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High levels of arsenic in the groundwaters of southeastern New Hampshire: a geochemical reconnaissance

by

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Introduction

The presence of high arsenic levels (>50 ppb)[1/] in some ground waters of southeastern New Hampshire (Concord Monitor, 3/12/81) and in adjacent areas of Maine and New Hampshire (F.G. Wolf, U.S. Environmental Protection Agency, written communication, 3/12/81) has been recognized since 1977. This naturally has been a matter of considerable concern to those families living in this region who obtain their drinking water from private wells.

The U.S. Environmental Protection Agency (EPA) was requested by New Hampshire officials to conduct an investigation to determine the source of such elevated arsenic levels. Initially, it was hypothesized that hazardous waste dumps or arsenic-bearing pesticides and defoliants would be responsible for the elevated levels of arsenic. However, the results of investigations by the EPA, as well as by other State and local agencies, did not support this hypothesis. The EPA concluded that the wells containing elevated levels of arsenic occur in an apparent random distribution unrelated to land use (U.S. Environmental Protection Agency, 1981). The EPA concluded that these levels of arsenic must be of natural origin, resulting from the breakdown of arsenic-bearing sulfide minerals in the bedrock, such as pyrite (FeS_2), which can contain as much as 0.1 percent arsenic. They did note, however, that there may be, in local areas, some minor contributions of arsenic to the groundwater from these man-made sources.

[1/] Parts per billion. 1 ppb is also, for dilute natural waters, essentially equivalent to 1 microgram per liter (μg/l).

After a consideration of the geology and hydrogeology of the area, the geochemistry of arsenic, and the available data on the major and minor element content of ground and surface waters in this and other nearby areas, we speculate that a natural source for the higher arsenic contents appears to be unlikely. The reconnaissance study described in subsequent sections was undertaken in the hope that the data obtained might suggest a principal source for the elevated arsenic levels. For a number of reasons that are described in subsequent sections, we believe that the bulk of the anomalous arsenic may have been introduced principally by man's activities. The door is necessarily open, however, to any number of alternative hypotheses to explain the origin of the arsenic.

Geology of southeastern New Hampshire

Southeastern New Hampshire is underlain by rocks of the Avalonian and Gander structural-stratigraphic provinces of the Caledonian-Hercynian orogen (Lyons and others, 1982). These are predominantly metamorphic rocks: varieties of gneiss, slate, schist, quartzite, and metavolcanic rocks. These rocks are intruded by two-mica granite in the northwest, by granodiorite near the coast, and by a subordinate volume of gabbro, diorite, and monzonite in the central part of the region (fig. 1, see also Billings, 1956). Diabase dike swarms are found along the coast, and lamprophyre dikes are distributed throughout the region. The major rock units (metamorphic rocks, granite, and granodiorite) occur in northeasterly trending belts parallel to the regional structural grain (Billings, 1956).

The bedrock is generally covered by unconsolidated deposits of glacial origin formed during the later part of the Pleistocene Epoch. In some places, the glacial deposits are thinly masked by alluvium and swamp deposits of Holocene age. Till, generally an unsorted mixture of grain sizes from clay to boulders, was deposited directly by glacial ice. Beneath active (moving) ice, basal till was deposited discontinuously on the bedrock surface. The thickness of basal till is generally less than a few meters. Till deposited beneath the ice is generally compact. Ablation till discontinuously overlies the compact till. This latter till formed as residual material from the wasting ice and was gradually laid down on the underlying land surface. Ablation till is less compact than basal till and occasionally "washed" or winnowed of the fine grain fraction and may be faintly stratified. Till is the most common surficial deposit in the region, and it is by far the dominant surficial material in upland areas and on the hills and many undulating surfaces of the coastal ramp.

Stratified drift deposits within the region were formed during the waning stages of glaciation by sediment-laden glacial meltwater streams and in standing water. Coarse-grained ice-contact deposits were formed by meltwater streams in ice-margin areas and commonly form small terraces along valley walls.

Outwash deposits were formed by meltwater streams beyond or away from the ice margin and are generally better sorted than ice-contact deposits. Characteristically, outwash forms thin deposits in valley lowlands.

Coarse sediment in meltwater streams entering standing water was deposited as deltaic deposits while finer sediment (silt and clay) temporarily remained in suspension. These types of deposits are most common in the larger river systems.

Bottom deposits, which result from the settling of the suspended sediment in standing water (ponds and lakes), consist of silt and clay. The most extensive bottom deposits occur in the lowlands of the eastern part of the region where they formed in estuarine or marine environments.

Groundwater in southeastern New Hampshire

The crystalline bedrock has essentially no primary porosity and contains recoverable water only in open fractures (secondary porosity). Structure is considered more important than rock type in determining potential to yield water. The size, number, distribution, and degree of interconnection of fractures are highly variable, but commonly combine to represent only a small volumetric percentage of the rock mass. Thus, bedrock has little storage capacity, and this capacity generally decreases with depth. Nevertheless, wells penetrating bedrock commonly yield dependable supplies of water for single family domestic needs. Zones where bedrock is extensively fractured may be expected to yield larger quantities of water.

Unconsolidated deposits have primary porosity. The ability of these deposits to yield water depends on hydraulic conductivity which in turn is dependent on the number and size of the pores and the degree of interconnection of these pores. Till (hardpan), being an unsorted mixture of wide-ranging grain sizes, has both relatively low primary porosity and hydraulic conductivity. Deposits of silt and clay have significant porosities, but because both pores and interconnection of pores are very small, the hydraulic conductivity is low. Large-diameter dug wells in these materials may provide adequate supplies to single family homes, but this yield may not be dependable during droughts; when the water table declines there is less water in storage. Deposits of stratified sand and gravel have relatively high porosities and hydraulic conductivities. Domestic supplies may be provided by small well points or dug wells. Development of high-yield municipal and industrial wells has proven most successful in thick, water-saturated sand and gravel deposits.

Geochemistry of Arsenic

Arsenic is an element that is dispersed widely throughout the crust of the earth and is found in trace amounts in living organisms and in their fossil remains. Average crustal abundance is about 2 ppm [2] (Mason, 1958, p. 41). Arsenic commonly accompanies many different metals in a variety of mineral deposits. More than 25 principal arsenic minerals are known and arsenic also occurs in minor amounts in many other minerals; among these the more common are pyrrhotite ($Fe_{1-x}S$) and pyrite (FeS_2). Up to 0.01 percent arsenic can occur in pyrrhotite and up to 0.1 percent has been reported in some pyrites. Although not abundant generally, these last two minerals do occur in some units of metamorphic rocks in southeastern New Hampshire, but no tests have been made to determine if they contain arsenic.

The geochemistry of arsenic is complex because four oxidation states are possible for the element: 3^-, 0, 3^+, and 5^+. Upon oxidation in the zone of weathering, arsenic minerals and arsenic-containing minerals, such as pyrite and pyrrhotite, release arsenic to the groundwater in the form of anions. Hem (1970, p. 206) notes that from thermodynamic data it can be shown that the arsenate species $H_2AsO_4^{1-}$ and $HAsO_4^{2-}$ are the equilibrium forms over the pH range of most natural waters, and that the solubility of these arsenate ions depends on the cation concentrations and the solubility of the various arsenates that could be precipitated. Hem further notes (p. 207) that the sorption of arsenate on precipitated ferric hydroxide on other active

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[2] Parts per million. 1 ppm is also, for dilute natural waters, essentially equivalent to 1 milligram per liter (mg/l).

surfaces, such as insoluble phosphate compounds, is also an important factor limiting arsenic solubility in natural water systems. In connection with the sorption of arsenic by precipitated iron hydroxide, commercial laboratories have reported informally to us that high levels of arsenic have been occasionally measured in the reddish material (iron hydroxide?) filtered out of the water by water-tap filtration devices. In a comprehensive article on the geochemistry of arsenic, Boyle and Jonasson (1973) stress that the natural solution chemistry and migration behavior of arsenic is probably more complex than commonly believed. Their considerable field experience in the use of arsenic in geochemical prospecting investigations leads them to suspect the element may also migrate as various uncharacterized complexes, as a variety of chelated and other organic compounds resulting from the decay of plant and animal matter, and, as also suggested by Hem, in a colloidal form or adsorbed to hydrous iron oxide, silicate, and humic colloids.

Shacklette and others (1974, p. 11) report that the mobility of arsenic in soils is generally low because the arsenate ion is strongly adsorbed by limonite. They found that most of the arsenic is held in the upper 30 centimeters (cm) of soil, and any lost to leaching would be incorporated in groundwater recharge. The arithmetic mean for arsenic content in soils analyzed in the lower 48 United States by Shacklette and others (1974, p. 11-13, fig. 4) was 7.4 ppm; relatively high values occur locally in parts of the Appalachian Highland, but no extensive arsenic-rich metallogenic province is indicated.

Commercial arsenic in the environment

Gualtieri (1974, p. 51) estimates the annual industrial use of arsenic in the U.S. to be between 20,000 and 30,000 short tons. Loebenstein (1981b, p. 47) revises the industrial use downward and estimates that 16,200 short tons were used in 1979. Most arsenic is used as "white arsenic" (arsenic trioxide, As_2O_3). Lesser amounts are used as arsenic-metal in metallic alloys and in other chemical forms such as arsenic acid (see U.S. Buraeu of Mines, 1980). Some 230 companies are registered with the Federal Government to manufacture arsenic-bearing products, but 90 percent of the arsenic is used by four major pesticide and desiccant producers and by two major wood-preservative producers (Loebenstein, 1981a). Loebenstein (1981a, p. 10) estimates that the 1980 distribution of use is as follows:

50 percent--agricultural chemicals (herbicides, plant desiccants, defoliants, and soil sterilizers)

40 percent--industrial inorganic chemicals (wood preservatives and mineral flocculants or detergents)

5 percent --glass and glassware

3 percent --non-ferrous alloys (usually with lead and copper)

2 percent --other uses (includes feed additives, pharmaceuticals, and electronics such as semi-conductors)

Abundance of arsenic in natural waters

The basic problem is whether the anomalous levels of arsenic in the groundwaters of southeastern New Hampshire are due to activities of man or represent a natural enrichment resulting from the oxidation of arseniferous pyrite and other minerals in the bedrock. However, there is no direct evidence for the presence or absence of sulfide minerals in the water-bearing joints and fractures in the bedrock. Therefore, a knowledge of the natural levels of arsenic in ground and surface waters in northern New England, which are apparently free from chemical alteration by the activities of man, can be helpful in ascertaining the sources of arsenic.

In connection with its program of research in geochemical exploration techniques, the U.S. Geological Survey has determined the arsenic content of a large number of surface water samples in north-central New Hampshire and adjacent northwestern Maine (see area "EX" on fig. 1). For a group of 460 samples collected in a very lightly populated area of western Maine, the geometric mean value for arsenic was 0.45 ppb and the highest content found was 4.8 ppb (G.A. Nowlan, oral commun.). For a group of 43 water samples collected from streams in the Hampshire Hills region of north-central New Hampshire, the mean arsenic content was 0.3 ppb and the highest value measured was 0.6 ppb (G.A. Nowlan, oral commun.). These data from the Hampshire Hills survey are especially pertinent to the arsenic problem in southeastern New Hampshire in view of the belief by some investigators that the oxidation of arseniferous pyrite is possibly responsible for the excessive levels of arsenic in some of the groundwaters of southeastern New Hampshire. Many of the rock units in the Hampshire Hills region are highly pyritic and undoubtedly contain minor amounts of arsenic. Also, a reconnaissance survey of surface waters in an area in west-central Maine that contains 3 to 5 million tons of massive pyrite and is close to the New Hampshire border, yielded arsenic contents of 0.1 to 0.4 ppb with a mean of 0.2 ppb for 9 samples.

Elsewhere in New Hampshire, available data suggest that the concentration of arsenic in New Hampshire streams is low. Briggs and Ficke (1977, p. 54) estimated the mean concentration of dissolved arsenic in stream water to be below 2.0 ppb during the 1975 water year (October 1974 through September 1975). Total arsenic concentrations of 3 ppb or less were determined for 11 stream samples in Nashua (five from the Nashua River and six from the Merrimack River) taken between October 1978 and July 1980 (U.S. Geol. Survey, 1979, p. 52; 1980,

p. 52). Similar concentrations were obtained from six Merrimack River samples taken in Concord between April 1979 and July 1980 (U.S. Geol. Survey, 1979, p. 41; 1980, p. 39). We emphasize that the chemical data from surface waters cannot be compared directly with data for groundwater because streams integrate the element concentrations over a large area, whereas a well water sample may represent a point source.

Collection and analysis of water samples

At the time our investigation started in 1981, groundwater from many wells had already been sampled and analyzed, but very little data existed on its chemical composition, except for arsenic content. We believed, therefore, that some leads to the source(s) of the arsenic might be developed by analyzing a selected group of well waters for a much more inclusive suite of major and minor constituents.

Three categories of groundwater and potential groundwater (snow samples) were selected for analysis (table 1):

I. Water from fifteen drilled and dug wells where arsenic levels were unknown and elevated levels of arsenic in the aquifer could either be explained or considered unlikely (wells 1-11, G-1, G-2, and 23-24). Wells G-1 and G-2 were specifically chosen because they were wells drilled into the most sulfide-rich rocks in the region (fig. 1). The rocks of this unit are, in fact, a pyrrhotite deposit. This unit forms the substrate to bog iron exploited in colonial times.

II. Water from drilled wells with arsenic contents known to exceed 50 ppb and based on previous analytical data by New Hampshire State Laboratories, Eastern Analytical Laboratories, Bow, New Hampshire, or other commercial laboratories (wells 12-22).

III. Integrated precipitation samples from selected sites in New Hampshire and Vermont for the 1980-81 winter. All samples were analyzed in the laboratories of the U.S. Geological Survey. The concentration of arsenic in the unfiltered water samples was determined by graphite furnace atomic absorption spectrometry (GFAAS) and by inductively coupled plasma atomic emission spectrometry (ICP-AES). Because the two procedures gave very comparable results, only the GFAAS values are given in table 1. The GFAAS technique was described by Tam (1974).

The other cations were determined by ICP method to improve the detection limits; prior to analysis, the samples were concentrated by evaporation to about one-fifth of their original volume. The values given are based on the original sample. Because the concentration factors varied somewhat between samples, the detection limits shown for phosphorous vary accordingly.

The contents of F^-, Cl^-, NO_3^-, and $SO_4^=$ were determined by ion chromatography (Fishman and Pyen, 1979).

The analytical data on the 26 samples of well water and 11 samples of snow water are given in table 1. As noted in the headnote of the table, numerous elements were looked for but were not detected. For these elements, it is important to realize that their detection limits for the most part, are considerably above the normal background levels for these elements in natural waters. Thus, some elements that were not detected could possibly be present in anomalous amounts. Because of the relatively small size of the data set, we emphasize that the data must be viewed cautiously.

Results

The data we have obtained (table 1) are background data that are too few and dispersed (fig. 1) to allow any meaningful statistical analysis. Analyses of some additional elements were not determined that are now prerequisite to a comprehensive synthesis of a model to explain the arsenic anomaly. These include uranium, gold, molybdenum, selenium, and boron. We, therefore, recommend that a much expanded study be performed by specialists in water quality before any precise conclusions can be advocated.

In Group A (fig. 1), sample 3 is from a dug well in till overlying a metamorphosed calcareous sandstone/semipelite unit (which rarely is associated with mineral deposits) in which well no. 4 is drilled. Water from this bedrock is expected to be closest to regional background in arsenic content. No other determined chemical components were anomalous. Samples of Group B with elevated iron content were significantly higher in arsenic, but were not excessive (<13 ppb). The sulfidic pyrrhotite-rich bedrock substrate of these wells would presumably provide the highest natural arsenic levels. Phosphorous concentrations are negligible in these wells. Nine samples of Group C and 21 and 22 of Group E have either excessive (>50 ppb) or elevated levels (>15 ppb) of arsenic, but none of these anomalies are apparently related to phosphorous. All samples of Group D are all elevated or excessive, and all correlate with a phosphorous anomaly. The relationship between Groups C and E and Group D is curious because there is no known difference in their geologic substrates. There is some unknown, local effect indicated in Group B that is contributing phosphorous. Furthermore, this contrast suggests the complexity in explaining the occurrence of arsenic in the environment. Chloride levels above 3 ppm in groundwater away from the coastline are considered anomalous (see Hall, 1975). The elevated levels in 19 wells are significant in that they indicate that the groundwater in many areas has been altered by man's activities, but no obvious correlation between arsenic and chloride is apparent.

Among the constraints and boundary conditions outlined from the background data from this study are:

1. There is a suggestion of a correlation between arsenic and phosphorous at one locality. The three samples highest in arsenic (nos. 18-20) are also highly anomalous in phosphorous content (250-430 ppb). These samples are also closely grouped geographically. The normal background level of phosphorous in the groundwaters of this area is not well known, but is probably not over 10 ppb. An As-P correlation would suggest that these elements may be coming from the same source, but the possibility of such a conclusion is necessarily tentative until additional data on a larger group of arsenic-containing wells can be obtained.
2. If the accepted background level for chloride in pristine New Hampshire aquifers away from the coastline is 1-3 ppm for New England aquifers (see Hall, 1975), then 88 percent of the wells listed are contaminated to some degree with chloride, probably from disassociation of various chloride-containing chemicals used in road-salting activities or from chloride in household effluents. A survey of the data suggested that there is no relationship between chloride and arsenic, which suggests strongly that the process contributing high levels of chloride to the groundwaters is, for the most part, independent of the process contributing arsenic. The anomalous levels of chloride are of interest,

however, in that they indicate the ease with which many aquifers can be contaminated by activities of man.

3. Slightly anomalous amounts of sulfate (>10 ppm) are present in the waters of 8 wells. The highest content found was 28 ppm in well 22. The data suggest a relationship between chloride and sulfate, but we have no explanation for this relationship. Of greatest significance to this report is the complete lack of any apparent relationship between arsenic and sulfate, and also the relatively low levels of sulfate in all the wells. As mentioned in an earlier section, it has been suggested that the source of most of the arsenic in the wells is the breakdown of arseniferous pyrite contained in the bedrock.
4. A consideration of the sulfate content of the groundwaters studied in the investigation provides, we believe, the strongest line of evidence against arseniferous pyrite being the source of the anomalous arsenic. Oxidation of enough arseniferous pyrite to provide the high arsenic levels measured in many wells would also introduce very high levels of sulfate ion levels greatly in excess of those found (table 1). For example, assume that 100 mg of an arseniferous pyrite containing 0.1 percent arsenic was oxidized and the resulting oxidation products dissolved in 1 liter of water. Such water would contain about 100 ppb arsenic and 150 ppm sulfate ion.
5. The presence of appreciable amounts of another arsenic-bearing mineral, arsenopyrite (FeAsS), which contains 46 percent arsenic, in the bedrock of southeastern New Hampshire would, of course,

yield much greater amounts of arsenic to the groundwater upon oxidation. This mineral is quite common in certain gold districts, and contamination of groundwater with arsenic has been attributed to leaching of gold-mine dumps and mill tailings in Alaska and Nova Scotia (Grantham and Jones, 1977; and Wilson and Hawkins, 1978). However, gold deposits are not known to be present in southeastern New Hampshire, and significant amounts of arsenopyrite have not been found in the bedrock of the area.

6. Background values for copper and zinc in groundwaters in southeastern New Hampshire are probably in the range of 0.3-2 ppb for copper and 2-10 ppb for zinc, so it is obvious that many wells contain anomalous contents of these metals. There is no correlation of arsenic with either metal, however, which would be expected if the sources were Cu-Zn-As-bearing sulfide minerals; this tends to support the conclusion reached in the previous section--that the arsenic is not being derived from the breakdown of sulfide minerals in the bedrock. The anomalous copper and zinc contents may possibly be attributed to the copper and galvanized-iron components of the plumbing systems of the wells.

Discussion

Any model for the explanation of the anomalous arsenic levels must take into consideration the following conditions:

1. The geographic extent of the arsenic anomaly is unknown and is limited only on the southeast by the Atlantic coast.

2. Wells with anomalous arsenic content are randomly dispersed among several geologic domains without apparent correlation to surficial deposits, structure, lithology, or metallogenic province (see fig. 1).
3. About 10-15 percent of the wells in bedrock tested for arsenic in state, private, and municipal programs contain concentrations at levels above 50 ppb in unfiltered waters (the EPA mandatory contaminant level is 50 ppb in filtered water).
4. The wells known to have elevated levels of arsenic are generally, but not always, the deeper-drilled wells in bedrock, a number of shallow-dug wells in surficial deposits are also known to contain anomalously high levels of arsenic.
5. The geographic extent of the arsenic anomaly in southeastern New Hampshire as measured so far is approximately coincident with the highest average population density in the state, with much of the region characterized by development where septic leachate is dispersed and water supplies are exploited, sometimes in relative proximity.
6. High values for both arsenic and phosphorus are found in the waters of certain wells (well numbers 18, 19, and 20) that occur close to one other.
7. Arsenic-bearing minerals are reported from the bedrock of southeastern New Hampshire (Hitchcock, 1878, p. 68-69) but they are also widely distributed over the state (Meyers and Stewart, 1956), and their unit volume is probably greater in geologic units in the western part of the state where, to date, no widespread arsenic anomalies are reported.

This preliminary screening investigation into the arsenic levels in southeastern New Hampshire has not located the source or sources of the anomalous content of arsenic in well waters. Nevertheless, we believe that some suspected sources can be dismissed as highly improbable.

1. As discussed in the previous section, the chemical data do not support the hypothesis that the arsenic anomaly is natural and attributable to the breakdown of any mineral species such as arseniferous pyrite. We do not want to imply that no arsenic whatsoever is being derived from natural sources; however, such natural arsenic would probably not exceed 10 ppb in most groundwaters in New Hampshire. Rarely, for example, in a sulfide-bearing shear zone carrying oxygenated water, considerably higher values might be found.

2. The use of phosphate fertilizers that might contain arsenic as a trace constituent has been mentioned as a possible source. Agriculture in southeastern New Hampshire has declined rapidly since World War II, and this decline has brought diminished use of phosphate fertilizers. However, the recent influx of suburban housing in this area has resulted in a greatly increased use of phosphate lawn fertilizers and herbicides that may contain arsenic. Other possibilities include wood preservatives and stains that contain arsenic.

3. Investigations by various state, local, and federal officials have ruled out hazardous waste dumps and arsenic-containing pesticides and defoliants as sources for the high levels of arsenic in the wells, although these officials believe that there could be, in restricted areas, contributions of arsenic to the groundwater from these sources.

We believe that arsenic- and phosphate-rich detergents and possibly other commercial detergents should be considered as one possible source of the arsenic. That washing machine effluents might contaminate ground and surface waters was first suggested by Angino and others (1970), who called attention to the possible danger and pollution hazard of the arsenic content of detergents in a study done in Kansas. Angino and his colleagues analyzed several common presoaks and detergents and found arsenic contents to range from 10 to 70 ppm. They calculated that use of several of these brands in 10-gal. washers could yield wash water with arsenic contents that exceed the upper limit for arsenic in drinking water (50 ppb). While wash water is obviously not used for drinking water, its discharge into leach fields certainly offers the possibility for the contamination with arsenic of the more open aquifers. We have no information on whether such Arsenic-bearing washing-aid products were distributed or sold throughout the United States, and we want to emphasize that we have absolutely no evidence that such products were actually sold or used in New Hampshire.

4. Further, we wish to emphasize that the three above listed possible sources of arsenic enrichment in groundwater are neither mutually exclusive nor do they represent all the possible sources of arsenic in waters of this area. Changes in the geochemistry of recharge waters from disturbance of surface soils and additions of other chemicals in suburban development, or changes in the geochemistry of the aquifer by lowering the water table through ground-water withdrawal could induce changes in the equilibrium chemistry of the aquifer near the well which could affect the solubility and mobilization of naturally occurring or anthropogenic arsenic. These and other possible sources of the arsenic enrichment cannot be discounted without additional study.

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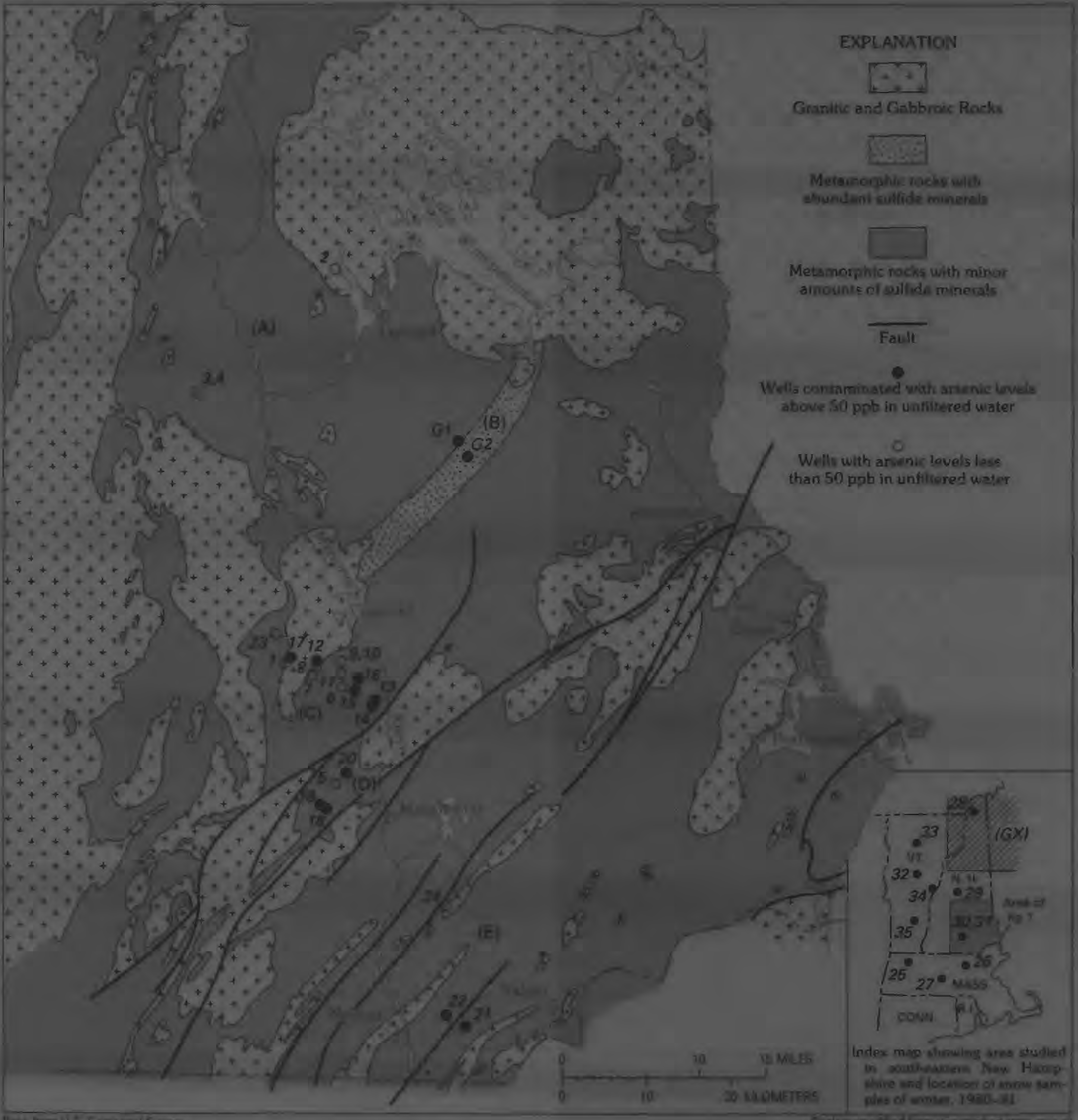

Base from U.S. Geological Survey

Geology modified from unpublished state map of New Hampshire, 1983 (J. B. Lyons, ed.)

FIGURE 1.—Generalized geologic map showing distribution of major rock types, especially those containing abundant sulfide minerals, and location of wells sampled in southeastern New Hampshire.

7½" x 8¼"
(INCL. CAPTION)

Table 1 -- Analytical data on selected well-water and snow samples

[--, either not determined, not known, or not applicable; N ( ), not detected at limit of determination shown in ( )]

Looked for but not detected:2/ Ag, Au, Be, Bi, Ce, Cd, Co, Cr, La, Mo, Nb, Ni, Pb, Sb, Sn, W

Sample	Latitude			Longitude			Dpth (ft)	yld (gpm)	Csng (ft)	pH	As (ppb)	Ca (ppm)	Fe (ppm)	Mg (ppm)
well 1	43°	9'	13"	71°	36'	38"	300	30	20	--	8.0	44	.040	7.6
well 2 1/	43	34	18	71	32	16	14	.3	--	--	1.3	5.7	.022	.68
well 3 1/	43	27	15	71	44	24	16	--	--	--	1.5	3.3	.025	.51
well 4	43	27	15	71	44	24	270	4	140	--	2.6	11	.16	8.3
well 5	43	1	16	71	32	26	85	15	15	--	41	13	2.7	5.2
well 6	43	7	45	71	32	59	285	--	--	--	4.0	--	--	--
well 7	43	8	12	71	34	45	185	5	15	--	1.8	11	.14	3.0
well 8	43	8	45	71	34	37	335	3.5	100	--	23	9.6	.22	2.7
well 9	43	9	7	71	32	23	220	2	6	--	19	8.5	1.2	2.9
well 10	43	9	7	71	32	23	23	--	--	--	4.8	13.4	6.6	1.9
well 11	43	8	11	71	32	18	200	30	50	--	3.5	9.0	.34	5.5
well G1	43	23	12	71	21	32	350	3	13	--	12	--	--	--
well G2	43	22	49	71	21	13	110	120	10	--	9.5	28	.78	8.4
well 12	43	8	48	71	34	38	320	45	80	6.58	80	11	.058	1.6
well 13	43	6	20	71	29	10	300	2	10	7.41	300	28	.21	3.2
well 14	43	6	18	71	29	12	275	35	30	7.35	190	18	.46	3.1
well 15	43	6	51	71	31	17	--	--	--	6.40	110	24	.074	3.8
well 16	43	7	26	71	31	0	130	8	10	--	100	28	.054	2.8
well 17	43	8	49	71	35	49	--	--	--	7.55	250	63	.11	6.8
well 18	42	59	31	71	33	22	405	5	23	7.40	580	5.2	N (.005)	1.3
well 19	42	59	32	71	33	24	210	12	25	6.71	340	12	.046	2.7
well 20	43	1	39	71	31	58	220	6	7	7.44	320	8.1	1.6	3.0
well 21	42	46	5	71	21	41	500	--	20	7.13	120	62	.85	2.7
well 22	42	46	42	71	22	16	168	6	5	6.20	240	7.0	.005	.28
well 23	43	10	4	71	36	53	111	30	26	7.09	2.8	60	.058	8.4
well 24	42	53	46	71	23	55	125	--	7	6.07	14	18	.036	1.1
1980-81 Snow Samples														
snow 25	42	41	2	72	56	59	--	--	--	4.65	N (1)	.23	N (.005)	.063
snow 26	42	38	24	71	39	19	--	--	--	4.42	N (1)	.31	.007	.14
snow 27	42	19	59	72	21	4	--	--	--	4.51	N (1)	.33	.016	.096
snow 28	42	2	50	71	23	0	--	--	--	4.78	N (1)	2.4	.010	.063
snow 29	43	56	51	71	42	30	--	--	--	4.49	N (1)	.33	.023	.062
snow 30	43	9	12	71	36	34	--	--	--	4.62	N (1)	.46	.007	.065
snow 31	43	9	12	71	36	33	--	--	--	4.55	N (1)	.10	.010	.076
snow 32	44	6	20	72	44	45	--	--	--	5.15	N (1)	1.4	N (.007)	.043
snow 33	44	33	55	72	34	31	--	--	--	4.54	N (1)	2.9	.038	.083
snow 34	43	54	22	72	9	23	--	--	--	4.82	N (1)	.25	.017	.033
snow 35	43	7	25	72	46	36	--	--	--	4.61	N (1)	.46	.006	.070

1/ Dug well

2/ Approximate detection limits (ppm) are as follows:

As	0.003	Cd	0.002	Mo	0.008	Sb	0.07
Au	.01	Co	.02	Nb	.002	Sn	.05
Bi	.09	Cr	.002	Ni	.01	W	.03
Ce	.01	La	.003	Pb	.04		

Sample	Cu (ppm)	Mn (ppm)	P (ppm)	Sr (ppm)	Zn (ppm)	F (ppm)	Cl (ppm)	NO_3 (ppm)	SO_4 (ppm)
well 1	.013	.036	N (.084)	.55	.008	.45	110	.2	15
well 2	.001	.001	N (.050)	.033	.005	.16	2.2	.1	3.6
well 3	.001	.003	N (.024)	.037	.012	.02	11	.9	6.4
well 4	.001	.026	N (.064)	.18	.003	.10	2.1	.2	6.3
well 5	.002	.16	N (.068)	.083	.009	.10	40	.2	6.4
well 6	--	--	--	--	--	.33	2.1	.5	10
well 7	.20	.040	N (.040)	.087	.024	.60	74	1.0	3.7
well 8	.031	.044	N (.044)	.12	.006	.17	7.0	1.8	3.6
well 9	.15	.067	.067	.044	.017	.12	6.8	.8	8.0
well 10	1.2	.050	N (.050)	.071	2.1	.04	4.9	5.5	21
well 11	.011	.19	.19	.051	.017	.60	21	.3	7.3
well G1	--	--	--	--	--	.10	3.3	.4	14
well G2	.001	.005	N (.005)	.20	.003	.10	16	.6	12
well 12	.009	.001	N (.063)	.20	.007	1.2	4.1	.9	4.1
well 13	.012	.59	.11	.12	.007	.40	14	.2	8.8
well 14	.005	.26	.074	.10	.009	.40	2.5	.2	15
well 15	.13	.005	.066	.21	.37	.40	19	1.3	5.9
well 16	.120	.002	.098	.12	.009	.12	24	11	8.9
well 17	.013	.56	N (.058)	.50	.006	1.0	75	1.4	10
well 18	.013	.007	.43	.022	.006	.20	2.6	1.6	2.9
well 19	.037	.007	.26	.045	.921	.20	22	2.0	5.6
well 20	.002	.22	.25	.047	.003	.20	3.1	.4	14
well 21	.097	2.0	N (.069)	.12	.029	.30	27	3.4	23
well 22	.035	.002	N (.061)	.013	.011	.10	55	9.4	28
well 23	.048	.002	N (.058)	.50	.013	.10	110	17	27
well 24	.003	.006	N (.069)	.18	.009	1.0	6.9	.5	10
1980-81 Snow Samples									
snow 25	.002	.001	N (.063)	.001	.014	.05	.66	1.0	1.3
snow 26	.002	.002	N (.077)	.001	.045	N (.01)	1.6	1.2	1.4
snow 27	.003	.002	N (.070)	.001	.051	N (.01)	1.0	1.7	1.6
snow 28	.003	.005	N (.058)	.002	.62	.05	1.6	.6	1.0
snow 29	.003	.002	N (.061)	.001	.048	.06	.60	1.1	.8
snow 30	.001	.001	N (.069)	.001	.025	.05	.74	.5	1.0
snow 31	.001	.001	N (.057)	.001	.013	.04	1.0	.6	.9
snow 32	.004	.004	N (.087)	.001	.052	.05	.20	.4	.3
snow 33	.002	.008	N (.085)	.002	.23	.06	.80	1.8	1.8
snow 34	.003	.003	N (.058)	.001	.005	.05	.50	1.2	1.5
snow 35	.004	.002	N (.074)	.001	.033	.01	1.1	1.5	1.3