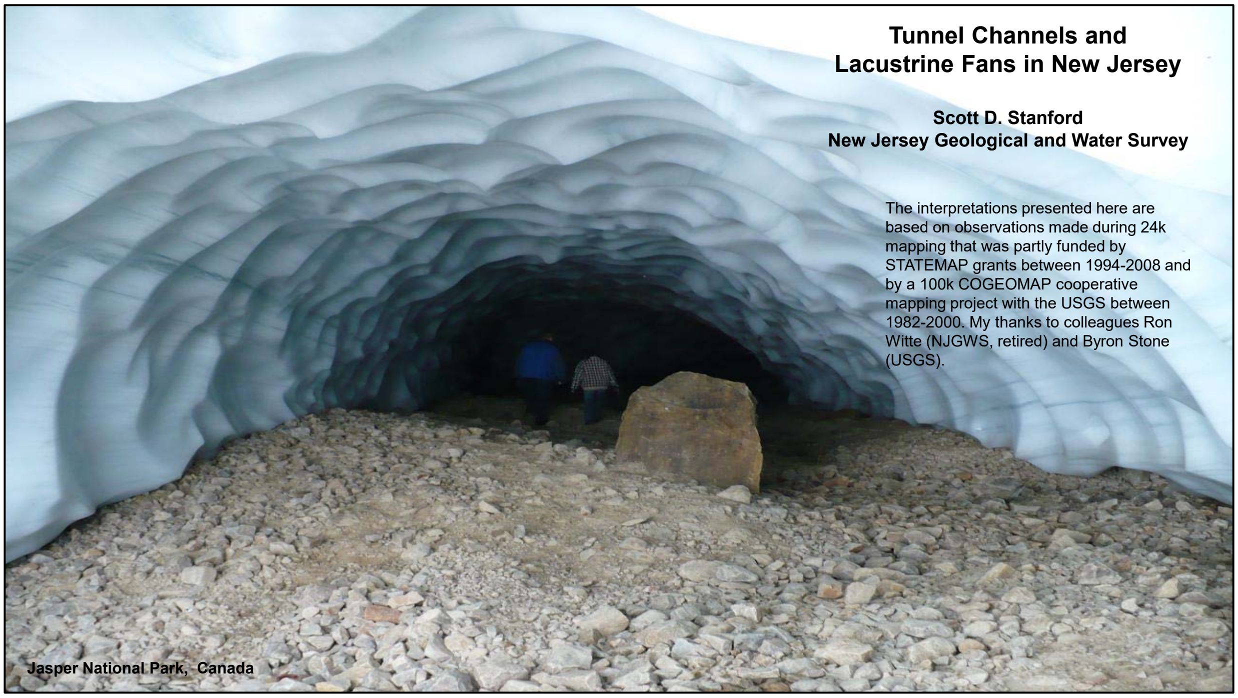
Tunnel Channels and
Lacustrine Fans in New Jersey
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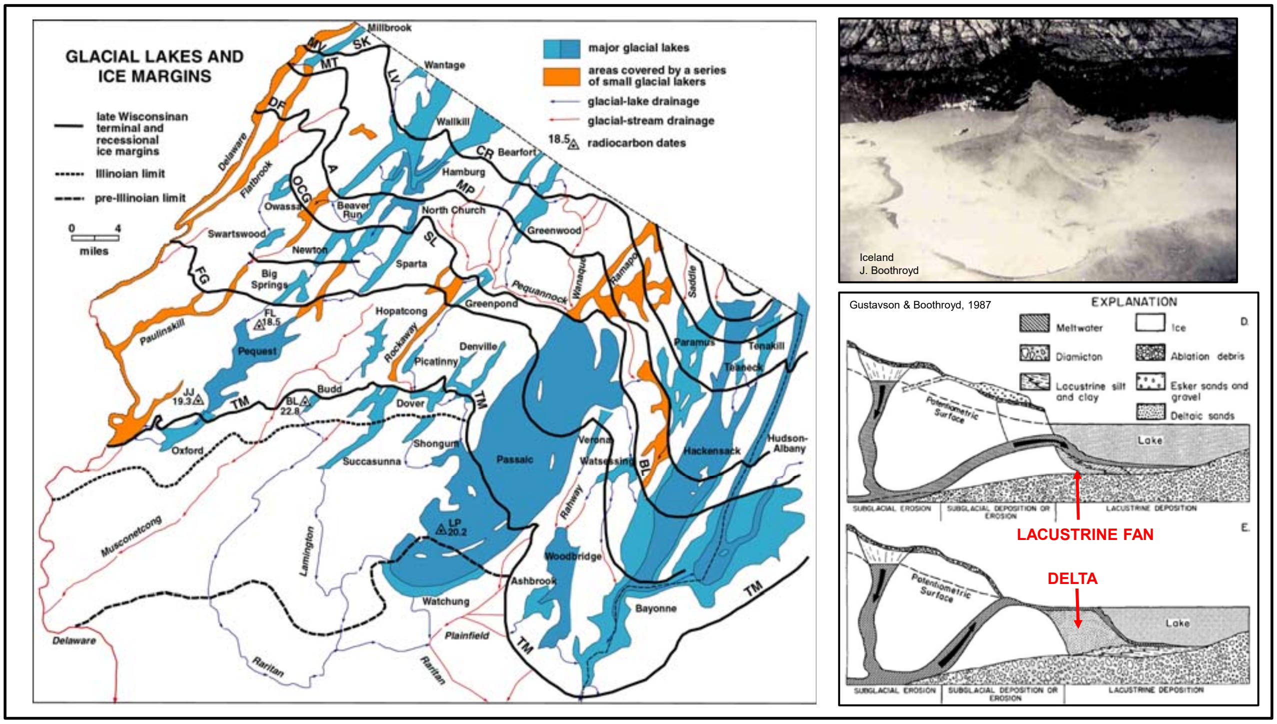
The interpretations presented here are based on observations made during 24k mapping that was partly funded by STATEMAP grants between 1994-2008 and by a 100k COGEOMAP cooperative mapping project with the USGS between 1982-2000. My thanks to colleagues Ron Witte (NJGWS, retired) and Byron Stone (USGS).
Jasper National Park, Canada



Most valleys in New Jersey were occupied by glacial lakes during the late Wisconsinan retreat. The map shows larger lakes in blue and small lakes that filled completely with deltas in orange. I think much of the sediment in these lakes was deposited from tunnel channels in the manner illustrated in the figure in the lower right by Gustavson and Boothroyd (1987) based on their observations on the Malaspina Glacier in Alaska, and as shown in the photo above of a tunnel-mouth fan in Iceland that was exposed when a proglacial lake drained.

EVIDENCE FOR TUNNEL CHANNELS

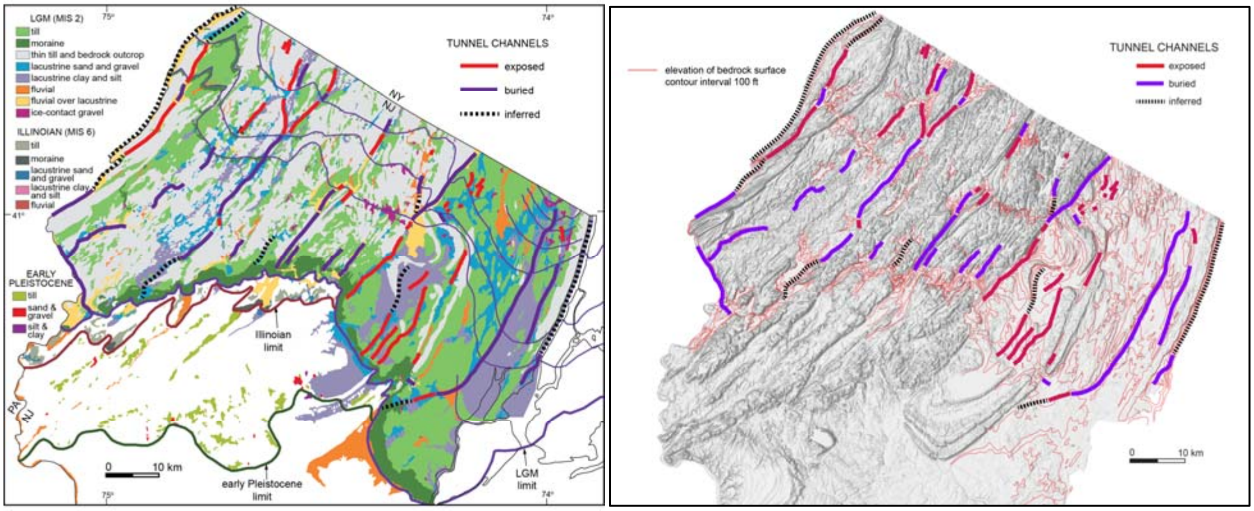
Sediments

- Massive, open-work cobble gravels in thick subhorizontal beds with channeled bases
- Plane-bedded sands in subhorizontal to low-angle bed sets
- Compact, matrix-supported diamictons with sharp basal erosional contacts overlying deformed sands and gravels
- Little evidence for collapse
- Like tunnel-fed subaqueous fan deposits in Canada (e.g., Banerjee and McDonald, 1975; Rust and Romanelli, 1975; Brennand, 2000; Russell and Arnott, 2003) and Maine (Ashley and others, 1991)
- Gravel composition rich in local valley-bottom rock types

Landforms

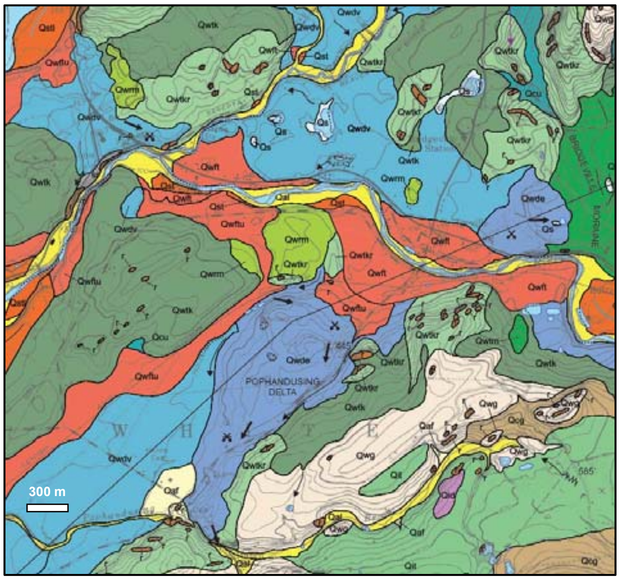
- "Beaded eskers" consisting of linear chains of lacustrine fans that trend perpendicular to ice margins
- Smaller, continuous-ridge eskers
- Eskers connect to ice-marginal deltas
- Generally, in bottoms of bedrock valleys

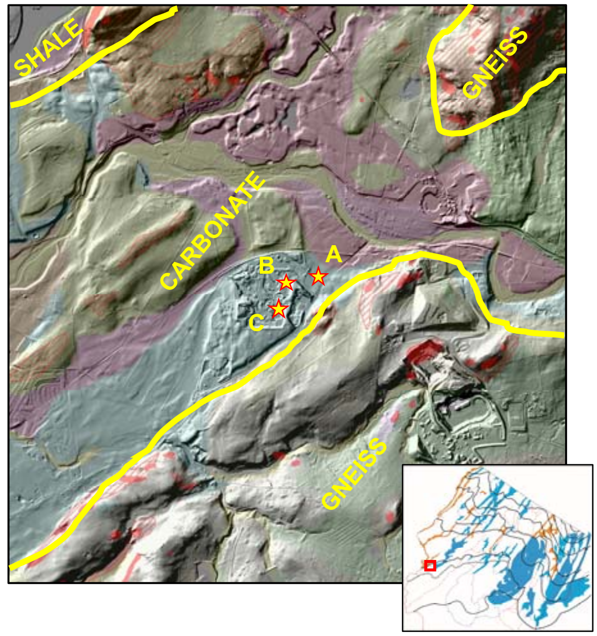
The evidence for this interpretation comes from sediments and landforms.



Tunnel channels marked by beaded or single-ridge eskers are shown in red. Those that are buried by lake clay or deltas but known from wells and borings are in purple. Those likely present beneath lake clay or deltas but where there are too few wells and borings to prove so are dotted. Map on right shows that most tunnel channels are in lows on the bedrock surface, including many in overdeepenings.

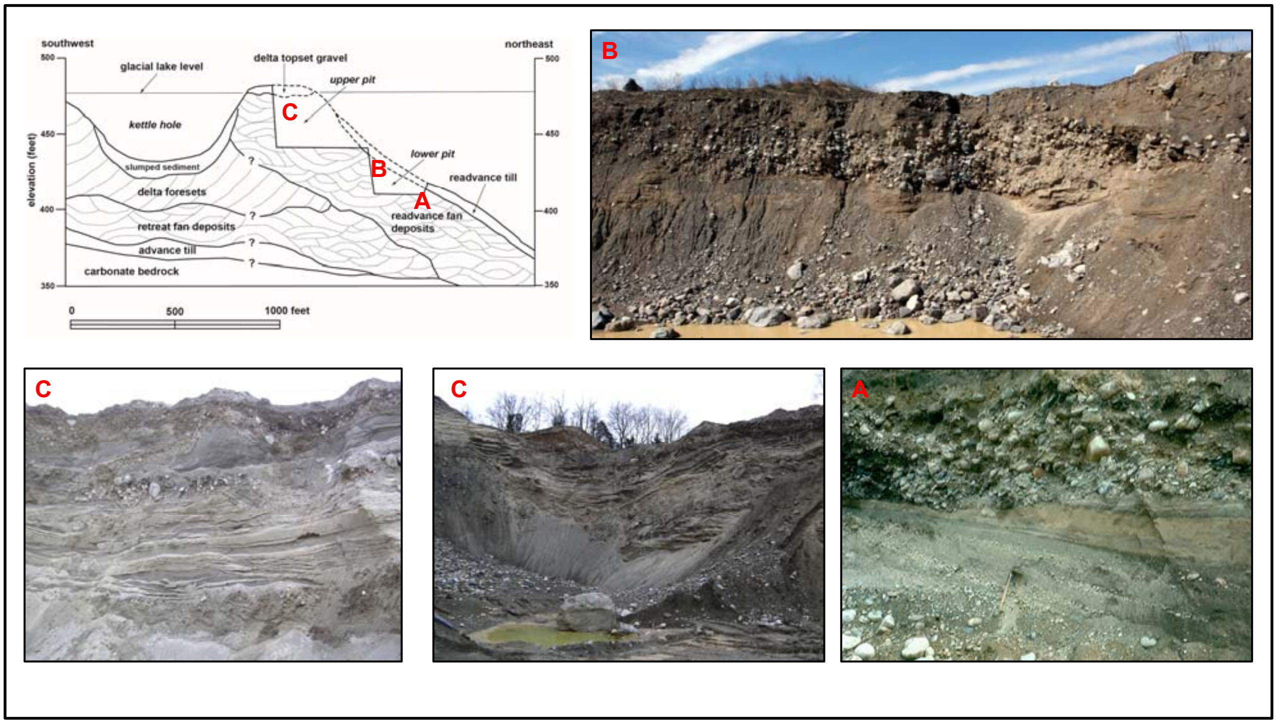
Pophandusing Delta



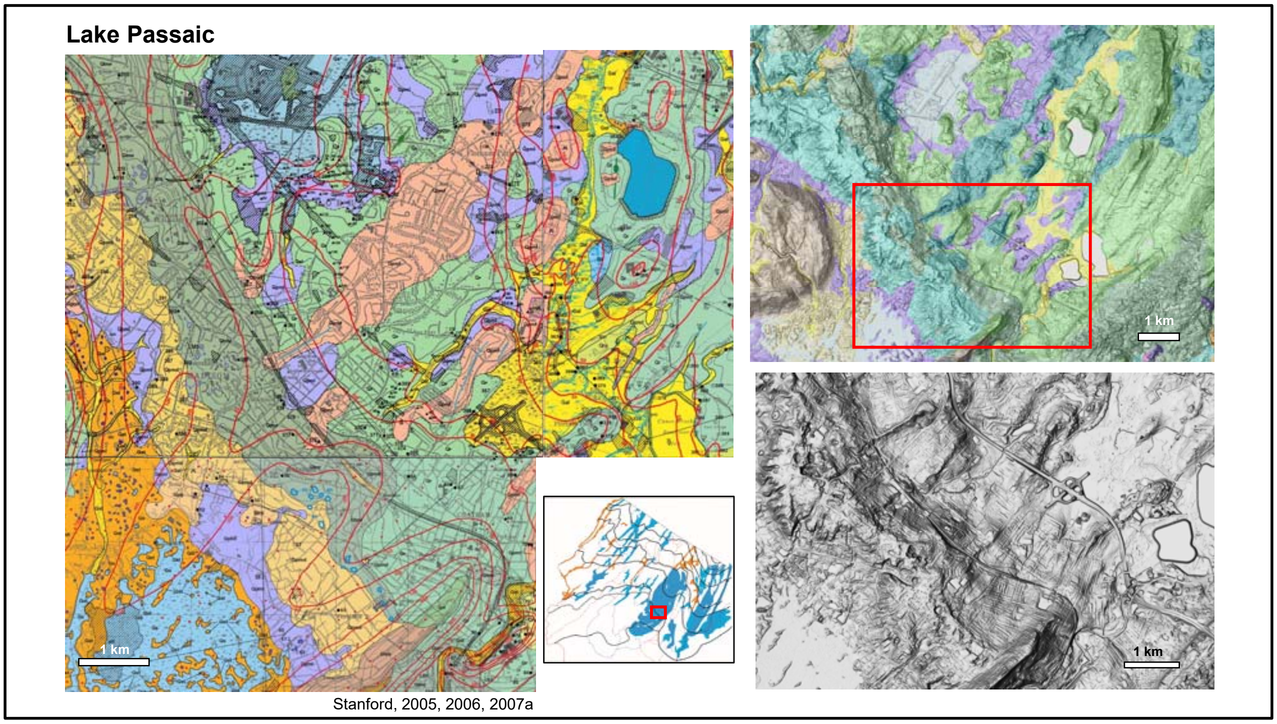


Witte and Ridge, 2021

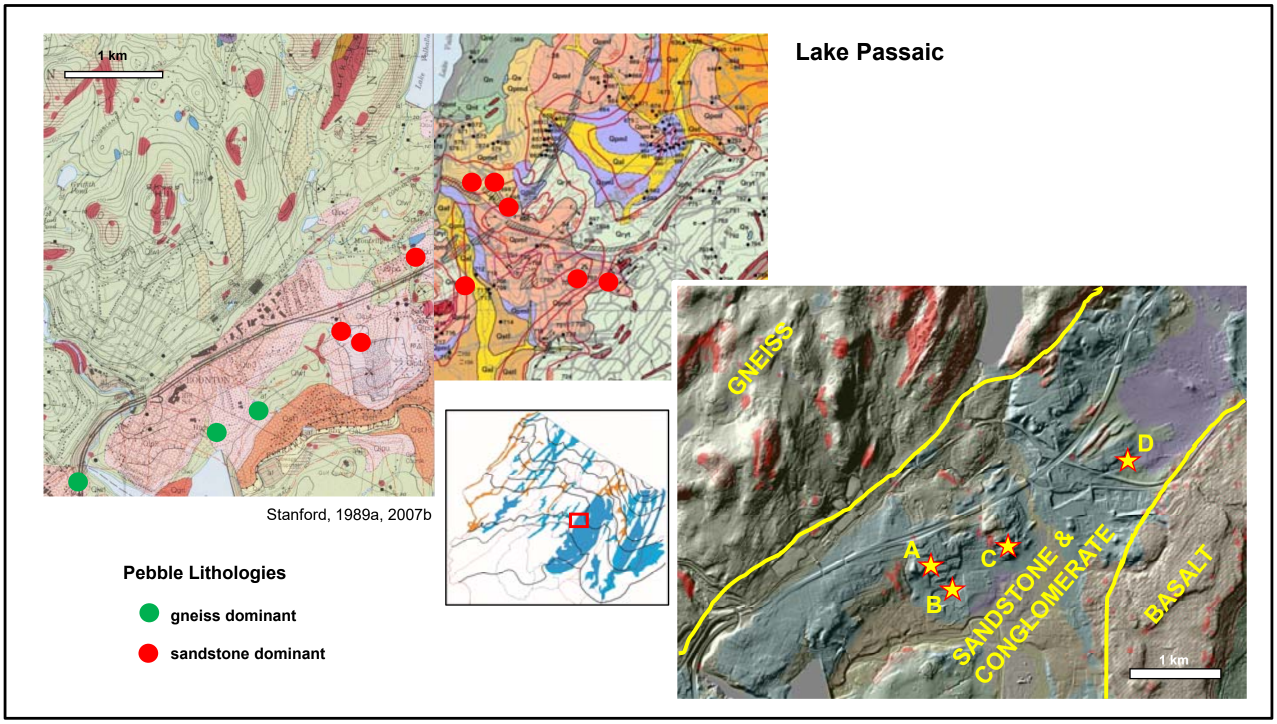
We'll look now at some case examples. This and the following examples are illustrated by paired geologic maps and LiDAR hillshades with a transparent geology drape. The Pophandusing delta is in the terminal moraine belt in the Delaware valley. It was deposited in a lake in a tributary valley to the east that was dammed by an ice lobe in the Delaware valley. The ice margin wrapped around the west and north side of the delta. Although it is at the base of a gneiss upland it is composed of carbonate gravel, indicating a source from the valley to the north and west. Next slide shows photos at A, B, and C.



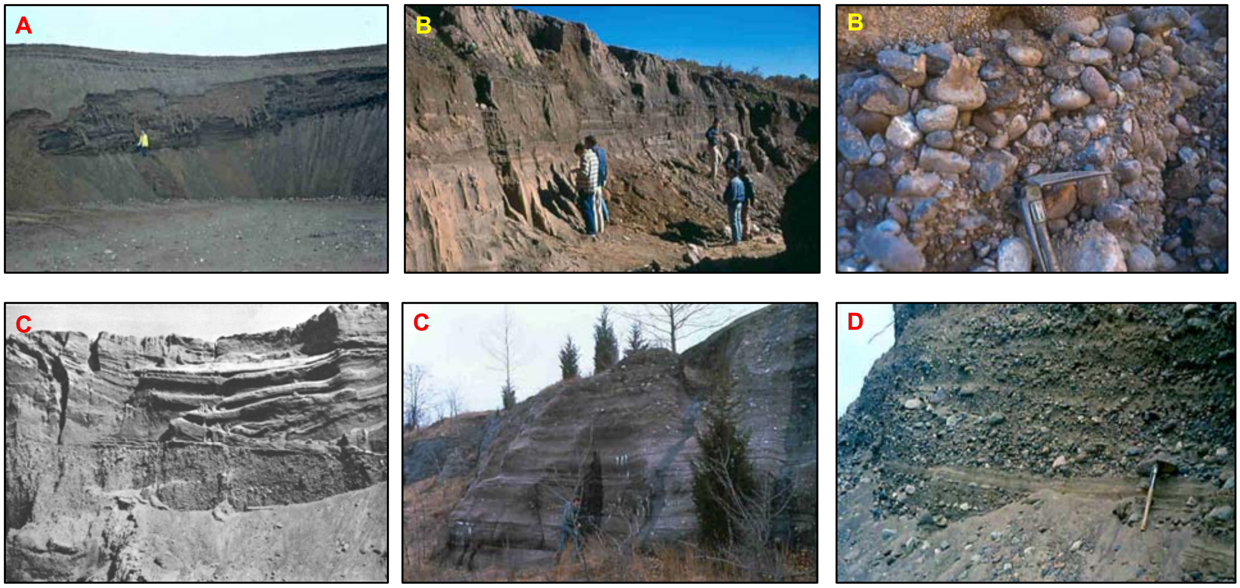
Sites A and B are proximal and lower than C, which is distal and higher in the deposit. Note massive cobble gravel and plane-bedded sand indicating high flow velocities at A and B, with channeled contact at base of gravel. Till overlies the gravel in photo B and approximately marks the original land surface. C shows sand with inclined bedding that records incipient foreset progradation as the deposit aggraded in the lake.



Now we'll move east to Lake Passaic. The map shows till of the terminal moraine (dark green) fronted by deltas (yellow) deposited in Lake Passaic (Moggy Hollow stage). Eskers and beaded eskers (pink) trending northeast from the back of the moraine mark the tunnels feeding the deltas and match to the delta lobes, as the hillshade images on the right show (lower image is a detail without the geology drape of the red box in the top image). Note that the blue shading on the hillshade image is the delta and fan sediment. Purple on both map and image is lake clay and green on both is till.



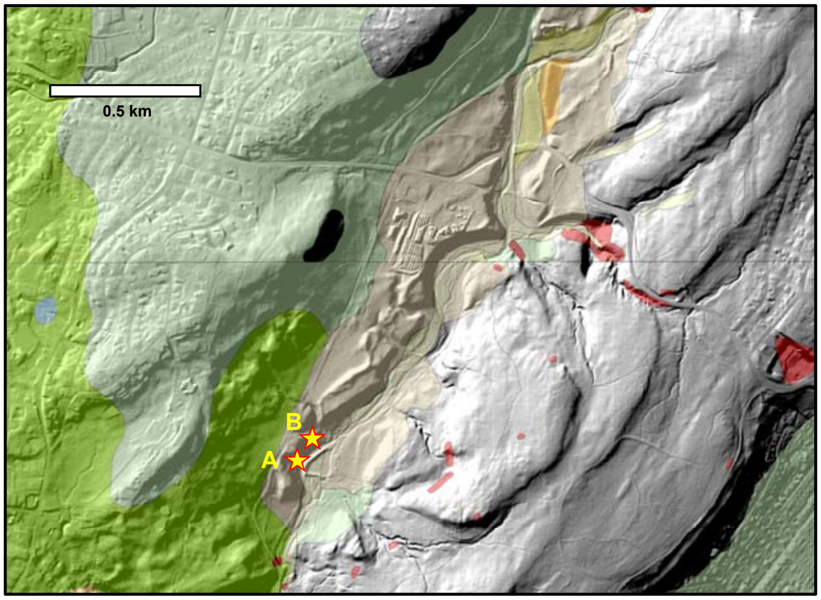
Now we'll move a bit north in Lake Passaic. The west side of Lake Passaic is bordered by a gneiss upland, with the lake floor on sandstone and conglomerate. Deltas in the southwest part of the map (pink) are fed by ice-marginal meltwater channels descending the gneiss upland and eroded into the gneiss-rich till (green) on the upland (scarp-bounded boulder terraces marking the channels are shown by orange diamond pattern). These deltas are composed of gneiss-rich gravel. Deltas and lacustrine fans to the east (pink and yellow) are tunnel-fed and are composed of sandstone-rich gravel from the valley bottom. The next slide shows photos at A, B, C, and D tracking along the tunnel route.

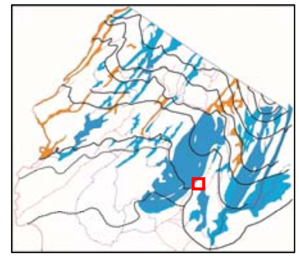


Minard and Rhodehamel, 1969

Photo A shows the topsets and foresets in the tunnel-fed delta. B shows plane-bedded sand (B-left) and massive cobble gravel (B-right) in the fan deposit below the delta in the same pit. C-left shows a fan deposit about a km upglacier from the delta that was mined away to expose the current-scoured conglomerate bedrock shown on C-right (note figure for scale). This is the tunnel. It is 30 m below lake level and so requires pressurized pipe flow to overcome the head in the lake at the tunnel mouth. D shows cobble gravel and plane-bedded sand in another fan deposit about 2 km farther up-tunnel.

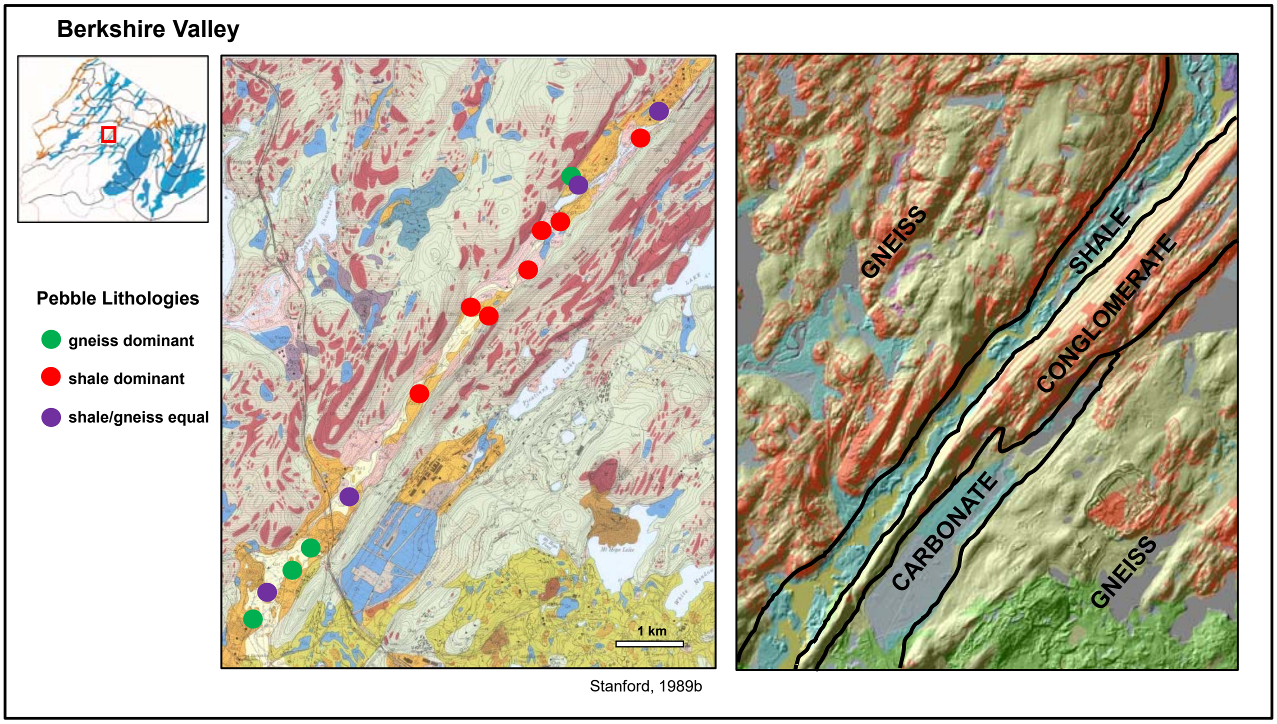
South Mountain



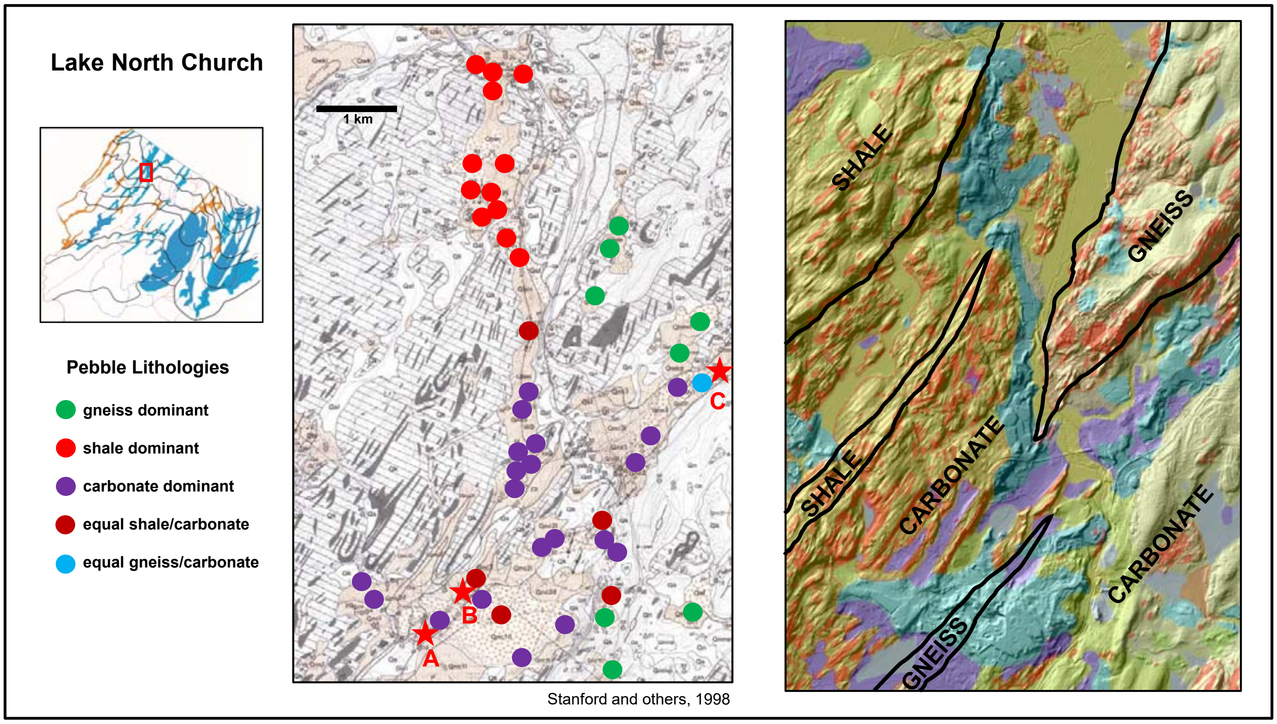


This is a small lake at the foot of South Mountain to the east of Lake Passaic. The hillshade image shows an esker partially buried by a delta (both in tan color). Next slide shows photos of a streambank outcrop at A and B.

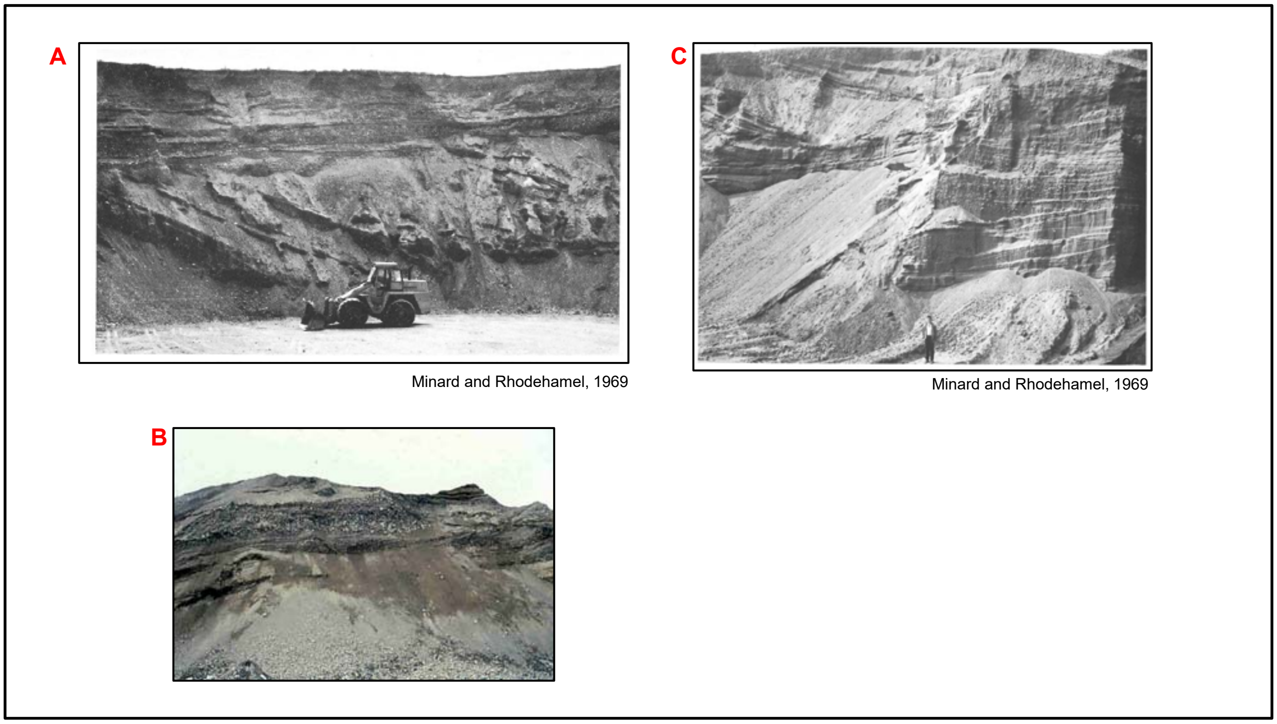
At A the base of the bank exposes a cobble gravel (lower photos) with a sharp planar top a and constant thickness of >5 m (base not exposed) over a horizontal length of >60 m. This gravel is overlain by a thick (10-15 m) section of delta bottomsets consisting of climbing-rippled fine sand with silt and clay drapes (top photo). The gravel appears to have a muddy matrix but that is a coating of the bottomset fines from above; the gravel is clean where washed (A-right). The geometry and stratigraphic position of the gravel suggest it is a tunnel deposit along the line of the esker visible on the hillshade image in the previous slide. At B, which is upglacier from A in the same bank, thinly bedded sand and pebbly sand is rotated to vertical and overlain in sharp contact by till. The sand is either a plane-bedded fan deposit (there is a vertical cobble gravel bed about 2 m thick in the sand just north of photo B consistent with this alternative) or delta foresets. The deformation and overlying till here indicate a subglacial setting rather than collapse of superglacial or englacial deposits.



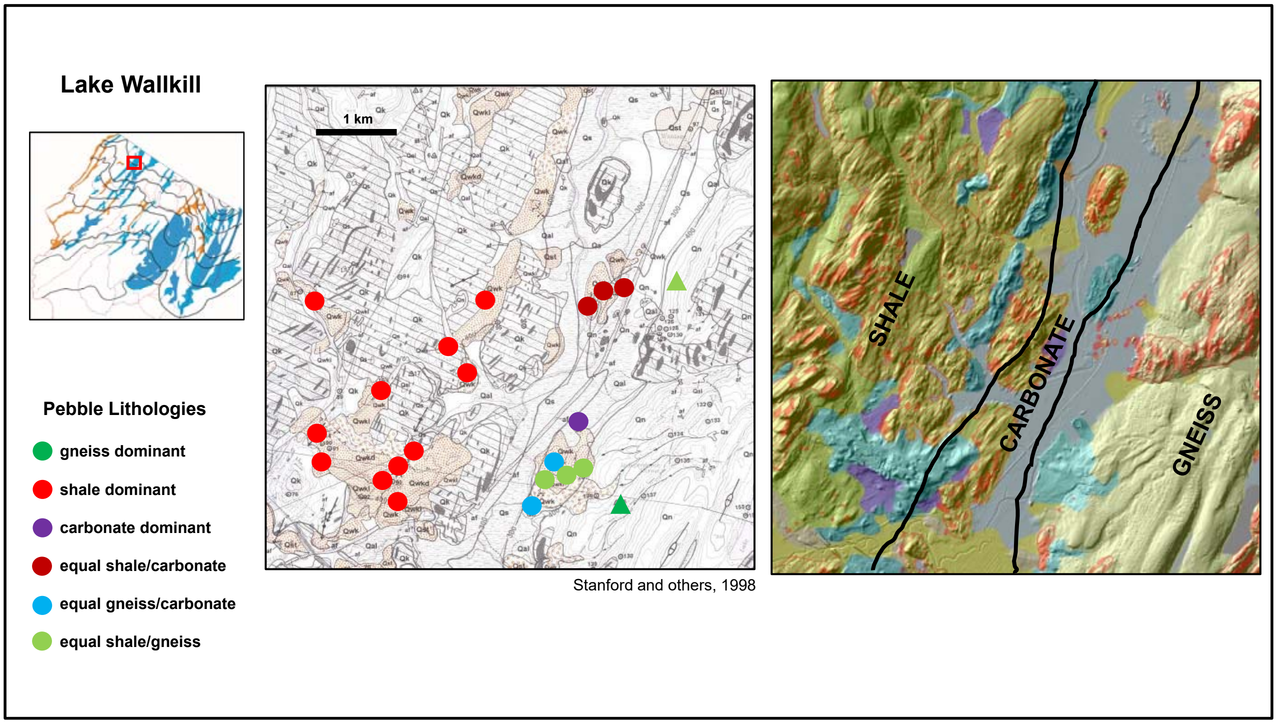
Move west to Berkshire Valley in the New Jersey Highlands. Berkshire Valley is a narrow, deep valley floored by shale and bordered by gneiss and quartzite-conglomerate. It is filled with deltas and lacustrine fans composed largely of shale gravel, indicating a valley-bottom tunnel source. Gravel at the south end of the valley is gneiss-rich, possibly because the deposits here lap onto the north edge of the terminal moraine, which is composed of gneiss-rich till, and the tunnel flow eroded the till rather than the bedrock.



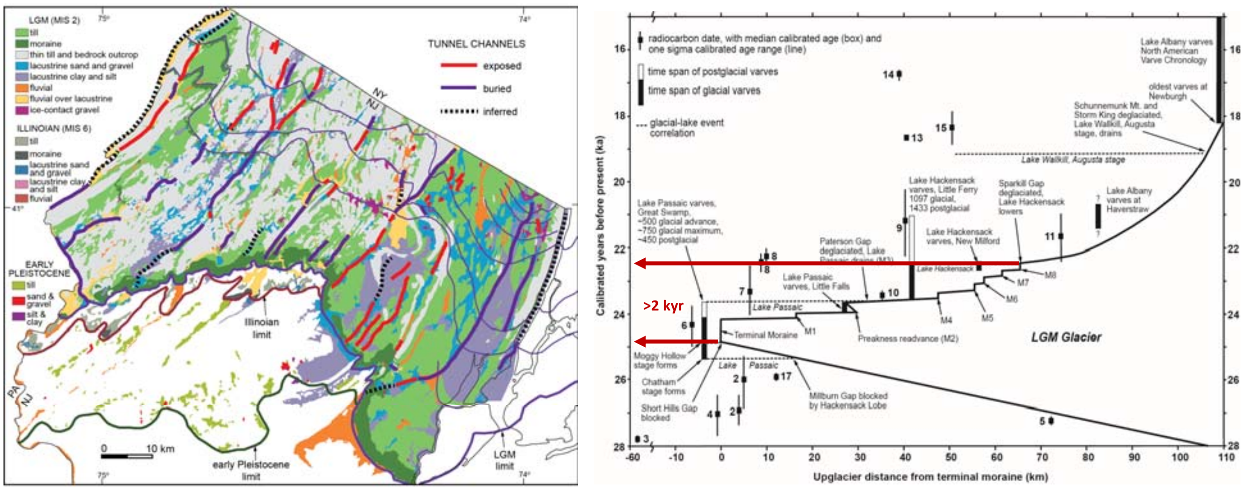
Moving north into the Wallkill basin, Lake North Church is in the north-draining Wallkill valley and is a precursor to Lake Wallkill. A large delta in the lake is fed by a beaded esker extending north up the Wallkill valley and another extending northeast up a tributary valley. The esker in the Wallkill valley crosses a shale-carbonate contact at the north edge of the map area and the gravel in the esker changes from shale-rich to carbonate-rich within 2 km of the contact and stays carbonate-rich throughout the delta. Gneiss forms uplands on the east side of the valley, and a large upland just out of frame to the southeast, but gneiss gravel is dominant in the lake deposits only in the small deltas at the mouths of meltwater channels descending these uplands. The gravel distribution indicates most of the deposits in the lake are tunnel-sourced. Next slide shows photos at A, B, and C.



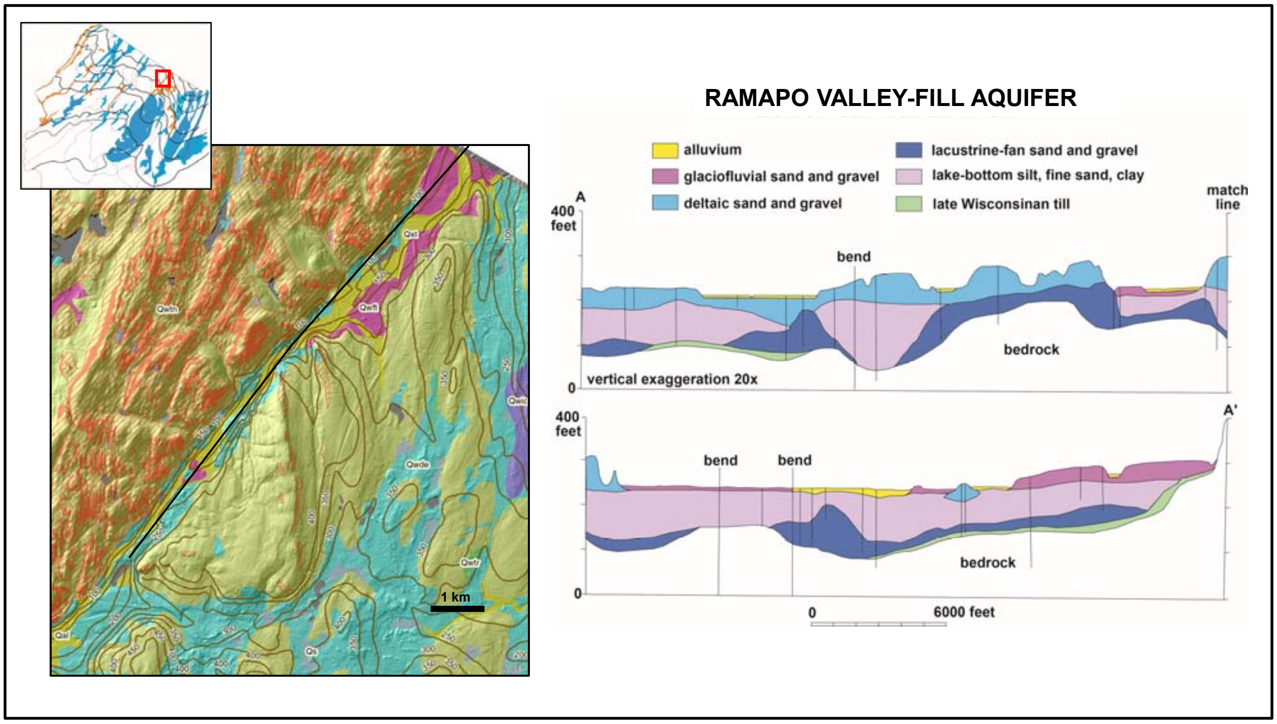
Topsets and foresets in the delta (A). Cobble gravel and plane-bedded sand in the fan deposits on the ice-contact (north) side of the delta (B). Incipient foreset beds of sand and pebbly sand in one of the beads of the beaded eskers (C).



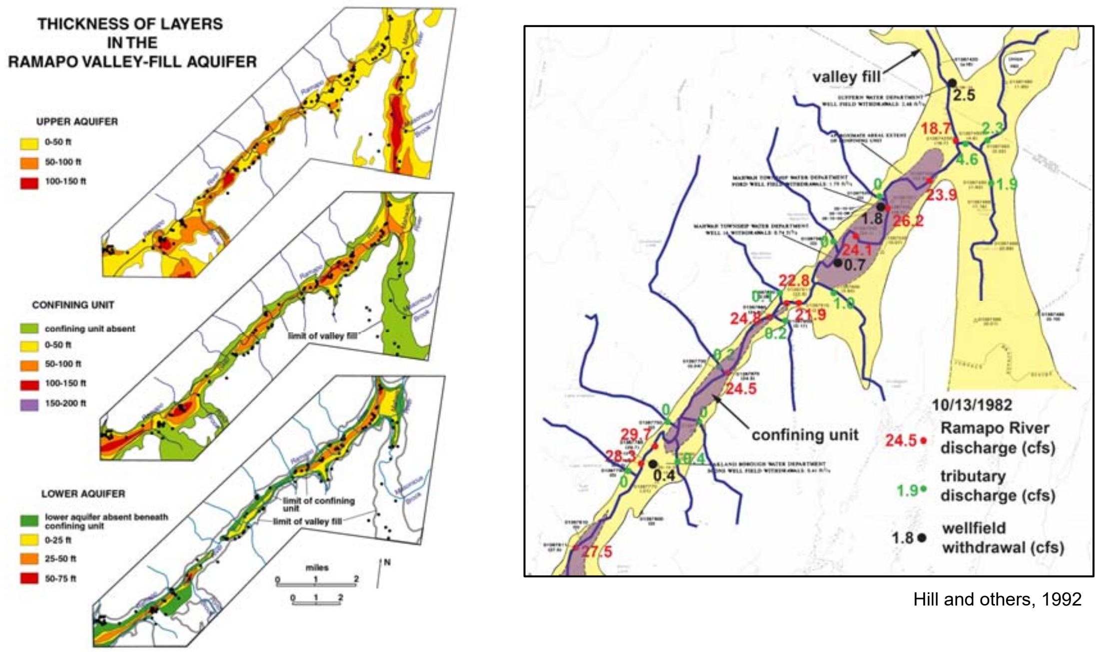
This area is in the Wallkill valley just north of the previous map. The lake here is the high (Augusta) stage of Lake Wallkill. A delta in the southwest part of the map is fed by another beaded esker which marks the same tunnel as in the previous map. This tunnel is on shale and the gravel in the delta and beaded esker is shale-rich. Another delta on the east side of the valley is fed by another beaded esker (partly buried by lake clay). This tunnel is on a narrow belt of carbonate rock and gneiss on the valley bottom and the gravel in the part of the delta fed by the tunnel is dominated by carbonate and gneiss. Part of this delta is also fed by ice-marginal meltwater channels (visible on the hillshade image) eroded into the thick gneiss- and shale-rich till on the upland to the east (triangular symbols on the map mark pebble counts in till). This part of the delta consists of shale and gneiss-rich gravel. Again, the pebble lithologies and landforms are in agreement and show that most of the deposits are tunnel-sourced.



Tunnels in New Jersey are up to 50 km long, which is a minimum because they do not end at the state line. A varve-radiocarbon chronology for the Hackensack Lobe in eastern New Jersey indicates that the tunnels persisted for more than 2000 years, again a minimum for the same reason These lengths and durations are at the low end of those for tunnels farther north in New England and Canada, but again are minimums. Their presence in New Jersey indicates that the thermal conditions and plumbing systems that characterized the Laurentide ice sheet later in the deglaciation history also likely were present during the glacial maximum and early deglaciation.



One practical application of these observations is in valley-fill aquifer studies. Glacial aquifers provide about 40% of the groundwater used in northern New Jersey. Most of this production is from lacustrine valley fills more than 30 m thick. In these settings the dominant producing beds are lacustrine-fan gravels at the base of the valley fill, as illustrated by the Ramapo valley-fill aquifer in northeastern New Jersey. This aquifer is tapped by several municipal well fields. A longitudinal section (AA', heavy line on map) through the valley fill shows lacustrine-fan gravels at the base, overlain by lake clay which acts as a confining or semi-confining bed. An upper deltaic and glaciofluvial sand and gravel caps the lake clays and is an unconfined aquifer. At recessional stillstands the fans aggraded to the lake surface and then prograded into the lake as deltas. The lake clay is absent at these spots and so they are potential recharge zones for the confined lacustrine-fan aquifer.



Hill and others, 1992

The left panel shows isopach maps of the three layers in the valley-fill aquifer: the upper unconfined aquifer, the middle confining unit, and the lower confined aquifer. The green areas on the middle panel are where the confining unit is absent and so highlight prime recharge zones. The right panel is from a USGS study of the northeastern part of the valley fill and shows stream losses and gains in relation to the confining unit and wellfields. Knowing that the lower gravels are subglacial eskers and beaded eskers that aggrade to deltas rather than preglacial or proglacial fluvial gravels following a stream valley, or randomly distributed superglacial or englacial ice-contact gravels let down from stagnant ice, improves groundwater models and data interpretation.

References

Ashley, G. M., Boothroyd, J. C., Borns, H. W., Jr., 1991, Sedimentology of late Pleistocene (Laurentide) deglacial-phase deposits, eastern Maine: an example of a temperate marine grounded ice–sheet margin: Geological Society of America Special Paper 261, p. 107-125.

Banerjee, I., and McDonald, B. C., 1975, Nature of esker sedimentation, *in* Jopling, A. V., and McDonald, B. C., eds., Glaciofluvial and glaciolacustrine sedimentation: SEPM Special Publication 23, p. 304-320.

Brennand, T. A., 2000, Deglacial meltwater drainage and glaciodynamics: inferences from Laurentide eskers, Canada: Geomorphology, v. 32, p. 263-292.

Gustavson, T. C., and Boothroyd, J. C., 1987, A depositional model for outwash, sediment sources, and hydrological characteristics, Malaspina Glacier, Alaska: a modern analog of the southeastern margin of the Laurentide ice sheet: Geological Society of America Bulletin, v. 99, p. 187-200.

Hill, M. C., Lennon, G. P., Brown, G. A., Hebson, C. S., Rheaume, S. J., 1992, Geohydrology of, and simulation of ground-water flow in, the valley-fill deposits in the Ramapo River valley, New Jersey: U. S. Geological Survey Water Resources Investigations Report 90-4151, 92 p.

Minard, J. P., and Rhodehamel, E. C., 1969, Quaternary geology of part of northern New Jersey and the Trenton area, *in* Subitzky, S., ed., Geology of selected areas in New Jersey and eastern Pennsylvania and guidebook of excursions: Rutgers University Press, p. 279-313.

Russell, H. A. J., and Arnott, R. W. C., 2003, Hydraulic-jump and hyperconcentrated-flow deposits of a glacigenic subaqueous fan: Oak Ridges Moraine, southern Ontario, Canada: Journal of Sedimentary Research, v. 73, p. 887-905.

Rust, B. R., and Romanelli, R., 1975, Late Quaternary subaqueous outwash deposits near Ottawa, Canada, *in* Jopling, A. V., and McDonald, B. C., eds., Glaciofluvial and glaciolacustrine sedimentation: SEPM Special Publication 23, p. 177-192.

Stanford, S. D., 1989a, Surficial geology of the Boonton quadrangle, Morris County, New Jersey: N. J. Geological Survey Geologic Map Series GMS 89-1, scale 1:24,000.

Stanford, S. D., 1989b, Surficial geology of the Dover quadrangle, Morris and Sussex counties, New Jersey: N. J. Geological Survey Geologic Map Series GMS 89-2, scale 1:24,000.

Stanford, S. D., 2005, Surficial geology of the Caldwell quadrangle, Morris and Essex counties, New Jersey: N. J. Geological Survey Open-File Map OFM 66, scale 1:24,000.

Stanford, S. D., 2006, Surficial geology of the Morristown quadrangle, Morris and Essex counties, New Jersey: N. J. Geological Survey Open-File Map OFM 67, scale 1:24,000.

Stanford, S. D., 2007a, Surficial geology of the Chatham quadrangle, Morris, Union, and Somerset counties, New Jersey: N. J. Geological Survey Open-File Map OFM 69, scale 1:24,000.

Stanford, S. D., 2007b Surficial geology of the Pompton Plains quadrangle, Morris, Essex, Passaic, and Bergen counties, New Jersey: N. J. Geological Survey Open-File Map OFM 68, scale 1:24,000.

Stanford, S. D., Harper, D. P., and Stone, B. D., 1998, Surficial geology of the Hamburg quadrangle, Sussex County, New Jersey: N. J. Geological Survey Geologic Map Series GMS 98-1, scale 1:24,000.

Witte, R. W., and Ridge, J. C., 2021, Surficial geologic map of the Belvidere quadrangle, Warren County, New Jersey, and Northampton County, Pennsylvania: N. J. Geological and Water Survey Open-File Map OFM 135, scale 1:24,000.