STRATEGIC

PETROLEUM RESERVES

IN

MAINE

A Discussion Paper
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Abstract

The purpose of this paper is to determine if the State of Maine should develop a State petroleum storage reserve to protect its economic and social vitality against future petroleum shortage.

The methodology consisted of determining existing storage capacity in Maine for all petroleum fuel types and comparing this with fuel consumption data. The maximum days supply available for specific types of product is thus determined, assuming (1) all storage is filled at the time of the onset of the supply disruption and (2) all deliveries to storage are stopped.

The Office of Energy Resources concludes that adequate storage capacity does exist for all product types except residual (No. 5 & 6) oil. However, there is a limitation to this conclusion in that instantaneous inventory of all product on hand is not yet being monitored.

This paper delineates the requirements for residual oil and describes alternate storage options. It also examines the adequacy of the National Strategic Petroleum Reserve Program (S.P.R.) as a tool for alleviating shortfalls of residual oils. We conclude that the existing National S.P.R. program may be inadequate. The two major problem areas are:

(1) The availability of Caribbean refineries to handle S.P.R. crude, and

(2) The effects of the Jones Act on availability of tankers to transport the crude.

We further feel that the time lag required to extract, refine, and market this oil in Maine will be too long and the supply mechanism too tenuous to guarantee continuity of supply.

This Office endorses the recommendation of the New England Federal Regional Council which calls for a regional storage of No. 4 distillate oil to alleviate potential supply problems. A regional reserve of No. 4 should be developed as part of the S.P.R. program. The choice of No.4 over No. 5 or 6 is based on the fact that it is a viable substitute for residual oil and does not require heating which would result in an added storage expense.

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INTRODUCTION

The United States is dependent on petroleum for 46% of its energy needs. 42% of that petroleum is now imported. Embargoes have occurred in the past, and may occur again at any time. For this reason, the nation has embarked on an ambitious program of strategic crude oil storage which has a goal of 500 million barrels by December 1982.

Maine is even more dependent on petroleum (77%) and specifically on foreign petroleum. Recognizing this extreme vulnerability, the Office of Energy Resources assigned a high priority to determining the nature and extent of existing strategic storage capacity in Maine.

MAINE BULK STORAGE CAPACITY BY COUNTY/TYPE
(Barrels)

COUNTY	BUTANE	JET FUEL	KEROSENE *	NO. #2	DIESEL	GASOLINE	NO.#4	No.#5 & 6	BUNKER-C	OTHER **	TOTALS
Aroostook	-----	-----	6,310	4,762	------	-----	------	------	2,381	10,381	23,834
Cumberland	-----	840,003	455,568	2,553,190	50,493	2,240,312	204,071	811,762	1,391,000	924,977	9,091,376
Franklin	-----	-----	-----	------	------	------	------	1,191	------	------	1,191
Hancock	-----	-----	205,000	300,000	120,000	151,000	------	150,000	------	------	926,000
Kennebec	-----	-----	74,862	1,115,952	4,328	52,549	------	------	------	58,723	1,306,414
Knox	-----	-----	238	643	------	1,905	------	952	------	1,048	4,786
Lincoln	-----	-----	-----	------	------	2,762	------	------	364,000	------	366,762
Penobscot	-----	-----	402,095	333,347	11,000	366,971	57,839	160,000	------	143,667	1,474,919
Waldo	-----	15,000	20,000	235,123	45,476	115,952	------	342,000	------	730,000	1,503,551
Washington	-----	-----	246,129	131,941	115,571	123,042	95,238	------	-------	------	711,921
York	139,190	-----	1,191	1,191	56,571	------	1,191	1,191	-------	------	200,525
Totals	139,190	855,003	1,411,393	4,676,149	403,439	3,054,493	358,339	1,467,096	1,757,381	1,868,796	15,991,279

* Includes No.#1 Heating Oil
** Includes Empty Tanks

Note:
The above table does not include the Portland Pipeline complex or the Harpswell Fuel Depot in Harpswell. The former has a combined effective working capacity of 3,356,000 bbls. The Harpswell Fuel Depot is an above ground storage facility that has a total capacity of 2.1 million gallons. This facility was used during the embargo by a group of distributors in Maine and for the moment is vacant. This table also includes 380,000 bbls of residual storage in Cumberland County owned by C.M.P.

SOURCE: New England Energy Management Information System (N.E.E.M.I.S.)
Massachusetts Institute of Technology, Cambridge, Massachusetts

INVENTORY OF STORAGE CAPACITY IN MAINE

Bulk Storage Capacity by Product and by County

There exists within the State of Maine a total bulk storage capacity of 15,991,279 bbls. Table 1 outlines this storage capacity by county and type of product. These figures include military storage capacity which will be discussed later in the report.

Retail Storage Capacity

Maine is serviced by 475 independent fuel oil dealers. Table 2 shows the storage capacity of this sector by type or product stored. The data indicates that these dealers have a total combined capacity of 590,788 barrels for distillates and 38,477 barrels of diesel.

End-User Storage Capacity

The pulp and paper industry has the ability to store large quantities of petroleum. Outlined below is the amount of storage held by this industry by product type.

TABLE 2

Pulp and Paper Industry Storage

No. 1 (Kerosene)	666 Barrels
No. 2	1,302 Barrels
Diesel	4,191 Barrels
No. 4	10,476 Barrels
No. 5 & 6	99,547 Barrels
Bunker C	232,428 Barrels
Totals	348,610 Barrels

SOURCE: Industry Data

1/ Industry data held by the Office of Energy Resources

STORAGE CAPACITY OF
DISTILLATE AND RESIDUAL
RESELLERS*
(BARRELS)

COUNTY	#1	#2	DIESEL	#4	#5	#6
Androscoggin	8,226	62,849	261	0	0	0
Aroostook	23,216	86,707	8,026	0	0	0
Cumberland	3,952	54,345	166	0	0	0
Franklin	5,814	1,307	595	0	0	0
Hancock	6,112	11,665	595	0	428	428
Kennebec	9,497	45,791	0	0	0	0
Knox	2,890	10,040	238	0	0	0
Lincoln	4,737	13,014	261	0	0	0
Oxford	8,710	31,132	1,083	0	0	0
Penobscot	8,500	28,255	1,333	0	0	0
Piscataquis	2,632	4,809	314	0	0	0
Sagadahoc	1,750	4,761	0	0	0	0
Somerset	9,412	8,341	71	0	0	0
Waldo	2,619	3,900	369	0	0	0
Washington	35,888	64,083	24,714	0	0	0
York	6,613	19,221	452	0	0	0
Column Total	140,568	450,220	38,477	0	428	428

* does not include major oil companies

Military Storage Capacity

The military stores a great deal of refined product throughout the State. The breakdown for military storage capacity is as follows:

TABLE 3

Military Storage

Cumberland	
Jet Fuel	840,000 bbls.
Other	100,000 bbls.
Sub Total	940,000 bbls.
Waldo*	
Jet Fuel	15,000 bbls.
No. 2	125,000 bbls.
Other	730,000 bbls.
Sub Total	870,000 bbls.
Washington	
Diesel	20,000 bbls.
York	
Butane	138,000 bbls.
Diesel	56,600 bbls.
Other	139,500 bbls
Sub Total	334,100 bbls.
Total (All Products)	

*Product for military installations in Bangor, and the Loring Air Force Base.

SOURCE: N.E.E.M.I.S.

The use of stored military petroleum for civilian purposes is questionable. The Disaster Relief Act of 1970 says in part:

> "The President may designate major disaster areas and direct Federal agencies to provide assistance by utilizing or lending, with or without compensation therefore, to States and local governments, their equipment, supplies, facilities, personnel, and other resources."

It is the opinion of Brigadier General L. F. Sullivan of the Department of Defense that the above authority may cover petroleum products in times of an emergency.

Airport Storage Capacity

In addition to military storage, a sizable quantity of product can be stored at airports. This product is normally used for the support of air operations at these facilities but there may exist the potential for using portions of this storage for civilian purposes in times of a severe shortage. Bangor International Airport is a case in point here. This airport has one above ground facility with a capacity of 21,191 barrels and six below ground tanks with a capacity of 1,190 barrels each. This facility is presently being leased by Exxon Oil Corporation. 1/

State Government Storage Capacity

State Government storage capacity is outlined below by product type.

TABLE 4

State Government Storage

Kerosene (No. 1)		531 Barrels
No. 2		15,185 Barrels
No. 4		5,813 Barrels
No. 6		6,928 Barrels
	Totals	28,457 Barrels

NOTE: The above figures do not include the University System.

SOURCE: Bureau of Purchases

University of Maine Storage Capacity

The University of Maine system comprising nine campuses throughout the State, also stores product that may be used in an energy emergency. Table 5 outlines the storage capability of the University System for the various locations in the State.

1/ Bangor City Government, Airport Division

TABLE 5

University of Maine System*

Campus	No. 1 (gals)	No. 2 (gals)	No. 4 (gals)	No. 6 (gals)
Augusta	550	3,570	10,120	
Bangor		14,600		
Farmington		103,500		
Fort Kent		30,825		
Gorham		17,825		19,970
Machias		39,000		
Orono	550	58,425		200,000
Portland	275	2,775		20,000
Presque Isle		21,150	38,300	
Totals	1,375	300,670	48,420	239,970

SOURCE: Office of the Chancellor
University of Maine, Bangor

*Quantities too small for conversion to barrels

Total State Government Storage Capacity

By totaling the storage of regular State facilities and universities a figure for all product capacity is found equal to 42,513 barrels. Any portion or all of this product can be diverted to more critical uses should the Governor decide to exercise his authority outlined in the Civil Emergency Preparedness Act. of 1974.1/

1/ See Civil Emergency Preparedness Act., PL 1973, C. 757; subparagraph MRS 37-A, Section 57, subsection 2, paragraph b

Total Storage Capacity

The table which follows indicates summary figures for petroleum storage in Maine.

TABLE 6

Maine Total Refined Product Storage Capacity

(Barrels)

No. 1 (kerosene)	1,553,190
No. 2	5,025,014
No. 4	375,780
No. 5 & 6	1,580,140
Bunker C	1,989,809
Diesel	369,507
Other*	1,100,896
Gasoline	3,054,493
Totals	15,048,829

*Does not include Portland Pipeline Facility, but includes all military storage. Excludes butane, propane, jet fuel.

RELATIONSHIP OF DEMAND FOR PETROLEUM TO STORAGE CAPACITY

The State of Maine consumed 36.2 million barrels of petroleum products in 1975, or 1.5 billion gallons (1 U.S. barrel = 42 gallons). Since this paper is concerned with guaranteeing adequate supplies to our industrial, commercial, and residential sectors, only data relating to residuals (No. 5 & 6) and distillates (kerosene, No. 2 & 4) are included in our discussion.

The table below reveals the total consumption of those products compared with our ability to store them.

TABLE 7

Ratio of Demand to Storage Capacity

Product Type	Storage[1/] (Barrels)	Consumption[2/] (Barrels)	Storage to Consumption Ratio	Days Supply
Kerosene (No.1)	1,553,190	1,387,800	111.9%	405
No. 2	5,025,014	8,007,500	62.8%	226
No. 4	375,780	246,390	152.5%	554
No. 5 & 6	1,580,140	10,423,878	15.2%	54
Bunker C	1,989,809	1,578,865	126.0%	459.9
Totals[3/]	10,523,933	21,644,433	48.6%	175

The data in Table 7 indicates that Maine has from six months to a year and a half storage capability for all products except No. 5 and 6. Maine apparently has adequate storage for most products to sustain its economic and social vitality until the Federal Strategic Petroleum Reserve starts delivering product to our State. However, the State of Maine stores product destined for out-of-state markets, such as Vermont and New Hampshire.

1/ Includes storage for bulk terminals, retailers, pulp and paper, Universities and State Government.

2/ Figures given may constitute some degree of double counting. At present these figures represent the best available information.

3/ Gasoline storage is available for approximately 91 days at normal 1975 consumption rates. This may seem like a fairly low figure relative to the day's supply for other fuels. However, under embargo conditions, it is adequate for essential driving. For example, the Office of Energy Resources has calculated that 12% of gasoline consumption occurs on Sunday. Also, a Federal allocation program would almost surely be activated in the event of a gasoline shortage.

Table 8 shows the amount of refined product exported by type. The sources for this data did not differentiate between states, or other markets where this product was ultimately consumed. However, some consumers can be identified in New Hampshire and Vermont.

Our Terminal's Supply Companies in Vermont with 592 bbls of No. 2 and 1,666 barrels of No. 4. Residual requirements for Vermont supplied by Maine Terminals equal 28,969 barrels of No. 6

TABLE 8

Export of Refined Product

	Deliveries	Consumption	Assumed Exports
Kerosene (No.1)	1,656,407	1,387,800	268,600
No. 2	10,619,926	8,007,500	2,612,426
No. 4	248,056	246,390	1,666
No. 5 & 6	11,986,847	10,423,878	1,562,969
Bunker C	1,578,865	1,578,865	-0-
Gasoline	12,450,000	13,859,009	1,409,009

Ratio of Assumed Exports to Deliveries

Kerosene	=	16 %
No. 2	=	25 %
No. 4	=	1 %
No. 6	=	13 %
Bunker	=	0 %
Gasoline	=	11 %

SOURCE: F.E.A. 1,000 and O.E.R. fuel use survey

Similarly we can trace 1,534,000 barrels of No. 6 oil to individual companies in New Hampshire supplied through Maine terminals. The data is by no means a complete evaluation of our export picture. However, it does signify Maine's importance as an intermediary supplier of petroleum products.

Residual fuel is essential to the maintenance and expansion of our economic posture and the availability of this product cannot be compromised in the short run. Present storage capacity for residual is adequate for 54 days supply if available storage is filled to capacity. If storage capacity is 60% full, the 54 day supply is reduced to 31 days. The inventory of residual oil available in Maine is an important factor in determining residual oil supplies for the State.

Maine's apparent storage-to-consumption ratio may be decreased when out-of-state demand served by Maine terminals is considered. Presently defined throughput to other New England states equals 1,562,969 barrels of No. 6 oil. Assuming Maine stores product for other states at the same level of 13% annual product receipts, Maine's commitment to New Hampshire and Vermont for 13% of annual product receipts will reduce storage space available to us by some 205,418 barrels*. Providing storage for the other Northern New England states has the effect of reducing our storage to consumption ratio of 13% or 47 days of maximum storage capacity.

*(known exports) x (13%) = 205,418 barrels

ANALYSIS OF NATIONAL STRATEGIC PETROLEUM RESERVE

The primary purpose of the National Strategic Petroleum Reserve (S.P.R.) is to protect the nation from economic disruption caused by curtailments in imported petroleum products. 1/ A large petroleum inventory also potentially allows the government to participate in petroleum markets for price stabilizing purposes.2/

The S.P.R. was created by the Energy Policy and Conservation Act (E.P.C.A.) of 1975. By legislative design E.P.C.A. specifies two stages for development of the reserve. By December 1978 an early stage is to be completed which calls for a minimum storage of 150 million barrels of crude oil. A second phase to be completed by December 1982 raises the minimum storage to a combined total of 500 million barrels and a maximum of one billion barrels of crude.

The Federal Energy Administration, Strategic Petroleum Reserve Office, was assigned the responsibility of determining the most cost efficient manner of storing petroleum. Their investigations revealed that salt dome storage is the most favorable. Among the primary reasons for favoring this storage method were:

(1) Cost is minimal ($.85 - $1.80 bbl. approximately).
(2) Close proximity to Gulf Coast refineries.
(3) The technology for developing the storage facility presently exists.
(4) The facilities are relatively secure.
(5) Close to inland pipeline networks.

The strategic petroleum reserve may be filled four ways.3/

(1) Purchase of foreign crude at prevailing import prices.
(2) Purchase of domestically produced fuel from private producers.
(3) Use of Federal royalty oil received as a condition of lease of offshore drilling rights.
(4) Use of petroleum produced from Federally owned Naval Petroleum Reserves (N.P.R.).

The cost of these options range from 30 - 50 cents for Naval Petroleum Reserve to $12 - $15 for imported crude.4/

1/ Petroleum storage. Congressional Budget Office background paper No.14. October 28, 1976. Page IX
2/ Petroleum Storage Page IX
3/ Petroleum Storage Page 23
4/ Petroleum Storage Page 36

The estimates for storage facilities and fill are outlined below.

Estimates of Unit Costs for Storage Facilities and Fill
(dollars per barrel)

Component	Cost Per Barrel
Storage Facilities:	
Salt Domes or Mined Caverns	\$0.85 - \$1.80
Steel Tanks	\$9.00 - \$12.50*
Crude Oil:	
NPR-1	\$0.30 - \$0.50
Domestic Crude	\$5.05 - \$12.00
Federal Royalty Crude	\$6.70 - (average)
Imported Crude	\$12.00 -\$14.00
Total Cost	\$2.35 - \$26.50

SOURCES: NPC "Petroleum Storage for National Security"
FEA "Early Storage Reserve Plan", and
Office of Naval Petroleum Reserves.

*A case has been reported in which \$3-4/bbl. cost for steel tanks were obtained. However, in the absence of a detailed engineering study of that case and others, there does not appear to be sufficient rational for altering the figures used here.

The combined costs of constructing and filling the S.P.R. even to the minimum level will total several million dollars. This expense will be met by Federal dollars from general treasury revenues or possibly through the sales of entitlements and/or the Federal gasoline tax.

Impact of the Strategic Petroleum Reserve on Maine

Maine, like the rest of the nation, stands to benefit from a S.P.R. program. Maine is highly dependent on petroleum, and increasingly dependent on imported petroleum. Thus, the S.P.R. concept represents a welcome cushion against petroleum supply disruptions. However, the proposed S.P.R. is not without its faults. The shortcomings of the program for the State of Maine are as follows:

Time

The recommended salt dome storage technique could mean a considerable delay before S.P.R. crude finally reaches our State in the form of refined petroleum products. It has been estimated that 35 days will be required to get crude from the S.P.R. into refineries once the decision has been made to use the reserve. 1/ Average delivery time from Gulf Coast refineries to Maine is approximately 10 days. Therefore, if imports were stopped on any given day, the loss of those supplies would not be replaced by S.P.R. crude for an estimated six weeks.

Petroleum product in shipment, refinery inventories, and increased domestic production serve to reduce the impact of a 35 day S.P.R. lead time requirement. An embargo by exporting countries does not have immediate impact because crude held at refineries or in transit may support refining output for a period of time. Similarly inventories of refined product at the refinery, in transit and in bulk storage terminals provide some cushion in case of a supply disruption.

Refining Capacity

Our State and region are highly dependent on direct and indirect petroleum imports. The nation as a whole is 42% dependent on imports. New England acquires 77% of its residual oil from direct imports and a sizable part of the remainder from indirect imports. Indirect imports represent imported crude product refined in U.S. refineries and direct imports represent refined product brought into the region from areas other than the United States and its territories. 2/

The U. S. has the capacity to refine only 50% of the nation's residual oil requirements, a product which is essential to the economic vitality of our State. The issue of adequate refining capacity in an embargo situation for residual oil has not been addressed to date. Since most residual fuels for New England are imported directly from Venezuela, a member of O.P.E.C., the question of available refinery capacity to produce residual oil is important.

Other problems exist with the refining aspects of S.P.R. crude. The Federal Energy Administration Strategic Petroleum Reserve Office assumes that S.P.R. crude will be refined in U.S. and Caribbean refineries. A significant curtailment of imported petroleum would overburden U. S. refining and to assume that Caribbean refining is "secure" may be a risky assumption.

1/ Peter Fairbanks, FEA Region 1, Boston, Mass.

2/ Emergency Petroleum Storage in New England, Federal Regional Council Energy Resource Development Task Force Emergency Storage Study Group. October 1976

Transportation and the Jones Act

Transportation is another area where some concern arises. Maine does not have any refining capacity and is not linked to large refining centers by pipelines. Our petroleum products arrive in Maine through waterborne transports.1/

The Jones Act (the Merchant Marine Act of 1920 as amended) declares that all shipping from one U.S. port to another must be done by U.S. flag ships. U.S. ships may not be available in sufficient numbers to keep up with petroleum demand in times of a petroleum embargo.

Labor

Manpower is required to move product into our region and from the S.P.R. sites to refineries, as well as at the refineries themselves. During a petroleum shortage, transportation of available crude and refined product becomes crucial. Disruptions in the transportation sector due to labor unrest would significantly impact the availability of petroleum.

The Office of Energy Resources is convinced that the strategic petroleum reserve is an extremely important effort. We also feel, however, that certain aspects of the S.P.R. program do not serve to protect Maine's supply of residual oil to the necessary extent.

1/ Emergency Petroleum Storage in New England, page 12.

NEED FOR RESIDUAL RESERVE

A ninety (90) day reserve is considered an acceptable cushion against short-term embargoes or other supply disruptions. The highest quarterly demand for residual during 1975 was 3,693,895 barrels.

Our available storage (580,140 barrels) less assured capacity committed to exports (265,705 barrels) equals 1,314,435 barrels. When this figure is deducted from the quarterly demand for residual (3,693,895 bbls.) a shortfall of 2,379,460 barrels is computed.

This computation assumes that all storage capacity is full at the time of the supply disruption. This is a dangerous assumption. Data held by the Office of Energy Resources indicates that residual users buy oil on a quarterly basis. The result of this purchase pattern is that residual users could be much more vulnerable to a supply interruption if it occurred just prior to a refill period when inventories may be extremely low.

OPTIONS TO CREATE RESIDUAL STORAGE CAPACITY

Since the U. S. has relatively little refining potential to produce residual oil and all other sources outside the U.S. may be considered relatively "insecure", alternative supply methodologies must be investigated. There appear to be four alternatives for Maine.

(1) Accept Federal Strategic Petroleum (Crude Oil) Reserve Plans Without Modification

Accepting this method would entail supporting the utilization of the salt dome storage concept in the Gulf States and accepting the proposed refining of S.P.R. crude in U.S. refineries and the Caribbean. The benefit of this alternative is the tax dollar savings (federal or state) for not accepting other alternatives. The risks include a residual shortfall that could temporarily damage our economy, cause unemployment, decrease gross state product and increase public expenditures for the support of those citizens needing assistance while unemployed or underemployed.

(2) Create Regionalized Strategic Petroleum (Refined Product) Reserves Utilizing Federal Funds

It is important to mention at the outset of this option and others that follow that Maine and the other states in New England feel No.#4 middle distillate oil should be stored in place of No.#6 residual oil. The primary reason for this recommendation is the relative cost of storing the oil. No.#6 residual oil has to be heated before it can be pumped out of storage, a considerable expense. No.#4 oil is an acceptable substitute for No.#6 oil and is chemically more stable in storage than the other alternative to No.#6 (No.#2 middle distillate oil). 1/

This option involves encouraging the federal government to alter the S.P.R. program to include economical petroleum product storage facilities within the New England Region.

The conclusions of the New England Federal Regional Council call for the utilization of federal funds for the construction within New England of a petroleum reserve system large enough to protect the residual oil requirements of the six New England States against any supply interruptions.

This alternative would also favor the utilization of underground rock-cavern storage as close to port/terminal facilities as possible. Rock cavern storage is proven to be economically feasible under existing technology and is presently utilized in other countries such as Sweden. The per barrel cost of developing a mined cavern is comparable to salt domes at $ .85 - $1.80. 2/

1/ Emergency Petroleum Storage in New England, Page-49.

2/ Petroleum Storage, Page-36.

The primary benefits of this alternative include an in-house supply of petroleum to meet the needs of our citizens without a prolonged waiting period. Only few sites would be required to meet the needs of the region, and "economies of scale" would be achieved.

The limitations of this alternative relate to site selection for caverns. 1/

(1) Suitably - large tracts of land must be available.

(2) Geologic structure of the sites must be suitable (i.e. should be hard, metholthic and stable; usually granites or granitic rocks).

(3) Since large volumes of products would be handled at each site, suitably large handling facilities would be needed at the nearby dock facility.

The Maine Bureau of Geology under the direction of Mr. Robert Doyle, State Geologist, has labeled twelve (12) below ground sites that may be adequate for the storage of refined product. The list and description of these sites are found in the appendix.

Maine may also be able to store product in existing above-ground storage facilities. The U. S. Navy Harpswell facility at Brunswick is the case in point here.

Harpswell is a 930,000 bbl., above-ground, steel-tank storage facility. This tank farm is in excellent repair and is environmentally suitable for a Regional or State storage site.

Further examination is presently underway to ascertain the conditions under which the Navy would allow the facility to be used for emergency storage.

(3) Regional Storage Reserve Utilizing Regional Funds

This alternative would be as outlined above. The important difference between the two is that the funds to create the reserve would be generated within the region. This would be an extremely costly undertaking and is probably not worth serious consideration at this time.

1/ Emergency Petroleum Storage in New England, Page-48.

(4) State Storage Reserve

Developing a State Storage Reserve utilizing State funds would entail either constructing steel tanks above the ground or outfitting below ground mined caverns. Assuming the number of barrels to be stored is 1,025,428, the cost would be:

ESTIMATED COSTS OF CONSTRUCTION AND FILLING OF A 90-DAY STRATEGIC STORAGE OF #4 FUEL OIL

	Construction Cost		Cost to fill*	
	Per bbl.	Total	Reserve	Total Cost
Steel Tanks	12.00/bbl	12,305,136	13,740,735	26,045,871
Underground	2.00/bbl **	2,050,856	13,740,735	15,791,591

* Assumes spot market price of $13.40/bbl for .05% Sulfur #4 distillate oil.

** This assumes a higher cost per bbl due to the smaller scale of the reserve.

Salt dome and mined cavern costs were estimated to be $0.85 - $1.80/bbl.

CONCLUSIONS

The Office of Energy Resources concludes:

(1) That the State of Maine apparently has adequate storage for all petroleum products except No.#6 residual.

(2) No.#6 residual oil is essential to maintaining industrial productivity in the State. Therefore an increased capacity to store No.#6 residual oil is needed.

(3) The National Strategic Petroleum Reserve is not an adequate system for guaranteeing No.#6 residual supplies during a petroleum shortage because of limited refining capacity, distance between markets, and transportation limitations.

(4) As the lowest cost alternative for storing No. 6 oil in Maine, the Office of Energy Resources concurs with the position of the Federal Regional Council that a No.#4 reserve be created within the New England region.

(5) That the Federal Energy Administration, in developing a petroleum product storage system for New England, must provide for the equitable distribution of No.#4 oil as a substitute for No.#6 residual oil.

APPENDIX

National Overview

Maine as an energy user is a very small segment of a vast and complex petroleum supply and marketing network. As domestic petroleum supplies become depleted, the crude petroleum eventually used in the U. S. to heat homes and shops and to run factories originates increasingly from foreign lands. This imported crude petroleum is transported by international shipping firms and/or multinational oil companies to refineries in the U.S.

In 1975, our nation's refineries processed nearly six billion barrels of petroleum products 1/ for direct energy and for uses such as petrochemical feedstocks for the manufacturing of rubber, medicine, fertilizer and other goods. Forty-six percent of all energy used in the U.S. in 1974 came from petroleum. 2/

It should be obvious from this information that our nation truly does run on petroleum. It is also obvious, as we found out through our experience during the Arab embargo of 1973, that our nation runs on petroleum controlled to a large extent by foreign and sometimes unfriendly sources. Any break in this complex national petroleum supply system can potentially cripple our economy and cause social hardships. As a nation our economy is highly dependent on petroleum today, and is becoming increasingly dependent on foreign sources of petroleum. Table I outlines national trends in that direction.

The U.S. imported 2.2 billion barrels of oil in 1975 which represents 36% of U.S. demand for that year as opposed to 1960 when the U.S. imported 664 million barrels or 18.5% of U.S. demand. If our nation's economy is to grow and prosper, the short and mid-term economic picture is one of continued dependence on an uninterrupted supply of fossil fuels.

The state and the nation may believe that the Outer Continental Shelf and Alaskan Oil fields represent a cure-all for our nation's foreign petroleum dependency. This is simply not the case.

The best estimates for available petroleum reserves and resources and their geographic location are outlined in the Table II. The figure not shown, but assumed, in Table II is the 63 billion barrels of known U. S. reserves. At present levels of consumption this quantity would last ten years. As evidenced in the chart, remaining undiscovered reserves estimates range from a low of 72 billion to a high of 154 billion barrels.

1/ Federal Energy Administration, "National Energy Outlook". U.S.Government Printing Office, Stock Number #041-018-00097-6, PP-xxiii

2/ Ibid-PP-xxii

If our consumption patterns do not increase, and are supported by a 35% import rate, the U.S. will run out of petroleum by 2028. This prediction is based upon reserve estimates made by the National Petroleum Council whose estimates are the highest.

The national petroleum reserve program outlined in the Energy Policy and Conservation Act of 1975 is designed to protect the entire nation against supply interruptions. This program calls for the creation, over a seven-year period, of a national reserve of up to a billion barrels of crude oil to alleviate any supply shortage.

The problem for Maine under this program is that the lead time required to extract, refine, and get this oil to markets in Maine may be too long to avoid a significant supply disruption, since we are at the geographical end of the distribution system.

The real energy crisis is just beginning and unless action is taken to protect our energy supply from disruption, we may well experience future shortages many times the magnitude of the 1973 Arab embargo.

A petroleum storage reserve is a good insurance policy against short-term supply disruptions until, as a nation, we become more energy self-sufficient through development of alternate energy sources, exploitation of our own petroleum reserves, and strong energy conservation measures. It is imperative that we establish such a reserve.

TABLE I

CRUDE PETROLEUM, PETROLEUM PRODUCTS

AND

NATURAL GAS LIQUIDS

(MILLION BARRELS)

PERIOD	CONSUMPTION	DOMESTIC PRODUCTION	IMPORTS	EXPORTS
1960	3,586	2.916	664	74
1961	3,641	2,983	700	64
1962	3,796	3,049	760	61
1963	3,921	3,154	775	76
1964	4,034	3,209	827	74
1965	4,202	3,290	901	68
1966	4,411	3,496	939	72
1967	4,584	3,730	926	112
1968	4,902	3,883	1,039	84
1969	5,160	3,956	1,155	85
1970	5,364	4,129	1,248	94
1971	5,553	4,078	1,433	82
1972	5,990	4,103	1,735	81
1973	6,317	4,006	2,283	84
1974	6,069	3,828	2,222	80
1975	5,967	3,661	2,164	76

SOURCE: U.S. Bureau of Mines

TABLE II

ESTIMATED REMAINING OIL RESOURCES IN UNITED STATES

SOURCE	ESTIMATED UNDISCOVERED RESERVES (BILLIONS OF BARRELS)	TOTAL REMAINING
National Petroleum Council	154	217
Mobil	88	151
National Academy of Science	113	176
Hubbert	72	135

ASSUMPTION NUMBER ONE:
(No Increase in Annual Consumption)

	No Imports	35% Imports
	Year of Exhaustion	Year of Exhaustion
National Petroleum Council	2009	2028
Mobil	1999	2012
National Academy of Science	2003	2018
Hubbert	1996	2008

ASSUMPTION NUMBER TWO:
(2.5 Percent Increase in Annual)
Consumption

	No Imports	35% Imports
	Years of Exhaustion	Years of Exhaustion
National Petroleum Council	2000	2009
Mobil	1994	2001
National Academy of Science	1996	2004
Hubbert	1992	1999

SOURCE: SENATE COMMERCE COMMITTEE

MAINE OVERVIEW

Consumption Trends and Degree of Dependency on Petroleum

Historically the State of Maine has always been highly dependent upon fossil fuels to meet its energy requirements. In 1966, 90% 1/ of Maine's energy needs were met by petroleum. The decrease in petroleum dependence over the last five (5) years is due to nuclear generation of electricity that displaced oil fired generators.

In 1975, Maine consumed 36.2 million barrels of petroleum. * The breakdown of our petroleum consumption was as follows:

TABLE - 1
1975 Petroleum Consumption in Maine

Fuel Type	Consumption (bbls)
Gasoline	12,661,347
Diesel	1,054,428
#2 Heating Oil	8,007,500
Kerosene (#1)	1,387,800
Propane	840,945
Bunker C	1,578,865
#4	246,390
#5 & #6	10,423,878
	36,210,152

Source: Industry Data and F.E.A. Form 1,000 Column I

Table 2 outlines Maine's projected energy demand through 1985 under various scenarios.

The petroleum product in greatest demand is gasoline, followed closely by distillate and residual fuels. However, distillate and residual products are extremely important to the social and economic well being of our state as these products support the commercial and industrial sectors, as well as the residential sector.

1/ "Energy fuel flows in New England", New England Regional Commission Report prepared by Resource Planning Associates, Exhibit 7.

* Maine used 1.8 trillion BTU's of natural gas which represents .5% of our energy requirements. For this paper natural gas consumption is insignificant.

TABLE 2

ESTIMATED FUEL DEMANDS
1980 AND 1985
IN UNITS OF MEASURE

FUEL	UNIT OF MEASURE	BTU CONSERVATION FACTOR (Btu/Bbl)	DEMAND SCENARIO	ESTIMATED 1980	DEMAND 1985
Petroleum	10^3 Barrels	As noted for Specific Type	Low	41,278	43,983
			Base	44,926	51,493
			High	49,597	57,175
Residual	10^3 Barrels	6.3×10^6/BBL	Low	12,264	13,039
			Base	13,355	15,272
			High	14,533	16,142
Distillate	10^3 Barrels	5.8×10^6/BBL	Low	12,182	12,785
			Base	13,250	14,959
			High	14,486	16,623
Kerosene	10^3 Barrels	5.7×10^6/BBL	Low	848	434
			Base	924	508
			High	985	548
LPG	10^3 Barrels	4.0×10^6/BBL	Low	857	686
			Base	932	803
			High	1,002	874
Jet Fuel	10^3 Barrels	5.5×10^6/BBL	Low	1,758	1,968
			Base	1,905	2,287
			High	2,138	2,621
Gasoline	10^3 Barrels	5.2×10^6/BBL	Low	13,369	15,071
			Base	14,560	17,664
			High	16,453	20,367

SOURCE: Maine Comprehensive Energy Plan

According to the 1970 Census, Maine had 339,969 year-round housing units. Of these units 92% were heated by home heating oil (kerosene and No.#2.) By 1985 the total year-round housing units may number 468,000. We anticipate the dependence on petroleum for residential space heating will remain in excess of 85% of households in 1985. 1/

Therefore, it is important to consider home heating oil in any storage plan. Any significant mid-winter shortage of this type of product would have catastrophic effects on the health and well-being of Maine's citizens.

Distillate products are also utilized by other segments of our society which are as important as the residential sector. Heating oil and kerosene are used in large quantities to heat hospitals, municipal buildings and schools.

State government uses approximately 2.5 million gallons of home heating fuel to heat its office buildings, houses and garages. 2/ Nineteen hospitals throughout the state also use home heating fuels at the rate of 1.1 million gallons annually. 3/

The exact data on consumption by public schools and universities is not readily available without further research but it is expected that most schools rely on distillates.

The public sector also consumes large quantities of residual fuel. State government requires 5.8 million gallons of residual (No. 4, 5 & 6) which, when combined with distillates, meets their total requirements for space heating. 4/

Hospital requirements for residual oil add another 6.1 million gallons, one priority reason why we must protect residual supplies. 5/ The remaining energy requirements for schools, universities, and municipal buildings which is not filled by distillate fuels is met by residual products and, in some cases, electricity.

To put in proper perspective the concept of a storage program, it is vitally important that we discuss the economic considerations.

1/ Personal contact Gerald Dawbin, Office of Energy Resources.

2/ Data compiled from bid requests obtained from Maine Department of Finance and Administration.

3/ Maine Hospital Association, Augusta, Maine.

4/ Maine Department of Finance and Administration.

5/ Maine Hospital Association.

Impact of Petroleum Shortfalls

As is evidenced by Table 3, Maine's per capita gross state product for 1974 is lower than any other New England State. The growth and stability of the Maine economy is now contingent upon petroleum supplies.

Table 4 demonstrates that Maine is a manufacturing state with manufacturing representing 30.5% of our gross state product (G.S.P.) in 1970 and 25.2% in 1974.

Manufacturing employed 29.1% of our labor force in 1970. Although manufacturing dropped to 24.5% in 1975 it is still the largest employer of Maine's working people. Another important consideration is that manufacturing represents a potential growth area for our state.

Closer examination of Maine manufacturing will further clarify our economic dependence on petroleum. Table 5 rank orders manufacturing segments of our economy.

PER CAPITA GROSS STATE PRODUCT

NEW ENGLAND 1970 & 1974

	1970 Population *	Per Capita Gross State Product **	1974 Population *	Per Capita Gross State Product **
Maine	992,000	3729.84	1,028,000	4925.10
New Hampshire	738,000	4025.75	791,000	5292.04
Vermont	444,000	4083.33	464,000	5043.10
Massachusetts	5,689,000	5117.95	5,818,000	6518.05
Rhode Island	947,000	4426.61	973,000	5438.85
Connecticut	3,032,000	5518.14	3,076,000	7267.56

* SOURCE: United States Department of Commerce: Bureau of Census

** SOURCE: Federal Reserve Bank of Boston

TABLE 4

GROSS STATE PRODUCT[1] BY ECONOMIC SECTOR
MAINE 1970-74
(IN MILLIONS OF DOLLARS)

	1970	Percent of Total	1974	Percent of Total	Percent Increase 1970-74
Total GSP	$3,700	100.0%	$5,063	100.0%	36.8%
Manufacturing	1,128	30.5	1,277	25.2	13.2
Trade	633	17.1	930	18.4	46.9
Government	497	13.4	676	13.4	36.0
Services	395	10.7	596	11.8	50.9
Finance	421	11.4	573	11.3	36.1
Agriculture	124	3.4	288	5.7	132.3
Construction	205	5.5	274	5.4	33.7
Communication & Public Utilities	168	4.5	262	5.2	56.0
Transportation	125	3.4	181	3.6	44.8
Mining	5	0.1	6	0.1	20.0

[1]Gross State Product equals market value of goods and services output less the cost of intermediate products.

SOURCE: Federal Reserve Bank of Boston

EMPLOYMENT BY ECONOMIC SECTOR 1970-75
(IN THOUSANDS)

	Total	Percent of Total	1975	Percent of Total	Percent Change 1970-75
Total State Employment	378.9	100.0%	391.1	100.0%	+18.3%
Manufacturing	110.4	29.1	95.8	24.5	-14.6
Government	59.0	15.6	78.4	20.0	+32.9
Services	42.9	11.3	59.0	15.1	+37.5
Retail Trade	51.6	13.6	57.7	14.8	+11.8
Transportation & Public Utilities	17.5	4.6	17.5	4.5	
Contract Construction	16.8	4.4	17.4	4.4	+ 3.6
Whole Sale Trade	14.3	3.8	16.3	4.2	+14.0
Finance, Insurance & Reale Estate	12.2	3.2	14.0	3.6	+14.8

SOURCE: Maine Department of Manpower Affairs, Employment Security Commission

TABLE 5

SUMMARY OF MAINE MANUFACTURING ACTIVITY, 1970-74

	Value of Product (million $)		Production Workers (000's)		Average Gross Wage	
	1970	1974	1970	1974	1970	1974
All Manufacturing	$2,450	$3,804	112.4	105.8	$5,950	$7,646
Paper	714	1,220	16.8	16.5	7,937	10,392
Food	419	615	11.8	10.8	5,119	6,597
Lumber & Wood	215	378	12.6	13.9	5,371	7,038
Leather	344	377	24.6	17.6	4,594	5,619
Texiles	186	253	10.3	8.6	5,074	6,774
Electrical Machinery	95	213	4.9	5.8	4,991	5,510
Transportation Equipment	70	158	11.4	11.6	8,993	10,555
Rubber & Plastics	62	111	3.2	3.5	4,907	6,376
Fabricated Metals	77	100	2.8	2.8	6,839	8,873
Machinery & Ordnance	61	81	3.4	2.8	6,363	8,388
Printing	43	60	2.6	2.9	5,790	7.294
Chemicals	32	54	0.8	0.8	6,055	7,341
Apparel	31	49	3.2	3.3	3,989	5,032
Stone, Clay, Glass	34	41	1.6	1.1	7,127	8,729
Petroleum	6	32	0.6	0.9	8,528	9,992
Furniture	17	23	0.9	1.0	5,374	7,200
Primary Metals	35	9	1.0	0.4	7,158	6,829
Instruments	4	8	0.3	0.4	5,129	6,579
Miscellaneous	7	24	0.6	1.1	4,363	5,147

SOURCE: Census of Maine Manufacturers: Maine Department of Manpower Affairs; Bureau of Labor

The first and third categories on the above table relate to Maine's Forest Product Industry, and they are interdependent. When production of timber from forest lands is combined with transportation to get the wood to mills and plants for the production of lumber and paper, this industry is by far the highest consumer of energy in the State. Pulp and paper accounted for about 75% of all industrial energy consumption in Maine in 1974, or about 25% of total State energy consumption.

The extent to which this industry uses petroleum is outlined below:

TABLE - 6

MAINE PETROLEUM CONSUMPTION BY PULP AND PAPER INDUSTRY

(1973)	(Gallons)
No. #1 (Kerosene)	280,526
No. #2	1,245,985
Diesel	2,144,000
No. #4	642,000
No. #6	156,372,347
Bunker C	151,783,049
Totals	312,467,907

The second category of the "Maine Manufacturing Activity" table is food production. Although undefined, one can easily imagine the gallons of petroleum necessary to supply tractors, and other machinery as well as the petroleum required for transportation and processing at plants and canneries.

Table 6 based on a Social Science Research Institute (S.S.R.I.) survey show most of Maine's major industries to be non-seasonal in nature. This data indicates that a shortage of certain types of petroleum in the summer would be the same as a shortage of the same type in the winter. However, the difference in throughout (the amount of fuel consumed) would make a supply interruption in the winter a more severe problem. The conclusion to be drawn from this is that any storage program must be done on the basis of maximum monthly demand for product.

The S.S.R.I. survey showed another important fact. Of the respondents 77% indicated they could not substitute fuels for their operations.

TABLE - 7

SEASONALITY (MOST ACTIVE PERIOD)

(Absolute & Percentage Distribution)

Period	Percent	Number of Firms
Non-Seasonal	65	100
January, February, March	3	5
April, May, June	9	13
July, August, September	13	20
October, November, December	9	13
Not Ascertained	1	2
	100	153

SOURCE: Social Science Research Institute, University of Maine, Orono

Table 8 based on a study by the Maine Department of Manpower Affairs, assesses the impact of a hypothetical 20% petroleum shortfall over a one year period from December of 1973 to December of 1974.

This study indicates a change in manufacturing employment for the period from 105.2 thousand down to 83.5 thousand, or a difference of 21.7 thousand jobs. The Arab embargo resulted in supply shortages for this first quarter of 1974. The actual curtailment was approximately 10% of our monthly demand for the period. Thus, the projected employment impact of the Department of Manpower Affairs Study never materialized.

TABLE - 8

IMPACT OF ENERGY SHORTFALL ON EMPLOYMENT IN MANUFACTURING

Industry Group	Actual Employment Dec. 1973 (in thousands)	Estimated Employment Dec. 1974 (in thousands)	Net Change
Total Manufacturing	105.2	83.5	-21.7
Durable goods	34.7	27.0	- 7.7
Lumber and wood products*	14.3	10.9	- 3.4
Furniture*	0.9	0.7	- 0.2
Stone, clay and glass products	1.2	1.0	- 0.2
Primary metal industries	0.7	0.6	- 0.1
Metal fabrication*	2.3	2.0	- 0.3
Machinery, except electrical	2.6	2.1	- 0.5
Electrical machinery*	6.8	5.0	- 1.8
Transportation equipment	5.4	4.3	- 1.1
Professional and scientific products*	0.5	0.4	- 0.1
Other durables (ordnance)**	0.4	N.A.	N.A.
Non-durable goods	70.5	56.5	-14.0
Food and kindred products	11.4	9.1	- 2.3
Textile mill products	9.4	7.5	- 1.9
Apparel	3.7	3.0	- 0.7
Paper	17.8	14.2	- 3.6
Leather and leather products	19.5	15.6	- 3.9
Printing and publishing	3.1	2.5	- 0.6
Chemicals	1.3	1.1	- 0.2
Petroleum*	0.1	0.1	0.0
Rubber and plastics	4.2	3.4	- 0.8
Other non-durables (misc.mfg.)**	1.0	N.A.	N.A.

* Data for these industries derived from national figures.
** These data not included in totals.
N.A. data not available.

Sources:

Census of Manufactures: Fuels and Electric Energy Consumed, 1972, Bureau of the Census, 1971 figures, Tables 2 and 4

Employment and Earnings, 1909-1972 Bureau of Labor Statistics

Energy Policy for the State of Maine Public Affairs Research Center, Bowdoin College, Brunswick, Maine, June 1973

A direct correlation exists between the cost of energy and the competitive position of an industry. Since a free market dictates the allocation of goods and services through a pricing mechanism, a shortage of petroleum causes price to go up as available consumers compete for limited supplies.

If the price of a manufactured item becomes prohibitive, due to energy costs, consumers may seek lower priced substitutes or reduce their purchase of the item. The resulting reduction in demand may reduce the total labor force employed to produce the manufactured good.

It is in Maine's best interest to protect our petroleum supplies from disruptions so that our industrial climate will remain competitive. A petroleum reserve program provides insurance against short-term petroleum supply disruptions while we try to reduce our state's dependence on petroleum.

Types of Storage Facilities

Should the State of Maine decide that a state petroleum reserve is necessary a variety of "containers" are available at differing costs. 1/

The most common type of storage is above-ground steel tanks. These are constructed with either a fixed (or cone) roof or a floating roof. Both types of storage are simply metal containers usually clustered in tank farms which can be utilized to store all types of liquid petroleum. The cost of a fixed roof (excluding painting, land costs and petroleum heaters) ranges from $3.25/barrel for a 50,000 barrel tank to $2.75 barrel for a 100,000 barrel tank.

The drawback of the fixed roof is that potentially combustible vapor can accumulate between the product surface and the inside top of the tank.

The floating roof design is supposed to alleviate this vapor situation, but does so at a correspondingly higher price. Floating roof costs are approximately 40% higher than fixed roofs. In addition, floating roofs are not recommended for areas where snow accumulations are high because the tendency is for the weight of the snow to break the seals in a floating roof, exposing the product to contamination and spillage.

An alternative to metal tank storage is cement tanks. Essentially the same as metal tanks in design and function, this type has a distinct safety advantage in that they are virtually fireproof. The safety advantage, it is generally felt, is considerably outweighted by the expense of building these facilities. Concrete tanks can also be used to store product underground. Again, the already high costs of cement tanks would be increased by the additional funds required for earth-moving and excavation operations.

The best storage option is the unlined rock cavern. This method consists of drilling and blasting large underground caverns in homogeneous and solid rock formations. High fixed costs for any sized cavern tank dictates that only very large installations are economically feasible. Under favorable geologic conditions a completed 600,000 barrel cavern may cost less than $1/barrel. Therefore, careful scrutiny of possible sites is necessary to determine the type of option that may be required in an effort to get the most storage per dollar spent.

1/ Data on containers acquired from the "Emergency Storage Task Force Report" to the Federal Regional Council.

Consideration also has to be given to the length of time various petroleum products can be stored. 1/ Kerosene can be stored indefinitely, however A.S.T.M. (American Society for Testing Materials) studies show that this type of product tends to oxidize over a period of one year. As kerosene oxidizes it tends to burn less efficiently resulting in a smokier burn and possibly fouled burners. The No. #2 home heating oil is more stable and can be safely stored, with no chemical breakdown, for four (4) years. After this amount of time the wax contained in the product tends to thicken resulting in a smokier burn. A thicker product develops and the flowability to the burner may be reduced causing burner shutdowns.

A.S.T.M. testing shows the No. #4, 5 and 6 products to be relatively stable and may be stored indefinitely.

An important consideration relative to this study is the economic repercussions resulting from storing product over the recommended period. For example, the investment for No.#2 home heating oil should be protected by rotating inventories so that marketability is not reduced to the point where possible buyers are only willing to purchase this product at the lower No. #4 bid price.

1/ Data on storage time supplied by Jack Shea, Chemical Engineer and Lab Manager for the Division of Standards, Motor Fuel Laboratory, Massachusetts Department of Consumer Affairs.

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Preliminary Geologic Survey
of Potential Underground Oil Storage Sites in Maine

A Report to

Maine Bureau of Geology, Department of Conservation

by

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8 July 1977

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Preliminary Geologic Survey
of Potential Underground Oil Storage Sites in Maine

Purpose

This report contains a discussion of 12 general localities on the coast of Maine that are considered to be suitable, representative sites for the storage of strategic oil supplies in underground rock caverns. There are probably other sites on the Maine coast that are equal from a geotechnical point of view and may be superior in other respects. However, the discussion of the characteristics of the localities mentioned in this report should establish that suitable geological conditions for rock cavern storage can be found in Maine. This report concludes that there are a number of sites on the Maine coast with nearby port facilities or deep water anchorage that appear to be very satisfactory for the construction of large underground rock caverns with capacities of 1,000,000 to 20,000,000 barrels of oil.

Criteria

The localities discussed in this report were suggested by individual geologists that are mapping rock units in the respective areas. Experience in Finland (Johansson and Lahtinen, 1976) has shown that construction of rock caverns is more economical in acid granitic and high grade crystalline metamorphic rocks than in most other rock types. Support requirements and grouting are usually minimal in these rock types, provided they are relatively free of joints and fractures. These rocks generally transmit very little ground water flow below several hundred feet from the rock surface, thus oil losses are small and the chance of ground water contamination is low. The localities discussed in this report are representative of these more desirable rock types. The Maine geologists avoided choosing highly jointed or sheared rocks or low grade metamorphic, sedimentary, or volcano-clastic rocks. Sulfide bearing rock was also avoided.

The potentiometric ground water level must be higher than the elevation of the cavern roof so that a resultant hydrostatic pressure is maintained to contain oil within the cavern. The thickness of overburden should also be small to simplify shaft construction. Overburden thickness is very small in most of the Maine sites and in all cases less than 60 feet.

In addition to geotechnical considerations, a prime criterion for large oil storage facilities is proximity to oil terminal facilities or potential ocean tanker transfer sites. Most of the Maine sites are within several miles of 60 foot ocean depth.

This report does not deal with specific land parcels or the legal and environmental problems of rock cavern construction with ancillary oil transfer facilities. The report focuses mainly on the geotechnical characteristics of the suggested sites.

Generalized Geology of the Maine Coast

The Maine coast can be divided into three generalized regions based on topographic and geologic consederations: 1) the "southern sand plains" (Portsmouth to Portland), 2) the "central embayment" (Portland to Acadia), and 3) the "eastern headlands" (Acadia to Eastport).

The southern sand plains have little topographic relief which can be partially attributed to the moderately thick surficial cover of sandy glacial outwash that blankets much of the area. Most of the bedrock is phyllite, schist or quartzite derived from shale, sandstone, siltstone, and graywacke. Some marble and meta-volcanic rock is also present. In most cases the metamorphic grade is only low to moderate; the properties of the rocks have not changed greatly since they initially formed.

The bedrock in the southern sand plains also includes several large Devonian granitic plutons, and at least one complex of younger (Permian to Jurassic) intrusives.

The central embayment section of the coast is characterized by numerous long peninsulas separated by tidal estuaries. Although most of this part of the coast has low relief, a few areas such as Camden Hills and Acadia National Park have hills with elevations exceeding 1000 feet.

The central embayment is underlain by metamorphic and igneous rocks with the latter accounting for at least a third of the total area. The metamorphic rocks derived from sedimentary and volcanic rocks and consist of mica schists and gneisses, quartzites, meta-volcanics, and some belts of marble. Some unmetamorphosed volcanic rocks are also present. The metamorphic rocks range from weakly metamorphic to very intensely recrystallized rock. The highly metamorphosed rocks underlie much of the southern half of the coastal embayment section, especially near the Bath and Boothbay regions. The physical properties of these rocks have been greatly changed from those of the original sedimentary rocks.

The igneous bodies are primarily various types of granite, however, some darker colored diorite and gabbro are also present.

The third segment of the coast, the eastern headlands, extends from Acadia in Frenchman Bay, northeasterly to the Canadian border at Eastport. Much of this part of the coast is underlain by igneous rock such as granite, granodiorite, and gabbro. The non-igneous rocks are largely volcanic in origin and some have not been metamorphosed. These consist of rocks that can be termed flows and volcano-clastics (tuffs, ashflows, agglomerates, etc.). Because few of the rocks in the eastern headlands are highly metamorphosed, they have properties similar to non-indurated sedimentary rocks.

Joints, Foliation, and Faults

Comprehensive information on bedrock jointing is not available for many of the sites discussed here. However, some of the sites have been studied in some detail by geologists and other sites lie near old quarries that were studied by Dale (1907). Foliation is not an important feature of the sites of this study since most sites are either massive plutons or are rocks with no weakness along the planes of foliation.

Table 1 shows that for those sites for which jointing information is available, sheet jointing is common in granite and there are generally several sets of nearly vertical joints with spacing of several feet to forty feet or more. Dale (1907) states that the greatest depth at which sheet jointing has been found in Maine was 175 feet below the rock surface. Many of the vertical joint patterns have strikes conforming to regional physiographic lineaments.

Slickensided joints were only specifically noted in the Agamenticus Pluton (Boston Edison, 1976). No mineralization of joint faces is noted for the sites presented here, however, it would not be unusual to find some calcite or pyrite in joints in granite near the rock surface. Weathering of Maine granite was cited by Dale (1907), however, it is often confined to near-surface zones--particularly between open sheet joints--where percolating ground water and frost have worked. Deep weathering should not be found at the sites discussed here.

Indirect data on the extent of jointing and fracturing is available from bedrock well records. Joints become tighter and fewer in number with depth in crystalline rocks such as granite. Clapp (1911a) found that the chances of drilling a successful well in Maine granite decrease with depth (see also Davis and Turk, 1969) and that very little ground water yield can be found below a 200 foot depth. (Clapp, 1911b, noted that wells drilled in slate may have greater yields at depths between 200 and 400 feet than wells in granite.)

Faults are a group of features that should be avoided in caverning because of the difficulties in construction and a potential for ground water contamination from stored oil leaking into highly permeable rock zones. High yield bedrock well zones and known faults were generally avoided in the selection of the sites since tunneling experience has shown (Davis and Turk, 1969) that highly permeable rock zones in crystalline rock are usually associated with faulting. Caswell (1974) has also inferred that high yield bedrock wells in Maine seem to occur in zones that coincide with known or inferred fault zones.

Seismicity and Unrelieved Stress

Although Maine can not be classified as aseismic, the coast has a relatively low earthquake intensity potential. Moderate earthquakes would do little damage to underground liquid-filled rock caverns, however, the caverns should obviously not be located across faults in "active" seismic areas since ground water contamination could occur.

In historical times, none of the sites has been subjected to an earthquake with an equivalent Modified Mercalli scale Intensity of more than VI at the site. Using conservative empirical correlations relating Intensity with ground acceleration, it is calculated that no more than 0.1 times the acceleration of gravity (g) has occurred in historical time at any of the sites. (Technology Review, 1977, reported that the expected 50-year recurrence interval earthquake-induced acceleration for the coast of Maine is about 0.1g.) The only sites lying near relatively "active" seismic zones are the Mt. Waldo and Lucerne Plutons and the Addison-Great Wass Island-Jonesboro region.

Unrelieved stress was reported in a quarry in the Mt. Waldo Pluton (Dale, 1907). During quarrying, vertical joints developed, trending north-northwest. (This trend is parallel to a fairly active seismic zone running from Orrington to Milo, Maine.) Some studies suggest that New England is under an overall compressive stress; some people believe the unrelieved stress that seems to be inherent in many plutonic bodies is only a surface phenomenon that rapidly diminishes with depth. Although some unrelieved stress can be expected at least near the surface of Maine granites, it is not expected to affect normal rock cavern construction.

Hydrogeology of Coastal Maine

Most of the hydrogeology of granites and other rocks in Maine must be inferred from records of bedrock wells. These records suggest that most Maine granites have a relatively high ground water table that can be utilized for containment of oil stored below the potentiometric surface.

Clapp (1911b) found that 86% of wells drilled more than 50 feet in granite were successful in striking a suitable quantity of water for domestic use. Prescott (1963) found that about 20% of Maine bedrock wells yielded more than 10 gallons per minute, but wells yielding more than 100 gallons per minute are rare and are probably in a fault zone or in limestone.

The potentiometric level of ground water as measured in bedrock wells in Maine, generally conforms to a subdued version of the bedrock surface topography. Potentiometric levels in Maine bedrock wells generally fluctuate less than 20 feet over the seasons. With the exception of Mt. Waldo in Prospect, all of the localities have a potentiometric ground water level that lies relatively close to the ground surface (less than 60 feet).

Overburden Character and Thickness

Many of the sites have little or no surficial cover. The Maine granites and gabbros are normally more resistant than the surrounding country rock. The plutonic bodies were usually left as topographic highs by the Wisconsinan glaciations. The glaciers rarely left more than 40 feet of drift on these topographic highs.

In most cases the bulk of the surficial cover at the sites consists of a dense lodgment till with a fine-grained matrix immediately overlying the bedrock. The till may be overlain in turn by several feet of silty sandy ablation till, silty marine-laid sediments, or sandy outwash deposits. Thus the depth and type of cover at most sites would not significantly increase cavern construction costs over a "bare rock" site.

Oil Transfer Capability

Although Maine is obviously not centrally located with respect to high population centers, it does offer potential for deep water tanker transfer which is not available elsewhere on the eastern seaboard. In many cases, natural 60 foot ocean depths lie within several miles of a suggested site. Fairly direct rail connections to the Boston area can also be made from most of the sites. Sites in the Portland area (or the Searsport-Bucksport area) could take advantage of existing oil transfer capabilities.

Summary of Individual Site Characteristics

Table 1 is a summary of the pertinent geologic and locational aspects of the sites selected for discussion. The individual sites were not examined in the field for this study. Literature references and the comments of the Maine Survey geologists were assembled in selection of the sites and description of site characteristics. As mentioned in the statement of purpose, these should only be considered representative sites. Given more time for a thorough study, localities with similar geology but better locational characteristics might be found.

The sites are discussed in the following pages in order from southwestern Maine, moving up the coast to eastern Maine. No relative ranking of the sites is attempted. The Westbrook Pluton, Clark Island granite, Mt. Waldo Pluton, and Sedgwick Pluton would be favored sites, however, because of their combination of geologic and locational factors.

Agamenticus Pluton - 1

This pluton consists of a core of binary granite and a formation of alkali syenite on the northeastern side of the pluton, both of which would be suitable for cavern construction. Several strong sets of physiographic lineaments and some slickensided joints are found in the southwestern portion of the pluton. There are no nearby port facilities, but deep water lies 3 miles to the east of the site.

Webhannet Granite - 2

Although there is little detailed information on the site, it appears to be excellent from a geologic point of view. Overburden thickness may be greater (up to 60 feet) than average for the Maine sites. There are no nearby port facilities, however, deep water lies 5 miles to the east and the Boston and Maine Railroad passes near the site.

Westbrook Pluton - 3

This foliated biotite granite does have locally closely spaced joints and scattered high yield bedrock within the pluton. However, surficial cover is minimal and the well-developed Portland Harbor oil terminal lies only 7 miles away. Maine Central Railroad also runs nearby.

High Grade Metamorphics of the Cape Elizabeth Formation - 4

Lying just southeast of Bath in a region of many peninsulas bordered by deep ocean channels, these rocks consist of high grade quartzose metapelites. The nearly vertically dipping foliation is not a plane of weakness; joints are widely spaced. Surficial cover is generally minimal. Subsite 3 has a relatively deep potentiometric surface (100 feet below ground) and has a regional fault just to the east. Oil transfer to the sites in this rock formation would probably be made by barge.

Clark Island Granite (St. George Pluton) - 5

This biotite-muscovite granitic body has many excellent geologic and locational attributes. There are no significant faults or seismicity sources in close proximity. Other than sheet jointing, only one set of widely spaced vertical joints has been reported. Overburden is thin or non-existent and the ground water table is within 30 feet of the ground surface. Excellent deep ocean water tanker access is within 2 miles and the Maine Central Railroad is within 5 miles.

Mt. Waldo Pluton - 6

This very high strength granite rises steeply to over 1000 feet above adjacent sea level. To get below the water table, one would probably tunnel down into the mountain from somewhere near the base. A northwestly trending zone of active seismicity begins just to the northeast of the pluton. Although only widely spaced vertical joints are reported, vertical north-northwest fissures developed during quarry operations here indicating unrelieved stress in the rock. The Bangor and Aroostook Railroad lies adjacent to the site; a 20 foot navigable channel lies 2 miles to the east in the Penobscot River. Oil handling facilities are present in Bucksport, 4 miles to the southeast, and in Searsport, 9 miles to the south. A U.S. Airforce pipeline running from Searsport to Limestone also runs nearby.

Lucerne Pluton - 7

This large granitic body is at the southeast end of an active, northwesterly trending seismic zone. Strong northwest physiographic lineaments run through the Lucerne. Some moderately high bedrock well yields are reported throughout the pluton and the potentiometric ground water surface is 50 to 60 feet below ground surface in the vicinity of the site. The best oil transfer point would be in Blue Hill Bay, 6 miles to the southeast where 60 foot water depths are found.

Sedgwick Pluton - 8

This biotite granite has four separate vertical joint sets, but each set has wide spacing. There is a northeasterly trending fault zone inferred to run along the southeastern contact of the pluton which correlates with a zone of high yield bedrock wells in that area. Surficial cover is less than 20 feet. Deepwater tanker access is possible 2 miles away in Eggmoggin Reach and is also possible through Blue Hill Bay.

Tunk Lake Pluton - 9

The Tunk Lake Pluton is a granite with Tunk Lake lying over most of the core. Not much information is available on jointing, however, the core is reported to be relatively massive. There is an east-northeastly trending fault along the south-southeast edge of the intrusion. Surficial cover may be relatively thick in the core area (40 to 60 feet) but is minimal on the flanks. Although Maine Central Railroad runs through the southern end of the pluton, it is 8 miles to deep water at Sorrento.

Gabbro South-southeast of Addison - 10

There is little information available on this gabbro. Surficial cover may be relatively thick (up to 60 feet). Strong northwest physiographic lineaments cut through the terrain in this area. Deep water access is possible in Western Bay, 2½ miles away. Maine Central Railroad lies 7 miles to the north.

Great Wass Island Granite - 11

This biotite granite has two sets of widely spaced vertical joints, in addition to sheet joints. An instrumental MM Intensity V earthquake was recorded 2-1/3 miles to the north (a zone of moderately high yield bedrock wells are also found in the vicinity of the epicenter). The northeasterly trending Fundy Fault is inferred to lie one mile south of the site. There is no existing road transportation to the mainland, however, it is less than one mile to 120 foot ocean depths.

Jonesboro Granite Pluton - 12

The northeastern portion of the pluton is reported to have 3 sets of vertical joints, but there is no information on joints in the southwestern part of the intrusion. The ground water table may be fairly deep (about 60 feet) in the vicinity of the site but a surficial cover of lodgment till should be less than 20 feet thick. The Maine Central Railroad passes 3½ miles to the north. Chandler Bay has 60 foot depths within 5 miles of the site and 30 foot depths within 2½ miles.

Summary

Geologists mapping in Maine have selected 12 localities on the coast of Maine that they consider suitable for the storage of strategic oil supplies in large underground rock caverns. Ten of the sites are located in granite, one in gabbro, and one in high grade metamorphic rock. These sites are characterized as generally having a relatively massive structure with few joint sets, relatively low seismicity potential (Modified Mercalli Intensity VI or less), a high ground water table, and relatively thin surficial cover. Oil transfer to these sites can usually be made by deep draft ocean tankers within several miles of the sites. Railroad connections are also usually possible.

The combination of deep draft tanker transfer potential and suitable geologic conditions makes the Maine coast worthy of consideration of rock cavern storage of petroleum reserves.

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TABLE 1
Summary of Site Characteristics

Preliminary Geologic Survey of Potential Underground Oil Storage Sites in Maine
8 July 1977

Site, Rock Type & Age	Joints & Foliation	Seismicity & Faults	Hydrogeology	Overburden Thickness & Type	Distance to Oil Transfer Points
Agamenticus Pluton; binary granite, alkali syenite; 225 MY	Sheet joints; widely spaced vert. N20E, N40W joints, some slickensides; N10E, N45W lineaments in SW portion; no major joints in alkali syenite	Historical MM VIII 30 miles to SSE	Potentiometric level 60' below ground; moderately high well yields to SW & SE	Up to 40' fine-grained lodgment till	2½ miles to 60' ocean depth; Boston & Maine RR 5 miles to W; no nearby port facilities
Webhannet Granite; granite; Devonian	Generally massive; no detailed information on joints; reported to be locally free of closely spaced joints	Historical MM VIII 35 to 40 miles to SSE	Potentiometric level 10' or less below ground; no high yield wells in vicinity	20' to 60' of fine-grained lodgment till, sandy outwash	5 miles to 60' ocean depth; Boston & Maine RR runs near site; no nearby port facilities
Westbrook Pluton; biotite granite; Devonian	Sheet joints ½' to 2½' apart at surface; locally closely spaced N10E joints dipping 55W; granite often foliated	Historical MM VI 15 miles to N; instrumental MM VI 25 miles to SE; inferred regional faults trending NE run along SE and NW contact with country rock	Potentiometric level 50' below ground; high yield wells around contact with country rock; several moderately high yield wells within pluton	Generally less than 5' of lodgment and ablation till	7 miles to Portland oil port facilities; Maine Central RR runs nearby
Cape Elizabeth formation (high grade metamorphics); high grade quartzose metapelites; Ordovician-Silurian	nearly vert. bedding & foliation striking N5E with no parting on foliation; nearly horizontal joints several feet apart; widely spaced nearly vert. N75W joints	Historical MM IV 4 mi. to W; historical MM VI 25 miles to N; historical MM VI 20 miles to NW; instrumental MM VI 20 miles to S; NNE trending regional fault just east of subsite 3	Subsite 1--potent. level 20' to 40' below ground; mod. high well yields to S & W Subsite 2--potent. level 60' below ground; high yield wells to N, E, and S Subsite 3--potent. level 100' below ground; high yield wells to E	Generally less than 10' of till and silty marine-laid sediments	Subsite 1--2½ miles to 60' ocean depth in New Meadows River Subsite 2--1½ miles to 30' depth in Kennebec R. Subsite 3--2½ miles to 60' ocean depth; 0.3 miles to 30' ocean depth
Clark Island granite (St. George Pluton); biotite-muscovite granite, fine to med. even-grained texture; 367 MY; crushing strength 13,000 to 15,000 psi	sheet joints 2' to 10' apart at surface; vert. N65W joints at 10' to 20' spacing	No significant seismicity or faults nearby	Potentiometric level 30' below ground; one high yield well to NE	Generally less than 5' ablation till	2 miles to 60' ocean depth; Maine Central RR 5 miles to N
Mt. Waldo Pluton; fine even-grained biotite granite; 325 MY; ult. comp. strength 30,000 psi	sheet joints 8" to 8' at surface; vert. N85W & N60W at 20'-40' spacing; NNW vert. joints developed in quarrying	3 Hist. & 1 instr. MM V 15 mi. to NE; NE trending Norumbega Fault 5 miles to NW	Potent. level 100' below ground at el. 200'; high yield wells around northern contact	Generally less than 5' ablation till	2 miles to 20' ocean depth in Penobscot R.; Bangor & Aroostook RR adjacent to site; oil port 4 miles to SE

TABLE I
Summary of Site Characteristics

Preliminary Geologic Survey of Potential Underground Oil Storage Sites in Maine
8 July 1977

Site, Rock Type & Age	Joints & Foliation	Seismicity & Faults	Hydrogeology	Overburden Thickness & Type	Distance to Oil Transfer Points
Lucerne Pluton; coarse-grained granite 356 MY	No detailed information on joints; strong N35W physiographic lineaments	3 Hist. & 1 instr. MM V 20 miles to NE; inferred fault along NW contact; at SE end of N35W trending seismic zone	Potentiometric level 50' to 60' below ground; some mod. high yield wells within pluton	Generally less than 20' lodgment till	6 miles to 60' ocean depth in Blue Hill Bay; Bucksport oil facilities 11½ miles to NW
Sedgwick Pluton; coarse to medium-textured biotite granite; 395 MY	Sheet joints 2'-8' apart at surface; vert. N40W, N50E, N67E, N67W joints at 15'+ spacing	No significant seismicity in area; NE trending fault along SE contact	Potentiometric level 40' below ground; high yield wells to the S	Generally less than 20' lodgment till	2 miles to 60' ocean depth in Eggmoggin Reach; ship transfer also possible in Blue Hill Bay
Tunk Lake Pluton; granite; Devonian	No detailed information on joints; reported to be relatively unjointed in the core	No significant seismicity in area; ENE trending fault along SSE edge of pluton	Potent. level less than 20' in core, but deeper in rock around core; no reported high yield wells in pluton	40' to 60' till & lacustrine deposits over core, but less than 10' till on rock around core	8 miles to 60' ocean depth at Sorrento; Maine Central RR just to S
Gabbro SSE of Addison; gabbro; Devonian	No detailed information on joints; strong NW physiographic lineaments	Instrumental MM V 5 miles to SE; NE trending Fundy Fault 8 miles to SE	Potentiometric level 40' below ground; mod. high well yields to E	Up to 60' of lodgment till	2½ miles to 60' ocean depth in Western Bay; Maine Central RR 7 miles to N
Great Wass Island granite; coarse-grained biotite granite; Devonian	Sheet joints 5'-15' apart at surface; vert. N10E joints at 5'-10' spacing; vert. N90W joints at 20'+ spacing	Instrumental MM V 2-1/3 miles to N; NE trending Fundy Fault 1 mile to S	Potentiometric level 20' below ground; mod. high yield wells to N	Less than 40' lodgment till and silty marine-laid sediments	1 mile to 120' ocean depth; no highway to mainland
Jonesboro Granite Pluton; medium-textured biotite granite; Devonian	Sheet joints ½'-5' apart at surface; vert. joints in NE part of pluton striking N60E, N50W, & N70W	Instrumental MM V 10 miles to S; NE trending Fundy Fault 12 miles to SE	Potentiometric level 60' below ground; high yield wells to NW within pluton	Less than 20' of lodgment till	5 miles to 60' ocean depth in Chandler Bay, 2½ miles to 30' depth; Maine Central RR 3½ miles to N

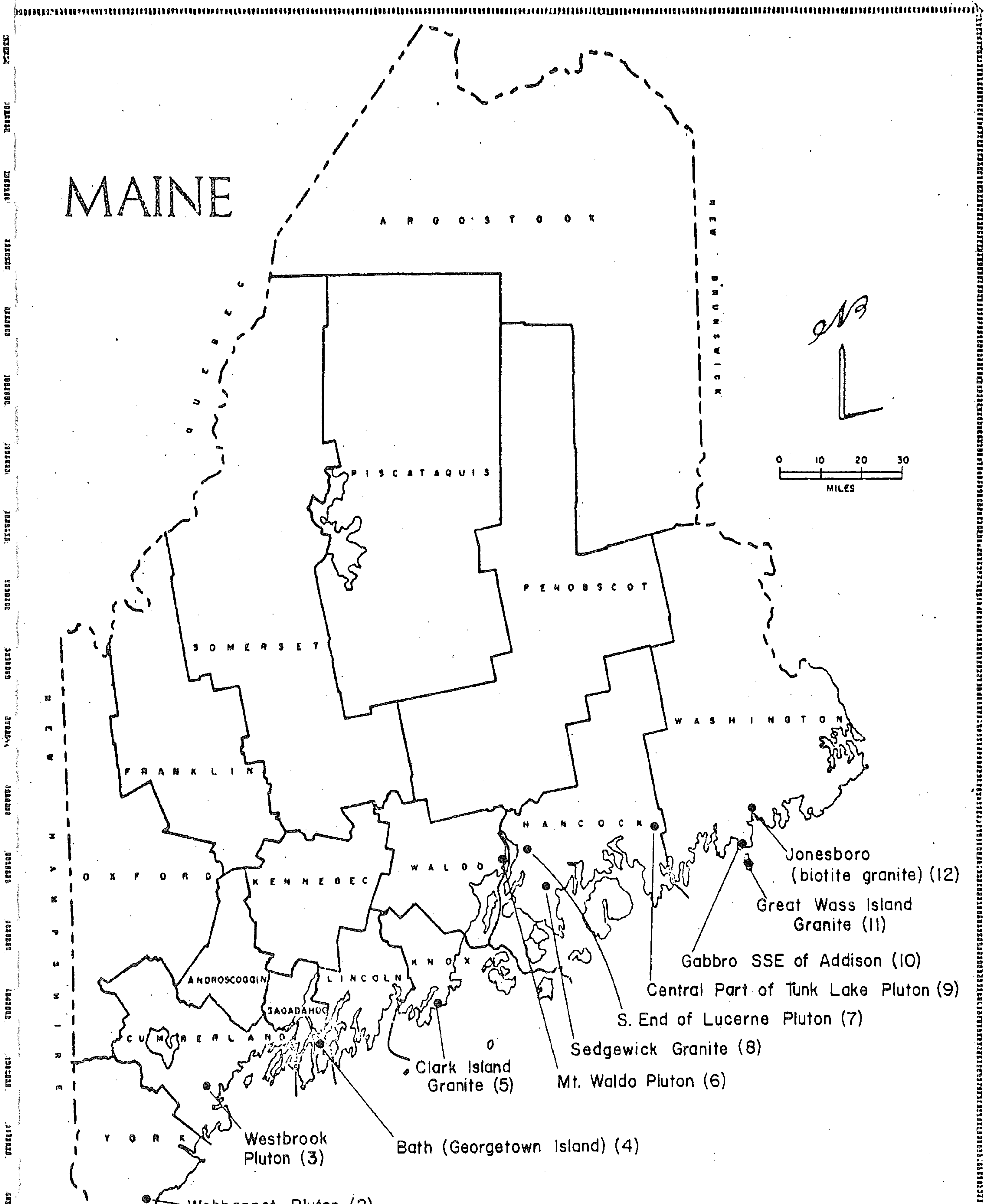
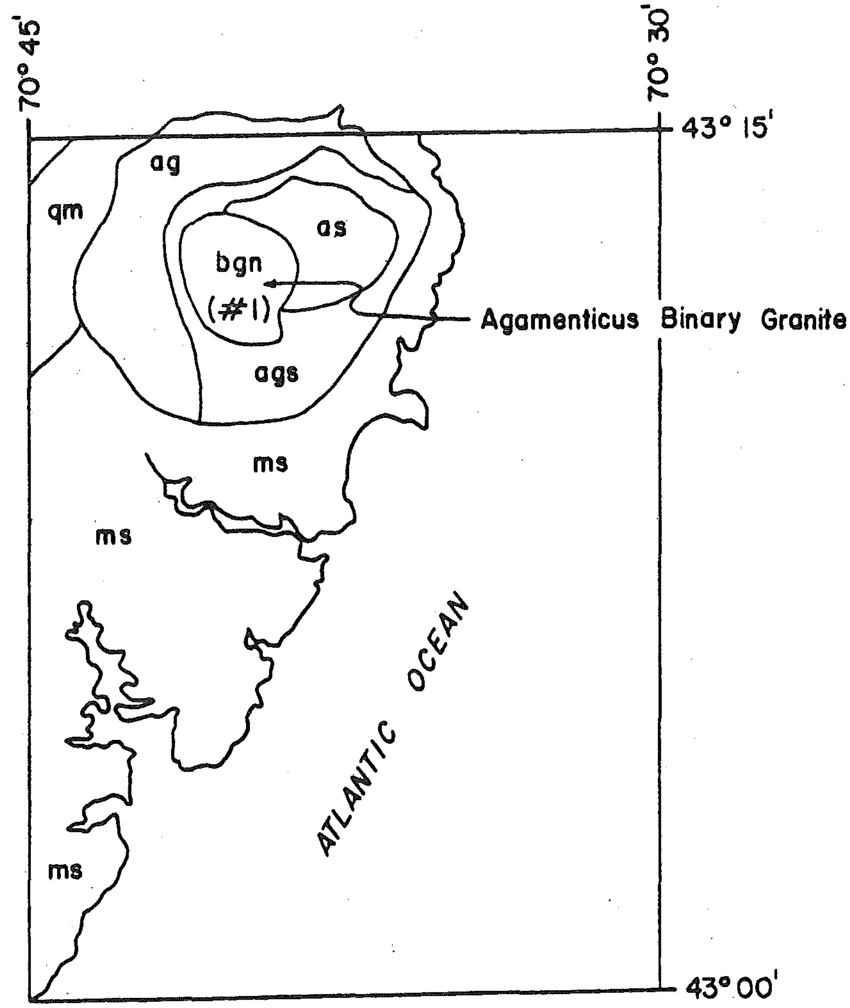


PLATE I : INDEX MAP



LOCALITY # 1: Agamenticus Binary Granite

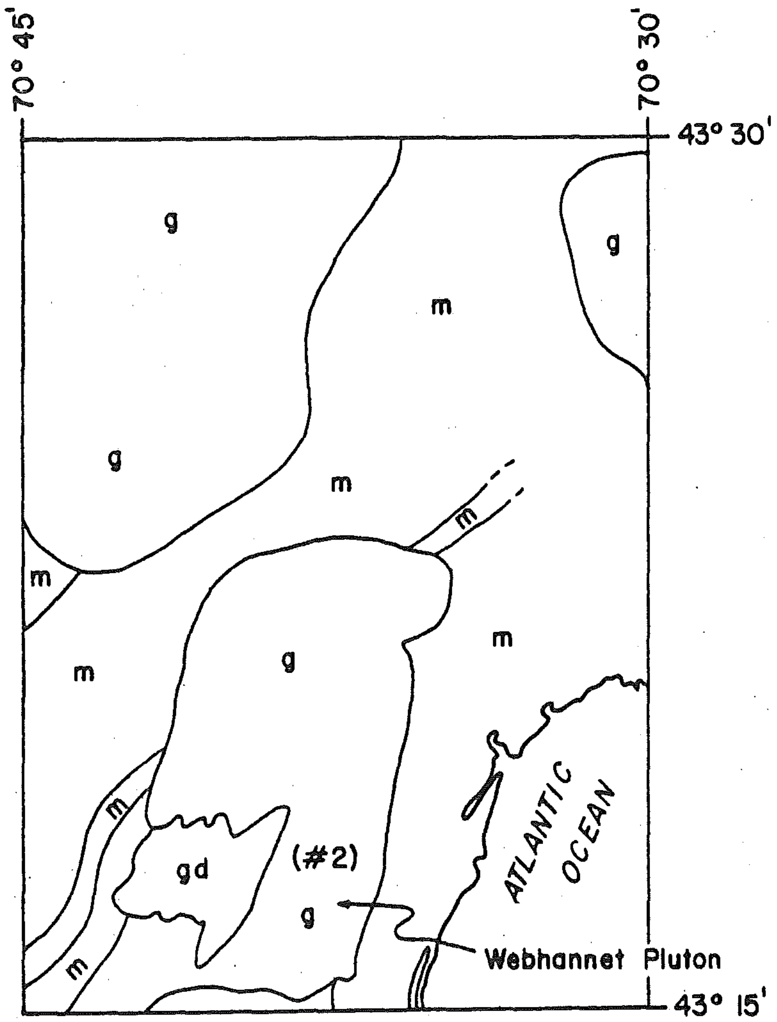
ms - metamorphic rocks
qm - quartz monzonite
as - alkaline syenite
ag - alkaline granite
ags - alkaline quartz syenite

Scale 1 : 250,000

N

FIGURE 1

MGS 1977



LOCALITY #2: Webhannet Granite

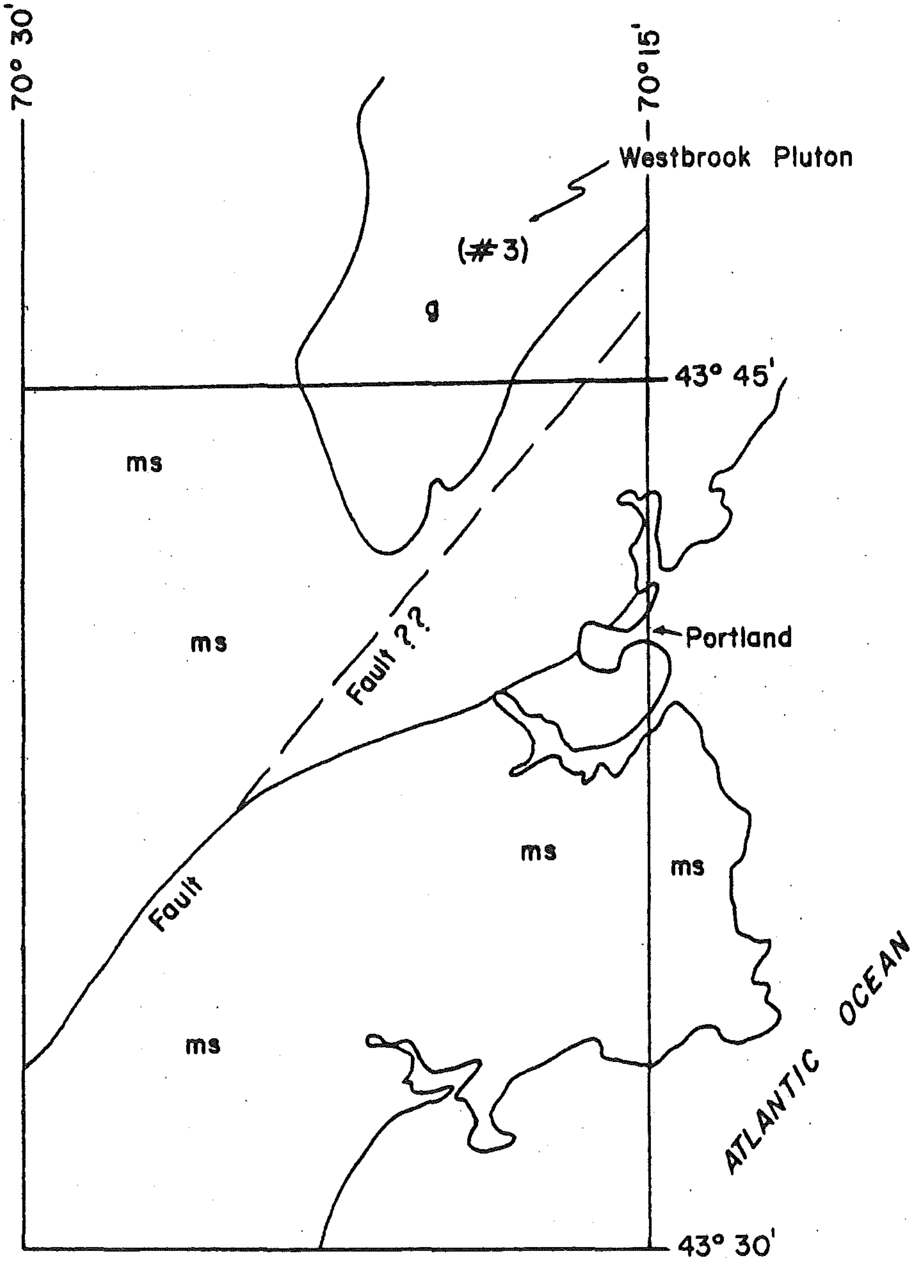
m - metamorphic rocks

g - granite

gd - granodiorite

Scale 1:250,000

FIGURE 2



LOCALITY #3: Westbrook Pluton

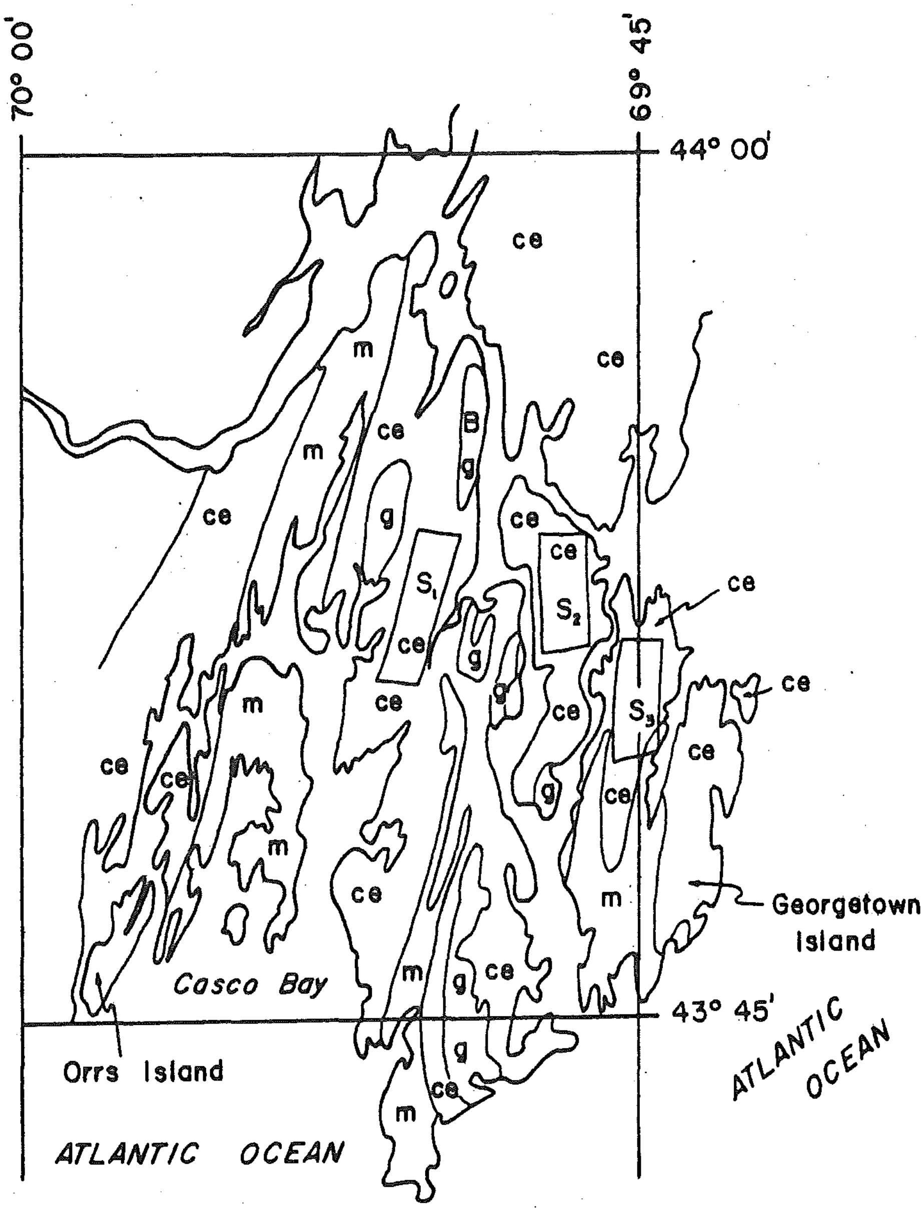
ms - metamorphic rocks

g - granite

Scale 1:250,000

FIGURE 3

MGS 1977



LOCALITY # 4: Highgrade Metamorphic Rocks Near Bath (shown by B)

Sites 1,2,3 in the Cape Elizabeth Fma

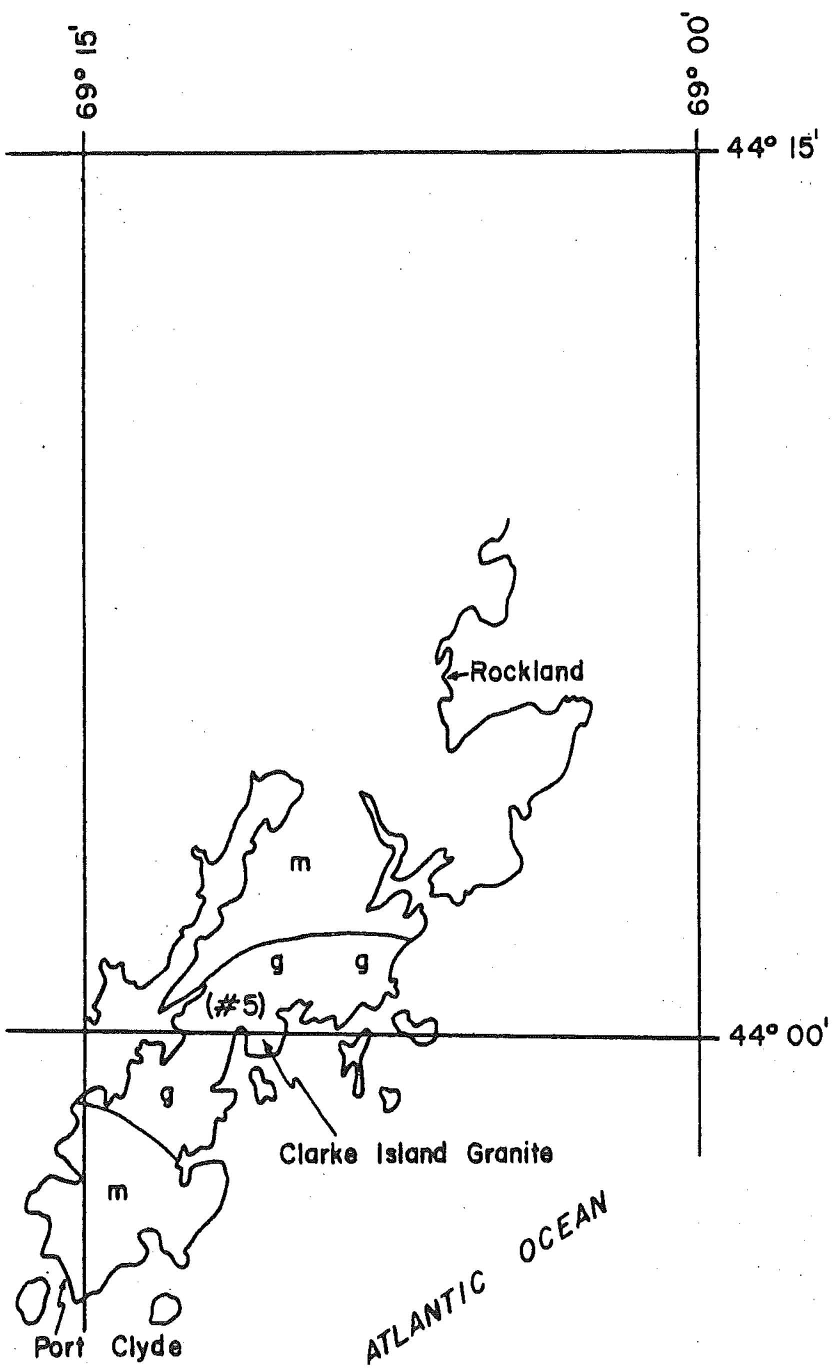
g - granite
m - other metamorphic rocks
ce - Cape Elizabeth migmatites

Scale 1:250,000

N

FIGURE 4

MGS 1977

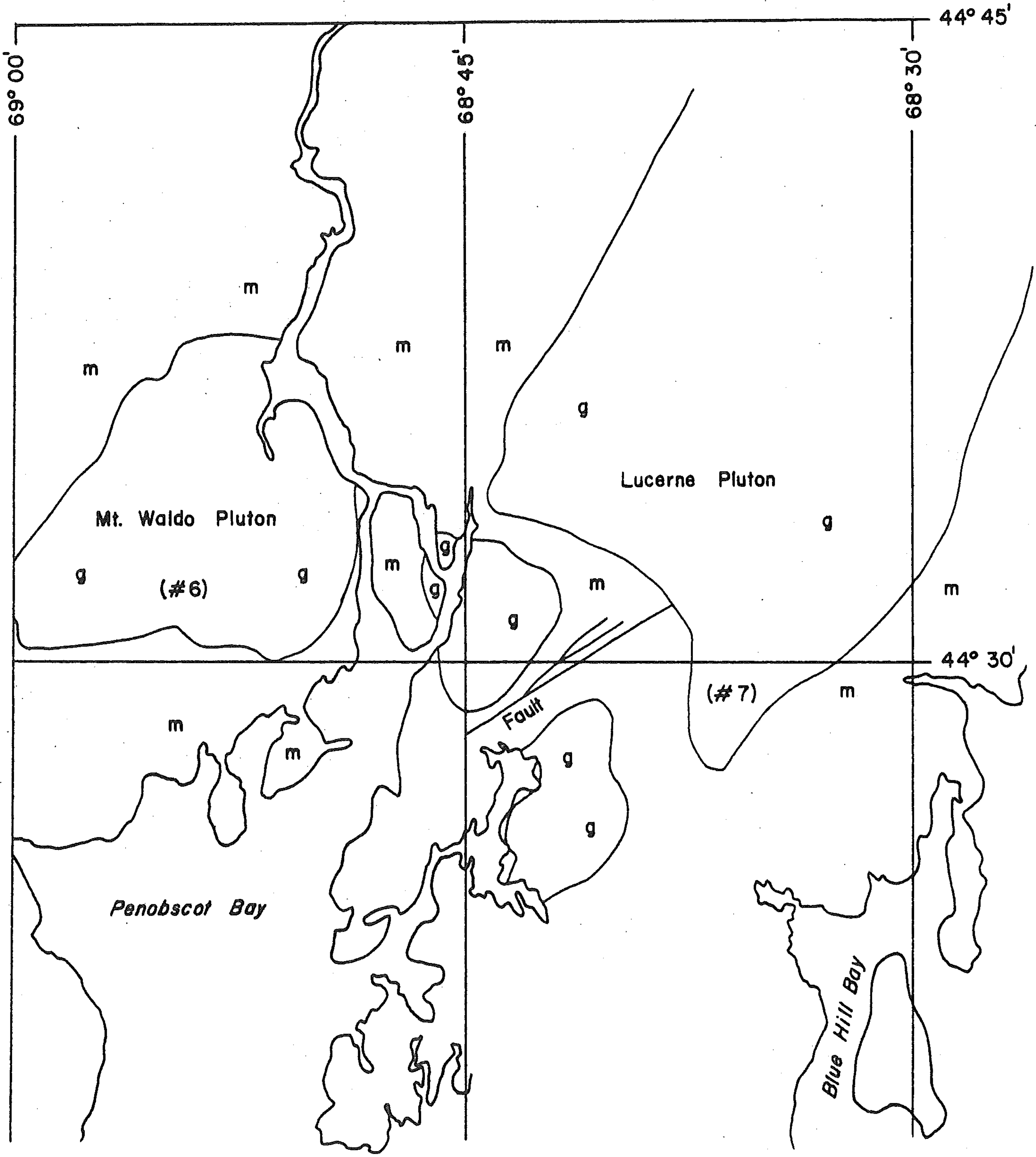


LOCALITY #5: Clark Island Granite
m - metamorphic rocks
g - granite

Scale 1:250,000

FIGURE 5

MGS 1977



LOCALITY #6: Mt. Waldo Pluton
#7: South End of the Lucerne Pluton

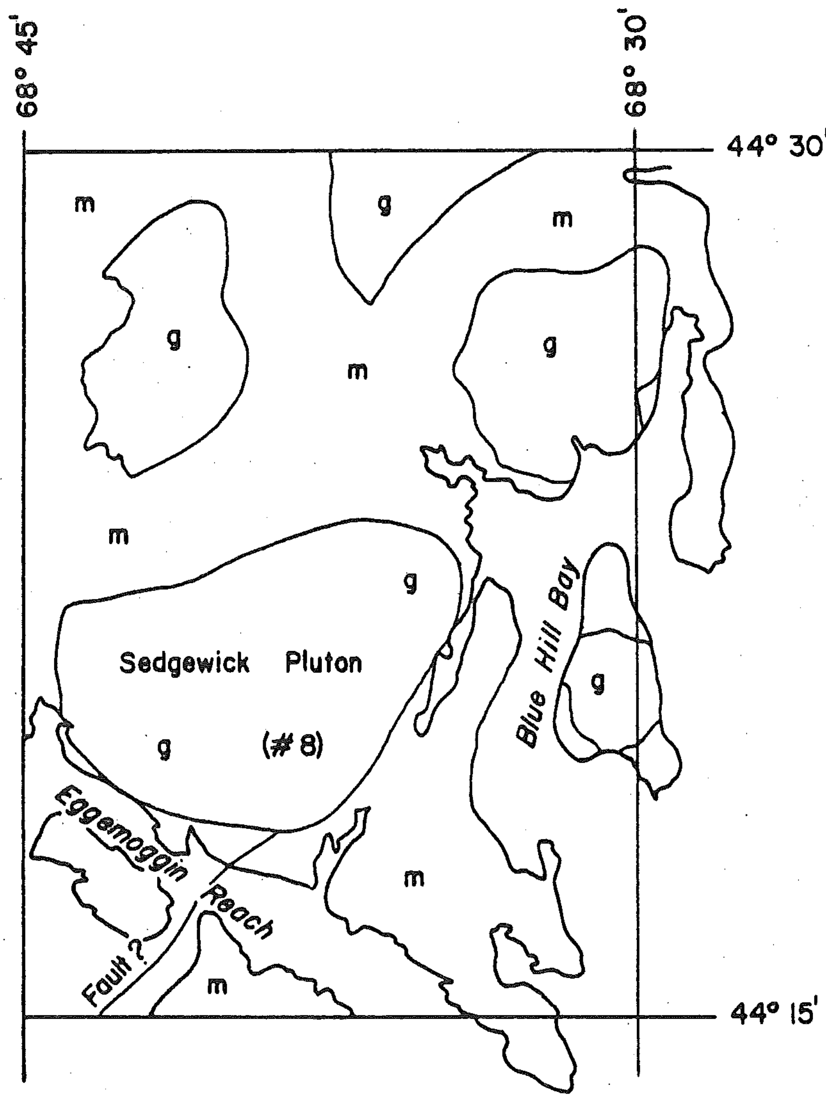
m - metamorphic rocks
g - granite

Scale 1: 250,000

N

FIGURE 6

MGS 1977

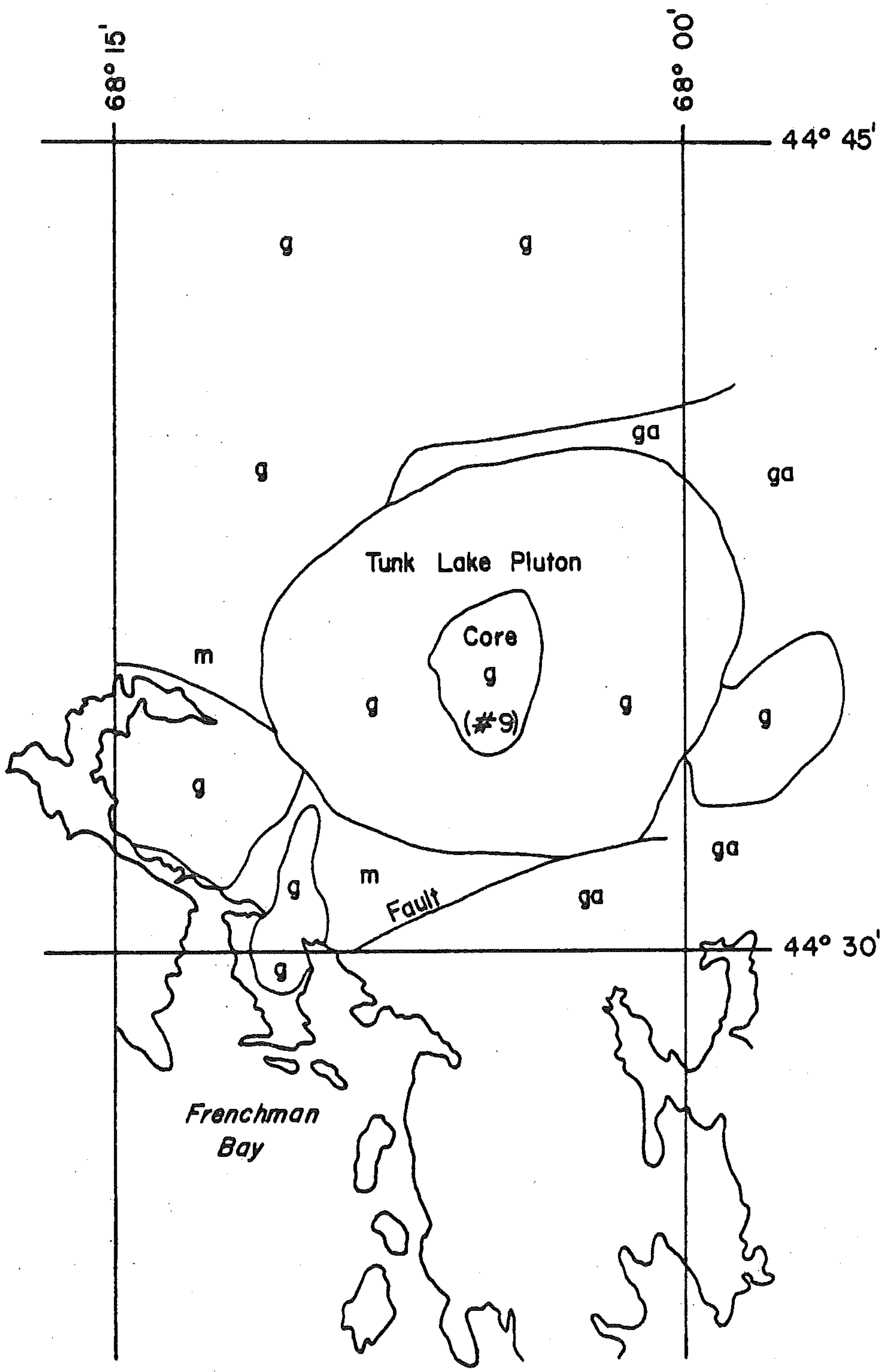


LOCALITY #8: Sedgewick Granite
m - metamorphic rocks
g - granite

Scale 1:250,000

FIGURE 7

MGS 1977



LOCALITY #9: Central Part of Tunk Lake Pluton

m - metamorphic rocks

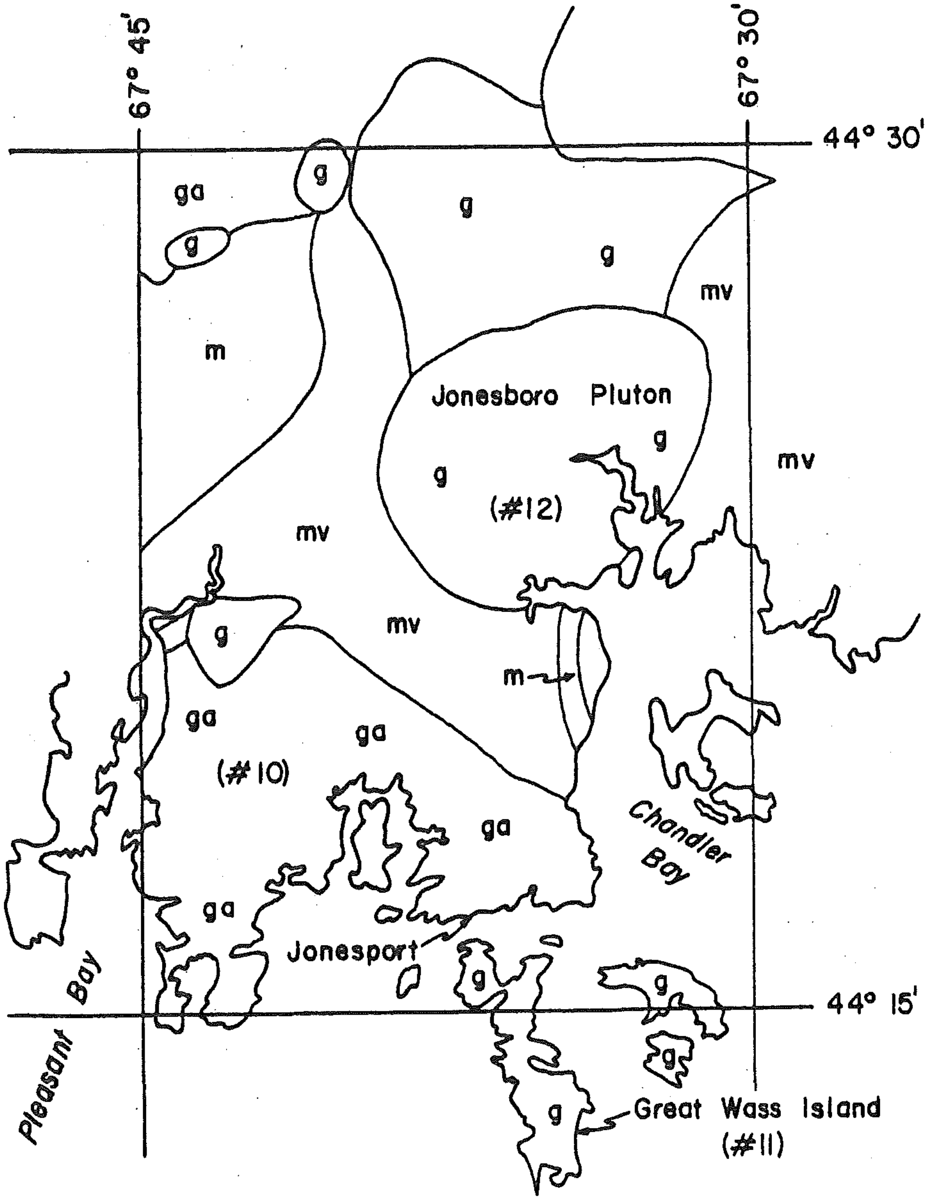
g - granite

ga - gabbro

Scale 1:250,000

FIGURE 8

MGS 1977



LOCALITY # 10: Gabbro to SSE of Addison
11 : Granite on Great Wass Island
12 : Jonesboro Granite Pluton

ga - gabbro
g - granite
mv - weakly metamorphosed volcanic rocks
m - weakly metamorphosed shales

Scale 1:250,000

N

FIGURE 9

MGS 1977