



during the Winter in 1996. The drillholes ranged in depth from 10 to 54 feet. Sample collection via coring was troublesome due to the presence of lacustrine clays, noncohesive silts, and well indurated crystalline salt beds. Mobil B-50 HSA rig was used to initiate the drilling operation. After a mechanical failure, unrelated to the drilling activity, a trailer-mounted Giddings soil probe was used to complete the drilling operation.

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

structures. Also, questions regarding the consideration of glacia

processes when searching for occurrences of shallow gas, eithe

Does isostatic loading and rebound, and the resulting

fractures that form, affect the location, extent or

How deep were the subglacial sediments fractured

the weight of the overlying glacial ice – and due to

fracturing to great depths. A significant hurdle that

permeability. Fracturing caused by isostatic rebound

improve the delivery of gas through the formation to the

• Did stresses caused by the weight of the glacier cause

whether the flow direction of the glacier was an

differing sets of intersecting fractures? We don't know

important factor influencing the kinds and directions of

materials beneath the ice. Earlier glaciers advanced

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

• Did repeated glaciations have a cumulative effect on

Repeated glacial advances, from a variety of directions,

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

during the Weichselian (Wisconsinan) interglacials.

bedrock materials beneath the glaciers in this area cou

been repeatedly reactivated during successive glaciation

as several hundred meters.

for the escape of gas.

The fractures, and movement of fluids within, may have

Questions About Glaciotectonic Structures

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

of the glacier that sediments would be affected by glaciotectonic processes, but it may have been as much

represent only a small fraction of the structures present at depth. It is uncertain how far beneath the base

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

• 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?

be quite complex and the fracture systems extensive.

Similarly, the array of fractures that formed in the

of faults during the Pleistocene glaciations, especially

may have resulted in many different stress fields

may have increased the permeability, and might

during isostatic depression and rebound? Strain due to

unloading when the ice melted – could have resulted in

integrity of shallow-gas accumulations in subglacial

brief overview of the characteristics of a few glaciotectonic

in the glacial deposits themselves, or in the immediately

Natural Gas Generation within Playa Lakes in North Dakota •



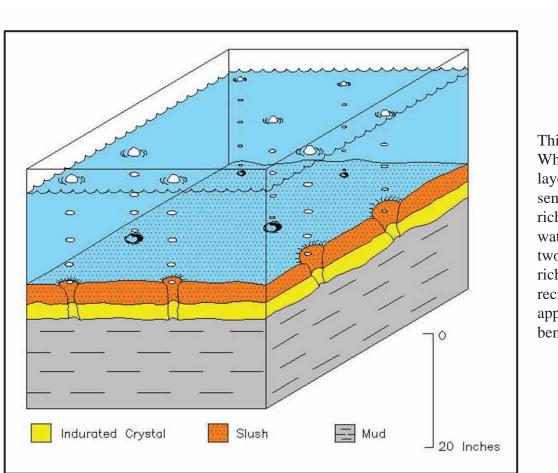
sulfate known as thenardite. Sodium Corporation of America diked off a portion of this lake in order to



es was perceived to be the highest in amount. Gas concentrations were greatest in the arkly colored organic-rich lake sediments cated 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 nin the hole 18-in or more high.



a depth of 22 to 22.8 feet within Hole No. 1 from Miller Lake. Workers have commented that drilling conditions were very difficult in the individual salt layers and stabilization of the salt layers was within question due to local influences



s well as the surrounding states and

acial drift cover averages between 45

over eastern and northern North Dakota,

and it is continuous over wide areas in the states and provinces surrounding

relationships of the sub-glacial deposit

action, in an en-echelon fashion, to form

ew showing the edges of a series of

slabs, stacked on each other. Glacier

novement in this area was from upper

acier from about 275 meters (900 feet)

Jeep. In both the Prophets Mountains

and Lincoln Valley area, these slabs no

00 to 300 meters (325 to 1000 feet)

nigher than their original positions

remote-sensing geophysical data

and 75 meters thick (150 to 250 feet)

provinces – is covered by a nearly

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

uteman missiles silos in eastern North Dakota.

meters deep, they had vertical walls, and they were

Road cut through a slab in the Prophets Mountains.

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

Generalized geology of the Red River Valley in eastern North Dakota. The past few hundred years, where rebound is still going on rapidly. Swedish

the south. Geologic evidence is present in that the beaches that formed along associated with rebound, are being manifested, albeit in a start-stop fashion. I

we presume that the lake level along any single beach must have been level at near Churchill, at sea level in the 1600's, are now way above the current sea

the time it formed). This provides an idea of the relative change in thickness of level – the rebound is taking place much more rapidly than sea-level is rising

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

that the amount of rebound over most of eastern North Dakota was at least 250 vertical or near-vertical partings, the subsurface expressions of the earthquake

hundred years. When the glacier melted, the underlying land rebounded. Most void-space. This situation is analogous to the fracturing found in coal beds,

(50 feet) high, have been observed in Lapland, caused by earthquakes within the sediments, not to glacial depression and rebound.

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

This is a road cut through one of the slabs shown on

20 meters (65 feet) deep. Each of the 165

juarried from as deep as 180 meters were entered and investigated.

This is a block diagram depicting the lacustrine stratigraphy at Miller Lake What has been seen based on previous drilling programs is a relatively uniform ayer of well indurated mirabilite crystals that serve as the capping and ni-permeable unit that provides for a restricted flux of gas from the organic ch muds across the mirabilite layer through the salt/sediment slush up into the ter column and finally to the surface. Vents were generally spaced between vo to ten feet and were windowed from the surface into the underlying organic ch muds. Vents that apparently were less active exhibited evidence of being ecrystallized over the vent mouth. Gas bubbles emanated at a rate of approximately one every few seconds. Gas trapped in the organic-rich sediment beneath the lakes was problematic during some of the drilling.

of an additional 30 to 35 meters (100 to 115 feet)

observation of the top 8 meters (25 feet) or so, in

addition to the borehole cuttings, was possible.

from the bottom of each missile-site excavation and

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

are closely associated with buried aquifers. It is

have been identified in North Dakota are closely

proportion of the ice-thrust features in North Dakota

likely that 90 percent of the ice-thrust features that

associated with specific glacial or pre-glacial thrust

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

on the order of 90 to 200 meters thick and covering

observed. The effects on movement and trapping of

substantial. Most features exist at or near the

throughout the glacial sediment stack and few

size of some of the thrust features where intact slabs

features which tend to occur over buried aquifers,

were cut entirely in glacial or stream or lake-lair

structural relationships in three dimensions of fresh

as no indication on the surface of the kinds of

ructures that were encountered while excavating.

materials. The excavations revealed comple

tructures in 75 of the 165 excavations wa

Gas generation and accumulation is occurring and is present within playa lakes in northwestern North Dakota that are associated with sodium sulfate deposits. It was concluded from this investigation by Murphy in 1996 that further study into the quantity and quality of the

e seasonal salt layer which can go back int

ances are supportive. Note the footprints in eground of the photograph. It was noted by rphy that it was possible to traverse on areas

Investigations into the quantity and quality of observed gas generation with the playa lake setting associated with sodium sulfate deposits should be conducted at Miller Lake and/or the Grenora #1 and #2 lakes in an effort to more fully characterize gas in these playa lake settings.

ciotectonic structures. Following work on the

naracteristics. The black areas shown on this map

e-thrust materials – are particularly abundant and

into them, usually by accident. However, some

glaciotectonic structures do have characteristic and

stinctive, or even spectacular, surface expressions.

North America showing glaciers. Over the past two million

12 times. The numerous glacial advances resulted in a

organic zones, and other sedimentary layers – and

Dakota. Clean ice weighs about a third as much as

sediment and once the glacier ice reaches a certain

minimum thickness, it depresses the underlying earth's

crust by about a meter for every three meters of overlying

ice. Each time the continental glacier melted, both while

was melting, and after it had finished melting, the crust

rebounded to its original, pre-glacial position. We have

been able to determine the amount of isostatic rebound in

some places, or at least we know the relative amounts of

rebound at one place compared to another.

Other questions that remain to be answered

Does organic material contained within glacial sediments

contribute to the generation of gas? In some places, slough

and lake deposits have been overridden and are overlain by

Could gas have been forced into the subglacial fracture systen

during times when sub-ice pressures were much higher than

area, it formed an impermeable seal, keeping underlying fluids

escaped, does the possibility exist for some of the gas to remain

Does the forcing of glacial meltwater into the subsurface carry

have collected in fracture systems as free gas. Methane can be

adsorbed to shale or coal surfaces and can be released by

lowering the pressure in the formations by removing water

they are today? During the times that glacial ice covered the

from reaching the surface. Water beneath the glacier was

considerable pressures. Although most of this water has no

forced into the subglacial sediments and it built up to

later glacial deposits. Many excavations, that cut through

extensive buried peat bogs, have been observed.

covering of glacial sediment that is complex, consisting of

sequences of glaciotectonic structures. The glaciers were.

perhaps, 1,000 meters thick in eastern and northern North

many layers of glacial material, interbedded with paleosols,

years, eastern North Dakota was glaciated – between 7 and

ciotectonic features off and on, for many years, in North

a, Canada and in Europe. As a result of original an

laborative work on these structures over a 20- to 30-year

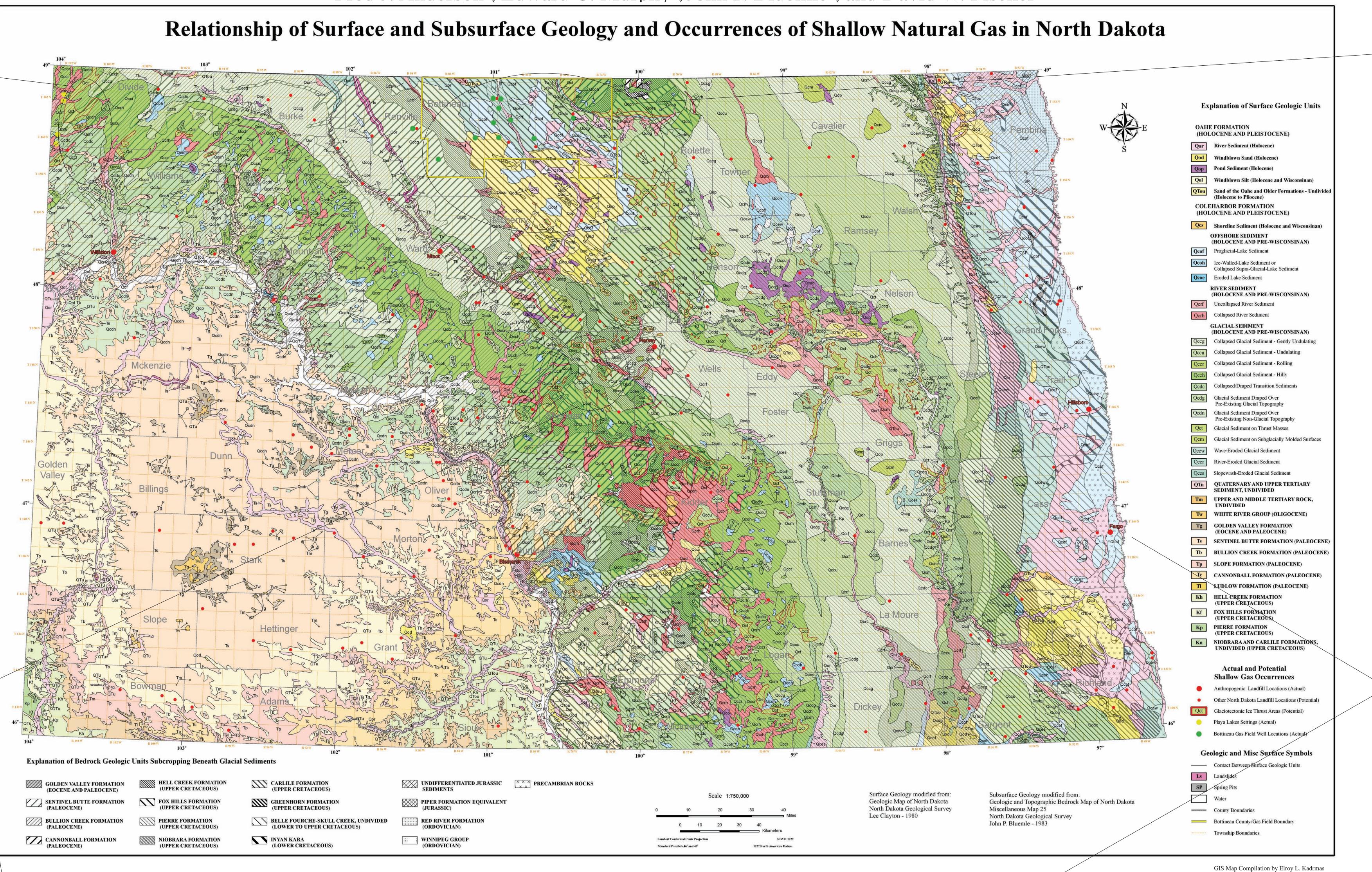
signate places where glaciotectonic structures – mainly

vious from surface topography. Buried glaciotectonic

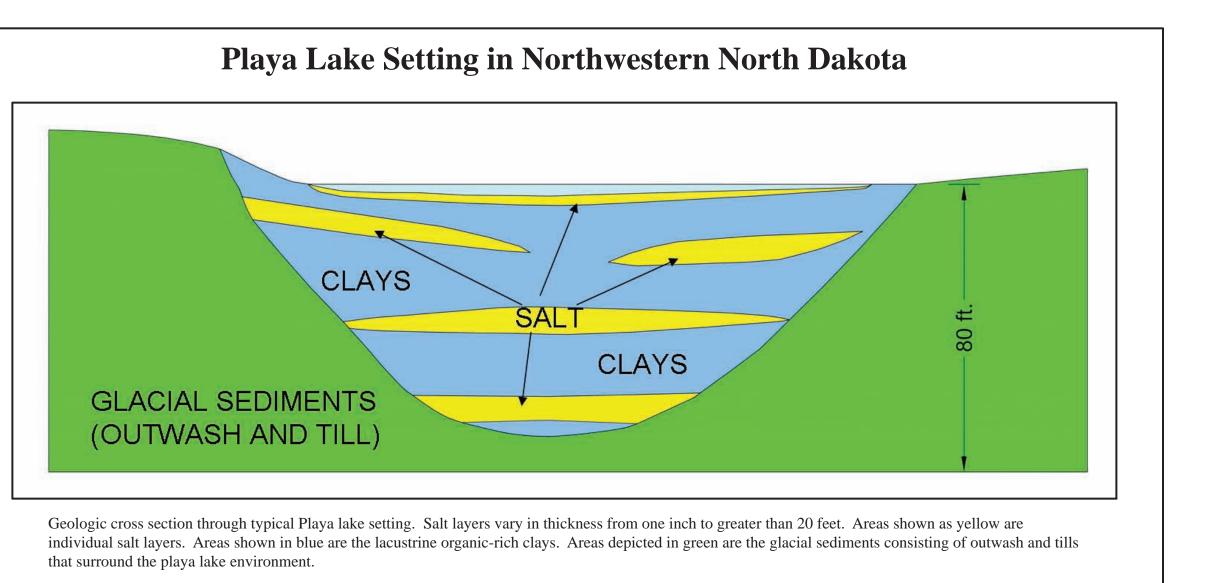
avations typically do not have any surface expression

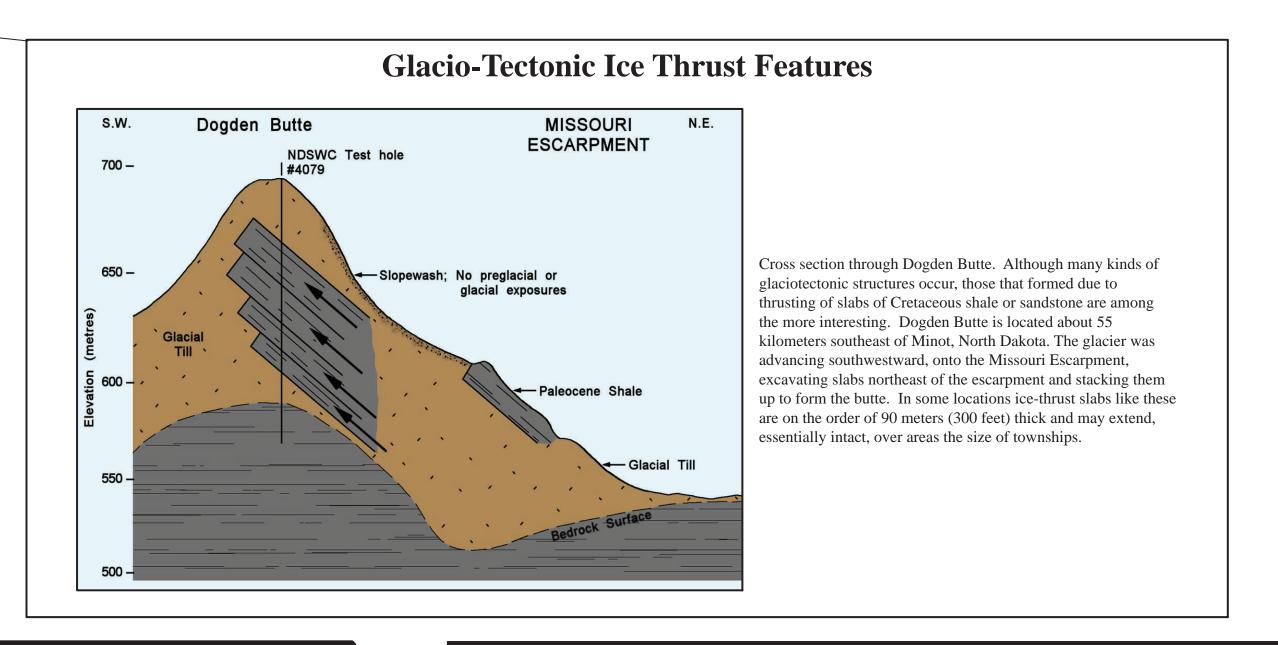
he only way we learn anything about them is by digging

structures such as those observed within the missile site

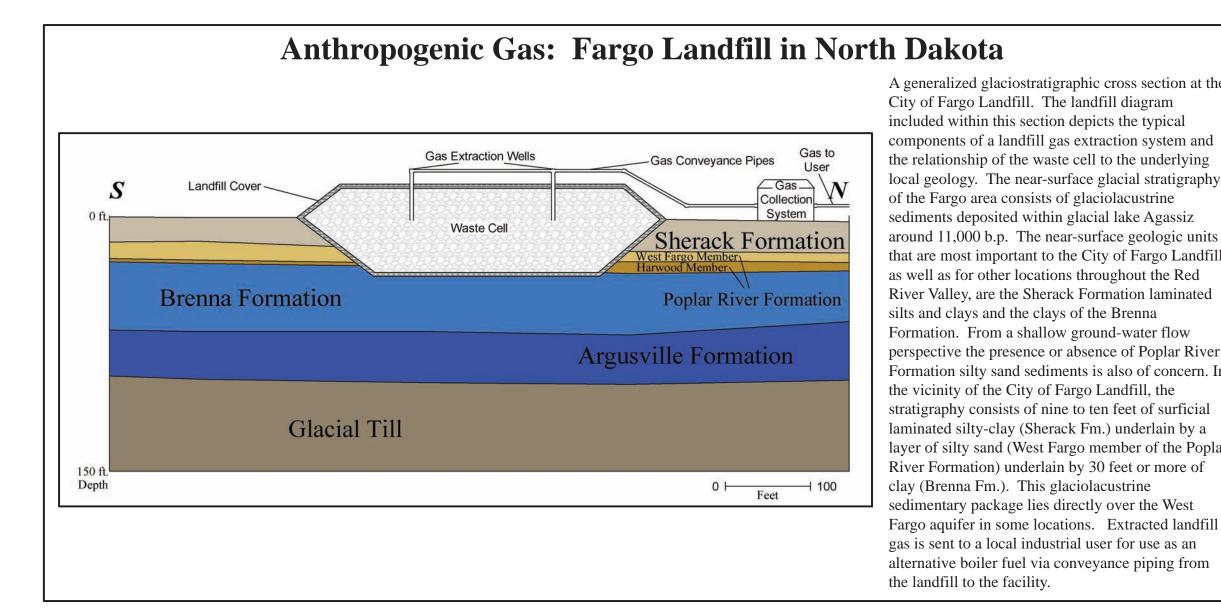


Conceptual Geologic Models of Shallow Natural Gas Occurrence





Glacial Drift and Shallow Cretaceous Geologic Setting ← Quaternary "Drift" Gas — — Shallow Cretaceous Gas — Simplified conceptual geologic model for occurrences of shallow natural gas in quaternar sediments in portions of North Dakota. This section depicts an idealized view from west to ea across North Dakota and features two types of occurrences shown together. Gas accumulation can occur within or beneath permeable quaterna glacial sediments sourced from within or from older Cretaceous age units through fracture an ineament zones. Units shown are Quaternary glacial sediments (Qg) undifferentiated and Cretaceous age marine shales of the Pierre (K₁ Niobrara (Kn), Carlisle (Kc), Greenhorn (Kg), an Dakota (Kd) Formations. Vertical scale and regional dip are greatly exaggerated.



clays and crystalline layers of sodium sulfate of Holocene age. Borehole gas nanations and gas pockets beneath salt layers were observed along with gas scaping from vents on the bottom of Miller Lake in Divide County. Anthropoger nethane generation within landfills occurs in Minot, Harvey, Williston, Grand Forks, and Hillsboro representing a local gas resource with more than 400 cfm o gas extracted from a recently installed gas collection system in Fargo. Over 300 MCF of gas has been used locally, since system construction, as an alternative industrial fuel source.

Anderson, F.J., and Murphy, E.C., 2005, Two Unconventional Sources of Methane in North Dakota, Geological Soci of America, Abstracts with Programs, North Central Section, Volume 37, Number 5, p. 28. Barry, J.G., 1908, The Bottineau Gas Field, North Dakota Geological Survey, 5th Biennial Report, pp. 247-251. Geological Society of America, Abstracts with Programs, North Central Section, Volume 37, Number 5, p. 2 Bluemle, J.P., 1983, Geologic and Topographic Bedrock Map of North Dakota, 1:670,000 Miscellaneous Map 25 Clayton, L., Moran, S.R., Bluemle, J.P., and Carlson, C.G., 1980, Geologic map of North Dakota USGS, Reston, VA Special Geologic Maps, 1 Sheet, 1:500,000. Geological Society of America, Abstracts with Programs, North Central Section, Volume 37, Number 5, p. 28 Murphy, E.C., 1996, The Sodium Sulfate Deposits of Northwestern North Dakota, North Dakota Geological Survey Report of Investigation No. 99 (RI-99), 73 p.

ABSTRACT

Shallow natural gas occurs within several near surface geologic environment

in North Dakota. Occurrence has been observed or inferred to originate within

anthropogenic means. Historically, gas has been produced from fields in Renville

and Bottineau Counties. Geologic conditions and potential sourcing consist of a

with contained organics as a potential source. Glaciotectonic ice-thrust masses,

several square kilometers in areal extent, and structures within Cretaceous units,

may impose structural control on shallow subsurface fluid flow. The advance and

unloading may influence development of horizontal partings and vertical fracturing

within glacial sediments and underlying sedimentary strata providing conduits for

shallow gas flow. Gas-rich deposits of sodium sulfate up to 80 feet thick beneath

playa lakes in northwestern North Dakota consist primarily of black, organic-ric!

retreat of glacial ice across the northern Great Plains and subsequent sediment

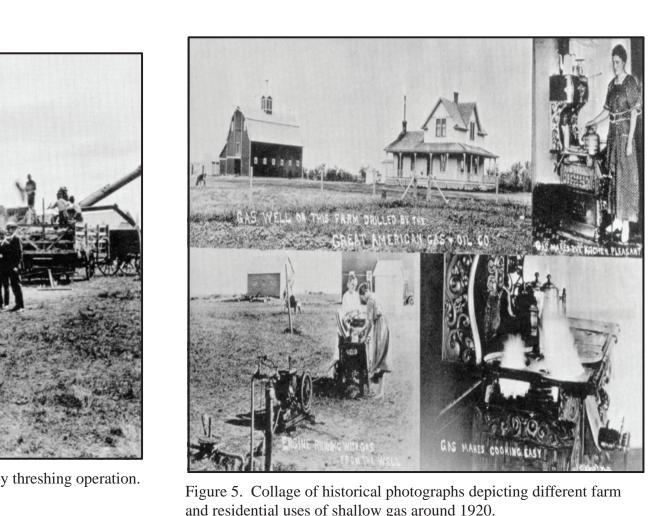
subcrop of Cretaceous marine sediments scoured and mantled by glacial sedimen

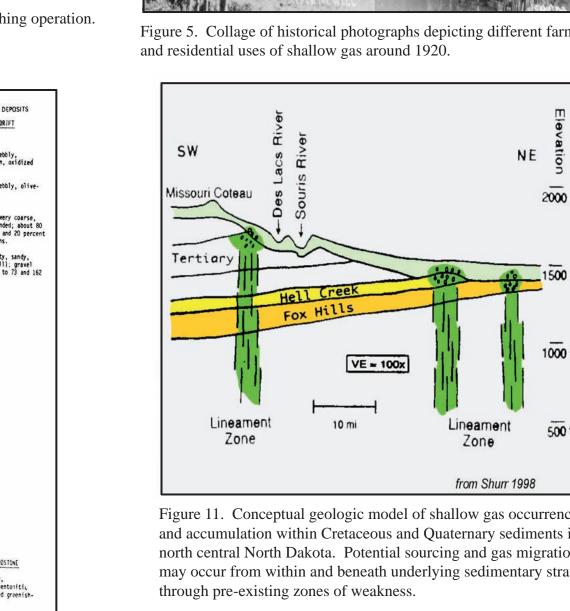
glacial sediments accumulating as the result of glaciotectonic processes and

Shurr, G.W., 1998, Shallow gas play around the margins of the Williston Basin, in J.E. Christopher, C.F. Gilboy, D.F. Paterson, and S.L. Bend, eds., Eighth International Williston Basin Symposium: Saskatchewan Geological Society Special Publication 13, p. 129-139. United States Environmental Protection Agency, 1998, Final Section of Supplement E, AP 42, Fifth Edition, Volume I, Chapter 2: Solid Waste Disposal, p. 2.4-3.

Cores and samples may be shipped upon request at the expense of the user. Generally, destructive purposes must be stated prior to shipment. Thin sections or other data must be

→ Natural Gas Production from Outwash in North Central North Dakota





migration and accumulation? • Does the potential for economic production still exist

→ Anthropogenic Methane Generation Potential at North Dakota Landfill Facilities

 $Q_{CH4} = L_o R (e^{-kc} - e^{-kt})$

 $_4$ = maximum expected methane generation flow rate (cubic meters per

= average annual acceptance rate (Megagrams per year)

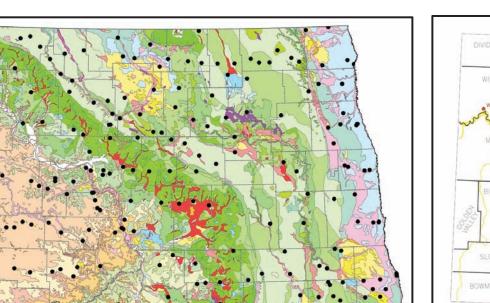
methane generation flow rate for each landfill.

Figure 3. Reference log for well drilled on the Parker Farm

Great Northern Gas Well

igure 9. Generalized structure map compiled from water well data on the base of

The gas producing horizon is shaded in yellow.



The locations of the numerous landfill facilities in North Dakota that are permitted and tracked by the North Dakota Department of Health are shown

There are six landfill facility locations where direct evidence exists for in the map at right. The majority of facility locations are located in areas landfill gas and methane generation based on previous documentation and

Figure 1. Well producing gas in the Mohall area around 1920.



The Hillsboro Landfill is located in central Traill County around three miles northwest of the City of Hillsboro. The landfill covers a relatively small area of approximately 4.5 acres. The landfill began operations in 1976 and closed in 1987 and received a variety of wastes. Further, it has been estimated that this landfill has received over 80,000 tons of solid waste during its 11 year operational time span. It has been estimated that the methane generation flow rate potential for this landfill could be around 12 million cubic feet per year. Evidence of gas generation, from within monitoring wells installed around the eastern end of the landfill

during NDGS investigative drilling, has been observed.

Anthropogenic methane has been observed and documented at

extracted at one location for beneficial economic use.

throughout North Dakota.

Recommendations

several landfill locations in North Dakota and is currently being

A potential for additional landfills to have the appropriate geologic

and anthropogenic conditions suitable for methane generation exist



locations. Passive gas vents and cleanouts (riser pipes that

extend upward from the leachate drain) were installed as a

the City of Minot. It has been estimated that the methane

generation flow rate potential for this landfill could be around

million cubic feet per year.

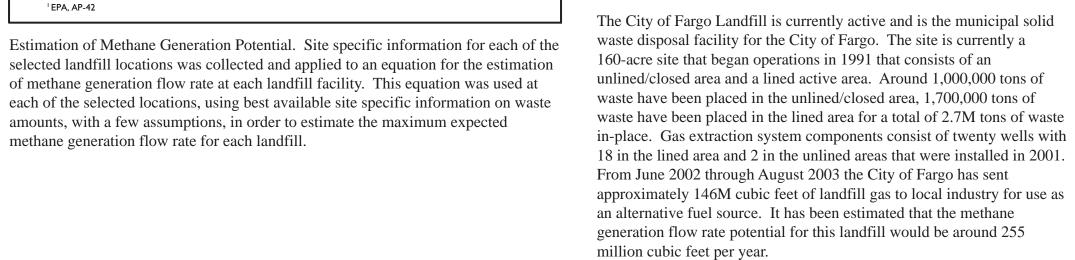
component of remedial design and are currently in operation by

in the southwestern Minot area of the Souris River Valley. The landfill was operated by the City of Minot and was used to • Investigations into the site specific geologic, anthropogenic, an economic factors associated with methane generation and potential 1971. It has been noted that waste was placed from the City of extraction for each and every North Dakota landfill location Minot, nearby towns, farms, local industry and military facilities (historic and recent) should be conducted in order to document the however, overall waste composition is undetermined. Based on a potential for each location to generate gas and enable estimates of 1992 remedial investigation and direct observation, methane was

Estimation of Landfill Methane Generation Flow Rate methane generation potential (cubic meters per Megagram solid waste)

Oct-57 Nov-57 Jan-58 Mar-58 Apr-58 Jun-58 Aug-58 Sep-58

c = methane generation rate constant (yr⁻¹⁾City of Fargo Landfill, the City of Grand Forks Landfill, the Hillsboro imation of Methane Generation Potential. Site specific information for each o Landfill, the Williston (Sand Creek) Landfill, the Old Minot Landfill, a



Landfill. The Williston landfill is located

oproximately one mile west of the City of

illiston situated within a north-south trendin

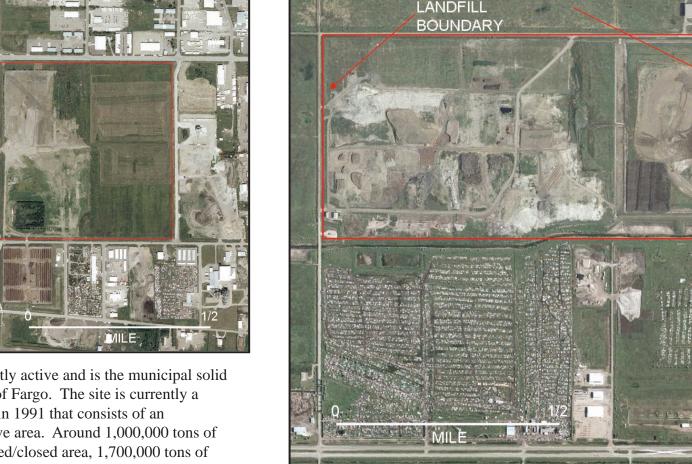
ndfill covers approximately 18 acres and has

om 1969 to 1987. Waste placement occurred

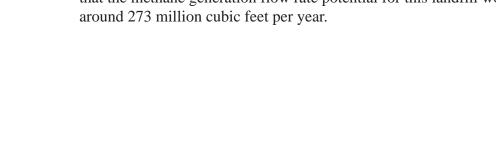
ithin the central portion of the drainage ravine.

osion has occurred along the central portion of

vine on a hillside overlooking Sand Creek.



approximately 146M cubic feet of landfill gas to local industry for use as etc.) throughout its history, and is currently active. It has been estimated around 273 million cubic feet per year.



	the covered surface. It has been estimated that the methane generation flow rate potential for this landfill could be around 12 million cubic feet per year. Heavy moisture infilitration across the waste placement area has also been observed which could lead to more favorable conditions for methane generation within the waste cell. The Harvey Landfill is located on the edge of the Sheyenne River valley around a mile and a half northeast of the City of Harvey. The landfill was located in a portion of an abandoned gravel pit and may have received as much as 170,000 tons of waste from as far back as the 1930's. The landfill was closed in 1988. It has been estimated that the methane generation flow rate potential for this landfill would be around 6 million cubic feet per year. Direct evidence for methane generation was observed by gas bubbling from within monitoring wells around the north-northwest portion of the landfill. (The potential effect of the wastewater	Landfill Location	Waste Amount ¹ (Mg)	Rate R (Mg/yr)	Landfill Age t (yr)	Closure c (yr)	Generation Factor ² (e ^{-kc} -e ^{-kt})	Ger (M
		City of Fargo (Active)	2,696,775	107,871	25	0	0.39	
		City of Grand Forks (Active)	3,636,364	82,727	40	0	0.55	
		Old Minot Landfill	249,113	24,911	44	34	0.09	
Y		Hillsboro	73,361	6,669	45	18	0.29	
2		Williston (Sand Creek)	172,900	9,606	35	18	0.20	
		Harvey	155,711	3,114	50	17	0.34	
		1 Methane generation potential L_{o} (m 3 /Mg sw) = 170 2 Methane generation rate constant k (yr $^{-1}$) = 0.02						

Figure 10. Comparison log from a well

drilled approximately 1 mile away from the

Parker well which highlights the missing

Bismarck, ND 58502

A summary table of the values used for the variables in the methane generation flow rate estimation equation. Each of the landfills looked at in this work are presented here in descending order of methane generation flow rate. It is interesting to note the difference between the rates in methane generation between the active and closed facilities – the active facilities capable of considerably higher amounts of landfill methane over time.

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

west-central North Dakota. This is an ice-thrust hi

movement was from the upper left to the lower righ

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

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

to do is move the material forward. In this way, slabs

of material are pushed upward into the glacier's path

naterial beneath so that, essentially, all the glacier has

The material that now is in the hill came from the are

underground aquifer – is also shown. Glacier

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.

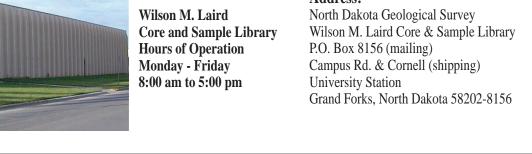


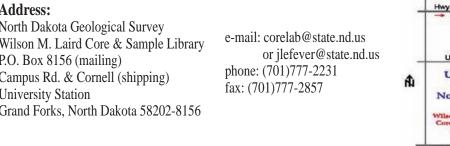












located on the University of North Dakota campus in Grand Forks, North Dakota. The In-House Use

18,000 square feet of core storage. It currently houses approximately 80 miles of cores advance. This is necessary because table space is limited. It also insures the availability and gas database. A set of well file and well logs on microfiche and microfilm, and and approximately 40,000 boxes of drill cuttings. The cores represent about 80% of the of the requested cores and samples. Use of the facility is free of charge. The facility petroleum scout cards, are also available for use. cores cut in the North Dakota portion of the Williston Basin and about 95% of the provides table space, acid, binocular microscopes, sample trays, black light box and a samples collected. The facility also houses an extensive collection of water-well samples camera system (film must be supplied by the user, suggested ASA 100). The user is responsible for laying out the core and returning it to the pallet when finished. Sampling is done by core library staff with the permission of the director and is dependent upon the condition of the core. The library attempts to preserve at least one continuous face. In an

performed or thin sections made from the State's collection must be returned to the

climate controlled facility consists of 2,000 square feet of office and laboratory space and there is no time limit for shipped cores or samples. The user is expected to return them in returned to the library upon completion of study. Thin sections are available for selected a timely manner or when requested by the director. We do not charge for the loan of formations on selected wells. These sections may be checked out of the library. The user cores, samples, or thin sections. Cores will be shipped only to a government (state or is responsible for all shipping expenses. It is the responsibility of the user to return federal) facility at the user's expense. The user is responsible for all shipping expenses. material to the library in a timely manner or upon request. Cores may be shipped to a core testing facility with the permission of the director. Test

results must be returned to the Core and Sample Library. Samples will be sent to the user upon request provided the library's collection can be divided into two parts. The user is

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s not fully understood).

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