXNESS AND ADAM CHUMLEY

INTRODUCTION

Rare earth elements and other critical minerals like gallium, germanium, and antimony are at the center of tariff and trade negotiations between the world's two largest economies. Decades of investment in mining and processing infrastructure have given China a near-monopoly on many of these commodities, and with that control comes the ability to significantly disrupt U.S. manufacturing across a broad swath of high-tech industries that require these metals. China's April 2025 export restrictions on rare earths were a significant factor in the June "truce," where the U.S. agreed to temporarily reduce tariff levels in exchange for resumed rare earth exports to select non-military U.S. manufacturers (Emont and Bade, 2025). This 90-day agreement is mainly viewed as a stopgap measure, prompting domestic automakers and other industries reliant on the critical mineral supply chain to stockpile these commodities ahead of any potential future interruptions to imports.

With so much uncertainty surrounding global critical minerals markets, it is perhaps no surprise that the metals and mining industries have been cautious with their investments in the United States, despite rising prices. A sudden and lasting trade deal would be welcomed by both U.S. manufacturers and China, which could resume its exports of low-cost rare earths and maintain the powerful leverage provided by its monopoly for future use. China could use its world-class rare earth deposits and mature (state-controlled) mining industry to temporarily undercut global prices, leaving upstart miners in other countries holding the bag if they did not have guarantees from buyers providing price support into the future. This would be the worst-case scenario for the U.S. negotiating position on trade, and for its military, which relies on critical minerals to produce its numerous defense systems that incorporate advanced technologies. For these reasons, there has been consistent bipartisan support in Washington for addressing this national strategic vulnerability by encouraging new domestic mining. In July, the Defense Department took a significant step in signaling federal support for American miners by acquiring a 15% stake in MP Materials, which operates the country's only major rare earth mine at Mountain Pass, CA (Onstad, 2025). Part of the agreement includes guaranteed minimum prices.

The Mountain Pass Mine produces significant quantities of the magnetic rare earths neodymium and praseodymium, but its ore contains comparatively low concentrations of the highly valued "heavy" rare earths. It also does not produce gallium and germanium, essential semiconductors for advanced microchips underpinning advancements in artificial intelligence, so the U.S. will need to develop new resources to meet the nation's needs for these elements. One such source for these specific elements could be coal (Seredin and Dai, 2012; Dai and Finkelman, 2018), but until recently, very little of the nation's coal deposits had been evaluated for these newly important tech metals.

Ten years of coal sampling (fig. 1) by the North Dakota Geological Survey (NDGS) identified two horizons of rare earth element enrichment in the Williston Basin of North Dakota, and the NDGS designed and implemented the first phase of an exploratory drilling program in the Fall of 2024 (Moxness, 2024; 2025). The two target horizons, the Bear Den Member of the Golden Valley Formation and the Rhame bed of the Slope Formation, are ancient weathering profiles. These fossil soils (paleosols) formed as acidic waters infiltrated downward and weathered thick sequences of

FIGURE 1. NDGS geologists sample the base of the Bear Den Member in northwestern Morton County. A sample of this thin lignite contained 4,443 parts per million of rare earth elements on a dry coal basis and 1.57% rare earth oxides on an ash basis, the highest yet reported from North Dakota.

smectitic claystones to kaolinite. Rare earth elements and other mobile elements were leached from upper portions of the weathering profile and concentrated in the strata immediately below, especially lignites where they are present. The scope of the NDGS exploration program involved drilling 50 holes to help map these zones across the southwestern quarter of the state, and document whether any underlying lignite seams became thick enough and enriched enough to be commercially viable as critical mineral ores.

TOOLS FOR CHARACTERIZATION

The easiest way to demonstrate that lignites below these two horizons can be an economic source of critical minerals is to find and describe the thickest, most enriched coal seam in the basin. Considering these two horizons occur within reasonable mining depths over an area of approximately 1,700 square miles in southwestern North Dakota, finding that exact location with just a 50-hole exploration program would require a considerable amount of luck. Fortunately, by quantifying the total amount of rare earth elements and other critical minerals which have moved within a given profile, and by documenting the amount that thinner lignites incorporate based on their position within it, we are able to put together a reasonable picture of what the economics of such a seam will look like before we, or industry, discover it.

The exact position of a lignite (rare earth host rock) in relation to the overlying kaolinitic claystone (rare earth source rock) appears to be very important in controlling the total amount of rare earth elements that are incorporated by the lignite. Characterizing this spatial relationship would constrain the stratigraphic window for more precise exploration and point to an optimal position where a lignite would become the most enriched. Field observations from half-eroded or half-covered outcrops can provide limited information for this purpose, but core offers the opportunity to examine fresh surfaces free of modern weathering. This is especially important when attempting to quantify relative degrees of ancient weathering through a profile and its relationship to rare earth concentrations. Typically, this is done by sending core sections to a laboratory for geochemical analysis, preferably by Inductively Coupled Plasma (ICP) methods. However, analyzing dozens of elements across thousands of samples would be necessary to characterize multiple cores in sufficient detail, and this is not practical as ICP methods are expensive.

Fortunately, the NDGS has a portable x-ray fluorescence device (pXRF), which can provide semi-quantitative geochemical data on demand. The pXRF works by radiating a targeted location on a material, causing certain higher energy state electrons of the atoms within that material to shift to a lower energy state and emit x-rays that are characteristic of specific elements on the periodic table. The pXRF was used to collect 4,860 analyses at closely spaced intervals along the entirety of the cored intervals from 12 different holes. It is not as accurate or precise as ICP methods, and it cannot reliably detect the lanthanide rare earths; however, it does measure a broad range of elements that can be used as chemical weathering indicators (Chumley, 2025). Its accuracy varies by element and matrix composition, so some additional scrutiny is needed before inferring the weathering history of a profile via raw pXRF data (Da Silva et al., 2023).

A subset of core sections analyzed with the pXRF was also later analyzed by ICP methods, the results of which are considered the true values, to verify which pXRF measurements are reliable. Results for elements like potassium (K) show strong statistical agreement between pXRF and ICP results. This is shown in Figure 2A, where K pXRF concentrations are plotted against a 1:1 line representing their corresponding ICP concentrations. The slope of the trendline through the K pXRF data is nearly identical to its 1:1 line (as represented by a y value close to 1) and has a coefficient of determination (r^2) value of 0.99 (values close to 1 indicate high precision). In contrast, the trend line through the zirconium (Zr) pXRF data does not closely match its 1:1 line and has a lower r^2 value of 0.75 (fig. 2B), appearing to show matrix effects in siliceous lithologies.

The results of the ICP vs pXRF comparison do validate the pXRF measurements for several other elements of interest. Rubidium (Rb), along with K, is a highly mobile element that, when depleted, can show a claystone has been leached by

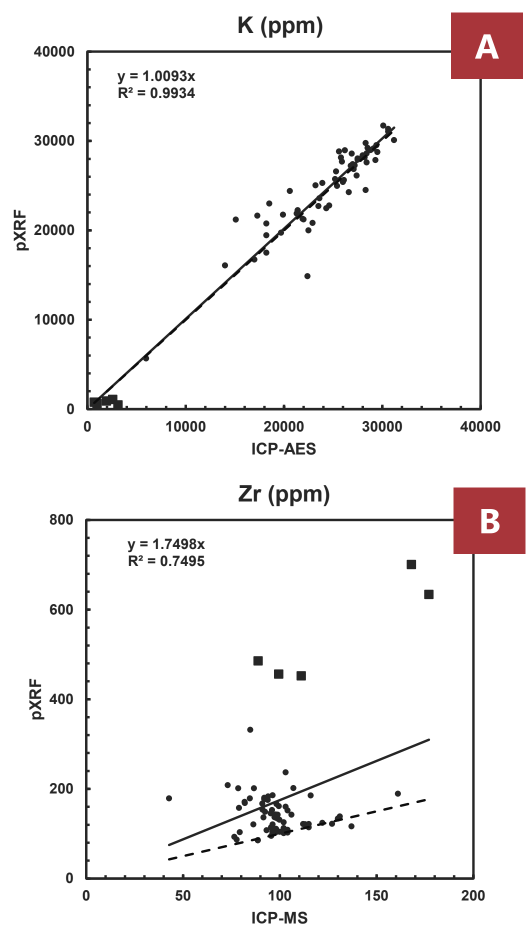

FIGURE 2. Plots of pXRF concentrations for K (A) and Zr (B) against those obtained thorough ICP methods. The solid line represents the trendline of the pXRF data, and the dotted line represents the 1:1 line, which corresponds to the true ICP concentrations. Results for K show close agreement between methods but pXRF concentrations for Zr are overestimated, especially in samples of silcrete (squares).

acidic soil waters (Nesbitt and Markovics, 1997). Yttrium (Y), which is one of the rare earth elements, and zinc (Zn) also leach from the weathering zone, but instead of leaving the profile, these elements appear to reprecipitate just below the weathering zone. Titanium (Ti) and niobium (Nb) are comparatively immobile. Because they stay in place as other elements leach away, they are residually enriched in the weathering zone and provide context on whether low concentrations of other elements are due to weathering or are a product of lithology (e.g., dilution by quartz-rich grains of silt and sand). Once armed with confidence in the pXRF's ability to detect these elements, it becomes an incredibly powerful tool for NDGS geologists, efficiently providing granular information about where enrichment occurs, how thick the enriched zone is, and where it developed in relation to overlying weathering.

NEW INSIGHTS FROM CLAYSTONES

Although enriched coals below the Bear Den Member and Rhame bed are the ultimate target, the most informative look at how rare earths are typically distributed at depth would be from a core without any lignites. Core 28, collected in northern Hettinger County, contained a thick sequence of bright white Bear Den kaolinite (frequently stained orange by iron oxides) which transitioned to darker gray claystone below without any primary organic beds to preferentially uptake rare earths. Analyses every inch or so along the core show significant depletion in Rb, K, Y, and Zn, and residual enrichment in Ti and Nb, starting at the top of the weathering profile at 17 ft depth (fig. 3). Concentrations trend back towards normal by a depth of 35 ft, except Y and Zn, which first show zones where they are enriched before returning to normal.

The detailed geochemical profile reveals a classic weathering zone, characterized by nearly 20 feet of light-colored clay, corresponding to zones of mobile element depletion. However, the underlying enrichment zone was narrower than expected. A few samples of gray claystone below the Bear Den kaolinite had previously shown slight rare earth enrichment, so it was assumed that rare earths were broadly distributed over the underlying 10 to 15 feet of claystone when no lignite was present to “catch” them. Instead, Core 28 showed a much more concentrated spike in rare earths within the five feet just below the color change from white to gray. Ten consecutive feet of core were submitted for ICP-MS analysis to confirm the pXRF readings, which showed 60 continuous inches of claystone exceeded 300 ppm of rare earth elements, averaging 715 ppm over that interval, with

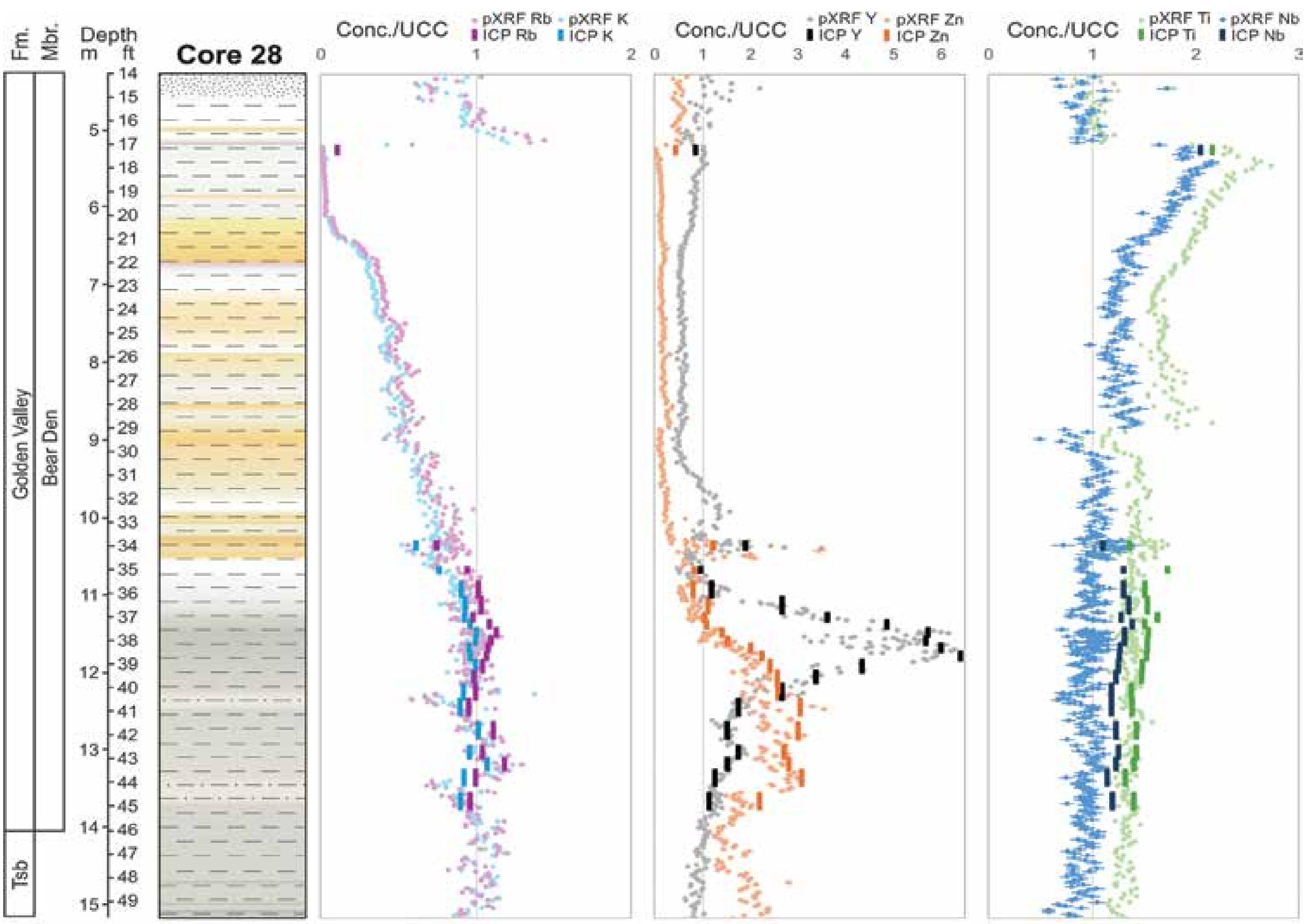

FIGURE 3. Concentrations for mobile (Rb, K), intermediate mobility (Zn, Y), and immobile (Nb, Ti) elements through the Bear Den Member in Core 28. Concentrations are normalized to upper continental crust (UCC) values of McLennan (2001), where values below 1 indicate depletion; above 1 indicate enrichment. ICP analyses (vertical bars) provide context for the accuracy of pXRF measurements (dots).

one sample reaching 1,233 ppm. Claystones at that grade approach those mined in South China, which supply most of the world's heavy rare earths, albeit in much thicker deposits.

Mudstones and claystones in the Fort Union Group are dominated by illite and smectite, except where these clay minerals were altered to their weathering product, kaolinite. Clechenko et al. (2006) reported an abrupt transition from kaolinite to smectite at the base of the Bear Den Member in a series of samples analyzed via X-ray diffraction (XRD) from Farmer's Butte in Morton County. Clechenko et al. were studying the climate event that formed the Bear Den, not rare earth elements, so the NDGS also submitted samples from Core 28 for XRD analysis to establish where the kaolinite-smectite transition occurs in relation to the "spike" in rare earths. Figure 4 shows that elevated rare earth concentrations appear to coincide with the first smectites at the base of the weathering profile, not the lowermost kaolinite like the deposits of South China. This raises interesting questions on how rare earth cations are bound within these claystones and whether they are similarly easy to commercially recover via ion exchange. Regardless of their ultimate economic prospects, the distribution of rare earths within these intervals of claystone has implications for the amount of enrichment that can be expected when this position is occupied by a lignite, a lithology where the extraction economics are much better understood.

HONING IN ON LIGNITE TARGETS

Now that we know most of the rare earths that leached from these weathering profiles can precipitate immediately into the claystones below, it explains why lignites on the margins of this enrichment window can contain widely variable concentrations. This was evidenced by a lignite encountered in Core 20, which was positioned just a few feet below the Bear Den kaolinite and was highly enriched in rare earth elements (fig. 5). This same lignite was cored again a half mile away (Core 21), where it appeared to occur in roughly the same position relative to the overlying kaolinite but contained roughly one quarter of the rare earth content that

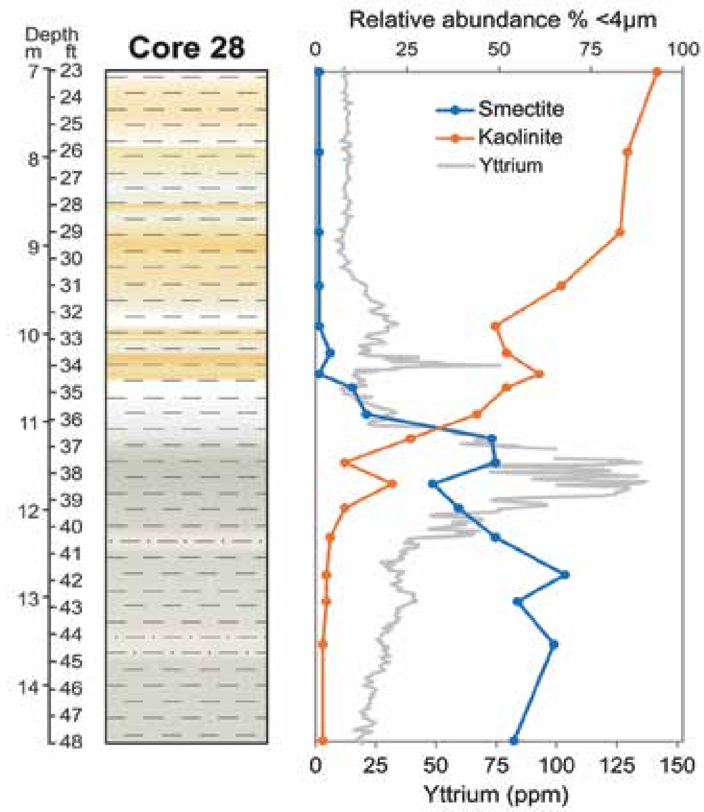

FIGURE 4. Concentrations for the rare earth element yttrium (measured via pXRF) plotted alongside the relative abundances of clay minerals smectite and kaolinite kaolinite (measured via XRD).

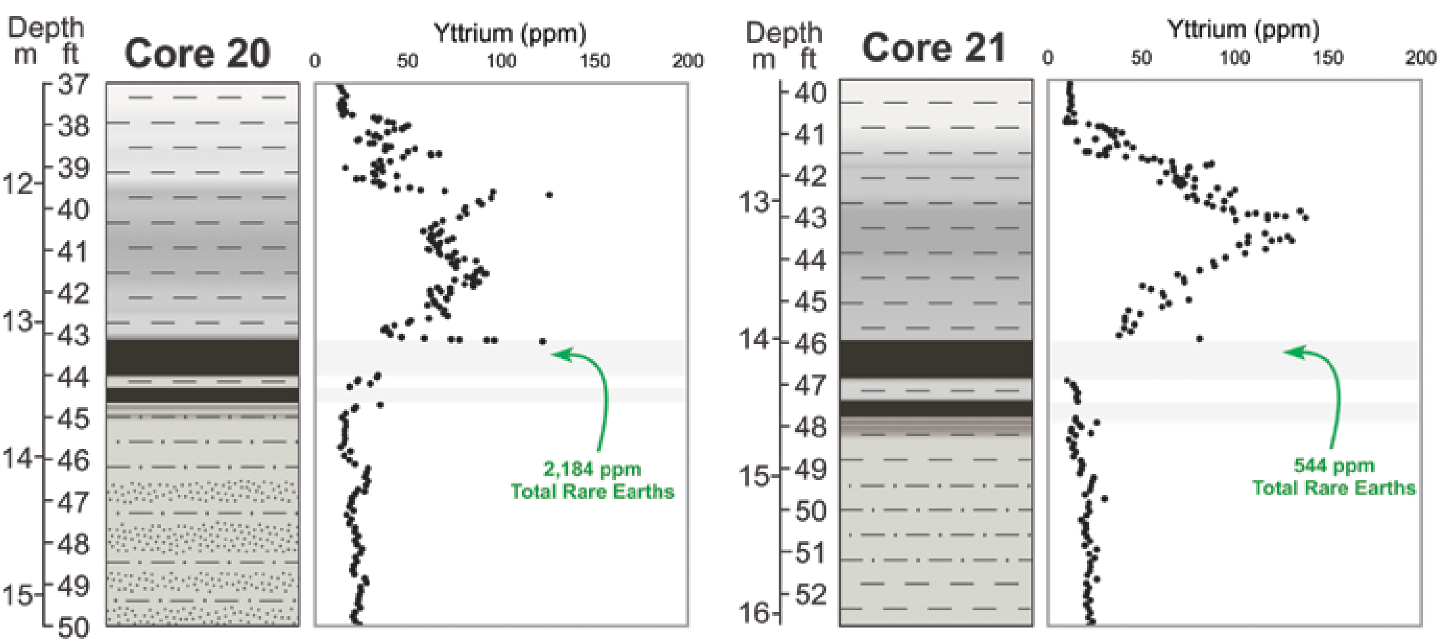

FIGURE 5. Yttrium concentrations from two cores of the same stratigraphic interval, 0.57 miles (0.92 km) apart in northwestern Morton County. The light-colored claystone at the top of each core represents the basal kaolinite of the Bear Den Member. Samples of the lignites (gray bars) were submitted for ICP-MS immediately after recovery and thus weren't available for pXRF analysis, but sample results show that rare earth element concentrations at the top of the lignite (in green) can vary significantly over short distances.

it did in the first hole. Detailed pXRF profiles through the overlying claystone hint as to why (fig. 5). The overlying five feet of claystone contained 20% more yttrium in Core 21, suggesting significantly less rare earth content reached the lignite below.

It's hard to say without additional study why the claystones took up more of the rare earths in Core 21 than Core 20. Maybe the kaolinite-smectite transition was more gradual or deeper in Core 20, or perhaps it contains subtly more silt content, leaving fewer clay surfaces for rare earth cations to adsorb to. Or maybe the rare earths are not bound to clay surfaces at all, and are instead controlled by the presence or absence of secondary organics that are finely disseminated within the claystones. Whichever the case, it is apparent the lignites in Cores 20 and 21 would have been more enriched if they occurred a few feet higher in the profile. Lignite stringers exposed in surrounding outcrops occur in just such a position, and samples submitted for ICP-MS analysis showed they are capable of incorporating as much as 4,443 ppm of total rare earth element content (dry coal basis, including Y and Sc).

Although extremely enriched, the lignites within this narrow stratigraphic window of enrichment in the Hebron area were thin. Since the start of the project, the goal of the NDGS has been to find "promising" rare earth grades of 300 ppm within a seam that is thick enough to be conventionally mined, preferably five feet or more. Equivalent total amounts have been found in thin lignites. A seam below the Rhame bed in Slope County, only ten inches thick but with average rare earth concentrations of 2,194 ppm, contains the same total rare earth content as would a 6-foot-thick lignite at 300 ppm. But these thin lignites often pinch out laterally and are not realistic mining targets. Further, because this thin lignite was highly enriched, top to bottom, it's likely it could have incorporated even more rare earth content had it been thicker. The drilling project was designed to find thick lignites in the optimal position to receive the most enrichment, which we now know is directly below the kaolinite as it first starts to transition to smectite at depth. A thick enough lignite in this position could theoretically incorporate all of the descending rare earth cations and is far more likely to be laterally continuous. Based on the total rare earth content observed to have mobilized in Cores 20, 21, 28, and others, a perfectly-positioned lignite could likely average 1,000 ppm of total rare earth elements across a thickness of more than three feet (fig. 6).

Last Fall's drilling by the NDGS did not encounter just such a lignite, but it may have come very close in the last hole of the project. Core 2 encountered the Bear Den at a depth of around 80 feet in northwestern Mercer County. Gravel collapsing downhole prevented the recovery of a complete profile, but a five-foot-thick carbonaceous zone was recovered starting at a depth of about 95 feet. This zone, roughly half lignite and half carbonaceous claystone (fig. 7), averaged 716 ppm of total rare earth elements over its 58.3-inch thickness, equivalent to 11.6 feet of lignite averaging 300 ppm. Gallium and germanium were also elevated, averaging 18 ppm and 12 ppm, respectively, on a dry coal basis.

Although much of the benefit of lignite as a rare earth ore is that extraction is relatively easy from raw (non-combusted) feedstocks (Laudal et al., 2018), it is noteworthy that Seredin and Dai (2012) proposed 0.1% rare earth oxides as an economic cutoff grade for coal ash. The upper 22.4 inches of enriched lignite from Core 2 averaged 0.85% rare earth oxides on an ash basis, with several samples exceeding 1%, as did intervals from several other cores recovered during the project.

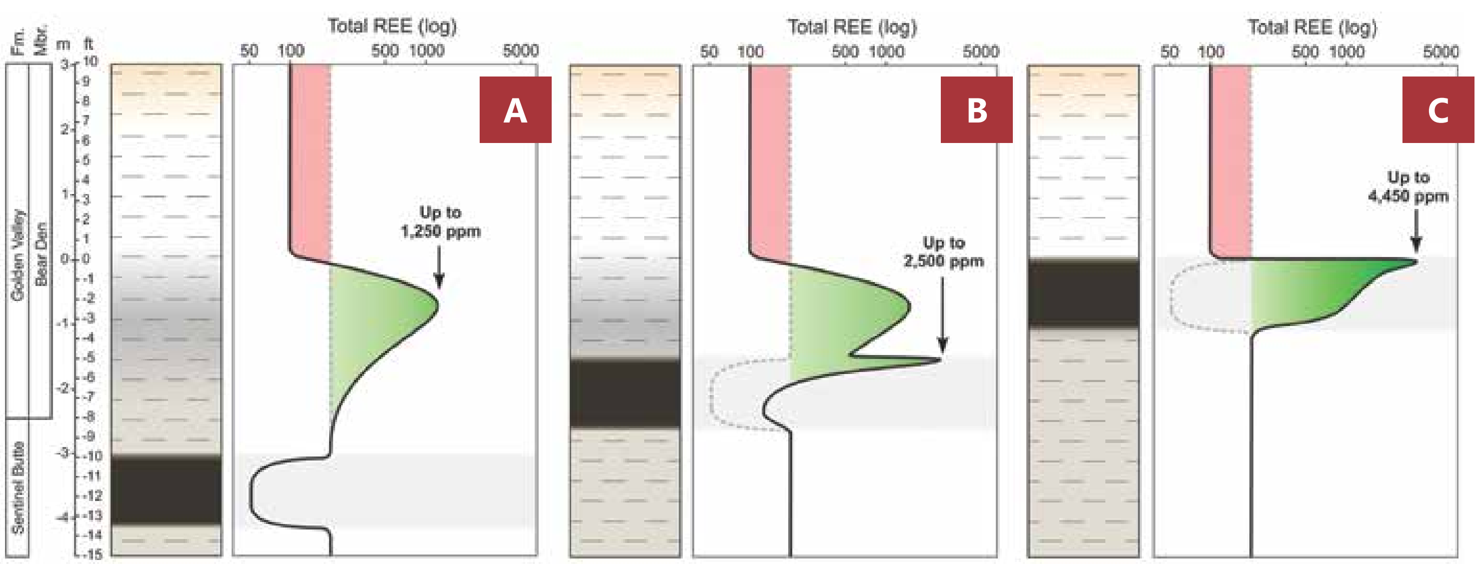

FIGURE 6. Generalized enrichment model for the Bear Den Member illustrating the theoretical total rare earth element (REE) concentrations for a 3.3-foot (1 meter) thick lignite at different depths relative to the kaolinite. A lignite 10 feet below (A) may not receive any of the descending REE content if it is sorbed within the overlying claystones. Coal, formed mostly from plant material, normally does not contain REE-bearing minerals, and contains very low REE content unless exposed to enriched fluids. A lignite 5 feet below the kaolinite (B) may become REE-enriched in its upper few inches, but lower portions of the seam are not as enriched as much of the REE content is still within overlying claystones. A lignite at the base of the kaolinite has the potential to preferentially incorporate all of the mobilized REE into its organics over just a few feet.

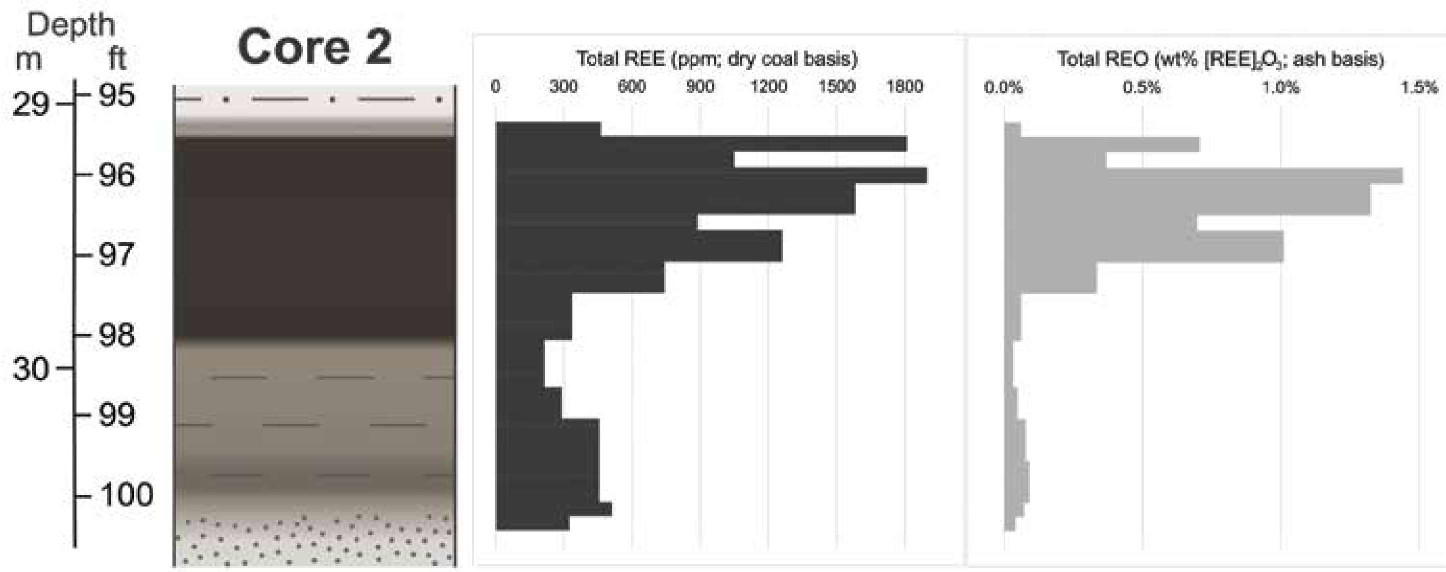

FIGURE 7. Rare earth element concentrations determined from 15 continuous samples submitted for ICP-MS from Core 2 in Mercer County. Dry coal basis samples are shown at left and ash basis oxide concentrations are at right. Both totals include Y and Sc.

Over the course of the drilling project, rare earth enrichment or kaolinitic source beds were successfully identified at 35 of the 53 drill sites, demonstrating to industry that these horizons can be predictably encountered in the subsurface and explored via drilling. Cores from Adams, Dunn, Mercer, Morton, Hettinger, and Stark counties expand known enrichment to west-central North Dakota, an area over which these zones were previously very poorly characterized. The lignite recovered in Core 2 roughly doubles the maximum overall grade and thickness of REE enrichment previously reported from the state.

Only one core (Core 2) was collected from the thick, highly enriched lignite encountered near the base of the Bear Den Member at the end of the project in Mercer County, so it isn't yet known if its thickness and concentrations are consistent over a large area. Results from the Rhame bed in Adams County were promising in that regard, where two lignites separated by 10 feet of siltstone contained similar thicknesses and levels of enrichment in two holes a half mile apart. The combined thickness and rare earth grades of the two lignites in each hole (60 inches at 531 ppm in Core 38 and 52 inches at 639 ppm in Core 38B) show that the Rhame bed may be just as promising as the Bear Den, although pXRF profiles from the first few cores of the Rhame bed may point to a distinct enrichment model. For more discussion on the Rhame bed, exploration, delineating the enrichment zones, and the rest of the results from the drilling project, see NDGS Report of Investigation RI-137 (Moxness et al., 2025). The NDGS was allocated funds for the 2025-2027 biennium to follow up on initial promising results and via a second phase of drilling, so look for future Geo News articles to provide new, needed details on the rare earth enrichment below the Rhame bed and the lateral extent of these potentially economic lignites.

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INCREASING THE ACCESSIBILITY OF CORE ANALYSIS DATA WITH ARTIFICIAL INTELLIGENCE

BY TED STARNS (NDGS) AND DAMIEN PARRELLO (UND)

"**Core is the only direct means of examining subsurface formations.** Logs, tracers, and well tests are invaluable, but they are all indirect indicators of formation characteristics and properties. The true worth of a reservoir can only be assessed with core."

— **Lee E. Whitebay**, CONOCO Wellsite Manual Series, Coring and Fracture Detection, 1992

A core is a cylinder of rock that is taken from depth and brought to the surface, where it can be observed, analyzed, and interpreted for critical understanding of the subsurface. One of the purposes of the effort and expense of retrieving a core from the subsurface is to evaluate the porosity and permeability of the rock at depth, where oil and gas are found, and where fluids can be injected for storage. Porosity, a measure of the amount of void space, is a way to assess the storage capacity. Permeability, a measure of the ability of fluids to flow through a rock, is a way to assess how quickly fluids can flow into a wellbore or be injected into the subsurface. An important part of the analysis of cores is the measurement of rock properties: principal among them include porosity, permeability, and fluid saturations of oil and/or water. Most of these properties can be measured with remote sensing techniques (i.e., geophysical well logs), but permeability, for example, can only be quantified via the analysis of core samples. The North Dakota Oil and Gas Division manages records of over 4,000 cored wells. Within these records are data describing rock properties generated from the laboratory analysis of the core, where analyzed and submitted. Most data acquired by operators and submitted to the State of North Dakota is in the form of Portable

Damien Parrello (UND, left) and Ted Starns (NDGS, right).

Document Format (PDF) files that are incorporated into individual well files. These well files contain an abundance of geological and operational data related to the wells and are accessible to the public. A limitation of these data is that to analyze or display them in another program, they must be converted to another form (e.g., an Excel spreadsheet). To convert to digital form, the individual must either hand-key or utilize other text recognition software to convert the data piecemeal. Image quality often hampers the use of text recognition plug-ins available with common PDF viewers, and automation can be slower, and/or less reliable, than the human eye coupled with manual entry.

The North Dakota Geological Survey, in collaboration with the University of North Dakota (UND), is nearing completion of a significant effort to convert legacy geological data stored in scanned PDF files into modern accessible digital formats using artificial intelligence (AI). Dr. Damien Parrello from UND has been instrumental in developing an AI-based analysis pipeline that automatically identifies and extracts core analysis data from the aforementioned 4,000 cored well PDF files (~370,000 pages), with records dating back to 1951. Older documents—created with typewriters and later Xeroxed before being scanned into PDFs—are the most abundant and pose significant challenges due to their poor legibility, including the potential for hand-keying errors and the significant time required for manual transcription. Dr. Parrello's pipeline addresses these issues using state-of-the-art Optical Character Recognition (OCR), a specialized AI technology designed to extract text from images - whether printed or handwritten (fig. 1).

Once completed, these digitized data will be made publicly available through the Premium Services section of the North Dakota Oil and Gas Division website. This initiative not only preserves valuable historical records but also enhances their accessibility and usability with current technologies.

One of the many strengths of the State of North Dakota lies not only in its rich natural resources but also in the wealth of publicly accessible data. Enhancing the utility and accessibility of this data through efforts like these promotes the responsible and efficient use of resources, benefiting the State of North Dakota and all its stakeholders.

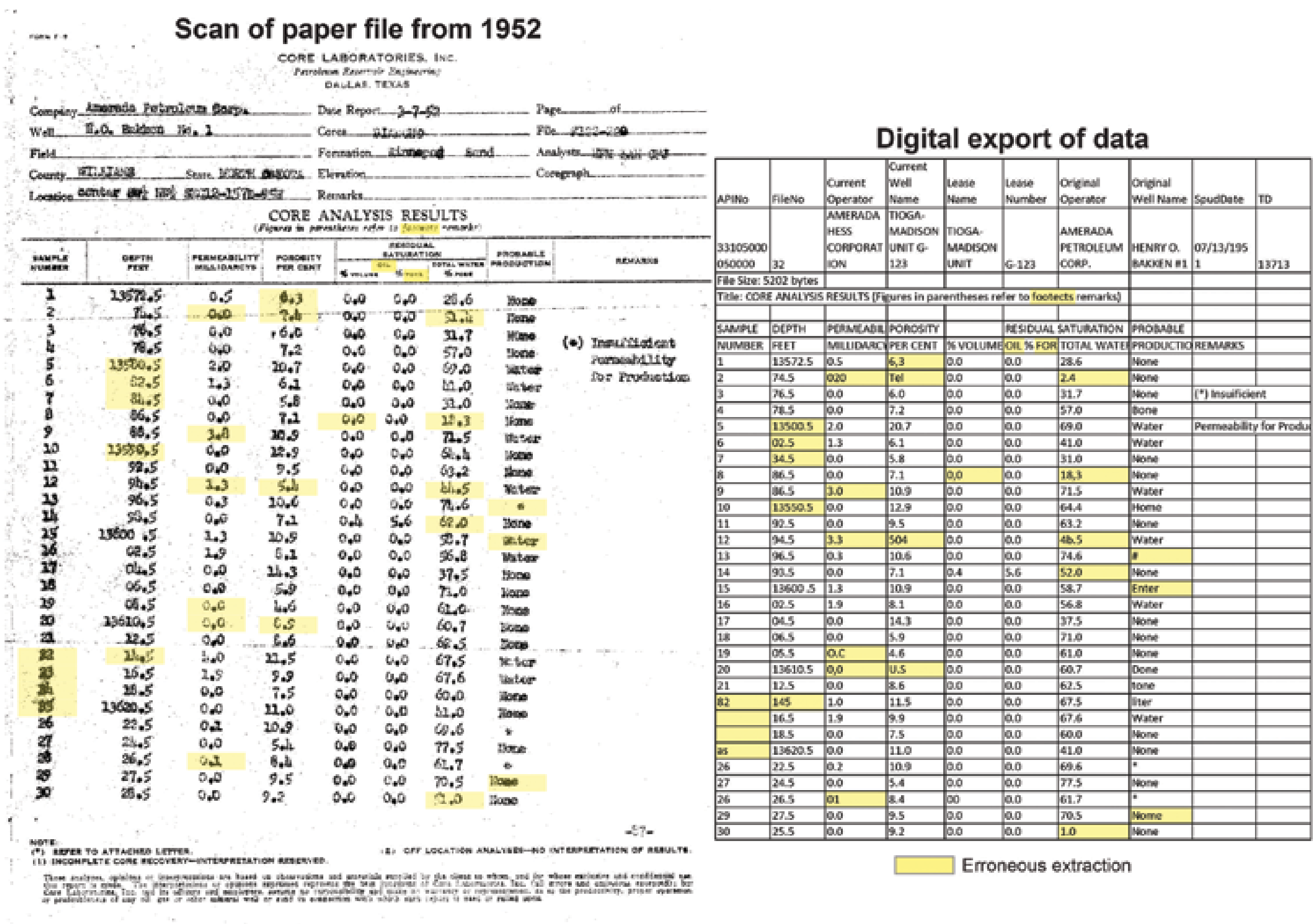

FIGURE 1. Example of the extraction of core analysis data from the Henry O. Bakken well, drilled in 1951-1952. This figure demonstrates both the low-quality images of some available core analysis records and the capability of the AI method to extract data from challenging files. Although some minor errors remain (highlighted in yellow), the time required to manually correct or omit problematic data is only a fraction of that needed for full manual data entry.

Providing a Home for Orphaned Fossil Collections

BY CLINT A. BOYD

The North Dakota State Fossil Collection was initially started to ensure that a portion of the fossils collected from the badlands, fields, streambanks, and roadcuts across North Dakota remained in the state to be placed on display for the people of North Dakota to view and enjoy, as well as to support teaching and research activities. One of the main ways the NDGS paleontology program fulfills that duty is by locating and collecting fossils across the state, especially through our Public Fossil Dig Program. However, another key role played by the North Dakota State Fossil Collection is to serve as a home for paleontology and geology collections that can no longer be supported or maintained by other institutions. In a previous issue, we discussed a large collection of over 4,000 fossil plant specimens previously collected from a site near Almont, North Dakota that preserves one of the most diverse Paleocene floras in North America. That collection was transferred from the University of Wisconsin-Stevens Point geology museum to our collection in 2022 (Boyd, 2023). This year, we have taken in two more collections in need of new homes, both of which include scientifically significant specimens.

CONCORDIA COLLEGE FOSSIL COLLECTION

In 2016, the NDGS Paleontology program signed an agreement with Concordia College to provide a permanent home for their paleontology collection, consisting largely of Jurassic and Cretaceous dinosaur fossils from the western United States. These fossils were assembled over the last thirty years by students and volunteers working under the supervision of biology professor Ron Nellermoe (now retired). Over 2,000 dinosaur bones were transferred at that time (fig. 1), but several hundred bones remained at Concordia College to support ongoing research and teaching efforts. This past spring, we were notified that it was time to transfer the remainder of the collection into our care. This was done in April, and NDGS paleontologists are currently working to sort and catalog this last batch of fossils from that collection. The majority of the fossils transferred from the Concordia College paleontology collection were collected from a single site in the Hell Creek Formation of Corson County, South Dakota: the Standing Rock Hadrosaur Site. The site is roughly 15 miles from the North Dakota border.

FIGURE 1. Ron Nellermoe (left) shows part of the Concordia College Fossil Collection to NDGS paleontologist Clint Boyd in 2016 during the initial transfer of specimens to the North Dakota State Fossil Collection.

Concordia College: Standing Rock Hadrosaur Site

This site preserves a mass death accumulation of dinosaur fossils from the Late Cretaceous Hell Creek Formation, most of which are from the duck-billed dinosaur *Edmontosaurus annectens*. The first expeditions to the site took place in 1993 and continued for more than a decade, resulting in the collection of thousands of dinosaur bones from at least 44 different individuals of *E. annectens*, spanning a wide range of ages from early juveniles to full adults (Ullmann et al., 2017). To date, this site is the best documented bonebed of *E. annectens* fossils, providing important insights into the anatomy, growth, and death of these animals, as well as providing important insights into the depositional conditions that result in the accumulation and fossilization of these mass death sites. The fossils at this site are exquisitely preserved, including the preservation of microscopic soft tissues within the bones (Ullmann et al., 2019). This collection is a critical resource for paleontologists seeking to learn more about the anatomy and life of *E. annectens* (fig. 2), as well as those studying the fossilization conditions required to produce exceptional preservation in dinosaur fossils. The latter fact makes them an important resource for NDGS paleontologists studying our own exceptionally preserved dinosaur: Dakota the Dinomummy.

FIGURE 2. Drawers of well-preserved individual skull bones from the hadrosaurid dinosaur *Edmontosaurus annectens* collected from the Standing Rock Hadrosaur Site stored at Concordia College prior to their transfer to the North Dakota State Fossil Collection.

FIGURE 3. NDGS paleontologists Clint Boyd (left) and Cathy Lash (right) and fossil preparator Trissa Ford (center) remove specimens from the geology display cases in Sugihara Hall on the NDSU campus and carefully pack them for transfer to Bismarck.

NORTH DAKOTA STATE UNIVERSITY GEOLOGY COLLECTION

In 2023, North Dakota State University announced it was closing down its geology program. The program was slowly shut down over the next two years, officially ending in December of 2024. Upon the closure of the department, plans began for reassigning space in Sugihara Hall to other programs. This raised the question of what would happen to the geology collection that had been assembled over the decades by geology faculty and students during research trips and student field trips. Negotiations between NDSU and the NDGS paleontology program culminated in an agreement for NDGS to transfer the existing geology collection, which includes a large paleontology collection, to Bismarck on loan. Under that agreement, NDGS paleontologists will compile an inventory of the collection over the next year and submit it to NDSU for review. Staff at NDSU will then review the inventory and determine which specimens are still needed on campus, which specimens will remain on long-term loan to NDGS, and what portions can be permanently transferred to NDGS for care. This process ensured the collection could be moved quickly out of Sugihara Hall (figs. 3-4) without NDSU worrying about permanently transferring specimens that might still be useful for teaching or research purposes on campus. This collection contains many scientifically significant specimens, a few of which are reviewed below.

NDSU Collection: Zap Bison Skulls

In 1963, a drag-line shovel operator working near Zap, North Dakota (Mercer County) recovered a bison skull at a depth of 20 feet below the surface. The specimen was brought to the Department of Geology at North Dakota State University for identification, prompting geology professor John Brophy to return to the site in 1964. While collecting stratigraphic data at the site, he uncovered a second bison skull and some wood from the same interval. The second skull was more complete than the first but had smaller horn cores and differed a bit in morphology from the first specimen.

Measurements of the first skull supported the tentative referral of the specimen to the extinct species *Bison crassicornis* (Brophy, 1965), which is now synonymized with *Bison priscus*, the Steppe Bison. This makes that specimen the first and, to date, the only specimen of *Bison priscus* recovered from North Dakota (fig. 5). A radiometric date obtained from the wood found with the second skull yielded a date of 5,440

FIGURE 4. NDGS paleontologists Cathy Lash (left), Jeff Person (upper right), and Clint Boyd (lower right) pose with one of the fully packed moving trucks containing part of the NDSU Geology Collection.

FIGURE 5. The skull referred to *Bison priscus* discovered near Zap, ND, in 1963 and described by John Brophy in 1965. Scale bar equals four inches.

years before present (Brophy, 1965), which is surprisingly young for *Bison priscus*. However, a well-preserved specimen of *Bison priscus* was recently reported from Canada that also dates to ~5,440 years before present (Zazula et al., 2017), supporting the persistence of this species in North America into the middle Holocene. Thus, these bison skulls provide us with important information regarding the persistence of bison species in North Dakota after the last glacial maximum.

NDSU Collection: Ransom County Mosasaur

In September of 1974, a geology field trip led by John Brophy discovered several mosasaur bones eroding from exposures of the Niobrara Formation on a road cut in northwestern Ransom County, North Dakota (Brophy, 1975). Several hundred bone fragments were recovered, including parts of at least 20 teeth, parts of both quadrates (a skull bone that forms the jaw joint and part of the inner ear), seven vertebrae, six phalanges from the paddles, and eight rib fragments. At that time, very few discoveries of mosasaur fossils were known from North Dakota, and this specimen represented one of the most complete specimens known from the state. Comparisons to mosasaur species known at that time allowed Dr. Brophy to narrow down the identification to either *Clidastes* or *Platecarpus*, both of which are relatively small-bodied species, typically less than 15 feet in total body length. Unfortunately, the specimen was too incomplete to make a definitive identification on its own.t

In 2016, an individual riding their bike on the hiking trails in the Pembina Gorge State Recreation Area in Cavalier County, North Dakota noticed some bones weathering out of a small hill along the trail. NDGS paleontologists were notified and investigated the site, recovering a quadrate and several vertebrae from rocks of the Niobrara Formation. The newly collected quadrate was more completely preserved than the NDSU specimen, but otherwise the two specimens are very morphologically similar, suggesting they represent the same species. This new specimen allowed for a confident referral of both specimens to *Platecarpus* (fig. 6), confirming the presence of this mosasaur in North Dakota during the Late Cretaceous and helping to solve the riddle of the Ransom County mosasaur. The Ransom County mosasaur still remains the most complete mosasaur specimen from the Niobrara Formation of North Dakota according to our records.

FUTURE COLLECTION MOVES

Work on organizing and inventorying the material transferred from Concordia College and North Dakota State University will continue over the next year. At the same time, the NDGS Paleontology Program is preparing to undertake an even larger collection move beginning this fall. This past spring, an agreement was reached between the NDGS and the Harold Hamm School of Geology & Geological Engineering at the University of North Dakota to work collaboratively to organize and assess the department's paleontology collections, with the ultimate goal of incorporating all specimens into the North Dakota State Fossil Collection. Specimens that are needed for teaching or research purposes will remain in Grand Forks, but the remainder of the collection will be transferred to Bismarck for long-term curation and storage. The size of the UND collection far exceeds any of the other collections we have accepted over the past decade, and it will likely take several years before the process of reviewing and transferring the collection is completed. However, given the historical connection between the UND geology program and the North Dakota Geological Survey, we are excited about the prospect of incorporating many of the first fossils collected in the state by early NDGS staff into the North Dakota State Fossil Collection.

FIGURE 6. The partial quadrate of the Ransom County Mosasaur (lower left inset) compared to a more complete quadrate recovered from the Niobrara Formation in Cavalier County (upper left) and a cast skull of the mosasaur *Platecarpus* (right).

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WINDBLOWN SAND IN THE WILLISTON AREA TESTED FOR PROPPANT USE

BY FRED J. ANDERSON

Recently, the oil and gas industry has shown new interest in finding proppant sand deposits in North Dakota ever closer to the heart of current oil and gas development trends in the Williston Basin (fig. 1). Recent geologic investigation by the NDGS has determined that the windblown sand deposited in the Hofflund Flats area, a fluvial terrace just north of the shoreline of Lake Sakakawea in southeastern Williams County, may be suitable for use as natural sand proppant (Table 1). This brings North Dakota's in-basin proppant sand resources even closer to the heart of Bakken oil production. Proppant sand has been supplied from sand deposits in the Denbigh and Hazen-Stanton Dunes and soon may be supplied even closer to activity from deposits in southeastern Williams County.

The sand tested from the eastern Hofflund Flats area, on ND Trust Land, is characterized as brown, moderately to well-sorted, medium to fine grained, quartz dominated, windblown sand (fig. 2). It contains 66% quartz, little clays, and is devoid of carbonates with an acid solubility value of 8% and crush factor of 6K (Table 1). It is likely that local sand suppliers will continue to investigate this area and find ways to effectively develop this emerging local proppant sand resource.

FIGURE 2. Photomicrograph of washed 40/140 (medium-very fine) windblown sand from the Hofflund Flats area.

Testing was performed by an out-of-state independent proppant testing lab and includes analysis of mineralogical and physical properties of proppants, as described in the American Petroleum Institute (API) Recommended Practice 19C (API, 2018). Details and discussion from this work can be found in NDGS Geologic Investigation No. 287.

FIGURE 1. Locations of windblown sand dunes and oil wells soon to be completed (at the time of this writing) in the Bakken.

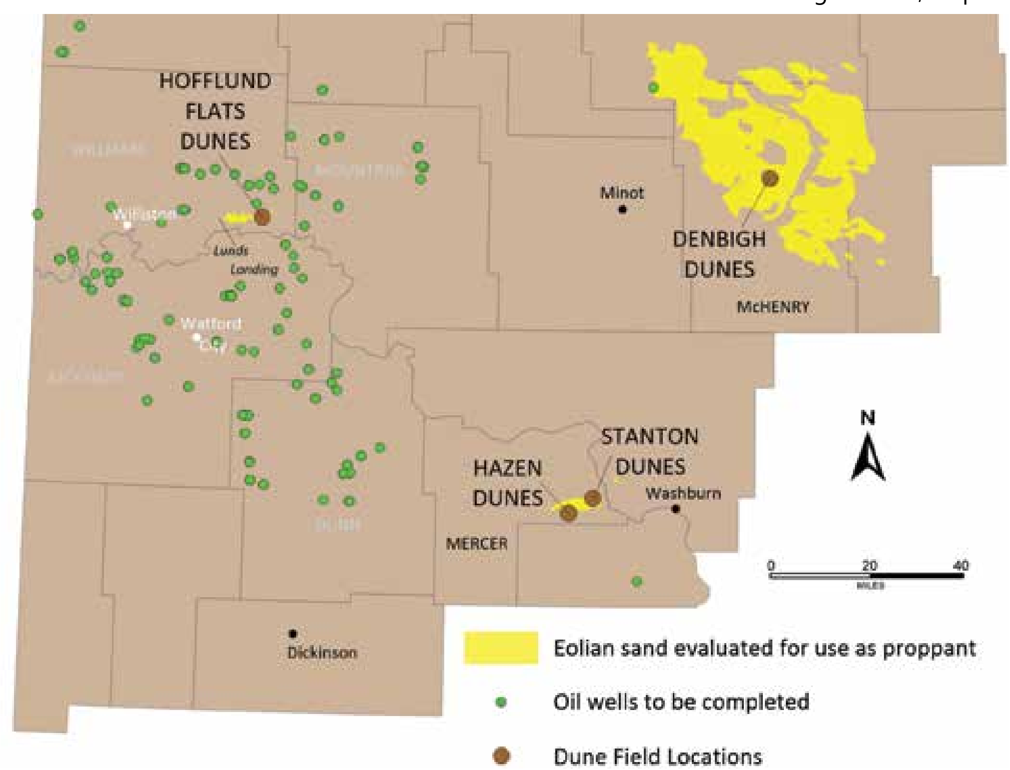

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TABLE 1. Sand Testing Summary

Sample No.	HFDTL-1
Tested Size Class[1]	40/140
Quartz Content (%)	66
Crush Resistance (K-Value)	6K
Acid Solubility (%)	5.3
Roundness	0.6
Sphericity	0.8
ISO Mean Particle Dia. (mm)	0.358
Median Particle Dia. (mm)	0.279
Turbidity (FTU)	73.9
Loss of Ignition (%)	0.7
Bulk Density (pcf)	87.3
Apparent Density (g/cm^3)	2.64

[1] washed sample

NEWPUBLICATIONS

All Survey publications (maps, posters, and reports) are available for free download from our website (https://www.dmr.nd.gov/dmr/ndgs/publications).

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LANDSLIDE MAPS - COUNTY SERIES

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LANDSLIDE MAPS - 24K SERIES

Maike, C.A., 2025, Areas of Landslides Alsen Quadrangle, ND Quadrangle: North Dakota Geological Survey 24K Map Series No. Alsn - I3.

Maike, C.A., 2025, Areas of Landslides Alsen SE Quadrangle, ND Quadrangle: North Dakota Geological Survey 24K Map Series No. Alsn SE - I3.

Maike, C.A., 2025, Areas of Landslides Belcourt Quadrangle, ND Quadrangle: North Dakota Geological Survey 24K Map Series No. Bcrt - I3.

Maike, C.A., 2025, Areas of Landslides Big Coulee Dam Quadrangle, ND Quadrangle: North Dakota Geological Survey 24K Map Series No. BgCD - I3.

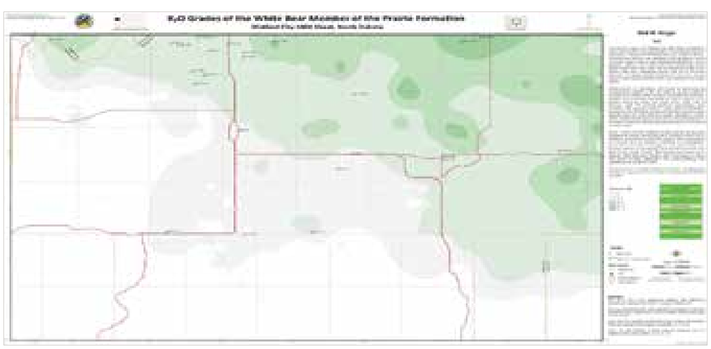
Maike, C.A., 2025, Areas of Landslides Bisbee North Quadrangle, ND Quadrangle: North Dakota Geological Survey 24K Map Series No. Bsbe N - I3.

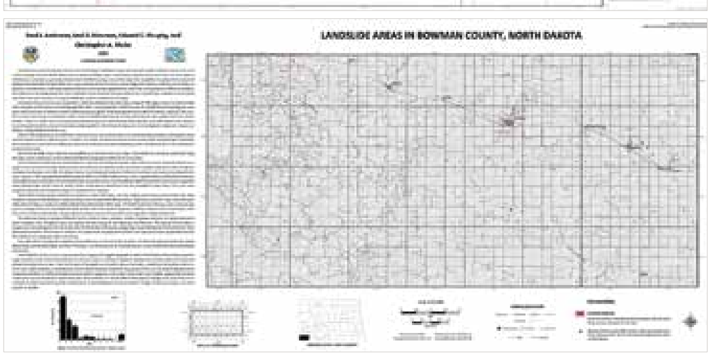
Maike, C.A., 2025, Areas of Landslides Bisbee South Quadrangle, ND Quadrangle: North Dakota Geological Survey 24K Map Series No. Bsbe S - I3.

Maike, C.A., 2025, Areas of Landslides Bucyrus Quadrangle, ND Quadrangle: North Dakota Geological Survey 24K Map Series No. Bcrs - I3.

Maike, C.A., 2025, Areas of Landslides Calio Quadrangle, ND Quadrangle: North Dakota Geological Survey 24K Map Series No. Clio - I3.

Maike, C.A., 2025, Areas of Landslides Calvin Quadrangle, ND Quadrangle: North Dakota Geological Survey 24K Map Series No. Clvn - I3.





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Maike, C.A., 2025, Areas of Landslides Cow Butte NE Quadrangle, ND Quadrangle: North Dakota Geological Survey 24K Map Series No. CowB NE - I3.

Maike, C.A., 2025, Areas of Landslides Cow Butte Quadrangle, ND Quadrangle: North Dakota Geological Survey 24K Map Series No. CowB - I3.

Maike, C.A., 2025, Areas of Landslides Egeland Quadrangle, ND Quadrangle: North Dakota Geological Survey 24K Map Series No. Egld - I3.

Maike, C.A., 2025, Areas of Landslides Egeland SE Quadrangle, ND Quadrangle: North Dakota Geological Survey 24K Map Series No. Egld SE - I3.

Maike, C.A., 2025, Areas of Landslides Egeland SW Quadrangle, ND Quadrangle: North Dakota Geological Survey 24K Map Series No. Egld SW - I3.

Maike, C.A., 2025, Areas of Landslides Hampden Quadrangle, ND Quadrangle: North Dakota Geological Survey 24K Map Series No. Hmpn - I3.

Maike, C.A., 2025, Areas of Landslides Hannah Quadrangle, ND Quadrangle: North Dakota Geological Survey 24K Map Series No. Hnnh - I3.

Maike, C.A., 2025, Areas of Landslides Hannah SE Quadrangle, ND Quadrangle: North Dakota Geological Survey 24K Map Series No. Hnnh SE - I3.

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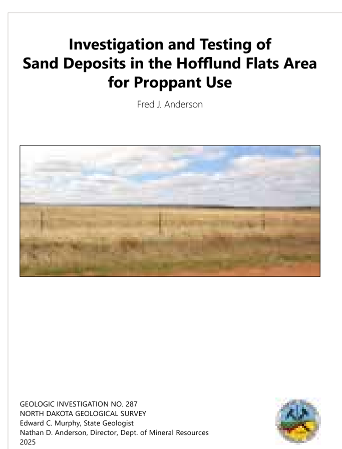

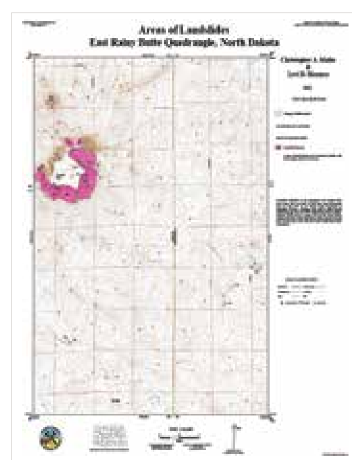

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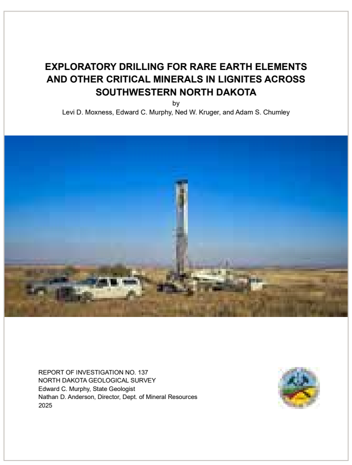

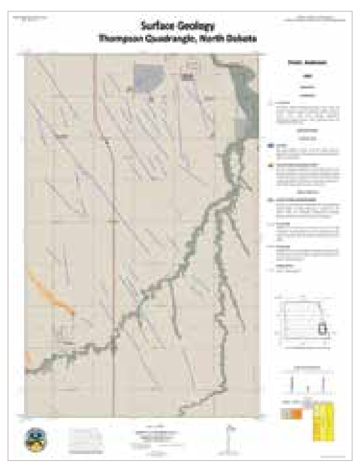

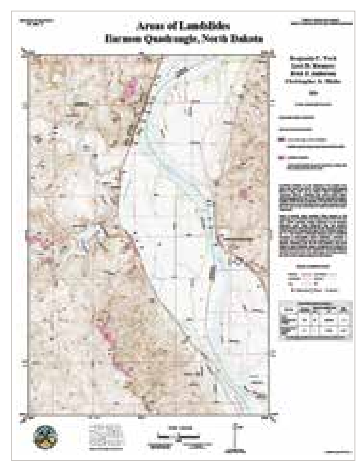

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Critical Minerals	Adam Chumley - GS
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	Ned Kruger - GS
Earth Science Education	Jeff Person† - GS
Earth Science Information Center (ESIC)	Christopher Maike - GS
Engineering Geology	Fred Anderson - GS
Geographic Information System (GIS)	Navin Thapa - GS
	Brock Wahl - OG
Geologic Hazards	Fred Anderson - GS
Geologic Mapping	Christopher Maike - GS
Glacial Geology (Sand/Gravel)	Fred Anderson - GS
Landslide Mapping	Christopher Maike - GS
Non-fuel Minerals	Ned Kruger - GS
Paleontology	Becky Barnes - GS
	Clint Boyd - GS
	Cathy Lash - GS
	Jeff Person† - GS
Petroleum Geology	Tim Nesheim* - GS
	Richard Suggs - OG
Remote Sensing (LiDAR & UAS Mapping)	Christopher Maike - GS
Sedimentary Geology (Southwestern ND)	Levi Moxness - GS
Shallow Gas	Fred Anderson - GS

Subsurface Geology/Mapping		Steve Chittick - GS
		Ismail Faruqi - GS
		Tim Nesheim* - GS
		Edward (Ted) Starns - GS
Surface Geology		Christopher Maike - GS
		Benjamin York - GS
Regulatory:	Coal Exploration	Ned Kruger - GS
	Cores and Samples	Tim Nesheim* - GS
		Richard Suggs - OG
	Geothermal Resources	Ned Kruger - GS
	Oil and Gas Permits	Todd Holweger - OG
	Paleontological Resources	Clint Boyd - GS
	Petroleum Engineering	Jared Thune - OG
	Seismic	Tom Torstenson - OG
	Subsurface Minerals	Ned Kruger - GS
	UIC Class II	Ashleigh Thiel - OG
	UIC Class III	Ned Kruger - GS
	Solid Waste Disposal	Fred Anderson - GS
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	Dickinson	Nicole Ewoniuk - OG
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