

ethane generation has been observed in the natural geologic environment in North Dakota in a variety of orthwestern North Dakota within playa lakes located in western Divide and northwestern Williams Counties es are (from north to south) North Lake, Miller Lake, Grenora #1, and Grenora #2. The lakes where g eneration has been observed have been developed on top of or within collapsed outwash. Methane generation was observed during investigations into the nature of sodium sulfate deposits in playa lakes in northwestern North Dakota in late 1996 by Murphy.



Natural Gas Generation within Playa Lakes in North Dakota •

a ring of evaporitic sodium sulfate deposits exposed along the margin of North Lake in Divide County, orth Dakota in the fall of 1995. Most of the visible salt shown here is of the anhydrous form of sodium sulfate known as thenardite. Sodium Corporation of America diked off a portion of this lake in order t hake it into a production pond to set the stage for artificial salt precipitation and extraction. These sa layers act as the capping structure which serves to retard the vertical migration of methane type gasses grating from the deeper water organic rich sediments to the water colum

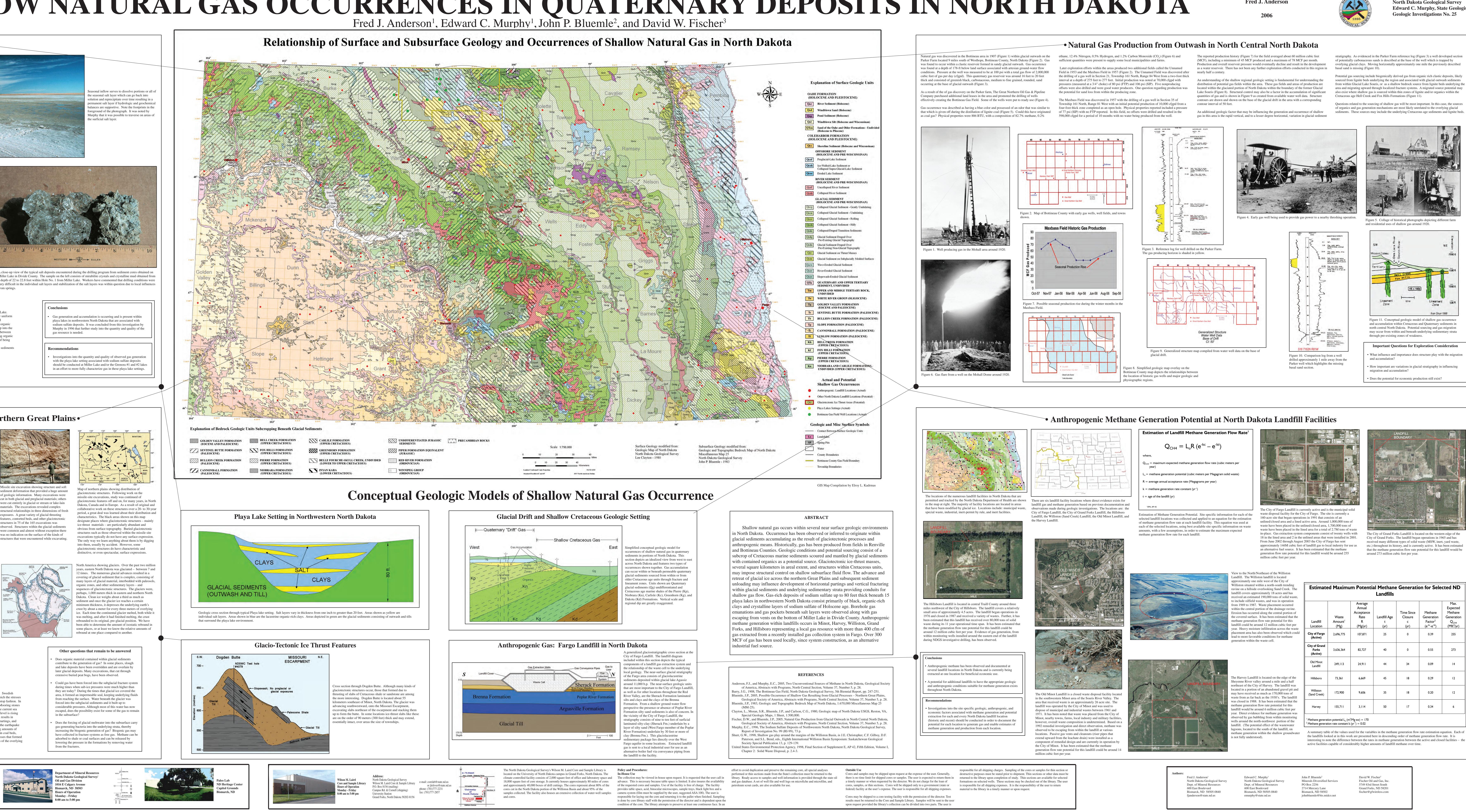


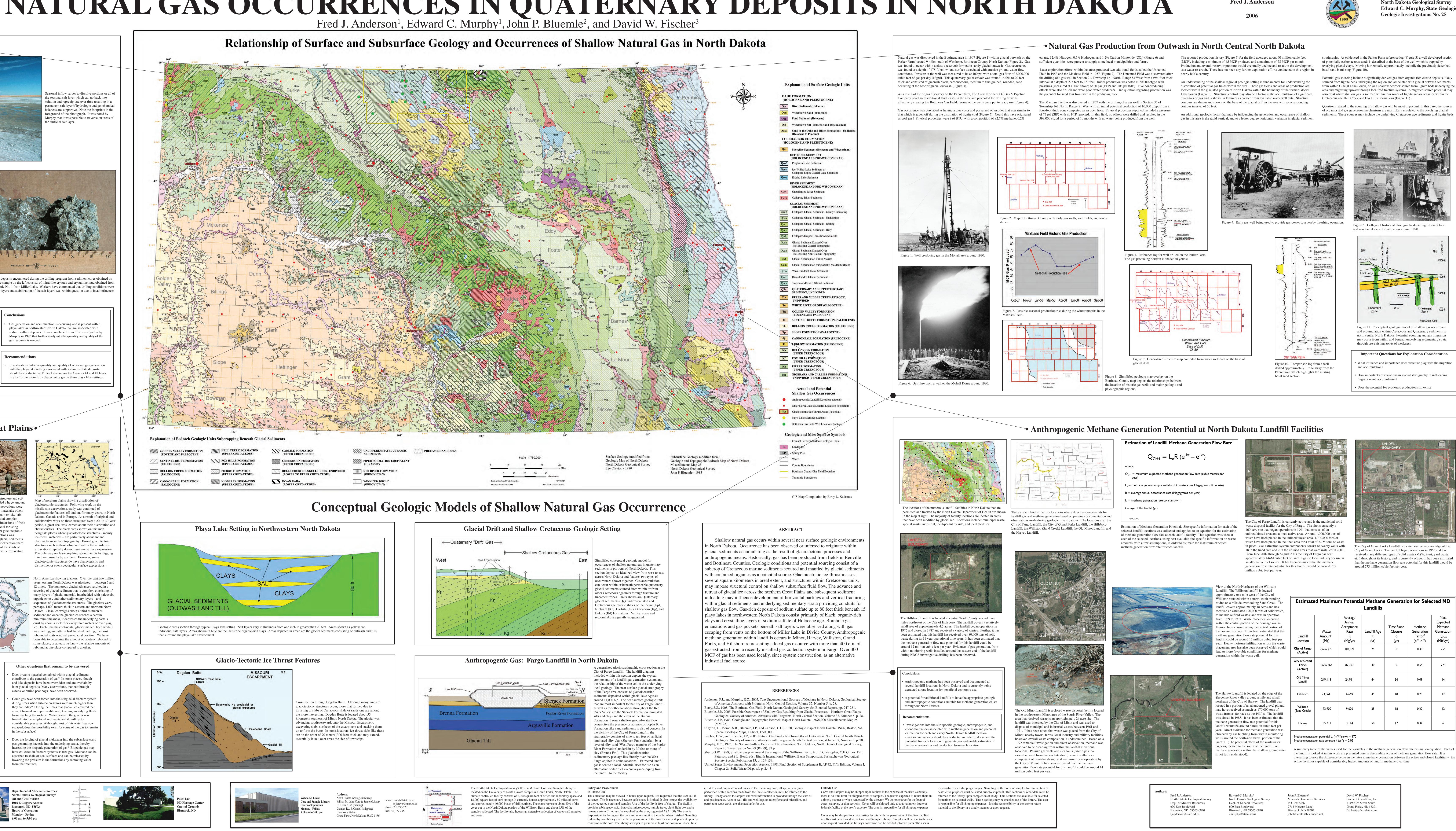




\_\_\_\_/ \_\_\_\_\_ · \_\_\_\_ \_\_\_ \_\_\_\_\_ Indurated Crystal 🔛 Slush 📃 Mud

image from Hole #2 at Miller Lake in Divide nty (24-ft hole). Bentonite pellets, used in abandonment, and mirabilite crystals are ed about in the foreground. Gas wa untered in the lacustrine clays. Gas untered in the Miller and Grenora #1 d es was perceived to be the highest in amount. ever, gas was encountered in every boreho g the drilling operation. Gas compose assumed to be that of a H<sub>2</sub>S and Meth x. Gas concentrations were greatest in the arkly colored organic-rich lake sediments ated directly beneath the crystalline salt beds. occasion, gas was observed to be emanating in the form of bubbles from within the borehole ds with enough force to spatter mud from in the hole 18-in or more high.





# **Possible Occurrence of Shallow Gas Resulting from Glacial Processes in the Northern Great Plains** •

There are many geologic factors that may bear consideration when looking for shallow gas in areas of thick glacial deposits. Some of these factors include glaciotectonic features that were observed and studied in North Dakota. This section provides a brief overview of the characteristics of a few glaciotectonic structures. Also, questions regarding the consideration of glacia processes when searching for occurrences of shallow gas, eithe in the glacial deposits themselves, or in the immediately nderlying preglacial sediments, are highlighted.

Questions relating to isostatic rebound Does isostatic loading and rebound, and the resulting fractures that form, affect the location, extent or integrity of shallow-gas accumulations in subglacial strata?

• How deep were the subglacial sediments fractured during isostatic depression and rebound? Strain due to the weight of the overlying glacial ice – and due to unloading when the ice melted – could have resulted in fracturing to great depths. A significant hurdle that restricts gas production from coal and shale is low permeability. Fracturing caused by isostatic rebound may have increased the permeability, and might improve the delivery of gas through the formation to the well bore.

• Did stresses caused by the weight of the glacier cause differing sets of intersecting fractures? We don't know whether the flow direction of the glacier was an important factor influencing the kinds and directions of subsurface fractures that might have developed in the materials beneath the ice. Earlier glaciers advanced over the plains states and provinces from a variety of directions. The variety of stresses they caused may have resulted in differing sets of intersecting fracture Repeated glaciations, with loading and unloading during each episode, could have had a cumulative effec on the overall fracture system.

• Did repeated glaciations have a cumulative effect on the overall fracture systems in the underlying materials Repeated glacial advances, from a variety of directions, may have resulted in many different stress fields developing in the materials beneath the glaciers. In the Norwegian sector of the North Sea, changes in stress fields are thought to have caused repeated reactivation of faults during the Pleistocene glaciations, especially during the Weichselian (Wisconsinan) interglacials. Similarly, the array of fractures that formed in the bedrock materials beneath the glaciers in this area could be quite complex and the fracture systems extensive. The fractures, and movement of fluids within, may have been repeatedly reactivated during successive glaciations

as several hundred meters.

for the escape of gas.

Questions About Glaciotectonic Structures

• Is there a relationship between glaciotectonic processes and the occurrence of shallow gas traps?

of ice-thrust features? Many ice-thrust features can be easily identified on air photos, or topographic

• Did changes in pore-water pressures due to thrusting have an effect on the occurrence of shallow gas

accumulations? Could the altering of pore water pressures, in addition to causing glacial thrusting, all

• Could areas of near-surface ice-thrust materials be places where gas escaped during thrusting? As a

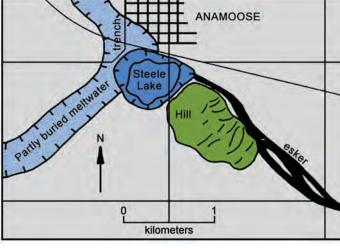
continued to escape since then? Ice-thrust features might serve either as traps or as continuing conduits

converse consideration: could areas of ice-thrusting be places where gas escaped during thrusting and has

maps. Is it possible to search for gas traps by first identifying the ice-thrust features?

have had an effect on the occurrence of shallow gas accumulations?

3 to 30 meters thick (bedrock exposed in places) Area of missile-site installations 150 meters thick
0 to 3 meters thick
(befrock surface with scattered boulders)
90 meters thick
Unglaciated area - bedrock surface



west-central North Dakota. This is an ice-thrust hi the greenish area – adjacent to a depression flooded a lake. The location of a buried meltwater trench underground aquifer – is also shown. Glacier movement was from the upper left to the lower righ The material that now is in the hill came from the are that is now a depression flooded by Steele Lal Probably 90 percent of the ice-thrust features observed are closely associated with buried aquifers. Thrusting occurs when high pore-water pressures build up beneath the glacier. During the thrusting process, pore pressures within the involved and underlying strata, are greatly increased. As a result, the mater are forced upward into the path of the advancing glacier. The upward force essentially reduces the friction between an overlying slab of material and the material beneath so that, essentially, all the glacier has to do is move the material forward. In this way, slabs of material are pushed upward into the glacier's path and moved.

s well as the surrounding states and provinces – is covered by a nearly continuous layer of glacial deposits. 7 acial drift cover averages between 45 nd 75 meters thick (150 to 250 feet) over eastern and northern North Dakota, nd it is continuous over wide areas in the states and provinces surrounding North Dakota. Throughout much of glaciated area, the character, relationships of the sub-glacial deposition are known only through drilling remote-sensing geophysical data

Ap of North Dakota, showing thickness

e excavations. Much of North Dakot

glacial deposits and area of missile



about 4 kilometers (2.5 miles) wide. juarried from as deep as 180 meters were entered and investigated. 600 feet) here and stacked up by glacier ction, in an en-echelon fashion, to form ridged landscape. This is an aerial ew showing the edges of a series of labs, stacked on each other. Glacier novement in this area was from upper ght to lower left. A few miles from here, sandstone and shale slabs were scovered that were excavated by the acier from about 275 meters (900 feet) Jeep. In both the Prophets Mountains and Lincoln Valley area, these slabs not occur at elevations ranging from about 00 to 300 meters (325 to 1000 feet) higher than their original positions fore glacial thrusting took place



1960s the NDGS was permitted to assist in the nvestigation of all of the excavations then being ade in preparation for the installation of uteman missiles silos in eastern North Dakota. ounted to 150 missile sites, laid out on a lly random six-mile grid, along with an litional 15 launch-control facility sites. The initial excavations that were made for the missile meters deep, they had vertical walls, and they were 35 meters (115 feet) long and 15 meters (50 t) wide. The launch-control site excavations larger. The walls of the excavations were table so great care was taken durin gation. The excavation shown here is about 20 meters (65 feet) deep. Each of the 165 excavations (except for a few of them that had been dug into aquifers, mainly in the Lake Agassiz Slabs of Cretaceous material have been beaches – these were basically mud pits, or pond

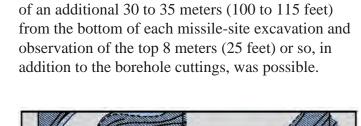


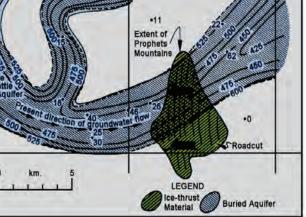
Road cut through a slab in the Prophets Mountains. This is a road cut through one of the slabs shown on the last Figure. The beds here are Cretaceous and Paleocene sandstone and shale that have been thr upward about 100 meters (325 feet) from their original (preglacial) position. The total thickness of the individual ice-thrust slabs here is about 25 to 30 meters (80 to 100 feet).

een estimated at about 1000 meters (3,300 feet) in thickness. It is safe to say fracturing of the underlying materials, causing both horizontal partings, and rs (800 feet) and that most of that rebound occurred in only several scars previously described. These partings may involve varying amounts f the rebound took place while the glacier still covered the area, but while most from which coal-bed methane is produced. However, the processes that formed f the glacial mass was melting away. Fresh, vertical scarps, up to 15 meters the fractures in coal are due to unloading resulting from erosion of the overlying (50 feet) high, have been observed in Lapland, caused by earthquakes within the sediments, not to glacial depression and rebound.



beneath the lakes was problematic during some of the drilling.





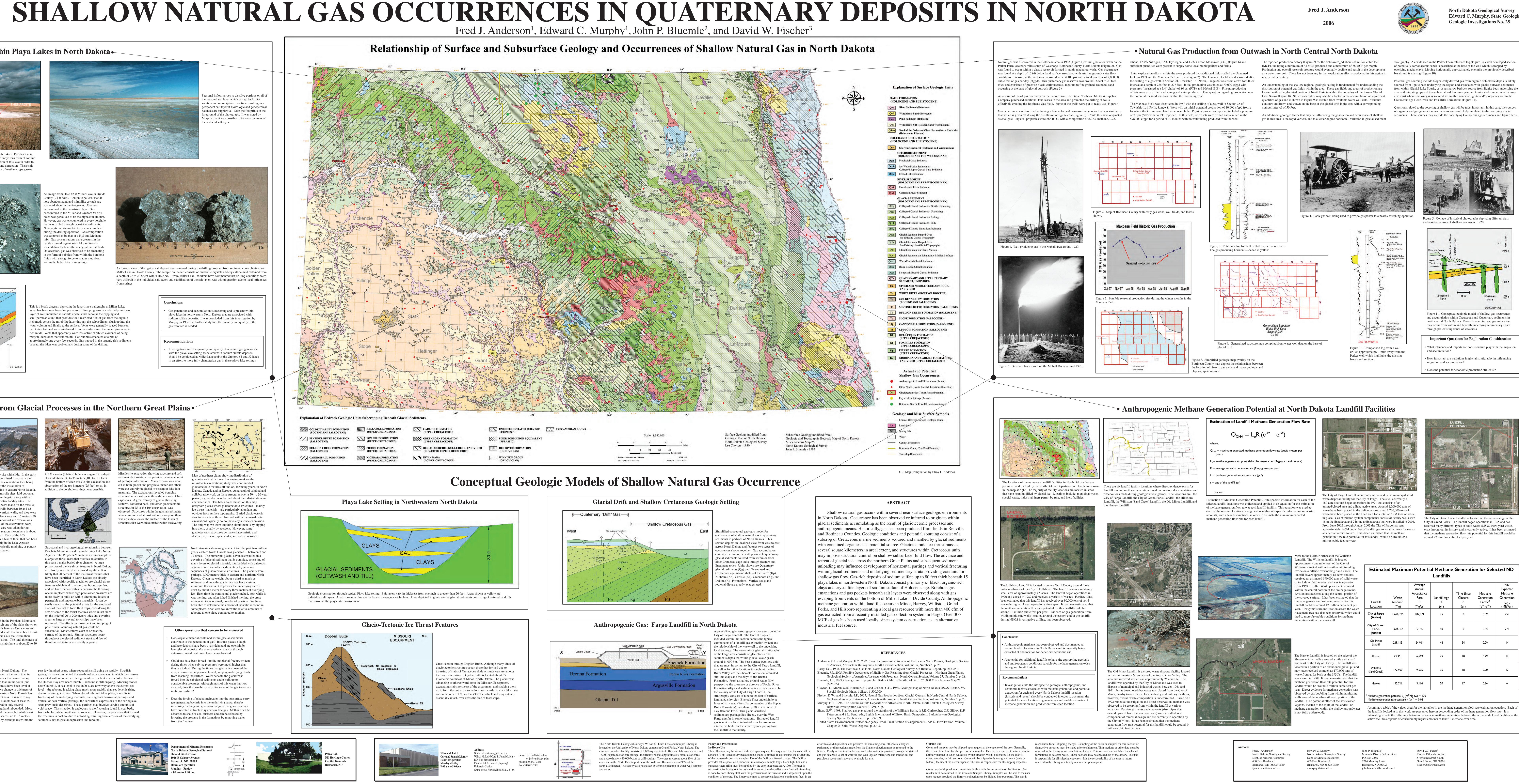
tructural and hydrogeological relationship between Prophets Mountains and the underlying Lake Nettie Aquifer. The Prophets Mountains are an example of a large ice-thrust mass that overlies an aquifer, in this case a major buried river channel. A large proportion of the ice-thrust features in North Dakota are closely associated with buried aquifers. It is likely that 90 percent of the ice-thrust features that have been identified in North Dakota are closely associated with specific glacial or pre-glacial thrust features which tend to occur over buried aquifers, and we have theorized this is because the thrusting occurs in places where high pore-water pressures are more likely to build up within alternating layers of permeable and impermeable materials. It can be easily seen that the potential exists for the emplaced slabs of material to form fluid traps, considering the size of some of the thrust features where intact slabs on the order of 90 to 200 meters thick and covering areas as large as several townships have been observed. The effects on movement and trapping of ore fluids, including natural gas, could be

substantial. Most features exist at or near the

surface of the ground. Similar structures oc

these buried features are readily apparent.

throughout the glacial sediment stack and few of

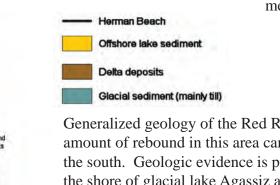




The mission of the North Dakota Geological Survey is threefold: **nvestigate** and report on the geology of North Dakota, emphasizing the state's energy resources and stressing applied research leading to economic benefits or quality of life improvements for residents of the state; Provide public service, and to collect, create, and disseminate geologic and map-related information, and;

Administer regulatory programs and act in an advisory capacity to other state, federal, and local agencies.

central North Dakota. The area shown is Ice-thrust hill near the village of Anamoose,





An understanding of whether traps form as a result of glacial thrusting and whether the thrusting process influences gas movement (as it does porewater pressure) is needed. Certainly, large, buried ice-thrust sla could serve as traps. Those ice-thrust features we have been able to identify are near the surface and like represent only a small fraction of the structures present at depth. It is uncertain how far beneath the bas of the glacier that sediments would be affected by glaciotectonic processes, but it may have been as much • If such a relationship exists, might it be possible to search for gas traps by first identifying the locatio

Fred J. Anderso



Williston	MOUNTRAIL	WARD .		RCE	RAMSEY	WALSH
Mc REN		Minot		BENSON	MAN NE	LSON GRAND FORKS
-	- A	Mê LEAN	SHERIDAN	Harvey WELLS	EDBY	TRAILL
BILLINGS		AERCER			-VS-EN	Hilsboro
ALL ALL	STARK	MORTON	BURLEIGH	KIDDER . S	TUTSMAN	BARNES CASS
SLOPE	HETTINGER		5	LOGAN	LA MOUR	P. RANSOM
BOWMAN		GRANT	EMMONS	-	-	RIC
BUYYWATA	ADAMS	SION	x	Mc INTO:	SH DICKER	SARGENT

Landinis										
Landfill Location	Waste Amount <sup>1</sup> (Mg)	Average Annual Acceptance Rate R (Mg/yr)	Landfill Age t (yr)	Time Since Closure c (yr)	Methane Generation Factor <sup>2</sup> (e <sup>-kc</sup> -e <sup>-kt</sup> )	Max. Expected Methane Generatio Q <sub>CH4</sub> (Mft <sup>3</sup> /yr)				
City of Fargo (Active)	2,696,775	107,871	25	0	0.39	255				
City of Grand Forks (Active)	3,636,364	82,727	40	0	0.55	273				
Old Minot Landfill	249,113	24,911	44	34	0.09	14				
Hillsboro	73,361	6,669	45	18	0.29	12				
Williston (Sand Creek)	172,900	9,606	35	18	0.20	12				
Harvey	155,711	3,114	50	17	0.34	6				