

Underground Storage of Refrigerated Natural Gas In Granites of the Southeastern U.S.

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Acknowledgements

Constructive comments were provided by Kenneth B. Taylor.

Underground Storage of Refrigerated Natural Gas in Granites of the Southeastern U.S.

By Robert H. Carpenter¹; Jeffrey C. Reid², and C. W. Myers³

Abstract

Conventional underground storage sites for natural gas (salt caverns, depleted gas and oil reservoirs, and aquifers) are either rare or absent along the eastern seaboard of the U.S. However, in this region the potential exists for underground storage of refrigerated natural gas in mined caverns (RMC) in granite*. We present the results of a study that examines pipeline-granite intersections in North Carolina and southern Virginia along the Williams/Transco pipeline (completed) and the Atlantic Coast Pipeline (planning and initial stage). With Google Earth Pro we took granite outlines from USGS digital state geologic maps and show those that are intersected by the pipelines. Search engines provided by the USGS provide more detailed information on the granites identified in this study. The USGS National Geologic Map Database is particularly useful as it provides detailed maps (geological, geophysical, and geochemical) of any particular area in the U.S. Many of these maps can be downloaded from their website. In addition, we use the conceptual design for a mined cavern in granite in the Maryland piedmont given by PB-KBB (1998) in a 1998 DOE sponsored study as an example of the type of natural gas storage cavern that could potentially be adapted for use in the NC and VA granites*. Liquid Natural Gas (LNG) plants are judged to be more competitive at the present time principally because of lower capex. However, RMC plants can meet multiple peak demands per year whereas LNG plants are limited in their cycle time. Existing knowledge of geology and locations of granite rock with potentially suitable geotechnical properties in the NC and southern VA region, coupled with modern advances in hard rock excavation technology, argue for the overall technical viability of the concept. Commercial viability, however, will depend on site specific conditions, market analysis, and other considerations requiring additional study.

This open-file report is adapted from an oral presentation at the Southeastern Section, Geological Society of America, March 30, 2017 (Richmond, VA).

*Granite as used herein is a broad term for massive and isotropic rock bodies with desirable ranges of physical, and mechanical properties that are capable of sustaining large underground openings, with suitable thermal properties.

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Foreword

The concept of underground storage of refrigerated natural gas in granites of the

Southeastern U.S. was presented March 30, 2017 at the Southeastern Section Meeting, of the Geological Society of America in Richmond, Virginia (see URL <https://gsa.confex.com/gsa/2017SE/webprogram/Paper290036.html> with attachment) (**Carpenter; Reid, and Myers, 2017**). It is reproduced here in slightly modified form to broaden the concept's exposure to policy-makers in North Carolina and the Southeastern U.S.

This presentation was paired with one by Carl W. Myers, "Potential for Special-Purpose Underground Facilities in Granites on the Southeastern U.S. (see URL <https://gsa.confex.com/gsa/2017SE/webprogram/Paper290326.html> with attachment) (**Myers, 2017**).

Objectives

The reports's objectives are to introduce the concept of storage of refrigerated natural gas in granites of the Southeastern United States. It was provided a facility design overview, showed a comparison and benefits of mined caverns vs. LNG plants (including security). Examples of potentially suitable granite bodies intersecting existing or planned natural gas pipelines were provided in North Carolina and Virginia.

Topics covered

The topics covered in this report include: 1) the distribution of underground storage sites in the U.S. and possible need for additional sites in the Atlantic Seaboard, 2) review of PB-KBB underground storage design for an excavated refrigerated natural gas underground storage site in granitic rock, 3) existing and proposed major pipelines in the eastern U.S., 4) intersection of major pipelines and granites in North Carolina and Virginia, locations of existing natural gas fired power plants, LNG plants, and population growth maps, and 5) relationship between Brunswick Country Power Station, Atlantic Coast Pipeline, and porphyroblastic biotite granite in southeastern Virginia; and the Sims granite, Atlantic Coast Pipeline, in Wilson County, N.C.

Potential investigation phases

Reid and others (2016) suggested a five-step plan to investigate potential sites. Initial concepts were formed in August 2016. Phases one through three would be performed by staff of the North Carolina Geological Survey. Subsequent stages would involve significant capital expenditures and technical studies would be performed by qualified contractors with expertise in the construction of underground caverns. The proposed phases are:

Phase 1 – Site identification

During this phase the current approach as described in this report would be expanded to define candidate granites intersecting pipelines. This would be coupled with a comprehensive literature review. Input would be sought from industry and other interested parties. The expected outcome would be the selection of 2-4 (nominal number) candidate sites.

Phase 2 – Rank candidate sites

This phase new geologic mapping complemented by geophysics would be used to rank order candidate sites.

Phase 3 – Core drill and geotechnical testing of the top 2 candidate sites

During this phase a program of core drilling and geotechnical testing will investigate the top two candidate sites identified. If needed, additional candidate sites may be added by going back to Phase 1.

Phase 4 – Engage private sector in concept

The engagement of the private sector in concept would occur during this phase so a potential client or group of clients would do the actual work. The client would issue a RFP for underground construction firms to bid on the top ranked candidate site. Note: There could be more than one highly ranked site, in which case it would be necessary to decide on soliciting bids for both, or postpone the evaluation of one of the sites.

The successful bidder's responsibility is to provide to the Client a conceptual design similar to what PB-KBB did in Maryland. Bidders would have to drill cores required for needed geotechnical data. Potential bidders would be expected to include PB-KBB and potential domestic and international firms.

Phase 5 – Client analyses results and decides on next steps.

Client analyses results and decides on next steps during this phase.

Conclusions

There are eleven major pipeline intersections with granite in North Carolina and southern Virginia identified in this report. If the need for underground storage justifies the higher costs of underground excavations, such as the type described by PB-KBB corporation, these granites would warrant further consideration as underground storage sites.

Initial follow-up would include: 1) additional literature searches, 2) geological traverses along pipeline- granite intersections and immediately adjacent areas documenting density of fractures and their orientation, and 3) baseline environmental impact studies to identify environmentally-sensitive areas along pipeline - granite intersections.

References

- Carpenter, Robert H.; Reid, Jeffrey C., and Myers, Carl W., 2017, Underground storage of refrigerated natural gas in granites in North Carolina and Southern Virginia: Southeastern Section meeting (Richmond, VA), Geological Society of America, Abstracts with programs, Vol. 49, No. 3. Available on-line at URL <https://gsa.confex.com/gsa/2017SE/webprogram/Paper290036.html>.
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Underground Storage of Refrigerated Natural Gas in Granites of the Southeastern U.S.

**Geological Society of America
2017 Southeastern Section Meeting
30-31 March 2017, Richmond, VA**

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Objectives:

- Introduce the concept of storage of refrigerated natural gas in granites.
- Introduce facility design concept.
- Comparison and benefits of mined cavern storage vs. LNG plants (including security).
- Show examples of potentially suitable 'granite' bodies intersecting existing or planned natural gas pipelines.

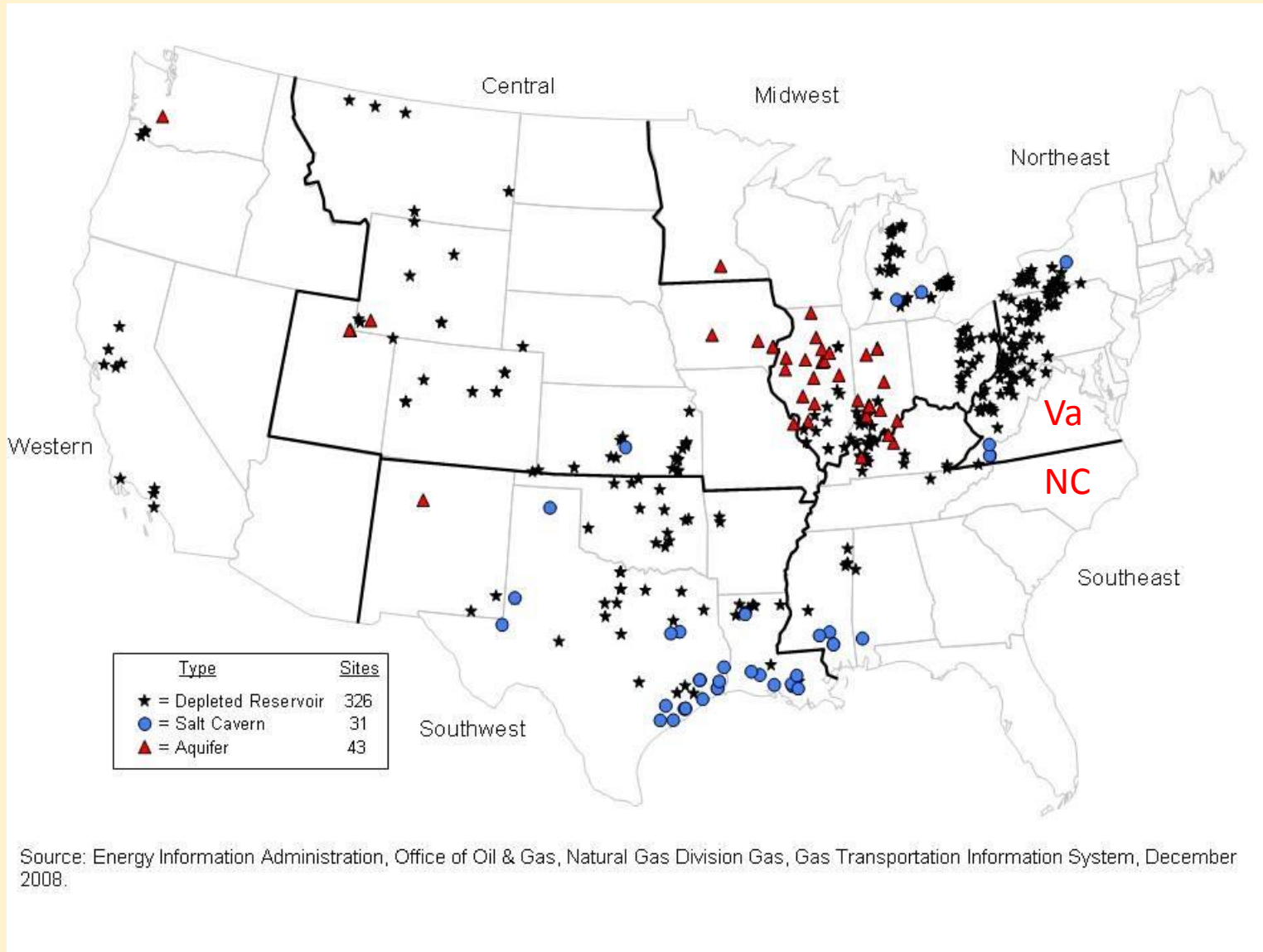
Topics Covered in This Presentation:

- Distribution of underground storage sites in the U.S. and possible need for additional sites in the Atlantic Seaboard.
- Review of PB-KBB Underground Storage Design for an excavated refrigerated natural gas underground storage site in granitic rock.
- Existing and proposed major pipelines in the eastern U.S.
- Intersection of major pipelines and granites in North Carolina and Virginia, locations of existing natural gas fired power plants, LNG plants, and population growth maps.
- Relationship between:
 - Brunswick County Power Station, Atlantic Coast Pipeline, and porphyroblastic biotite granite in southeastern Virginia; and
 - the Sims Granite, Atlantic Coast Pipeline, in Wilson County, North Carolina.

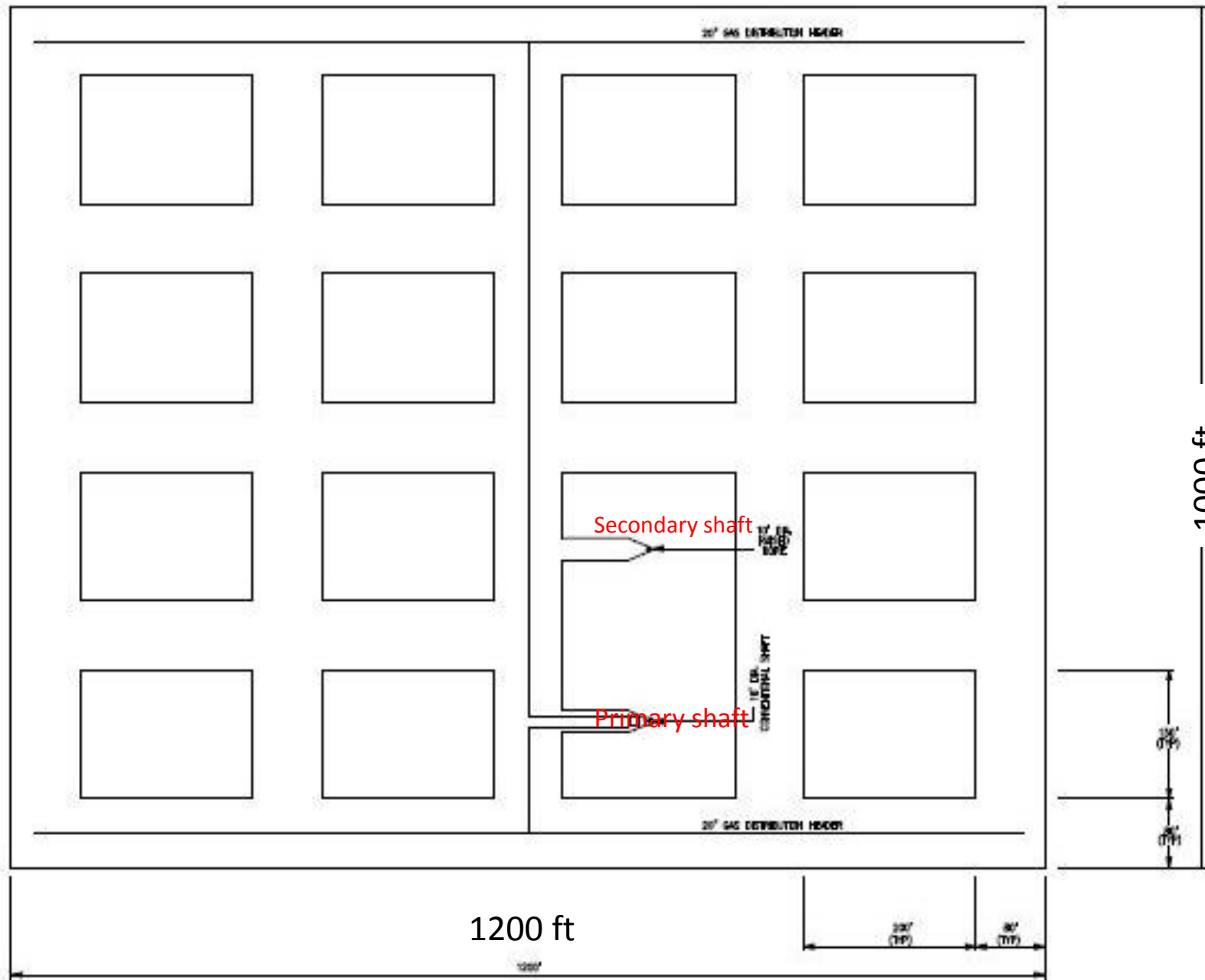
Need for natural gas storage – Southeastern U.S.

According to EIA, natural gas storage is essential as a supply backup and to balance gas supplies on the pipelines operating in a region. Conventional underground storage sites (including depleted reservoirs, salt caverns, and aquifers) are generally absent in Virginia and North Carolina.

Under contract to DOE the PB-KBB corporation, in 1998, investigated the feasibility of constructing a room and pillar underground excavation at a Maryland site. They concluded that mined cavity storage can provide high delivery rates and multiple fill – withdrawal cycles in areas where salt caverns are not available.



Source: Energy Information Administration, Office of Oil & Gas, Natural Gas Division Gas, Gas Transportation Information System, December 2008.



PB-KBB Design Underground Storage (plan view)

Design features:

Depth – 3000 ft

Volume – 37 million cubic ft

Storage Temperature - -20 degrees F.

Maximum Pressure – 1250 psig

Storage capacity – 5 billion standard cubic ft (BCF).

Plant cost – \$173 million or \$34.50 per standard thousand cubic ft stored.

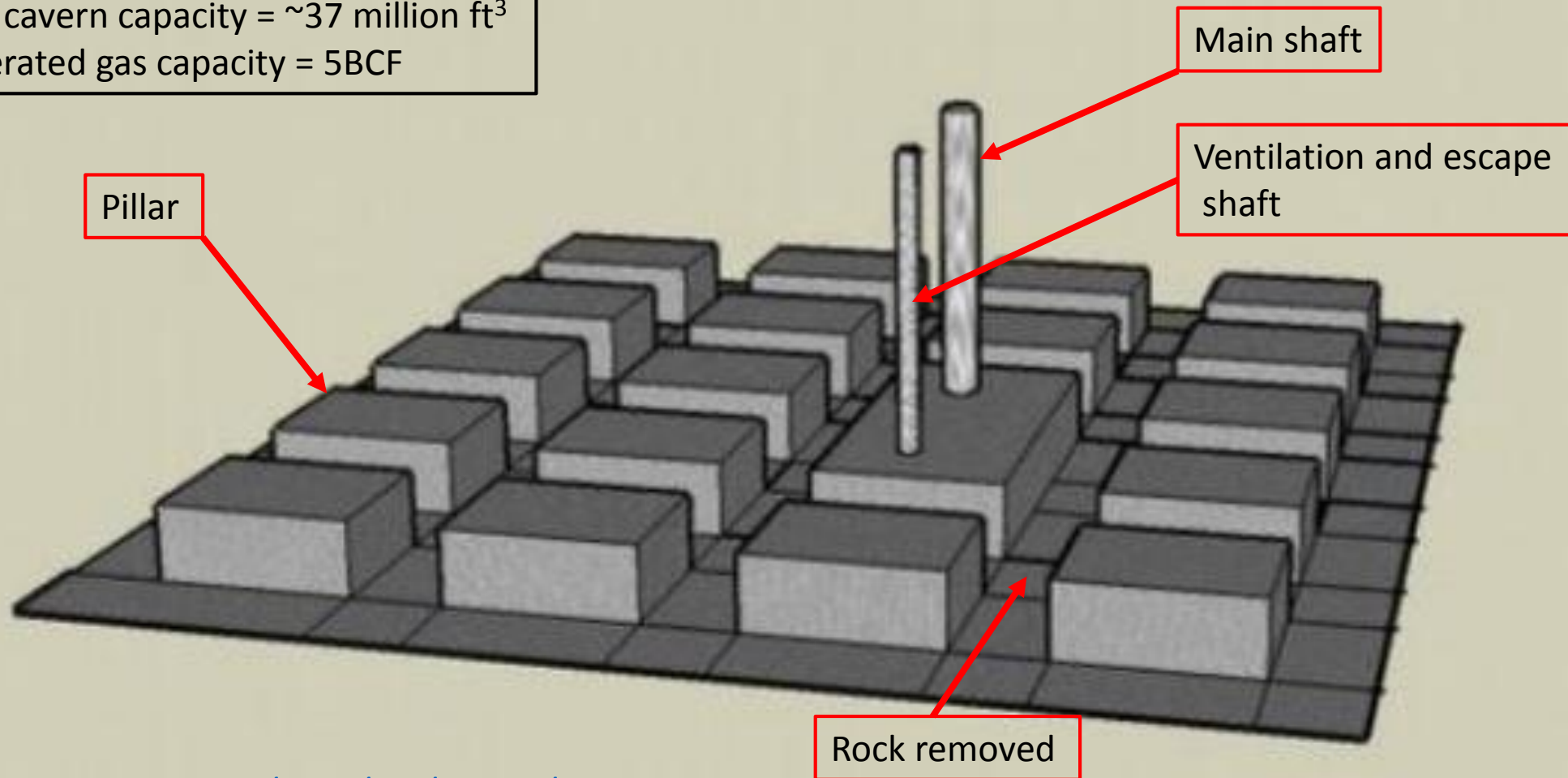
Surface footprint – 4 acres with additional 2 or 3 acres for mine shafts and mining operation.

Area of underground development ~ 27 acres.

Shafts – 2 shafts: one 18-20 ft diameter for moving equipment underground and lifting excavated rock during operation; and one 10 ft in diameter to serve for ventilation and escape route in case of accident during construction.

3D Graphic PB-KBB Design – Underground Storage

Mined cavern capacity = ~37 million ft³
Refrigerated gas capacity = 5BCF



Source:

<http://www.netl.doe.gov/KMD/cds/Disk19/FinalRpt.pdf>

From PB-KBB Report

General Requirements for Storage Sites

The following are some of the general requirements for storage sites:

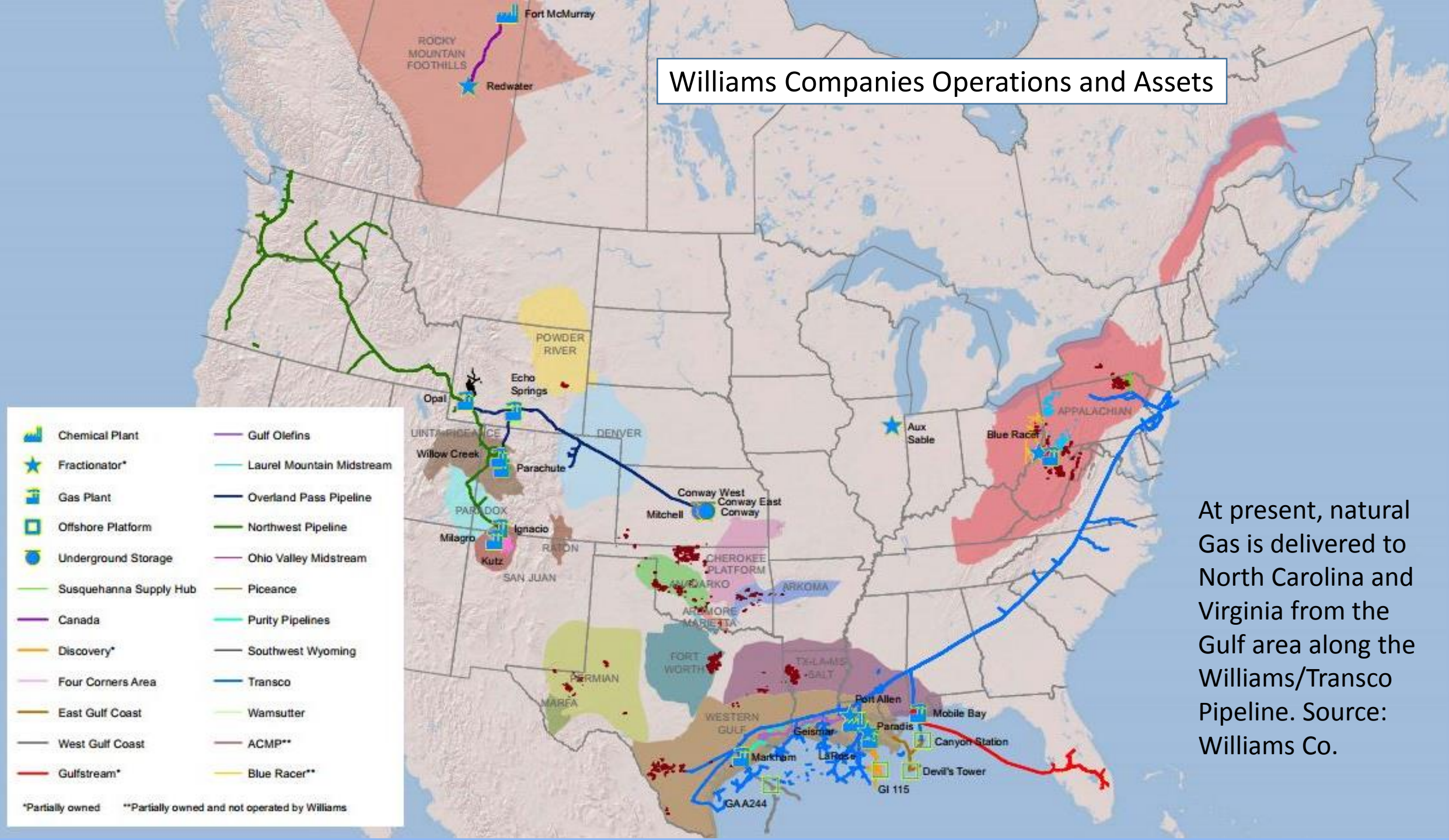
- Proximity to transportation systems, such as pipeline, that are to be used for bringing in or shipping out the stored gas to minimize the extent of new pipelines construction. This is of particular importance in areas where approval of new pipeline rights of way is often difficult to obtain.
- More advantageously, and especially for meeting the peaking needs, the storage space would be created near a marketing area, such as a metropolitan area or a strategically located point from which thickly populated areas may be served. Market centers, with their access to multiple pipeline interconnections and supplies, provide a natural platform for gas trading, risk management and opportunity for arbitrage. Storage in Market Center is a multi-purpose resource, such as to support short-term gas loans, gas balancing, and peaking services ("Natural Gas 1996 - Issues and Trends," Energy Information Administration, Dec. 1996).
- Adequate electric power and water supply should be available for storage
- Construction site should be easily accessible
- Congested areas should be avoided, especially environmentally sensitive areas (i.e., natural, state, and local parks, monuments, reservoirs, etc., and areas zoned "residential")
- Suitability of rock for storage - All rock types must be tested locally for site suitability
 - (a) The cavern host rock should be as impervious and free of fractures as possible to minimize leakage.
 - (b) The rock should be strong enough requiring little or no artificial support of the cavern roof for the given dimensions. Stronger the rock type, the larger the size of the cavern that can be constructed.
 - (c) The rock should be uniform and should have little or no jointing, faults and other discontinuities such as shear zone. This impacts the strength of the rock, leakage potential and the dimensions of the underground openings.
 - (d) For economic reasons, the rock should be easy to excavate for the shafts and underground caverns.

- (e) The rocks through which the shaft will pass should not be incompetent or be heavy water-bearing, since water control in shaft sinking would require stabilization techniques such as grouting, or freezing, which are expensive.
 - (f) Shale and siltstone have been most favorable types of sedimentary rocks because they are impervious, and relatively easy to excavate. However, these rocks require extensive artificial supports, such as roof bolts.
 - (g) Igneous and metamorphic rocks are also impervious, could form tight caverns and are strong enough to have self-supporting roofs of the caverns. Large size caverns can be constructed in these types of rocks.
- Availability of space nearby for disposal of the excavated material.
 - Sufficient water table to maintain a positive hydrostatic head at the pressures used for storage.

Granitoid rocks are well suited for the type of mined excavation described by PB-KBB. In this study, granites along principal pipelines in Virginia and North Carolina, were investigated using GIS technology – principally Google Earth Pro.

Not mentioned in the PB-KBB statements is the potential for radon accumulation in these excavations. Based on mineralogy, most accessory minerals are resistant to weathering and should not release either radium or radon. Uranium in silicate minerals such as biotite are probable sources of radium and radon in the zone of weathering, but at depths of several thousand feet would not likely release much radon to mined caverns. However, hydrothermally altered granite would be more susceptible to radon release.

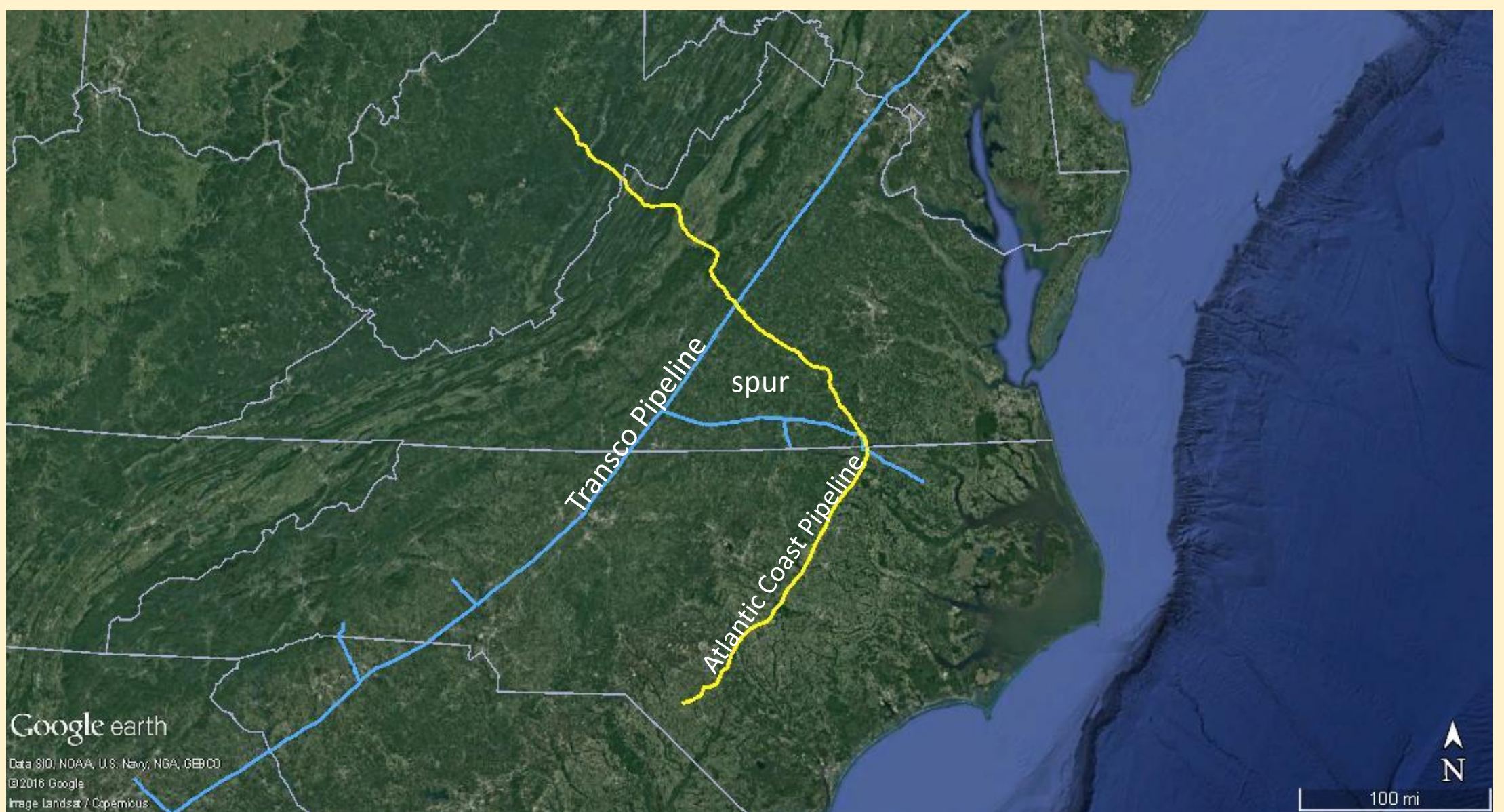
Williams Companies Operations and Assets



	Chemical Plant		Gulf Olefins
	Fractionator*		Laurel Mountain Midstream
	Gas Plant		Overland Pass Pipeline
	Offshore Platform		Northwest Pipeline
	Underground Storage		Ohio Valley Midstream
	Susquehanna Supply Hub		Piceance
	Canada		Purity Pipelines
	Discovery*		Southwest Wyoming
	Four Corners Area		Transco
	East Gulf Coast		Wamsutter
	West Gulf Coast		ACMP**
	Gulfstream*		Blue Racer**

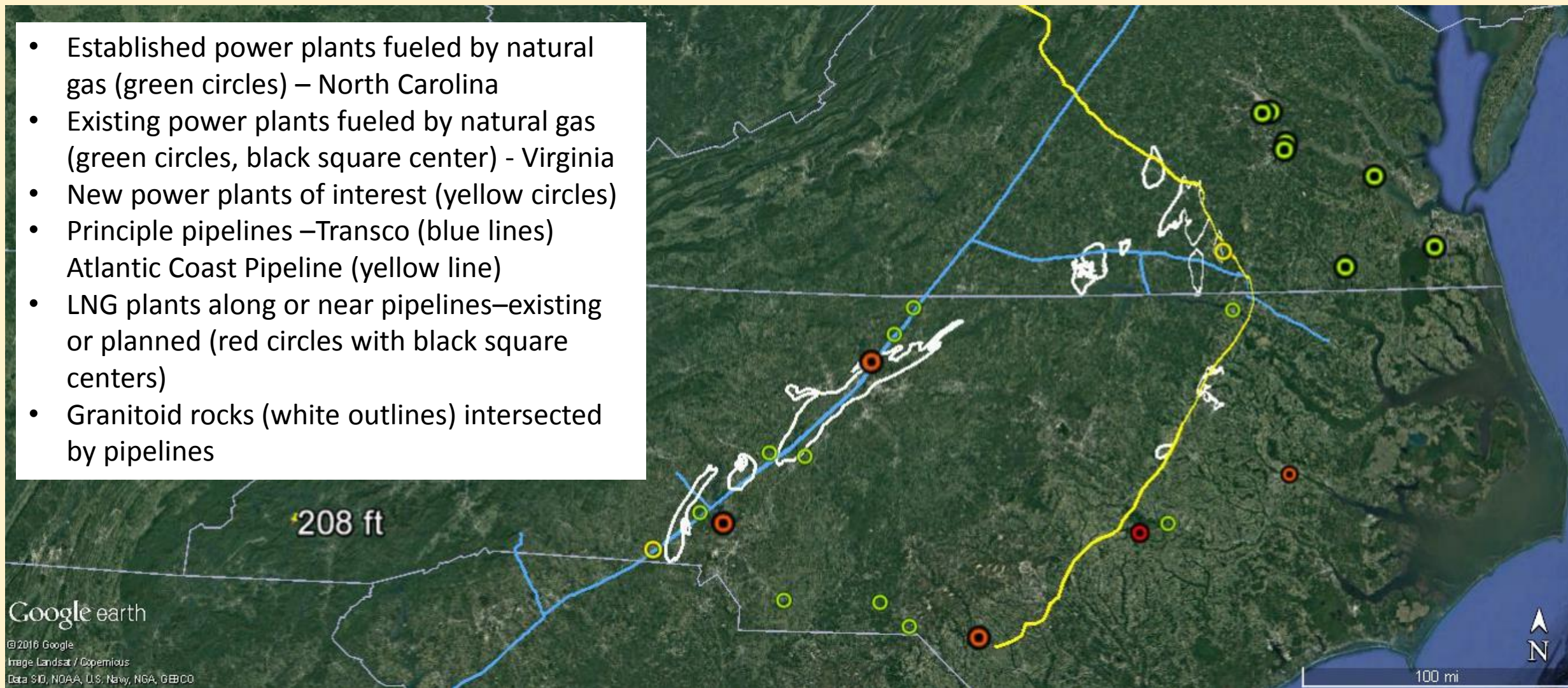
*Partially owned **Partially owned and not operated by Williams

At present, natural Gas is delivered to North Carolina and Virginia from the Gulf area along the Williams/Transco Pipeline. Source: Williams Co.



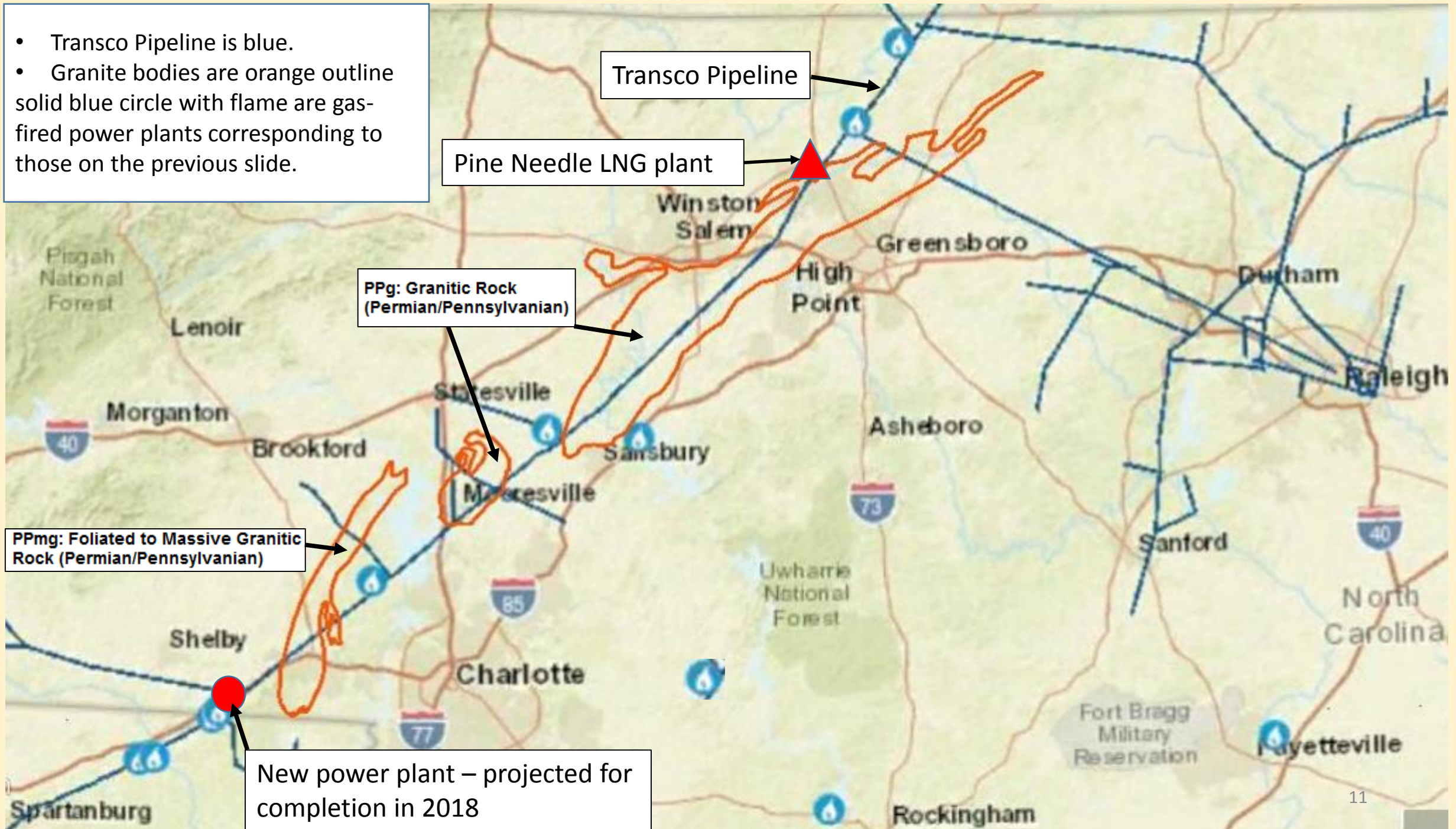
Pipeline Map. Transco Pipeline in blue; Atlantic Coast Pipeline in yellow. The Transco Pipeline has been in existence for many years. The Atlantic Coast Pipeline has only been recently proposed. It will obtain natural gas from the Marcellus shale in West Virginia, Ohio, and Pennsylvania. Subsequent slides will show these pipelines in relation to granite bodies, LNG plants, natural gas power plants, and population growth maps. 9

- Established power plants fueled by natural gas (green circles) – North Carolina
- Existing power plants fueled by natural gas (green circles, black square center) - Virginia
- New power plants of interest (yellow circles)
- Principle pipelines –Transco (blue lines) Atlantic Coast Pipeline (yellow line)
- LNG plants along or near pipelines—existing or planned (red circles with black square centers)
- Granitoid rocks (white outlines) intersected by pipelines

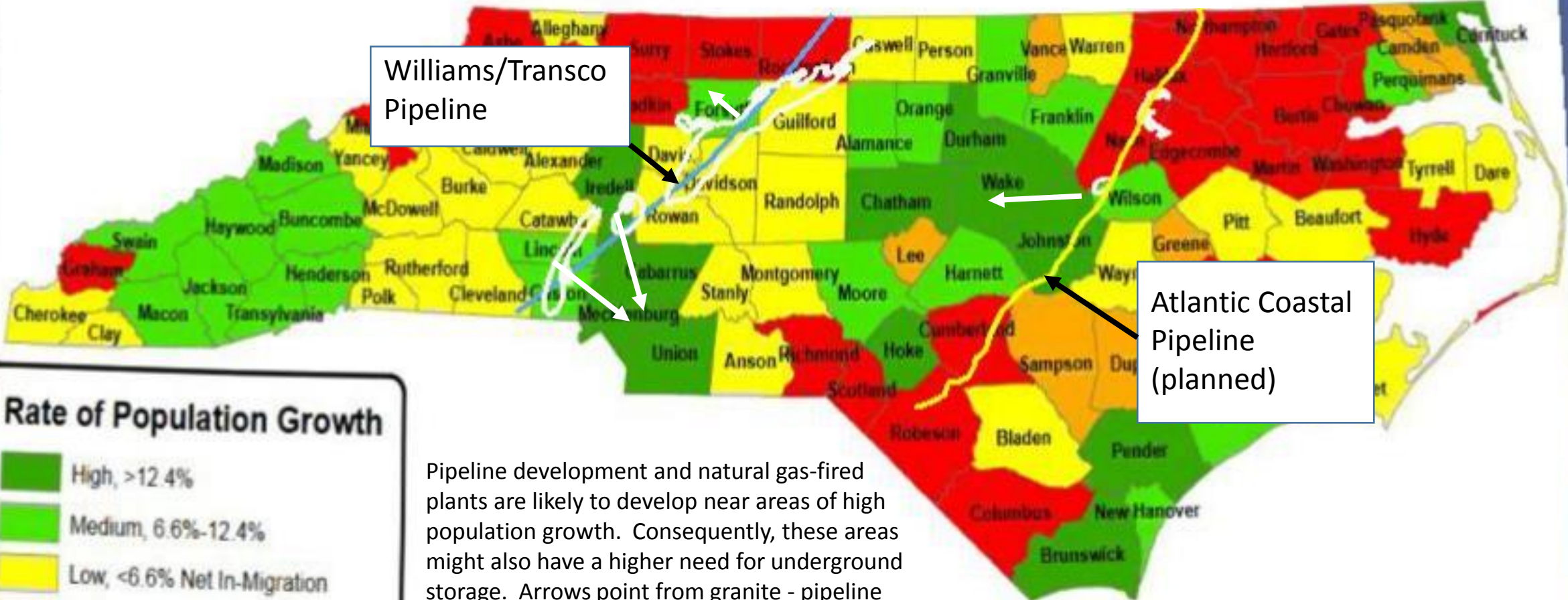


Currently, LNG plants are considered more viable than Refrigerated Mined Caverns (RMC) in the Atlantic Seaboard. Even though capital costs for LNG plants have more than doubled since 2000 (Songhurst, 2014), capex is still less than for RMC. Another advantage is that LNG plants can be built almost anywhere – those near the coast are built on unconsolidated sediment. RMC requires rocks with special geotechnical properties (certain granites, for example). **A principal advantage of RMC is that, like salt caverns, gas can be stored, and removed, more efficiently than LNG plants. Consequently, RMC plants can meet several “peak” demand periods each year, whereas LNG plants have much slower cycle times (some sources indicate 1 cycle/year).** Green dots with black centers are existing power plants.

- Transco Pipeline is blue.
- Granite bodies are orange outline
- solid blue circle with flame are gas-fired power plants corresponding to those on the previous slide.



Population Growth, 2020-2030



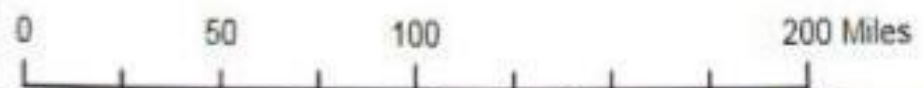
Williams/Transco Pipeline

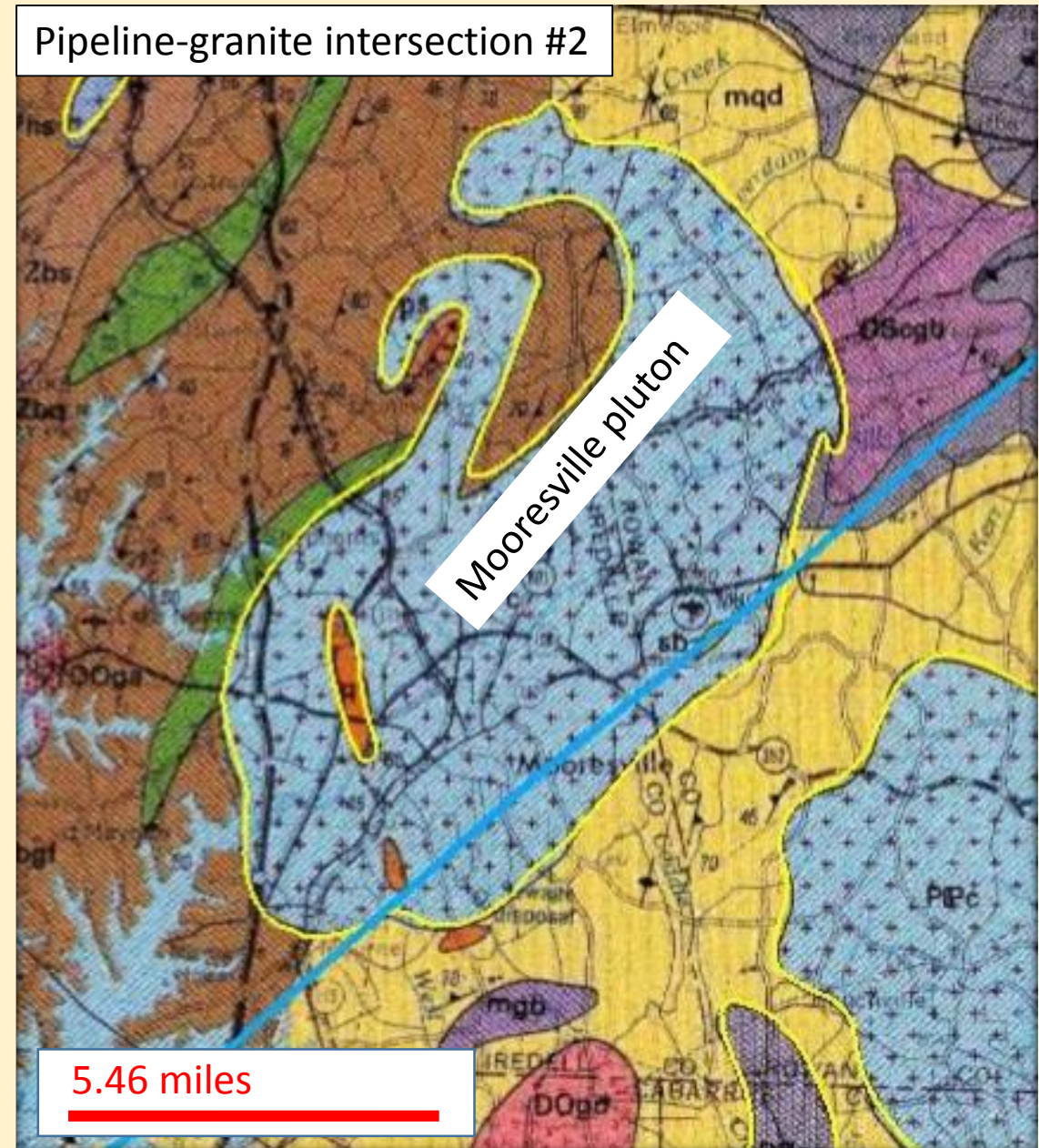
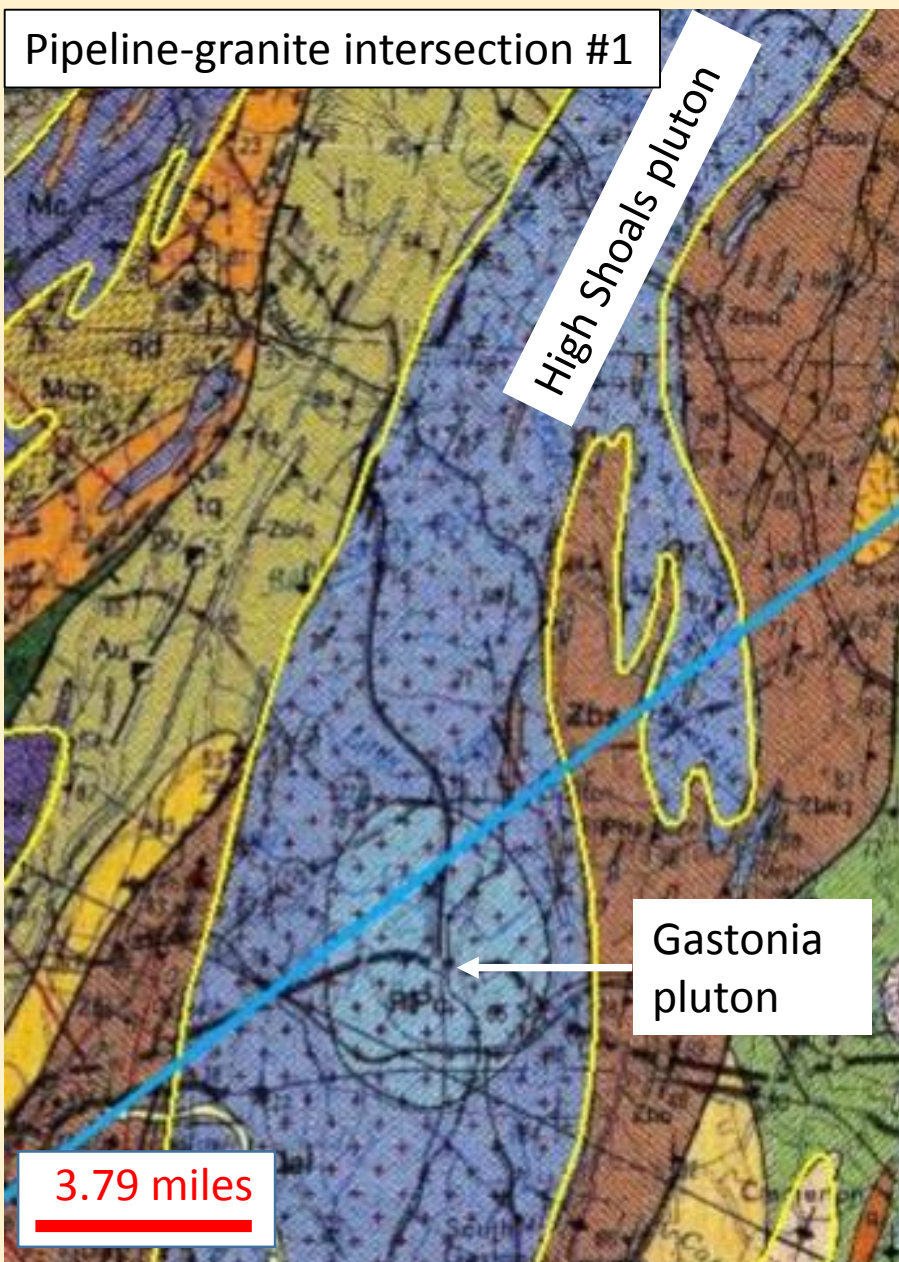
Atlantic Coastal Pipeline (planned)

Rate of Population Growth

- High, >12.4%
- Medium, 6.6%-12.4%
- Low, <6.6% Net In-Migration
- Low, <6.6% Net Out-Migration
- Population Loss, <0%

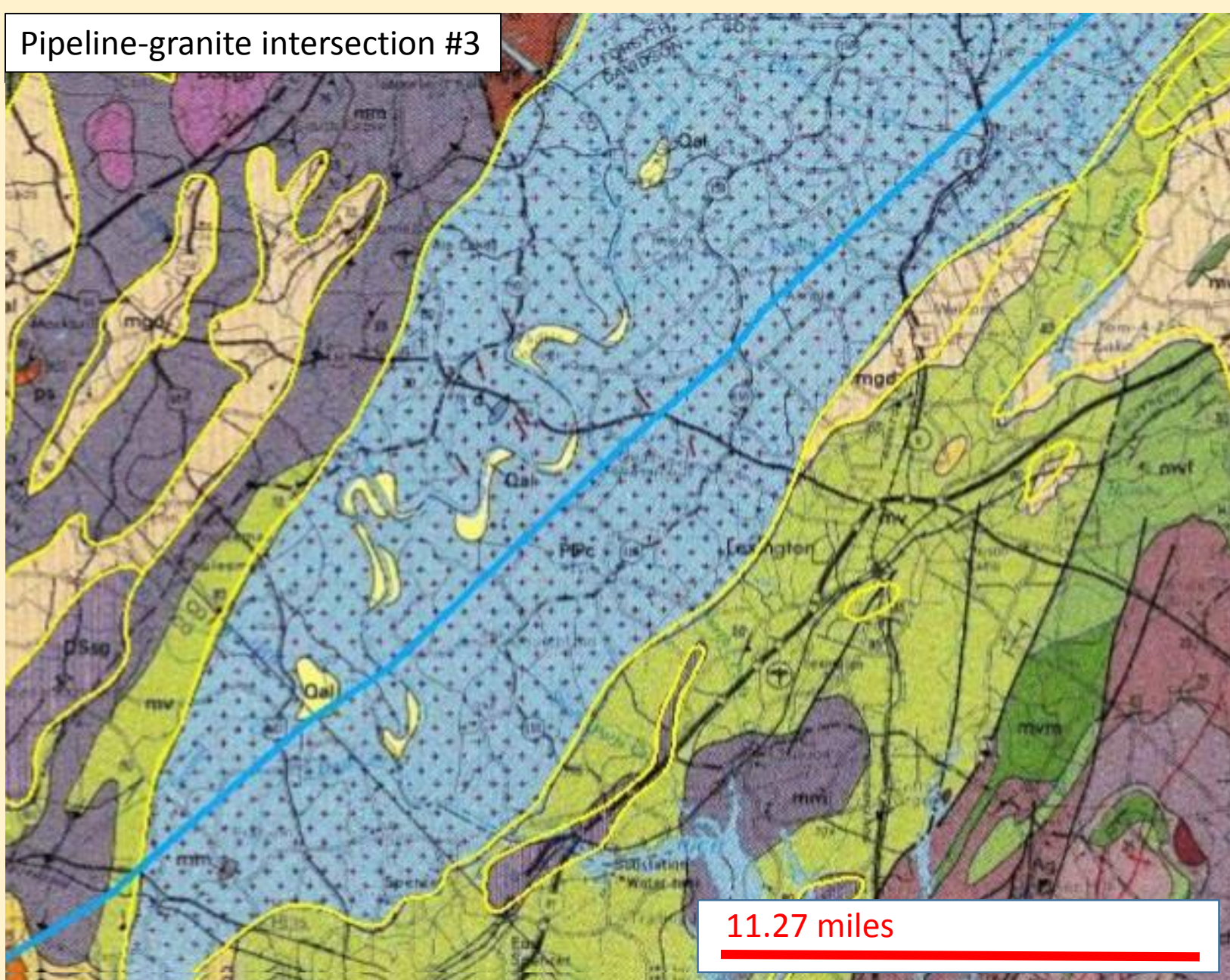
Pipeline development and natural gas-fired plants are likely to develop near areas of high population growth. Consequently, these areas might also have a higher need for underground storage. Arrows point from granite - pipeline intersections to population growth areas. Granites are shown as white outlines.





Granites intersecting Transco Pipeline (blue line) from Geologic map of the Charlotte 1 degree x 2 degrees quadrangle, North Carolina and South Carolina (Goldsmith; Milton and Horton, 1978) available on-line at URL https://ngmdb.usgs.gov/Prodesc/proddesc_9068.htm.

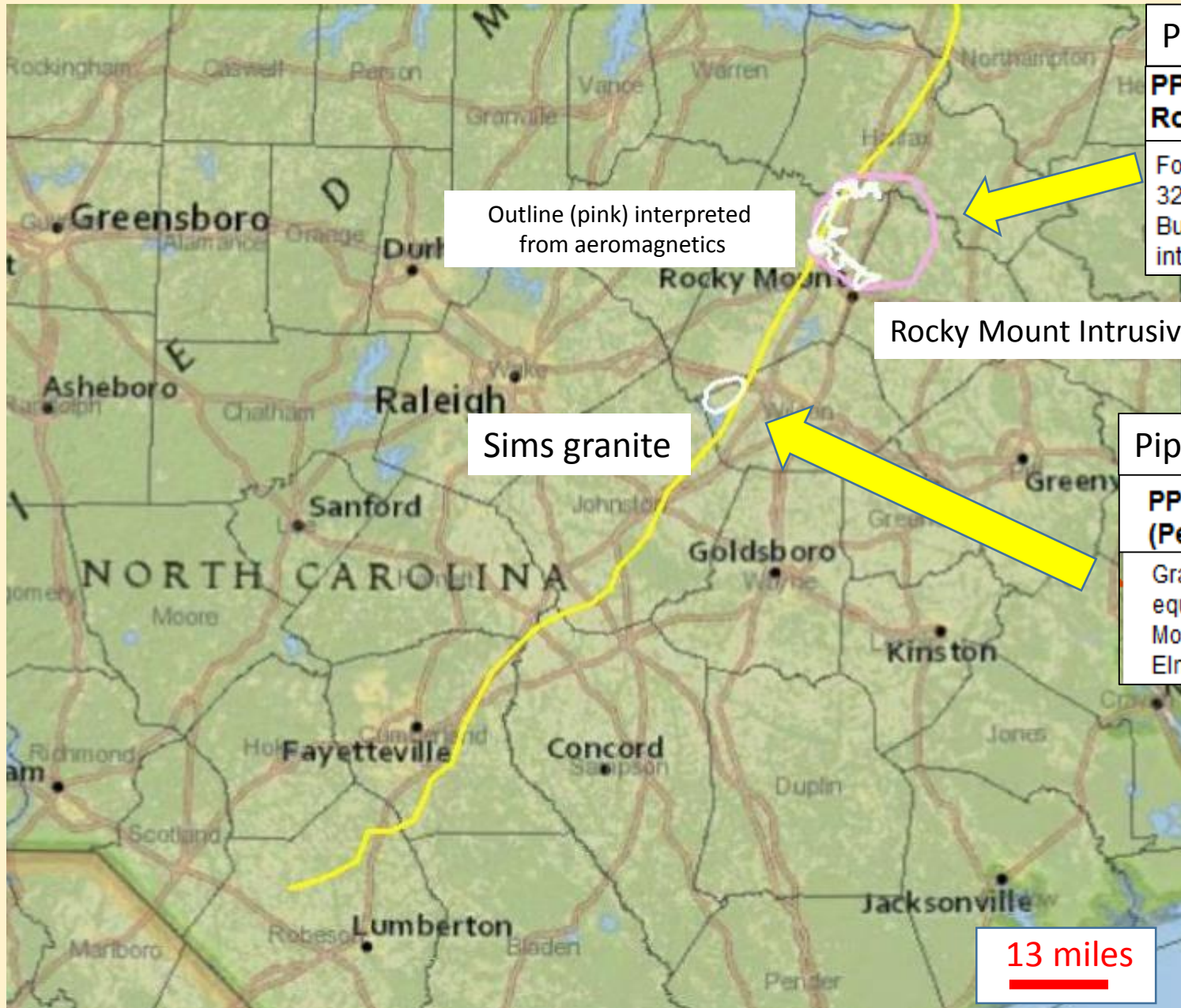
Pipeline-granite intersection #3



11.27 miles

Intersection of Transco Pipeline (blue line) with granite near Lexington, N.C. Geology from the Geologic map of the Charlotte 1 degree x 2 degrees quadrangle, North Carolina and South Carolina (Goldsmith; Milton and Horton, 1978) available on-line at URL

https://ngmdb.usgs.gov/Prodesc/proddesc_9068.htm.



Pipeline-granite intersection #5

PPmg: Foliated to Massive Granitic Rock (Permian/Pennsylvanian)

Foliated to Massive Granitic Rock (270-320my) - megacrystic to equigranular. Butterwood Creek intrusive and Rocky Mount intrusive suite.

Outline (pink) interpreted from aeromagnetics

Rocky Mount Intrusive suite

Sims granite

Pipeline-granite intersection #4

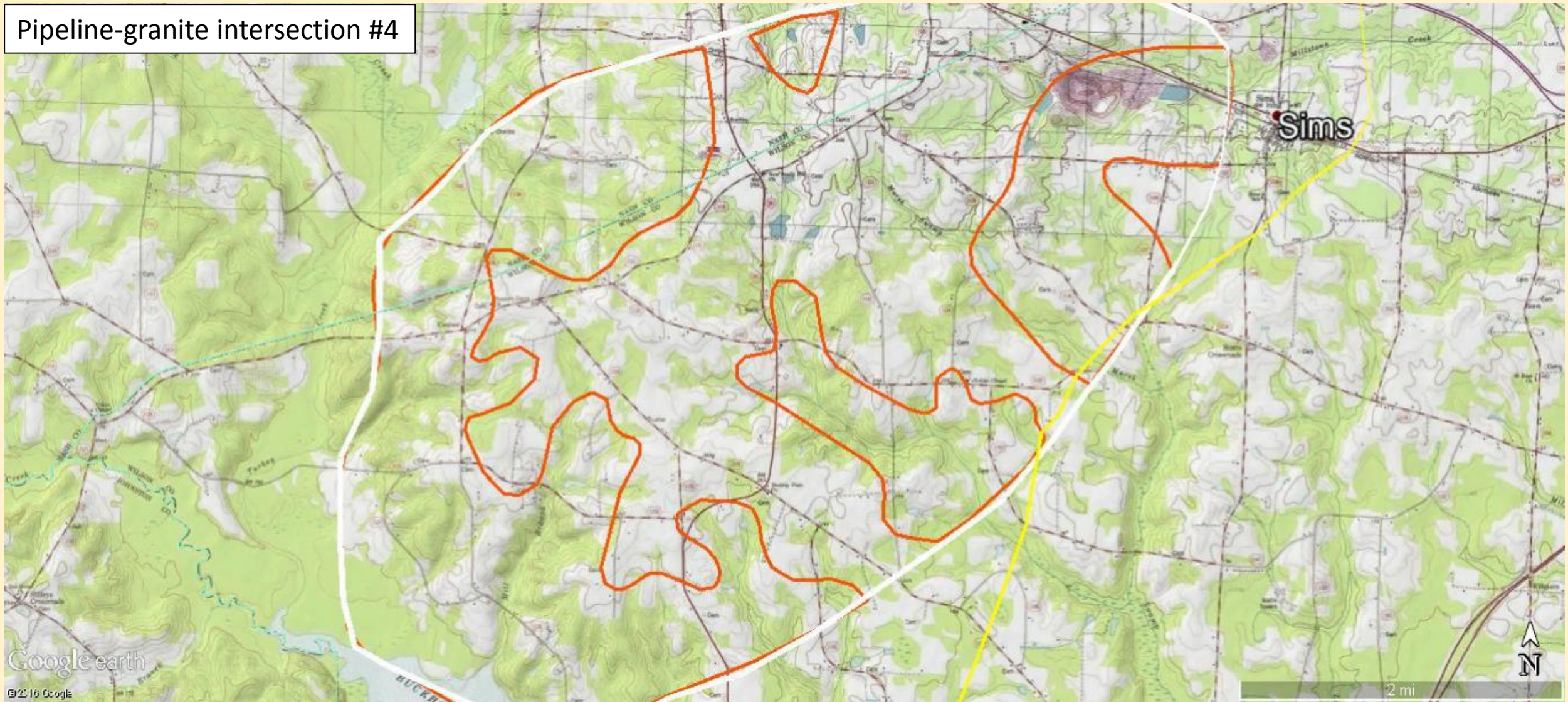
PPg: Granitic Rock (Permian/Pennsylvanian)

Granitic Rock (265-325 my) - megacrystic to equigranular. Castalia, Lillington, Medoc Mountain, Sims, Contentnea Creek (?), and Elm City (?) intrusives.

13 miles

Granites (white outlines) intersected by planned Atlantic Coast Pipeline in eastern N.C.

Pipeline-granite intersection #4



Sims Granite Area. Outline of granite shown in white. Outline of area of granitic outcrops shown in red. Interior areas (not outlined) are an overlap of Coastal Plain sediment. Proposed route of Atlantic Coast Pipeline shown in yellow. Modified from Speer, 1997.

Speer, J.A., 1997, [The Sims Pluton, Nash and Wilson Counties, North Carolina](#): North Carolina Geological Survey, Bulletin 97, scale 1:82,000.

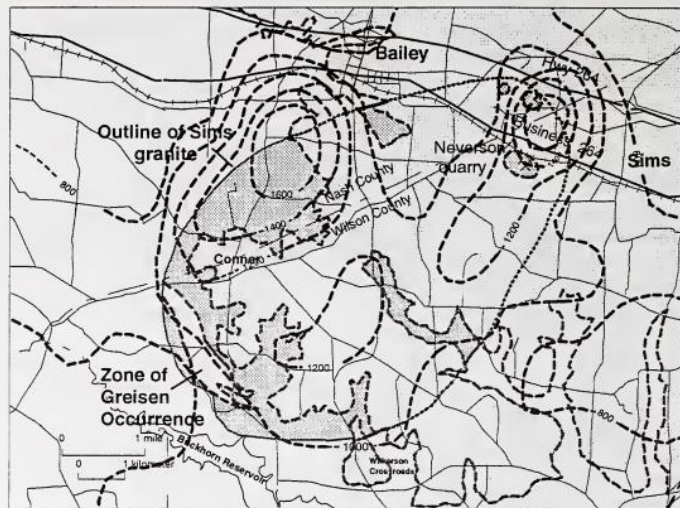


Figure 16. Aeroradioactivity map for the vicinity of the Sims pluton, N.C. (U.S. Geological Survey, 1975). Values are total count gamma ray intensity.

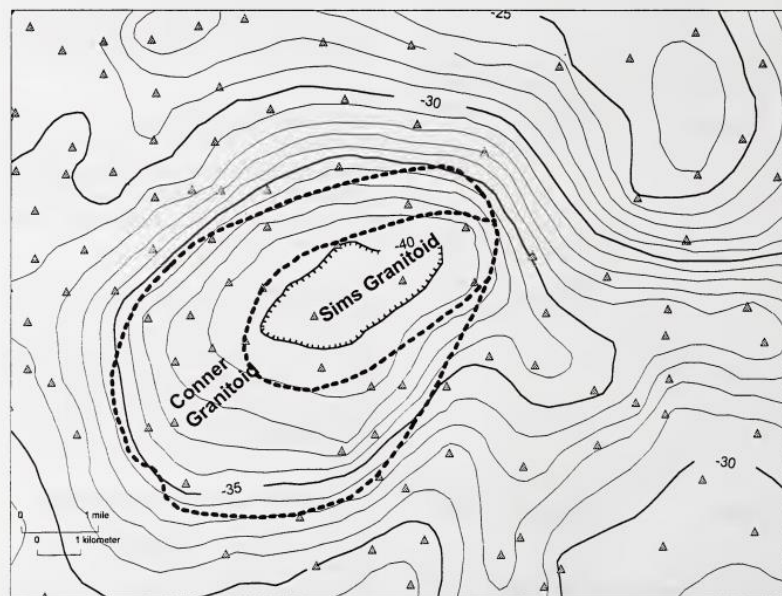
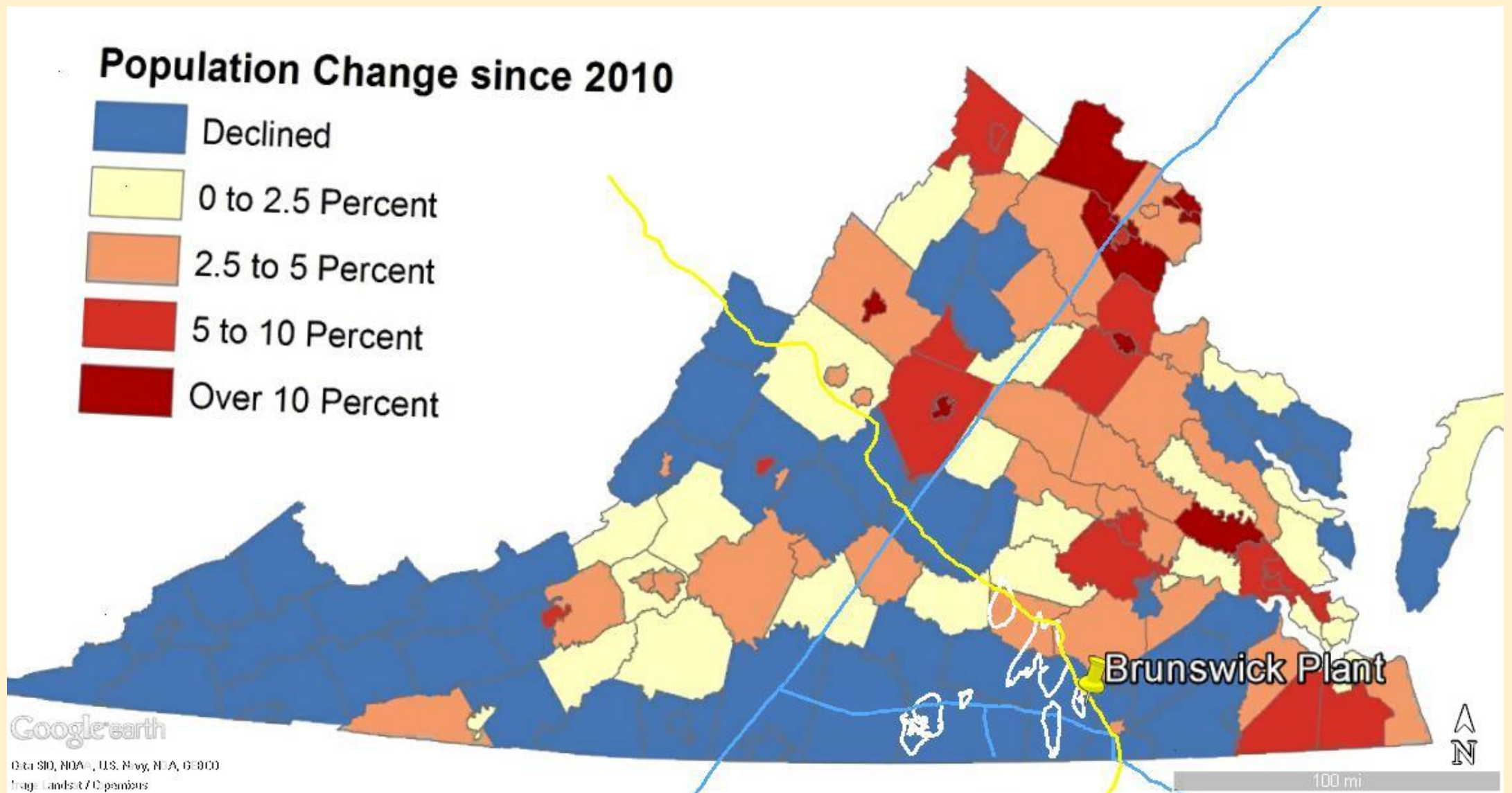


Figure 14. Bouguer gravity anomaly map for the Sims pluton and vicinity (Lawrence, 1996). Shaded triangles indicate location of the observations.

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This publication summarizes just about all information available for the granite body. It serves as a model for the type of information needed for evaluating sites for underground development.



From the standpoint of population growth, the likelihood for underground storage along the Transco spur is less than that along the planned Atlantic Coast pipeline (ACP). The Brunswick County Power Station (yellow pin symbol) is located about 2.25 miles from the planned ACP and a potentially suitable granite body.

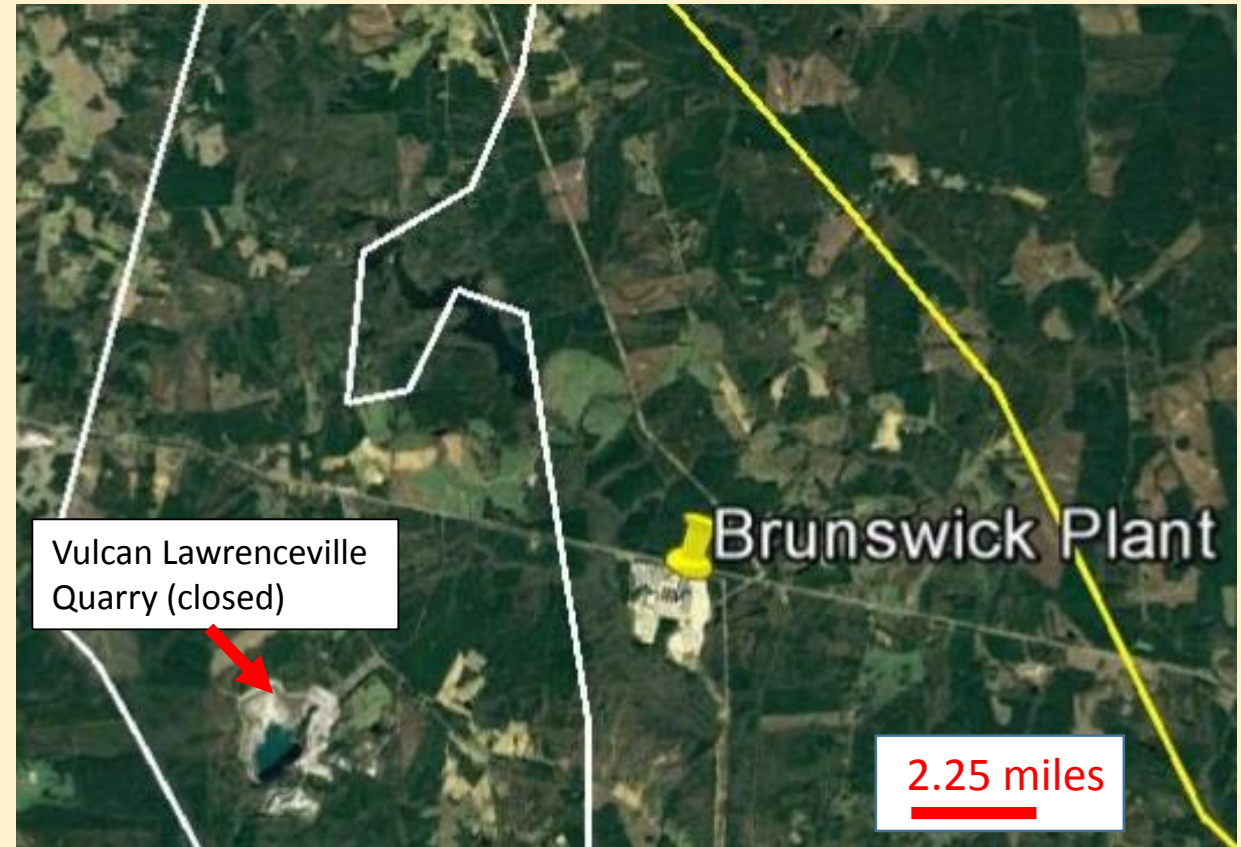
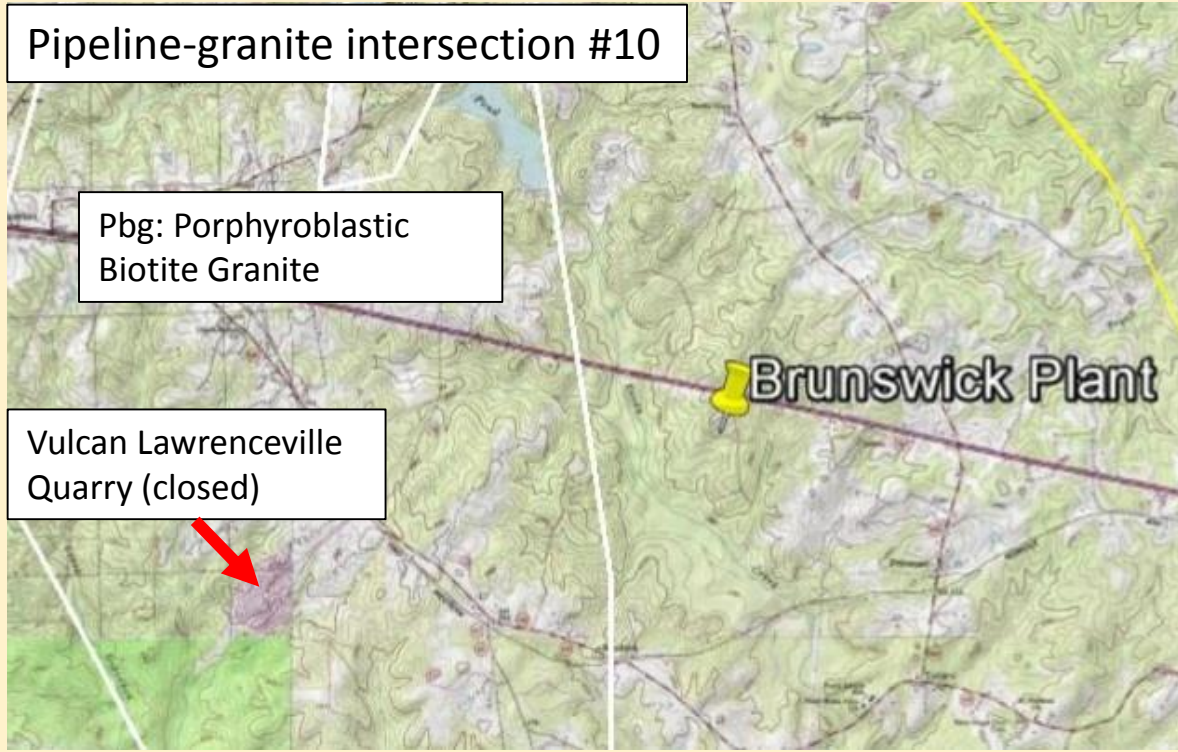


Brunswick County Power Station, Virginia – see URL <http://www.power-technology.com/projects/brunswick-county-power-station-virginia/>.

Construction on the \$1.3 billion power station began in summer 2013. At the peak of the work more than 1,500 workers were on site. The project was completed ahead of schedule and under budget. Development and construction employs about 380 workers annually and yields about \$824 million in economic benefits for the state.

The completed station employs 43 people. An additional \$1 billion in customer savings is expected over the life of the station, compared with the next-best option for supplying power.

Brunswick Power Station is a 3-on-1 combined cycle power station fueled entirely by natural gas. The station uses the latest technology and is among the most efficient power station in the country. Combined-cycle technology utilizes combustion turbines that are essentially gigantic jet engines. The station has three of the turbines that generate 280 megawatts each. The super heated air from the combustion turbines is used to generate steam that produces another 470 megawatts on a steam turbine.



Relationship between Brunswick County Power Station, Atlantic Coast Pipeline (yellow line), and porphyroblastic biotite granite (white line) on topographic base (left) and Google Earth base (right). The distance between the Vulcan Lawrenceville Quarry (closed) and the Brunswick power plant is about 2.25 miles.

Data from the USGS' National Geologic Map Database

- URL https://ngmdb.usgs.gov/ngmdb/ngmdb_home.html
- Map catalog: https://ngmdb.usgs.gov/ngm-bin/ngm_compsearch.pl
- Project search results along pipeline routes (catalog entries):
 - Scale 1:24,000 = 3
 - Scale between 1:24,000 and 100,000 = 1
 - Scale between 1:100,000 and 500,000 = 22
- All except one citation can be downloaded for use in Google Earth or a GIS system.

Conclusions

There are 11 major pipelines intersections with granite in North Carolina and southern Virginia. If a need for underground storage justifies the higher costs of underground excavations, such as the type described by PB-KBB corporation, these granites may warrant further consideration as underground storage sites.

Initial follow-up evaluation might include the following:

1. Detailed literature search of granites intersected by pipeline,
2. Geological traverses along pipeline intersections and immediately adjacent areas documenting density of fractures and their orientations, and
3. Documentation of parks, schools, subdivisions and potential environmentally-sensitive areas along intersections.

Thank you for your attention

For additional information

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