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"BIO-ACCUMULATION OF TRACE ELEMENTS IN  
SELECTED MARINE ORGANISMS"

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## 1. SUMMARY

A. Plant, animal and unscreened sediment samples were analyzed for Ag, Cd, Co, Cu, Fe, Ni, Pb and Zn by flame atomic absorption spectrophotometry following concentrated nitric acid digestion.

B. Subtidal and intertidal samples were collected at four midcoastal Maine study areas: W. Muscongus Bay (low mineral background); St. George River (mineralized, unmined); Cape Rosier (recently mined); and Blue Hill (currently mined). Limited collections were also taken from the Damariscotta and Sheepscot Rivers both of which are presumably low metal background watersheds.

C. Goose Cove (Station CR-3), Cape Rosier, is adjacent to a recent open pit copper/zinc mine. Levels of Cd, Cu, Pb and Zn are several times to several orders of magnitude higher in Goose Cove biota and sediments than in samples from other stations. Generally, all four metals are high in Goose Cove rockweed, Irish moss, bloodworms, soft-shell clams, blue mussels and sediments. One notable exception is the bloodworm Zn content which is similar to that of bloodworms from other stations. Except for the Carleton Stream mouth (Station BH-5), sediment Zn at Goose Cove is two orders of magnitude above the mean values of other marine sample stations.

D. The Carleton Stream mouth is the first marine sample station downstream from the active, Kerramerican metal mine and has sediment Zn levels which are roughly one-tenth those at Goose Cove. As with bloodworms at Goose Cove, sandworms at Carleton Stream do not have exceptionally high Zn contents. These findings indicate good Zn regulation by these polychaetes.

In addition to Zn, Carleton Stream mouth sediments have lower levels of Ag, Cd, Cu and Pb than sediments from Goose Cove and yet, except for

Pb and perhaps Ag, these values are still high relative to overall sediment levels. These gross interstation metal relationships exist for Carleton Stream mouth sandworms and soft-shell clams but not for blue mussels.

Sediments from the Carleton Stream proper have high Cu and Pb values both above and below the active-mine outfall. Preliminary indications are that Cd and Zn and possibly Cu, Pb and Ag sediment values are elevated downstream from the mine.

Carleton Stream empties into the four mile long Salt Pond, from which we collected deep sea scallops and European oysters. These Salt Pond molluscs do not appear to contain high metal contents with the possible exceptions of the scallop Cd and the oyster Zn.

E. No one major study area has high sediment metal concentrations (and presumably high ambient concentrations) at all or even most of its sample stations. The high area means of Cape Rosier and Blue Hill primarily reflect the greatly elevated levels at only one or two stations within each area. While sediments from Goose Cove (Cape Rosier) and Carleton Stream mouth (Blue Hill) stations are generally high in metals, certain other stations have high levels of one or two metals in the surface sediments. For example, the highest Cu values in sediments and in sandworms are from the Peters Point (Blue Hill Bay) station. These and at least some of the other high-metals sample values are likely from recent or current activities of man and are highly localized. Finally, a comparison of the metals contents of unmined areas, both "unmineralized" and mineralized, suggests that sediments from the latter area, i.e., St. George River estuary, are only slightly higher than those of low mineral sample areas, e.g., W. Muscongus Bay. Thus, estuarine biota in the St. George River may be poorly adapted to high ambient

heavy metals, a factor which may be important should increased metals loading to this watershed be considered in the future.

## 2. METHODS

### A. Metal Analyses

Sample preparations and flame atomic absorption analyses were modified to follow the routine procedures used at the National Marine Water Quality Laboratory, Rhode Island, for estimates of Ag, Cd, Co, Cu, Fe, Ni, Pb and Zn. Biological samples are prepared through an extended, repetitive nitric acid digestion at 80-85°C which is followed by clarification (paper filtration) and dilution with 5% nitric acid. Sediments are similarly prepared except for the use of a single, 14-18 hour digestion. Procedural standards and spiked samples are included with each preparation batch. Deuterium background correction is used for the spectrometric estimates of all elements except Ag and Cu, which are measured at wavelengths above 300 millimicrons. Coho salmon fillet homogenates were partitioned and spiked at three levels; mean percent recoveries and ranges were: Cd 98 (95-100); Cu 100 (96-104); Pb 100 (100); and Zn 85 (80-90). A review of all biotic and sediment sample spike recoveries within one project period resulted in the following mean and coefficient of variation percent values: Ag 81 (22); Cd 86 (12); Cu 98 (12); Fe 138 (20); Pb 82 (22); and Zn 91 (9). Recovery estimates for this grouping were based on comparisons of metal levels in spiked (nonpartitioned) samples to the mean levels of respective sample groups. Factors affecting the accuracy and precision estimates were poor sample homogeneity and the low levels of spikes used, especially for Fe and Pb.

## B. Field Activities

Initial field reviews, station siting and sample collections were made at two of the four proposed major study areas, the St. George River (mineralized, unmined) and the Cape Rosier area (recently mined), see Fig. 1-5. Also, several stations have been sited in two low metal areas, the Damariscotta and the Sheepscot Rivers (Fig. 6).

Other expansions to the field phase of the project include the collections of common, noncommercial as well as commercial species and of subtidal samples from each major study area. Sediment corings (2" dia.) are taken intertidally and subtidally at key stations within each area.

## 3. RESULTS AND DISCUSSION

### A. Macroalgae

#### 1. *Fucus vesiculosus* (Rockweed)

Metals in five intertidal collections of rockweed are presented in Table I. The values are from dionized water-rinsed fronds, and are based on oven-dried weights. Especially high levels of Zn, Cu and Cd are found in rockweed from Goose Cove (Cape Rosier, Station CR-3, Fig. 4), the discharge site of a recent open pit copper-zinc mine. Goose Cove rockweed has respective metal levels which are greater than those from the other combined stations by the following factors: Zn 18, Cu 4.6, and Cd 3.1. Slightly higher Pb, lower Fe and similar Ag levels are present in Goose Cove samples relative to those from other stations.

Concentrations of Zn, Cu and Cd in brown algae are reflective of the general ambient levels of these metals at specific growth sites (Bryan, 1969; Fuge and James, 1973; Morris and Bale, 1975 and others). Rockweed from stations other than Goose Cove have Zn, Cu and Cd concentrations

which are similar to those found at low ambient metal sites. In contrast, Goose Cove rockweed concentrations, especially Zn and Cu, indicate exposure to high ambient levels of these metals (Bryan and Hummerstone, 1973; Fuge and James, 1973; and Morris and Bale, 1975).

The above authors note various precautions which should be considered in using littoral seaweeds as geographic metal contamination indicators. One variable which we have not controlled up to now is the specific portion of the plant which is analyzed. The older part of the main thallus generally has many times the metal levels of the growing tips and is the preferred rockweed portion for metal monitoring studies (Bryan and Hummerstone, 1973). Generally we used the growing tips for our estimates.

## 2. *Chondrus crispus* (Irish Moss)

Lead (Pb) levels in Goose Cove Irish moss are an order of magnitude higher than those from other stations (Table I), a situation not found in rockweed samples. Zinc is about four-fold higher and Co several-fold higher in *Chondrus* from Goose Cove versus *Chondrus* from other stations.

Orr Cove (Station CR-8, Fig. 4) samples have Cu and Cd concentrations similar to those from Goose Cove. The possible origin of these metals is, as yet, unknown although a small spring does enter the head of this cove.

## B. Marine Worms

### 1. *Nereis virens* (Sandworm)

The summary of sandworm metal levels (Table II) includes data from samples collected near the mouth of Carleton Stream (Stations BH5A-5C, Fig. 2) which receives treated wastes from an active subsurface metal mine. Goose Cove (CR-3), the discharge site from the recent Cape Rosier mine, has bloodworms but no sandworms. Also, note that the data on both species of commercial worms is from specimens which are "purged" by holding them under refrigeration

for 24 hours between seawater dampened paper toweling.

A number of the metals (Ag, Cd, Co and Ni) are consistently found in low levels in Maine *Nereis virens* (Table II). A related species, *N. diversicolor*, from sites which include drainage from former metal mines, has .01-.51 ppm(wet) Cd (Bryan and Hummerstone, 1973). We find the highest Cd concentrations in sandworms from the Carleton Stream mouth (Station BH-5) where they average  $\geq .13$  and range up to .42 ppm(wet). Bryan and Hummerstone (1973) found *N. diversicolor* to be a good Cd indicator organism, i.e., it is apparently a poor Cd regulator. This correlation is based on the high correlation between Cd levels in the worms and their surrounding sediment.

Concentrations of Cu are also roughly proportional in worms and sediments, while *N. diversicolor* Zn levels are generally independent of sediment levels (Bryan and Hummerstone, 1971). Cross et al. (1970) similarly found Zn (as well as Fe and Mn) levels in six polychaetes to be independent of sediment metal concentrations; included in that study were a sandworm, *Nereis* sp., and a bloodworm, *Glycera americana*. In accord with the above studies we find evidence for good Zn and poor Cu regulation by both *N. virens* and *G. dibranchiata*. For example, *N. virens* has an overall average of 26 ppm(wet) Zn and the individual samples range is small, 10-37 ppm Zn (Table II). Conversely, the Zn concentrations in surface sediments at these stations vary widely (Table VIII). Furthermore, a station with high sediment Zn concentrations such as 116 ppm(dry) at BH-5 (Carleton Stream mouth) has sandworm Zn levels of 26 ppm which is only one ppm above the average for the other stations.

Surface sediments have variable but generally high concentrations of

Cu at the Carleton Stream mouth (Station BH-5, Table VIII). Sandworms at that site range up to 12 ppm Cu and average 7 ppm versus 2 ppm Cu at other stations (Table II). Bryan and Hummerstone (1971) studied *N. diversicolor* populations in areas of Southwest England, some of which have been receiving Cu mining wastes for over 200 years and which have sediment Cu levels up to 3,000 ppm(dry) and sandworm Cu levels up to 180 ppm(wet). Their toxicity and acclimation experiments indicate that the adaptation to high ambient Cu is genetic and mostly involves greater tolerance to higher Cu body loads rather than superior Cu regulation by "high-copper" sandworms. Mining activity has occurred sporadically for about 100 years in the Blue Hill area and some selection for Cu tolerance may have occurred in *N. virens* and other biota at sites such as the Carleton Stream mouth.

The highly variable levels of Fe in our samples are inconsistently related to respective sediment Fe levels (Tables II and VIII). Cross et al. (1970) noted similar findings for six polychaete species; surprisingly, they used unpurged specimens. They also discuss the effects of various feeding methods on metal accumulation. *Nereis* sp. is considered to be a nonselective deposit feeder at their sampling sites and contains a relatively high percentage, 34% (dry), of sediments. Since Fe is usually the most concentrated heavy metal in sediments, some of the scatter in our data may have been from incomplete purges of gut sediments. Also, *Nereis* individuals may vary their method of feeding within a limited area depending on what food is available quantitatively and qualitatively (Bryan and Hummerstone, 1971).

## 2. *Glycera dibranchiata* (Bloodworm)

Perhaps the most striking finding with this group is the ability of bloodworms from high-Zn stations to regulate their Zn body loads. Goose Cove sediments average 1,090 ppm(dry) Zn and range up to 1,800 ppm(dry)

while bloodworms from that site have about the same (26 ppm(wet)) Zn levels as from other stations (Table III). Incidentally, the overall levels of both our sandworms and bloodworms are 26 and 27 ppm(wet) Zn, respectively. Cross et al. (1970) also found similar Zn values for *G. americana* in a North Carolina estuary.

As with *Nereis*, Cu levels in *Glycera* roughly followed those of the surface sediments (Tables III and VIII). Peters Point (BH-14, Fig. 5) and Goose Cove (CR-3, Fig. 4) have sediment Cu concentrations one to three orders of magnitude above other, low-Cu bloodworm sampling sites. Average bloodworm Cu levels for these areas are: Peters Point 10.8; Goose Cove 4.7; and low-Cu sites 3.6 ppm(wet) Cu. Note that bloodworm samples are almost as high as the Goose Cove samples even though "total Cu" sediment concentrations are considerable lower. High Zn levels, such as at Goose Cove, inhibit Cd uptake in sandworms (Bryan and Hummerstone, 1973) and although not tested as yet, may have a similar effect on Cu uptake by other polychaetes. As Bryan and Hummerstone (1971) state in one of their sandworm reports (p. 851) "...the relationship between copper in *Nereis* and in sediments is not as straightforward as a comparison of the mean values from different estuaries...". Some factors which they found to variously affect sediment-worm Cu relationships included size of worm, salinity, interstitial metal levels and sediment type.

Despite the possible Zn inhibition of Cd uptake noted above for sandworms, Cd bloodworm levels at Goose Cove are extremely high (Table III) and average about 0.9 ppm(wet) which is almost twice the upper range for Cd found in *N. diversicolor* from sediments containing about one-third higher Cd levels (Bryan and Hummerstone, 1973). A species difference is indicated in our data which may partly explain the above concentration differences, i.e., bloodworms generally appear to concentrate more Cd than sandworms. This is despite the

sandworms' tendency to less discriminately ingest greater amounts of sediment (presumably containing high amounts of Cd) than the bloodworm (Cross et al, 1970).

Feeding method differences might explain the Fe level differences between our sandworms and bloodworms in that the latter have an order of magnitude lower Fe concentrations than sandworms. One other point, as with the sandworms we note no strong sediment:worm Fe level relationship.

### C. Molluscs

#### 1. *Mya arenaria* (Soft-shell Clam)

A number of metals are generally found in low levels in the soft-shell clam, specifically Ag, Cd, Co and Ni (Table IV). Pringle et al. (1968) analyzed clams from approximately 100 polluted and unpolluted stations on the U.S. East coast and found similarly low levels. They found an average (and range) for Cd of .27 (.10-.90) ppm(wet) as compared to our .09 (<.02-.56) values. Our two possibly mining-affected stations had clam Cd levels of .38 (Goose Cove) and .20 (Carleton Stream mouth) versus  $\geq$  .06 ppm(wet) Cd for the other *Mya* stations. In 1968-9, Dow and Hurst (1972) found Goose Cove *Mya* to range up to .9 ppm Cd which is 9-fold above the value of their eight background stations. Our Goose Cove sample is about 4-fold above the 1968-9 background level.

Copper reached 58.8 ppm(wet) in Goose Cove clams as compared to a background value of 1.6 Cu (Dow and Hurst, 1972). Two years later we found 6.0 ppm Cu at Goose Cove, while Carleton Stream mouth (Station BH-5) had 5.1 ppm and the other *Mya* stations average 1.8 ppm (Table IV).

Iron concentrations varied widely both within and between sample stations but were highest in clams near a high-Fe industrial discharge (Stations MB-7 and 8, Fig. 2). Overall, our samples averaged 730 ppm Fe with the MB-7 and -8

samples and 490 ppm without them. Pringle et al. (1968) reported values of 405 (50-1710) Fe for *Mya*.

Lead is considerably lower than Fe in soft-shell clams. Pringle et al. (1968) found 0.7 (0.1-10.2) ppm Pb while we estimated overall station values of  $\geq 1.3$  ( $\geq 0.3$ -7.0). The highest levels are at Goose Cove, 7.0 (4.2-13.5), and Carleton Stream mouth, 1.6 (1.0-2.7) ppm Pb, which are 10-fold and 2-fold above our unpolluted, background average. Dow and Hurst (1972) reported a background level of 0.8 ppm Pb for the Cape Rosier-Blue Hill areas. They found a Pb concentration of 55 ppm in a December 1972, Goose Cove sample which is 8-fold above our sample of December 1974.

Zinc station means range from 9-34 ppm(wet) (Table IV) and overall average 15 ppm, which compare closely with the Pringle et al. (1968) values of 17 (9-28). Note that our Goose Cove (34 ppm) and Carleton Stream mouth clams (28 ppm) are at or above the upper range of that rather large 1968 baseline study which included polluted as well as unpolluted sample sites. Even more impressive is the 195 ppm Zn found by Dow and Hurst (1972) in a December 1972 Goose Cove sample. Their background level is 11 ppm and ours (which excludes the two "mining" stations) is 12 ppm Zn.

## 2. *Mytilus edulis* (Blue or Edible Mussel)

Goose Cove, Station CR-3, blue mussels have elevated Cd and Zn concentrations as compared to values at other stations and in the literature. Cadmium values at Goose Cove are 0.96 (.63-1.39) ppm(wet) Cd (Table V) which averages about 7 times the overall value from other stations of 0.15 ppm. Young (1973b) reports an overall average and regional-mean range of 0.6 (ND-0.8) ppm Cd for Cape Breton mussels. Segar et al. (1971) find a similar Cd level, 0.57 ppm, in Irish Sea blue mussels. Zinc values in Goose Cove blue

mussels are 37 (16-88) ppm(wet) Zn, or about 3 times the combined average for the other stations. Some of the literature mean Zn values are 10 ppm, (Brooks and Rumsby, 1965 and Segar et al., 1971) and 26 ppm(wet) (Young, 1973b).

Copper in Goose Cove mussels is not outstandingly high, 1.5 ppm Cu as compared to an overall 1.2 ppm average. Although our data is sparse, Cu concentrations do not appear to follow Zn concentrations as they do in several oyster species (Pringle et al. 1968).

Interpretation of the relative values of blue mussel Pb (lead) concentrations is difficult because of numerous measurements below good detection levels (Table V). If all samples were above detection our overall mean of  $\geq .6$  ppm Pb would probably be close to the published values of .9 (Young, 1973b), 1.0 ppm (Segar et al. 1971) and 1.3 ppm (Brooks and Rumsby, 1965). Although some of our individual sample values are high, no one station appears outstandingly so. This is also the case as regards Fe levels.

Overall, Fe in mussels averages 42 ppm and station means range from 23-64 ppm. Goose Cove mussels are moderately low in Fe, 30 ppm. Note that this sample is made up of relatively large individuals. Since smaller individuals tend to have higher metal levels (Schulz-Baldes, 1973 and Young, 1973b), the Goose Cove mussel population likely has typical levels. Also, note the metal levels in the two BH-9 samples which differ greatly in average individual size.

Many of our biological samples from the Carleton Stream mouth station have had metal concentrations between those of samples from Goose Cove and from other stations. Obviously (Table V), this does not hold true for the blue mussel.

### 3. *Placopecten magellanicus* (Deep-Sea Scallop)

Relatively little open-literature information has been found concerning the Atlantic deep-sea scallop metal studies. As compared to other

genera such as *Pecten* and *Chlamys*, whole body levels of Ag, Cd, Cu, Pb and Zn are similar or slightly lower in Maine *Placopecten magellanicus* (Table VI), (Brooks and Rumsby, 1965; Bryan, 1973).

Cadmium concentrations are higher than those of our other biological samples and overall average 2.2 ppm(wet). Scallops from Salt Pond subtidal station 11 (Fig. 5) and the Bagaduce River (north of Station CR-4, Fig. 4) range up to 7-8 ppm Cd. Many studies, however, report higher Cd means and ranges. Segar et al. (1971) and Bryan (1973) estimated 4 ppm and Topping (1973) 5-23 ppm Cd in *Pecten maximus* while *P. novae-zelandiae* has about 71 ppm Cd (Brooks and Rumsby, 1965). The latter authors find that Cd has the greatest enrichment factor of the 12 metals measured. Although some scallops such as *Chlamys opercularis* (Bryan, 1973) may typically have low Cd levels, most scallops have high selectivity for this metal.

Copper, a metal which often has large regional concentration differences in various biological samples, is unusually uniform in our *Placopecten* samples (Table VI). The scallop studies cited above report similar Cu levels, 1-3 ppm(wet), in a variety of species which suggests a fair degree of Cu regulation by most scallops.

Zinc concentrations in our samples also show little variation, 14-20 ppm(wet) Zn, between different stations. These values are comparable to those of Topping (1973) for *Pecten maximus* but 2-3 fold lower than levels published by others (Segar et al. 1971; Brooks and Rumsby, 1965; Bryan, 1973).

One preliminary generalization concerning our scallop data is that the Blue Hill area Salt Pond, which receives the Carleton Stream, does not have scallops with outstandingly high metal concentrations.

One sample of Muscongus Bay scallops was dissected into gonad, adductor muscle and visceral mass. The gonad composed 8% of the soft body mass but

had 73% of the total soft body Pb. About 87% of total soft body Cd was in the visceral mass.

#### 4. *Ostrea edulis* (European Oyster)

Only one sample of raft-cultured European oysters from the Salt Pond (near Station BH-7, Fig. 5) has been analyzed (Table VI). This December 1974 sample is from the 1973 year-class and averages but 4 g(wet) meats and 7.1 cm shell width. Coombs (1972) measured Cu and Zn in "mature" *O. edulis* plus Brooks and Rumsby (1965) measured 12 elements in *O. sinuata* of undisclosed size or age. In that metal levels in a given population generally decrease as weight increases (Young, 1973a; MacKay et al., 1975), this information is important when making sample comparisons.

Oysters have an especially high affinity for Zn, as well as lesser selectivities for Cu, Cd and certain other metals. The Salt Pond *O. edulis* Zn concentration is 1080 (650-1420) ppm(wet) as compared to 715 (395-1050) ppm for larger individuals of the same species (Coombs, 1972). The difference in Zn levels can be due to discrepancies in individual oyster weights and/or ambient Zn concentrations. In contrast to the Zn, Cu is lower in the Salt Pond oysters, 16 ppm, than in Coombs' (1972) sample, 53 ppm Cu.

Metal ratios, such as Cu/Zn, have been used as indicators of local contamination of one or several metals (Hugget et al., 1973). Pringle et al. (1968) found Cu/Zn values to range from .05-.10 for both *C. virginica* (eastern U.S.) and *C. gigas* (western U.S.). While the sample of Coombs (1972) falls in that Cu/Zn range, our Salt Pond sample of *O. edulis* has a ratio of only .015. Whether there are "unnatural inputs" of Zn in the Salt Pond or not will require more data on both oysters and water samples.

Brooks and Rumsby (1965) report relatively low levels of both Cu and Zn in *O. sinuata*. Assuming 15% body dry weight and converting their metal values

to wet weight bases, they find 6.2 ppm Cu and 165 ppm Zn or a Cu/Zn value of only .04. The .05-.10 ratio noted by Pringle et al. (1968) may be mostly typical of *Crassostrea* species. Cadmium does not appear to be elevated in Salt Pond *O. edulis* which average 0.7 ppm Cd (Table VI) and are roughly comparable to the 1.5 ppm for *O. sinuata* (Brooks and Rumsby, 1965) and the 0.5 ppm for *C. virginica* (Pringle et al., 1968).

#### D. Finfish

With the exception of a few select samples we have not been collecting finfish this project year. In contrast to molluscs, finfish do not reflect localized coastal contamination by heavy metals (Holden and Topping, 1971/72; Eustace, 1974).

With the exception of the Goose Pond coho salmon, our samples are presumably from low heavy metal background sites (Table VII). The two juvenile alewife samples are from the upper Damariscotta River estuary and the West Harbor Pond, Boothbay Harbor, and the rainbow smelt sample from Round Pond (western Muscongus Bay).

Most of the heavy metals finfish literature relates to measurements of tissues and organs rather than whole bodies. Smelt whole body contents are generally much lower than those of juvenile alewives (Table VII). Our rainbow smelt metal levels are comparable to those of deheaded, dressed smelts (Uthe and Bligh, 1971) and also whole body sardines, *Sardinia pilchardus* (Gilmarten and Revelante, 1975).

Our two samples of juvenile alewives (about 7 cm length) have Cd and Co contents similar to the contents in even smaller ( $\leq$  2 cm length) alewives (Lucas et al., 1970). However, our samples Cu values are 3 to 4 times the values of the latter, Lake Michigan alewives. Large magnitude, regional differences in Cu levels of finfish sometimes occur. Trout-perch (*Percopsis*

*omiscomaycus*) in Lake Michigan and in Lake Superior have whole body Cu levels of 2.7 and 0.8 ppm, respectively (Lucas et al., 1970).

Our fillet samples (coho salmon), as expected, have metal contents lower than the above whole body contents. These samples are from fish which are being grown in salmon pens in Goose Pond (Cape Rosier). Our Goose Cove sediment and biological sample analyses indicate that the Goose Pond salmon are in high ambient Zn and Cu waters. Nonetheless, the levels of fillet Zn and Cu in the coho salmon appear typical of those found in many other finfish (Brooks and Rumsey, 1974; Eustace, 1974, Holden and Topping, 1971/72).

#### E. Sediments

Our major project study areas are selected on the basis of the presence or absence of extensive mineralization and of metal mining. The surface (8-12 cm) sediment data which is grouped accordingly shows that the mineralized and that the mined areas are relatively high in four heavy metals, specifically Cd, Cu, Pb and Zn (Table X). Gross comparisons of sediment levels grouped according to combinations of the above conditions (Table IX) indicate that sediment Cd, Cu, Pb and Zn are high in the mineralized/recently mined (Cape Rosier) area and in the mineralized/currently mined (Blue Hill) area. However, only one or two sample stations from each of these areas are high in two or more metals (Table VIII). The Cape Rosier area has one outstanding station, Goose Cove (CR-3), and the Blue Hill area has two high-metal marine stations, Carleton Stream mouth (BH-5) and Peters Point (BH-14).

Goose Pond (Fig. 4) is the site of a recent, 1968-72, open pit copper/zinc mine. The ore deposit is mainly sphalerite and chalcopyrite with lesser amounts of galena (Beck, 1970). In preparation for mining the Goose Pond ore deposit, the tidally-affected reversing falls at the head of Goose Cove

(Station CR-3) were dammed and a 16" diameter discharge pipe laid out to near the mouth of Goose Cove. Approximately 700 t/d of 6% Zn/1% Cu ore was processed in a saltwater-fed flotation mill. As expected, the highest metal levels (other than Fe) in Goose Cove surface sediments are Zn, Cu, Pb and Cd (Table VIII).

Mining in Goose Pond was terminated in June 1972 after which the discharge pipe and part of the dam at the falls were removed. Eleven June 1972 Goose Cove sediment samples (5-70 cm depth) were analyzed by the U.S. Army Corps of Engineers. Our 1974-75 Goose Cove values compare to the 1972 values in the following manner (1972 mean/1974-75 mean): Cd 4.5/6.9; Cu 2090/480; Pb 590/160; and Zn 1,500/1,000. Unfortunately, we are unaware of any similar before-mining (<1968) data.

Data are available for three of the Blue Hill area freshwater stations (Fig. 5, Table VIII). Station BH-1 is above the active, subsurface Kerr-american mine and its silt/clay type sediments are high in Cu, Pb and Zn. The sediments at station BH-3 are coarse-grained but nonetheless have relatively high Ag, Cd, Cu, Pb and Zn in comparison to most Blue Hill sediment values. Station BH-4 has fine-grained sediments which, except for Fe, are especially high in metal content. These high values are somewhat surprising in that this station is at the outlet of the long, boggy, low-flowage First Pond in which much of the Carleton Stream metals presumably settle out.

Values at Carleton Stream mouth (BH-5) vary widely, partly because of the diverse types and conditions of that station's sediments. With one exception, station BH-5 sediments have higher metal contents than other Blue Hill marine stations. The one exception is Peters Point (BH-14) which is near the head of Blue Hill Bay and the Blue Hill settlement (Fig. 5). As

at station BH-5 there is a patchy distribution of the metals in these intertidal surface sediment samples. Some individual Peters Point samples have elevated Cu values, up to 1,730 ppm(dry). These are even higher than sediment Cu values at Goose Cove (CR-3). We may have collected some of our BH-14 sediments at a site where boats have had anti-fouling paint applied.

Sediment-infauna metals relationships are frequently among a given project's objectives in that any infauna, regardless of feeding type, will absorb some metals directly from the sediments (Bryan, 1971). Visual reviews of our available data on the metal levels of marine worms, clams and sediments at respective sample stations indicate the following positive infauna-sediment relationships: for sandworms and bloodworms, Cd and Cu; and for soft-shell clams, Cd, Cu, Pb and Zn. Similar relationships exist for *Fucus* with Cd, Cu and Zn and for *Chondrus* with Co, Cd, Cu, Pb and Zn. This type of metals data is obviously an important consideration when selecting an indicator organism for metals monitoring.

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## 5. Tables

Table I. Means and Ranges of Metals (ppm (dry)) in *Fucus vesiculosus* and *Chondrus crispus* Sample Groups.

Table II. Means and Ranges of Metals (ppm (wet)) in *Nereis virens* Sample Groups. ND = < Detection Limit; NA = Not Analyzed.

Table III. Means and Ranges of Metals (ppm (wet)) in *Glycera dibranchiata* Sample Groups.

Table IV. Means and Ranges of Metals (ppm (wet)) in *Mya arenaria* Sample Groups.

Table V. Means and Ranges of Metals (ppm (wet)) in *Mytilus edulis* Sample Groups.

Table VI. Means and Ranges of Metals (ppm (wet)) in *Placopecten magellanicus* and *Ostrea edulis* Sample Groups.

Table VII. Means and Ranges of Metals (ppm (wet)) in *Osmerus mordax*, *Alosa pseudoharengus* and *Oncorhynchus kisutch* Sample Groups.

Table VIII. Sample Station Means and Individual Sample Ranges of Sediment Metal Levels. Values in ppm(dry) except Fe in %(dry).

ND = < Detection Limit.

Table IX. Study Area Means of Sediment Metal Levels. Ranges from Mean Sample Group Values. Concentration Units as in Table VIII.

Table X. Mean Sediment Concentrations of Areas Grouped According to Mineralization and/or Mining Activities. Ranges from Mean Study Area Values. Units as in Table VIII.

| Area-Station                                 | Site type | mean dry            |                    |                    |                   |                   |                    |                |
|--|-----------|---------------------|--------------------|--------------------|-------------------|-------------------|--------------------|----------------|
| Date Collected (n)                           | Weight    | Ag                  | Cd                 | Co                 | Cu                | Fe                | Pb                 | Zn             |
| SG-4- <i>Fucus</i> sp.<br>12-4-74 (7)        | 1.61      | .47<br>.41-.52      | 1.14<br>187-1.38   | NA                 | 2.2<br>2.0-2.4    | 513<br>435-584    | 3.1<br>1.6-4.1     | 17<br>16-20    |
| CR-3- <i>Fucus</i> sp.<br>12-7-74 (8)        | 1.47      | .52<br>.45-.60      | 3.53<br>2.43-4.88  | NA                 | 18.4<br>17.0-19.6 | 392<br>238-625    | ≥ 5.0<br>< 7.5-9.8 | 463<br>396-593 |
| CR-7- <i>Fucus</i> sp.<br>12-7-74 (8)        | 1.34      | .37<br>.29-.41      | 1.20<br>1.00-1.35  | NA                 | 7.2<br>5.5-8.0    | 676<br>582-791    | ≥ 2.8<br>< 7.2-7.7 | 28<br>23-36    |
| BH-8- <i>Fucus</i> sp.<br>11-7-74 (10)       | 1.40      | .45<br>.34-.54      | 1.34<br>1.13-1.73  | NA                 | 3.2<br>2.5-5.0    | 1080<br>805-1390  | ≥ 3.1<br>< 7.3-7.2 | 36<br>24-83    |
| BH-10- <i>Fucus</i> sp.<br>11-6-74 (9)       | 1.36      | .39<br>.28-.58      | 1.13<br>.88-1.52   | NA                 | 3.4<br>2.8-3.9    | 858<br>486-1150   | ≥ 3.7<br>< 7.3-7.0 | 25<br>13-78    |
| CR-3- <i>Chondrus crispus</i><br>12-7-74 (3) | 2.17      | .77<br>.64-.92      | .46<br>.42-.50     | 4.9<br>4.0-5.5     | 29.6<br>21.2-34.1 | 1230<br>1090-1360 | 19.5<br>16.9-22.1  | 188<br>165-216 |
| CR-6- <i>C. crispus</i><br>7-17-75 (9)       | 1.55      | ≥ .69<br>< .70-1.14 | ≥ .07<br>< .26-.34 | < 2.1              | 4.4<br>2.9-5.1    | 820<br>610-1220   | ≥ 1.5<br>< 3.7-4.5 | 59<br>39-66    |
| CR-7- <i>C. crispus</i><br>12-7-74 (6)       | 1.67      | .60<br>.52-.64      | ≥ .24<br>< .29-.52 | < 2.1              | 8.6<br>7.4-9.9    | 1270<br>990-2030  | 6.2<br>4.5-7.8     | 41<br>32-51    |
| CR-8- <i>C. crispus</i><br>12-7-74 (6)       | 1.22      | ≥ .27<br>< .58-.90  | .42<br>.29-.52     | ≥ .54<br>< 2.3-3.2 | 22.6<br>10.7-38.2 | 1660<br>550-2960  | < 4.0              | 52<br>39-64    |
| BH-8- <i>C. crispus</i><br>11-7-74 (2)       | 1.76      | .71<br>.58-.84      | .28<br>.28-.29     | < 2.2              | 4.4<br>4.3-4.5    | 460<br>310-620    | < 3.9              | 36<br>35-38    |
| BH-8- <i>C. crispus</i><br>5-29-75 (6)       | 1.64      | .66<br>.54-.95      | ≥ .11<br>< .27-.35 | ≥ .40<br>< 2.2-2.4 | 6.1<br>5.1-8.4    | 620<br>390-1120   | < 3.8              | 47<br>36-60    |

TABLE 11

| Area-Station-Sample Type<br>Date Collected (n) | Wet Wt.<br>g | Dry Wt.<br>g | Ag               | Cd               | Co              | Cu                | Fe                | Ni             | Pb               | Zn          |
|--|--------------|--------------|------------------|------------------|-----------------|-------------------|-------------------|----------------|------------------|-------------|
| Sh-1-Nereis virens<br>5-2-75 (5)               | 2.21         | .41          | .07<br>.05-.09   | <.06             | NA              | 2.36<br>2.11-2.78 | 1380<br>880-2330  | NA             | 1.2<br>.8-1.6    | 26<br>23-29 |
| Dam-3-N. virens<br>5-22-75 (9)                 | .86          | .24          | ≥.10<br><.12-.17 | <.11             | NA              | 2.92<br>2.47-3.48 | 3500<br>2390-5460 | NA             | 1.7<br>1.1-3.7   | 27<br>22-32 |
| MB-1-N. virens<br>11-5-74 (10)                 | 6.65         | .86          | ≥.03<br><.01-.10 | .07<br>.04-.12   | ≥.01<br><.2-.7  | 2.30<br>1.18-5.14 | 54<br>31-110      | ≥.6<br><.2-1.4 | ≥.4<br><1.3-1.0  | 20<br>13-33 |
| MB-1-N. virens<br>5-3-75 (6)                   | 21.2         | 2.84         | <.04             | ≥.02<br><.05-.08 | NA              | .71<br>.54-.79    | 101<br>62-207     | NA             | <.4              | 10<br>7-12  |
| MB-3-N. virens<br>12-4-74 (10)                 | 1.89         | .22          | .06<br>.02-.15   | ≥.07<br><.04-.23 | ≥.1<br><1.0-.7  | 3.31<br>1.88-5.71 | 120<br>33-308     | <.8            | <2.4             | 32<br>21-53 |
| MB-6-N. virens<br>5-28-75 (1)                  | 2.26         | .27          | <.07             | <.07             | NA              | .81               | 74                | NA             | .74              | 13          |
| MB-7-N. virens<br>12-20-74 (10)                | 3.46         | .46          | NA               | ≥.06<br><.04-.11 | ≥.15<br><.3-1.0 | 3.41<br>2.57-5.33 | 109<br>69-166     | NA             | ≥1.2<br><1.0-2.5 | 23<br>16-28 |
| SG-3-N. virens<br>6-2-75 (7)                   | 1.59         | .27          | <.15             | <.15             | NA              | 1.97<br>.50-2.51  | 726<br>288-1280   | NA             | <1.5             | 29<br>25-32 |
| SG-4-N. virens<br>12-11-74 (10)                | 5.70         | .80          | ≥.06<br><.15-.09 | ≥.01<br><.06-.11 | NA              | 1.55<br>.88-2.54  | 289<br>54-724     | .4<br>.1-1.2   | <3.0             | 19<br>16-23 |
| UK-7-N. virens<br>6-27-75 (10)                 | 1.32         | .17          | <.11             | ≥.02<br><.11-.18 | NA              | 2.02<br>1.34-2.86 | 411<br>114-1360   | NA             | <1.1             | 17<br>13-22 |
| BH-5A-N. virens<br>11-6-74 (3)                 | 2.85         | .33          | .06<br>.04-.10   | .12<br>.05-.18   | <2.7            | 9.41<br>5.17-12.1 | 393<br>73-619     | <.6            | ≥1.5<br><.7-3.4  | 37<br>30-47 |
| BH-5B-N. virens<br>11-6-74 (9)                 | 3.04         | .35          | .05<br>.02-.09   | .12<br>.06-.20   | ≥.6<br><1.6-1.4 | 7.38<br>4.48-10.5 | 245<br>156-449    | ≥.1<br><.1-.2  | ≥.9<br><1.3-2.4  | 31<br>23-44 |

| Area-Station-Sample Type<br>Date Collected (n) | Wet Wt.<br>g | Dry Wt.<br>g | Ag                     | Cd                     | Co                  | Cu                | Fe             | Ni                  | Pb                     | Zn          |
|--|--------------|--------------|------------------------|------------------------|---------------------|-------------------|----------------|---------------------|------------------------|-------------|
| BH-5B- <i>Nereis virens</i><br>5-29-75 (10)    | .88          | .10          | <.14                   | $\geq .14$<br><.14-.42 | NA                  | 5.07<br>3.25-8.37 | 252<br>99-765  | NA                  | 2.2<br>1.4-4.8         | 21<br>15-27 |
| BH-5C- <i>N. virens</i><br>11-6-74 (7)         | 5.16         | .72          | $\geq .03$<br><.01-.09 | .10<br>.05-.22         | $\geq .1$<br><.4-.6 | 6.65<br>4.08-8.68 | 473<br>146-757 | $\geq .1$<br><.1-.4 | $\geq 1.3$<br><5.3-2.2 | 32<br>22-54 |
| BH-7- <i>N. virens</i><br>6-27-75 (8)          | 1.14         | .15          | <.16                   | <.16                   | NA                  | 1.86<br>1.12-2.29 | 316<br>160-403 | NA                  | $\geq .4$<br><1.6-2.9  | 20<br>15-26 |

| Area-Station-Sample Type<br>Date Collected (n) | Mean<br>Wet Wt. | Mean<br>Dry Wt. | Ag                     | Cd                     | Co   | Cu                | Fe            | Ni              | Pb                    | Zn          |
|--|-----------------|-----------------|------------------------|------------------------|------|-------------------|---------------|-----------------|-----------------------|-------------|
| Sh-1-Glyceria dibranchiata<br>5-21-75 (1)      | 3.73            | .78             | .07                    | .05                    | NA   | 3.56              | 166           | NA              | .5                    | 24          |
| MB-1-G. dibranchiata<br>6-3-75 (3)             | 1.96            | .30             | <.08                   | $\geq .04$<br><.12-.12 | NA   | 2.07<br>2.00-2.16 | 74<br>68-84   | NA              | <.8                   | 19<br>19    |
| CR-1-G. dibranchiata<br>7-17-75 (10)           | 1.75            | .28             | $\geq .11$<br><.21-.27 | $\geq .02$<br><.13-.20 | NA   | 4.38<br>4.02-4.65 | 70<br>57-84   | NA              | $\geq .2$<br><1.3-1.7 | 21<br>18-29 |
| CR-3-G. dibranchiata<br>12-7-74 (10)           | 1.72            | .25             | $\geq .08$<br><.20-.21 | .89<br>.60-1.44        | NA   | 4.67<br>3.31-7.28 | 57<br>45-93   | .85<br>.18-2.65 | <5.4                  | 26<br>18-35 |
| CR-4-G. dibranchiata<br>6-26-75 (5)            | 1.87            | .34             | $\geq .17$<br><.19-.26 | $\geq .14$<br><.17-.43 | NA   | 2.94<br>2.62-3.36 | 73<br>60-88   | NA              | $\geq .2$<br><1.7-1.8 | 31<br>27-35 |
| CR-6-G. dibranchiata<br>7-17-75 (6)            | 1.51            | .28             | $\geq .06$<br><.20-.20 | <.17                   | NA   | 3.41<br>3.20-3.99 | 82<br>67-105  | NA              | <1.7                  | 35<br>30-40 |
| CR-7-G. dibranchiata<br>12-7-74 (10)           | 2.00            | .31             | .14<br>.07-.25         | .24<br>.08-.69         | <1.9 | 3.64<br>2.86-5.67 | 65<br>56-80   | <.4             | <4.6                  | 30<br>22-39 |
| BH-10-G. dibranchiata<br>6-27-75 (4)           | 1.14            | .21             | <.21                   | $\geq .08$<br><.21-.30 | NA   | 4.35<br>3.33-5.23 | 112<br>93-124 | NA              | <2.1                  | 33<br>31-35 |
| BH-13-G. dibranchiata<br>11-25-74 (9)          | 2.82            | .48             | $\geq .08$<br><.09-.19 | .45<br>.11-1.04        | NA   | 3.77<br>2.47-7.65 | 64<br>40-125  | .89<br>.28-2.50 | <7.5                  | 27<br>18-39 |
| BH-13-G. dibranchiata<br>6-27-75 (10)          | 2.34            | .41             | <.17                   | $\geq .31$<br><.19-.44 | NA   | 3.31<br>1.86-4.24 | 61<br>51-76   | NA              | <1.7                  | 24<br>18-29 |
| BH-14-G. dibranchiata<br>6-27-75 (7)           | 1.81            | .34             | <.23                   | <.23                   | NA   | 10.8<br>8.02-15.6 | 122<br>90-194 | NA              | <2.3                  | 27<br>23-32 |

| Area-Station-Sample Type<br>Date Collected (n) | Wet Wt.<br>g      | % Dry             | Ag               | Cd               | Co                | Cu                | Fe                | Ni               | Pb              | Zn          |
|--|-------------------|-------------------|------------------|------------------|-------------------|-------------------|-------------------|------------------|-----------------|-------------|
| MB-2- <i>M. arenaria</i><br>6-28-74 (9)        | 12.7<br>9.1-18.1  | 12.4<br>10.9-13.5 | ≥.04<br><.02-.09 | .07<br>.04-.08   | ≥.07<br><.14-.23  | 2.36<br>1.82-2.67 | 94<br>56-138      | ≥.40<br><.20-.64 | 0.7<br>.06-0.9  | 16<br>13-20 |
| MB-3- <i>M. arenaria</i><br>7-8-74 (10)        | 9.6<br>7.5-14.0   | 12.3<br>10.0-15.0 | .06<br>.01-.11   | .07<br>.02-.11   | ≥.18<br><.24-.58  | 2.39<br>2.06-2.87 | 235<br>116-349    | .41<br>.28-.70   | 1.0<br>0.7-1.6  | 20<br>13-34 |
| MB-3- <i>M. arenaria</i><br>12-4-74 (10)       | 9.21<br>7.60-12.8 | 10.4<br>9.5-11.4  | .09<br>.06-.15   | ≥.05<br><.05-.11 | NA                | 1.99<br>1.44-2.48 | 223<br>122-403    | .44<br>.12-.63   | ≥.3<br><.5-.9   | 7<br>5-10   |
| MB-7- <i>M. arenaria</i><br>12-20-74 (10)      | 4.43<br>3.56-7.00 | 9.8<br>8.5-10.9   | NA               | .08<br>.03-.15   | ≥.04<br><.28-.44  | 1.93<br>1.42-2.45 | 1390<br>803-3860  | NA               | 1.3<br>.7-2.4   | 13<br>10-2. |
| MB-8- <i>M. arenaria</i><br>12-20-74 (10)      | 15.2<br>9.1-19.4  | 10.9<br>9.0-11.8  | NA               | .03<br>.02-.04   | .21<br>.16-.32    | 1.95<br>1.38-2.35 | 1710<br>1220-2630 | NA               | 1.0<br>.7-1.6   | 10<br>7-14  |
| MB-8- <i>M. arenaria</i><br>3-25-74 (10)       | 3.47<br>3.01-3.96 | 13.3<br>11.5-14.2 | NA               | .19<br>.11-.30   | ≥.76<br><.66-1.16 | 2.88<br>2.13-3.34 | 1610<br>1070-2600 | NA               | 1.9<br>1.3-3.0  | 21<br>14-48 |
| SG-1- <i>M. arenaria</i><br>11-20-74 (10)      | 5.84<br>4.00-7.82 | 9.8<br>8.9-10.5   | NA               | ≥.02<br><.03-.08 | .74<br>.13-1.38   | 1.60<br>1.25-1.98 | 1200<br>1050-1760 | NA               | ≥.9<br><1.1-1.3 | 11<br>9-15  |
| SG-4- <i>M. arenaria</i><br>12-11-74 (10)      | 14.3<br>9.1-21.9  | 12.1<br>7.8-13.7  | NA               | ≥.02<br><.02-.05 | .31<br>.18-.55    | 1.59<br>1.32-1.93 | 601<br>357-1350   | NA               | .4<br>.2-1.0    | 9<br>7-11   |
| CR-3- <i>M. arenaria</i><br>12-7-74 (9)        | 9.6<br>6.9-13.8   | 12.8<br>10.8-14.7 | .09<br>.06-.11   | .38<br>.23-.56   | ≥.28<br><.18-.50  | 6.03<br>3.60-8.95 | 736<br>403-1136   | ≥.01<br><.04-.09 | 7.0<br>4.2-13.5 | 28<br>21-46 |
| CR-8- <i>M. arenaria</i><br>12-7-74 (10)       | 6.15<br>4.13-7.69 | 13.4<br>12.0-15.3 | NA               | ≥.03<br><.03-.07 | .71<br>.40-1.21   | 1.55<br>1.10-1.98 | 968<br>292-959    | NA               | .9<br>.6-1.2    | 12<br>10-16 |
| BH-5- <i>M. arenaria</i><br>6-6-74 (9)         | 10.1<br>8.4-11.9  | 11.2<br>9.2-13.4  | .04<br>.02-.07   | .20<br>.13-.26   | ≥.21<br><.21-.72  | 5.11<br>3.72-6.98 | 288<br>126-675    | ≥.17<br><.27-.48 | 1.6<br>1.0-2.7  | 34<br>23-50 |
| BH-6- <i>M. arenaria</i><br>6-6-74 (10)        | 8.8<br>4.7-12.6   | 8.5<br>7.2-10.3   | .05<br>.02-.09   | .08<br>.04-.16   | ≥.11<br><.25-.77  | 2.54<br>1.70-3.38 | 288<br>182-510    | ≥.21<br><.24-.94 | ≥.7<br><1.0-1.2 | 16<br>11-22 |

| Area-Station-Sample Type<br>Date Collected (n) | Wet Wt.<br>g     | % Dry            | Ag | Cd             | Co                     | Cu               | Fe             | Ni             | Pb           | Zn         |
|--|------------------|------------------|----|----------------|------------------------|------------------|----------------|----------------|--------------|------------|
| BH-10-M. <i>arenaria</i><br>11-6-74 (9)        | 11.7<br>7.2-19.8 | 11.6<br>9.4-12.7 | NA | .07<br>.05-.09 | $\geq .04$<br><.11-.25 | 1.29<br>.97-1.47 | 165<br>104-270 | .48<br>.25-.69 | .5<br>.2-.7  | 11<br>9-15 |
| BH-13-M. <i>arenaria</i><br>11-25-74 (10)      | 11.0<br>8.4-13.1 | 10.7<br>9.2-14.1 | NA | .04<br>.02-.05 | $\geq .15$<br><.15-.27 | 1.06<br>.78-1.41 | 521<br>316-924 | NA             | .6<br>.4-1.0 | 9<br>7-10  |

| Area-Station-Sample Type<br>Date Collected (n) | Wet Wt.<br>g | Dry Wt.<br>g | Ag               | Cd               | Co               | Cu                | Fe          | Pb               | Zn          |
|--|--------------|--------------|------------------|------------------|------------------|-------------------|-------------|------------------|-------------|
| MB-3- <i>Mytilus edulis</i><br>12-4-74 (10)    | 3.7          | .52          | NA               | .08<br>.04-.16   | ≥.06<br><.36-.62 | 1.08<br>.81-1.41  | 63<br>38-96 | ≥.9<br><1.0-1.7  | 14<br>9-19  |
| SG-4- <i>M. edulis</i><br>12-11-74 (9)         | 12.1         | 1.98         | .05<br>.03-.06   | .17<br>.10-.23   | NA               | 1.12<br>.79-1.71  | 43<br>17-55 | ≥.4<br><.5-.8    | 11<br>8-19  |
| CR-3A- <i>M. edulis</i><br>12-7-74 (10)        | 14.1         | 1.91         | ≥.06<br><.10-.14 | .96<br>.63-1.39  | NA               | 1.52<br>.79-3.00  | 30<br>15-68 | 1.4<br>.6-2.1    | 37<br>16-88 |
| CR-5- <i>M. edulis</i><br>5-29-75 (10)         | 4.7          | .43          | <.13             | .15<br>.08-.28   | <.51             | 1.69<br>.95-4.36  | 44<br>28-77 | ≥.2<br><.9-1.9   | 18<br>10-29 |
| BH-5- <i>M. edulis</i><br>5-29-75 (10)         | 6.5          | .60          | ≥.02<br><.10-.16 | >.09<br><.13-.37 | NA               | 1.36<br>1.03-1.64 | 55<br>39-77 | ≥.2<br><1.0-2.1  | 13<br>10-16 |
| BH-8- <i>M. edulis</i><br>5-29-75 (10)         | 14.9         | 1.65         | ≥.02<br><.05-.08 | .18<br>.11-.30   | ≥.05<br><.18-.33 | .93<br>.60-1.74   | 23<br>14-33 | ≥.2<br><.3-.7    | 11<br>8-16  |
| BH-9- <i>M. edulis</i><br>11-7-74 (10)         | 15.6         | 1.68         | ≥.03<br><.04-.09 | .14<br>.09-.22   | ≥.02<br><.17-.21 | .89<br>.45-1.27   | 29<br>18-45 | ≥.3<br><.3-.9    | 9<br>5-14   |
| BH-9- <i>M. edulis</i><br>6-17-75 (9)          | 5.4          | .64          | <.16             | ≥.06<br><.16-.24 | NA               | 1.06<br>.79-1.43  | 64<br>44-98 | ≥1.5<br><1.7-4.7 | 13<br>8-23  |
| BH-13- <i>M. edulis</i><br>11-25-74 (9)        | 8.9          | 1.33         | NA               | .23<br>.16-.37   | ≥.15<br><.20-.37 | .96<br>.72-1.36   | 47<br>31-63 | .8<br>.5-1.1     | 14<br>8-19  |
| BH-15- <i>M. edulis</i><br>11-7-74 (10)        | 6.0          | 1.13         | <.06             | ≥.22<br><.34-.34 | NA               | 1.46<br>.81-2.50  | 23<br>18-30 | ≥.6<br><.6-3.0   | 12<br>6-27  |

| Area-Station-Sample Type<br>Date Collected (n)               | Mean<br>Wet Wt. | Mean<br>Dry Wt. | Ag               | Cd                | Cu                | Fe             | Pb                  | Zn               |
|--|-----------------|-----------------|------------------|-------------------|-------------------|----------------|---------------------|------------------|
| MB-Subtidal 3- <i>Placopecten magellanicus</i> -12-10-74 (5) | 73.6            | 14.1            | .06<br>.04-.06   | 1.97<br>1.19-3.06 | .74<br>.66-.84    | 80<br>58-100   | .32<br>.14-.81      | 12<br>10-13      |
| MB-Subtidal 3- <i>P. magellanicus</i><br>12-10-74 (5)        | 11.6            | 2.2             | ≥.06<br><.24-.11 | 1.18<br>.95-1.40  | 1.62<br>.70-4.91  | 102<br>66-170  | ≥.74<br><.71-2.38   | 16<br>15-17      |
| Bagaduce River- <i>P. magellanicus</i><br>11-7-74 (9)        | 37.9            | 7.6             | .15<br>.11-.18   | 2.92<br>2.07-7.12 | 1.15<br>.91-1.32  | 104<br>46-212  | ≥.12<br><.18-.30    | 17<br>16-22      |
| MB-1- <i>P. magellanicus</i><br>12-6-74 (1)                  | 82.8            | 15.4            | .01              | 2.08              | 1.14              | 63             | .24                 | 16               |
| BH-11- <i>P. magellanicus</i><br>12-6-74 (5)                 | 44.3            | 7.0             | .07<br>.06-.08   | 3.48<br>.99-8.43  | 1.23<br>1.12-1.34 | 90<br>57-164   | .44<br>.29-.78      | 20<br>12-41      |
| BH-111- <i>P. magellanicus</i><br>12-6-74 (5)                | 92.2            | 19.3            | .06<br>.05-.08   | 1.79<br>1.23-2.37 | .77<br>.56-.95    | 31<br>20-41    | ≥.10<br><.12-.17    | 12<br>9-15       |
| BH-111- <i>P. magellanicus</i><br>12-6-74 (5)                | 24.7            | 5.1             | .07<br>.07-.09   | 1.52<br>1.32-1.76 | .96<br>.81-1.13   | 50<br>37-62    | ≥.15<br><.35-.41    | 15<br>13-17      |
| MB-Subtidal- <i>P. magellanicus</i><br>12-10-74<br>Gonad (3) | 6.9             | .92             | <.12             | .42<br>.28-.61    | .91<br>.81-1.04   | 155<br>52-302  | ≥1.31<br><1.24-2.03 | 21<br>14-23      |
| Muscle (3)   | 40.3            | 8.1             | .05<br>.04-.06   | .35<br>.18-.62    | .28<br>.22-.34    | 11<br>5-20     | ≥.29<br><.37-.56    | 12<br>11-13      |
| Viscera (3)  | 36.2            | 5.4             | .07<br>.06-.07   | 5.08<br>4.04-6.11 | 1.34<br>1.23-1.34 | 134<br>133-134 | .28<br>.24-.32      | 14<br>11-18      |
| BH-7- <i>Ostrea edulis</i><br>11-25-74 (11)                  | 4.05            | .81             | .20<br>.09-.41   | .69<br>.53-.83    | 15.8<br>11.8-20.7 | 74<br>49-137   | <1.2-<2.2           | 1080<br>650-1420 |

TABLE VII

| Area-Station-Sample Type<br>Date Collected (n)   | Wet Wt.<br>g      | Dry Wt.<br>%      | Ag             | Cd             | Co               | Cu                | Fe          | Ni                | Pb               | Zn          |
|--|-------------------|-------------------|----------------|----------------|------------------|-------------------|-------------|-------------------|------------------|-------------|
| MB-5- <i>Osmerus mordax</i><br>5-16-74 (8)   | 19.4<br>12.3-28.1 | 21.7<br>20.9-23.6 | .10<br>.06-.13 | .01<br>.01-.02 | <.09-<.29        | .72<br>.59-.85    | 10<br>8-11  | ≥.005<br><.02-.02 | 0.9<br>0.5-1.3   | 43<br>16-97 |
| Dam-0- <i>Alosa pseudo-</i><br><i>harenus</i> 10-22-74 (10)                              | 2.22<br>2.04-2.49 | 20.6<br>19.4-21.9 | .17<br>.11-.24 | .12<br>.02-.22 | <1.0-<1.2        | 3.88<br>3.34-4.52 | 35<br>32-48 | ≥.18<br><1.2-1.8  | ≥1.4<br><2.7-3.4 | 50<br>37-58 |
| BBH-0-A. <i>pseduoharengus</i><br>11-4-74 (10)   | 5.13<br>3.73-7.38 | 20.8<br>19.3-22.9 | .12<br>.08-.18 | .11<br>.06-.15 | ≥.11<br><.34-.62 | 2.30<br>1.87-2.86 | 22<br>19-25 | ≥.45<br><.41-.95  | 1.9<br>1.7-2.1   | 3<br>29-4   |
| CR-Goose Pond- <i>Onch-</i><br><i>rhynchus kisutch</i><br>10-75 (6)<br>(Skin-on fillets) | 45.3<br>26.2-71.5 | NA                | NA             | <.04           | NA               | .67<br>.64-.88    | NA          | NA                | <.7              | 8<br>5-10   |

TABLE VIII

| Site Groups (n) | Ag                 | Cd              | Cu                | Fe                | Pb                | Zn               |
|-----------------|--------------------|-----------------|-------------------|-------------------|-------------------|------------------|
| Sh-1 (2)        | >.20<br><.43-.62   | ND              | 10.3<br>6.4-14.8  | 1.88<br>1.18-2.56 | 15.6<br>9.1-20.3  | 44<br>26-61      |
| Dam-1           | .83<br>.55-1.65    | ND              | 12.1<br>8.6-17.7  | 2.01<br>1.59-2.78 | 17.2<br>12.9-28.2 | 45<br>36-65      |
| -2              | ND                 | ND              | 6.1<br>5.1-10.0   | .96<br>.88-.97    | 7.3<br>3.8-8.7    | 23<br>17-36      |
| -3 (3)          | >.30<br><.4-.60    | ND              | 10.7<br>8.8-13.2  | 2.13<br>1.74-2.58 | 12.0<br>5.0-22.7  | 41<br>31-56      |
| MB-1 (3)        | ND                 | ND              | 10.6<br>5.8-18.6  | 1.68<br>1.21-2.35 | 14.8<br>9.0-25.2  | 50<br>30-84      |
| -3 (2)          | .65<br>.05-1.14    | ND              | 7.9<br>4.2-12.4   | 1.68<br>1.04-2.60 | 11.3<br>6.1-15.5  | 39<br>26-58      |
| -6 (3)          | ND                 | ND              | 6.2<br>1.8-13.5   | 1.01<br>.54-1.63  | >6.6<br><7.2-68.2 | 32<br>13-54      |
| -7              | >.37<br><.46-.98   | ND              | 18.2<br>16.7-22.5 | 2.89<br>2.50-3.47 | 20.5<br>18.3-24.5 | 61<br>54-70      |
| -8              | ND                 | ND              | 2.6<br>2.1-3.8    | .40<br>.34-.47    | >2.1<br><.7-3.6   | 14<br>7-32       |
| SG-HT           | ND                 | ND              | 17.7<br>13.9-20.1 | 1.95<br>1.21-2.27 | 31.7<br>26.1-34.3 | 80<br>61-93      |
| -1 (4)          | ND                 | ND              | 10.8<br>4.85-19.3 | 2.10<br>1.25-2.99 | 17.1<br>8.9-30.0  | 42<br>19-82      |
| -2 (2)          | ND                 | ND              | 10.8<br>8.3-14.7  | 1.92<br>1.43-2.39 | 10.9<br>9.3-14.5  | 32<br>18-52      |
| -3 (2)          | >.06<br><.39-.50   | ND              | 9.8<br>5.4-12.5   | 2.08<br>1.75-2.70 | 11.2<br>4.6-20.0  | 53<br>22-68      |
| -4 (3)          | >1.21<br><.90-3.40 | ND              | 15.4<br>6.4-32.   | 2.33<br>1.11-4.54 | 43.9<br>10.9-125. | 43<br>20-88      |
| CR-3 (3)        | 1.49<br>.97-3.46   | 6.9<br>1.2-11.9 | 478.<br>90-811    | 2.03<br>.87-2.06  | 156<br>78-208     | 1090<br>290-1800 |
| -4 (2)          | ND                 | ND              | 13.6<br>11.8-16.9 | .96<br>.71-1.27   | 22.1<br>13.6-33.3 | 88<br>68-129     |
| -5 (2)          | ND                 | ND              | 8.0<br>5.3-10.2   | 1.97<br>.80-1.91  | 7.2<br>4.1-9.1    | 39<br>33-54      |

| Sample Groups (n)  | Ag                | Cd               | Cu                 | Fe                | Pb                 | Zn             |
|--------------------|-------------------|------------------|--------------------|-------------------|--------------------|----------------|
| CR-6 (2)           | >.55<br><.83-1.47 | ND               | 16.5<br>7.14-26.6  | 1.69<br>.88-2.44  | 22.0<br>8.9-37.0   | 30             |
| -7 (2)             | ND                | ND               | 13.5<br>8.98-18.13 | 2.10<br>1.19-3.12 | 15.4<br>10.7-22.3  | 45<br>36-58    |
| -8                 | >.20<br><.4-.98   | ND               | 4.7<br>2.1-7.8     | .94<br>.37-1.57   | >8.7<br><8.4-18.5  | 35<br>17-51    |
| BH-1 (Fresh-water) | ND                | ND               | 200<br>166-272     | 1.53<br>1.13-1.93 | 39.1<br>32.1-58.8  | 62<br>56-70    |
| -3 (Fresh-water)   | >.14<br><.4-.49   | >.85<br><.7-2.4  | 23<br>6-43         | 1.17<br>.84-1.50  | 15.9<br>4.7-26.5   | 203<br>20-420  |
| -4 (Fresh-water)   | .54<br>.49-.62    | 4.3<br>3.0-5.0   | 460<br>440-500     | 1.15<br>.98-1.24  | 65.0<br>63.7-66.5  | 560<br>530-600 |
| -5 (5)             | >.26<br><.4-.50   | >.38<br><.5-1.3  | 51<br>12-104       | 2.61<br>.60-4.73  | 15.8<br>4.8-29.4   | 116<br>32-222  |
| -6                 | ND                | ND               | 10.0<br>7.5-14.4   | 1.22<br>1.00-1.41 | 9.3<br>7.2-10.0    | 36<br>34-37    |
| -7                 | ND                | ND               | 5.2<br>4.6-5.8     | .78<br>.59-1.16   | 9.2<br>8.3-11.5    | 19             |
| -8 (5)             | ND                | ND               | 9.3<br>4.4-20.7    | 1.14<br>.29-1.66  | >11.7<br><9.2-42.0 | 29<br>10-41    |
| -9                 | ND                | ND               | 14.5<br>11.7-20.5  | 1.64<br>1.28-1.79 | 19.2<br>16.1-22.5  | 44<br>36-50    |
| -10 (2)            | ND                | ND               | 15.7<br>7.8-28.4   | 1.18<br>.46-1.57  | >7.5<br><9.0-18.5  | 38<br>25-45    |
| -13                | ND                | ND               | 4.5<br>3.7-5.6     | 1.07<br>.95-1.35  | 4.2<br>3.8-4.5     | 18<br>16-19    |
| -14 (3)            | >.47<br><.8-1.50  | >.11<br><.7-1.26 | 588<br>56-1730     | 1.03<br>.43-1.88  | 15.7<br>7.7-40.0   | 55<br>18-150   |

TABLE IX

|                    | Stations<br>Represented   | Sample<br>Groups (n) | Ag                         | Cd                          | Cu                   | Fe                    | Pb                          | Zn                      |
|--------------------|---------------------------|----------------------|----------------------------|-----------------------------|----------------------|-----------------------|-----------------------------|-------------------------|
| Sheepscot River    | 1                         | 2                    | $\frac{\geq .2}{< .1-.3}$  | ND                          | $\frac{10}{7-14}$    | $\frac{1.9}{1.4-2.4}$ | $\frac{16}{12-19}$          | $\frac{44}{32-55}$      |
| Damariscotta River | 1-3                       | 4                    | $\frac{\geq .4}{< .4-.8}$  | ND                          | $\frac{10}{6-12}$    | $\frac{1.7}{1.0-2.1}$ | $\frac{12}{7-17}$           | $\frac{37}{2 \quad 45}$ |
| West Muscongus Bay | 1,3,6-8                   | 10                   | $\frac{\geq .2}{< .3-.6}$  | ND                          | $\frac{9}{3-18}$     | $\frac{1.5}{.4-2.9}$  | $\frac{\geq 11}{2-20}$      | $\frac{39}{14-61}$      |
| St. George River   | HT, 1-4                   | 12                   | $\frac{\geq .2}{< .1-1.2}$ | ND                          | $\frac{13}{10-18}$   | $\frac{2.1}{1.0-2.3}$ | $\frac{23}{11-44}$          | $\frac{50}{32-80}$      |
| Cape Rosier        | 3-8                       | 14                   | $\frac{\geq .4}{< .4-1.5}$ | $\frac{\geq 1.2}{< .6-6.9}$ | $\frac{89}{5-478}$   | $\frac{1.6}{.9-2.1}$  | $\frac{\geq 38}{< 8-156}$   | $\frac{2}{35-10}$       |
| Blue Hill          | 1,3-10,13-14<br>(FW & SW) | 23                   | $\frac{\geq .1}{< .4-.5}$  | $\frac{\geq .5}{< .5-4.3}$  | $\frac{125}{4-588}$  | $\frac{1.7}{.8-2.6}$  | $\frac{\geq 19}{\geq 8-65}$ | $\frac{108}{18-56}$     |
|                    | 1,3-4 (FW)                | 4                    | $\frac{\geq .2}{< .4-.5}$  | $\frac{1.7}{< .6-4.3}$      | $\frac{228}{23-460}$ | $\frac{1.3}{1.2-1.5}$ | $\frac{40}{16-65}$          | $\frac{275}{62-56}$     |
|                    | 5-10,13-14 (SW)           | 19                   | $\frac{\geq .1}{< .4-.5}$  | $\frac{\geq .1}{< .5-.4}$   | $\frac{87}{4-588}$   | $\frac{1.8}{.8-2.6}$  | $\frac{\geq 12}{\geq 8-19}$ | $\frac{111}{18-111}$    |

TABLE X

Relative Mineralization

|                         | Ag      | Cd       | Cu     | Fe      | Pb      | Zn     |
|-------------------------|---------|----------|--------|---------|---------|--------|
| <u>Metal Background</u> | >.3     | ND       | 10     | 1.7     | >13     | 40     |
| <u>As: Sh, Dam, MB</u>  | >.2->.4 | ND       | 9-10   | 1.5-1.9 | >11-16  | 37-44  |
| <u>Metal Background</u> | >.2     | >.6      | 76     | 1.8     | >27     | 128    |
| <u>As: SG, CR, BH</u>   | >.1->.4 | <.5->1.2 | 13-125 | 1.6-2.1 | >19->38 | 50-225 |

Unmined Versus Mined Major Areas

|                       |         |          |        |         |         |         |
|-----------------------|---------|----------|--------|---------|---------|---------|
| <u>Unmined Areas:</u> | >.2     | ND       | 10     | 1.8     | 16      | 42      |
| <u>Dam, MB, SG</u>    | >.2->.4 | ND       | 9-13   | 1.5-2.1 | >11-23  | 37-50   |
| <u>Mined Areas:</u>   | >.2     | >.8      | 107    | 1.6     | 28      | 166     |
| <u>BH</u>             | >.1->.4 | >.5->1.2 | 89-125 | 1.6-1.7 | >19->38 | 108-225 |



Fig. 2 Muscongus Bay Area  
Sample Stations

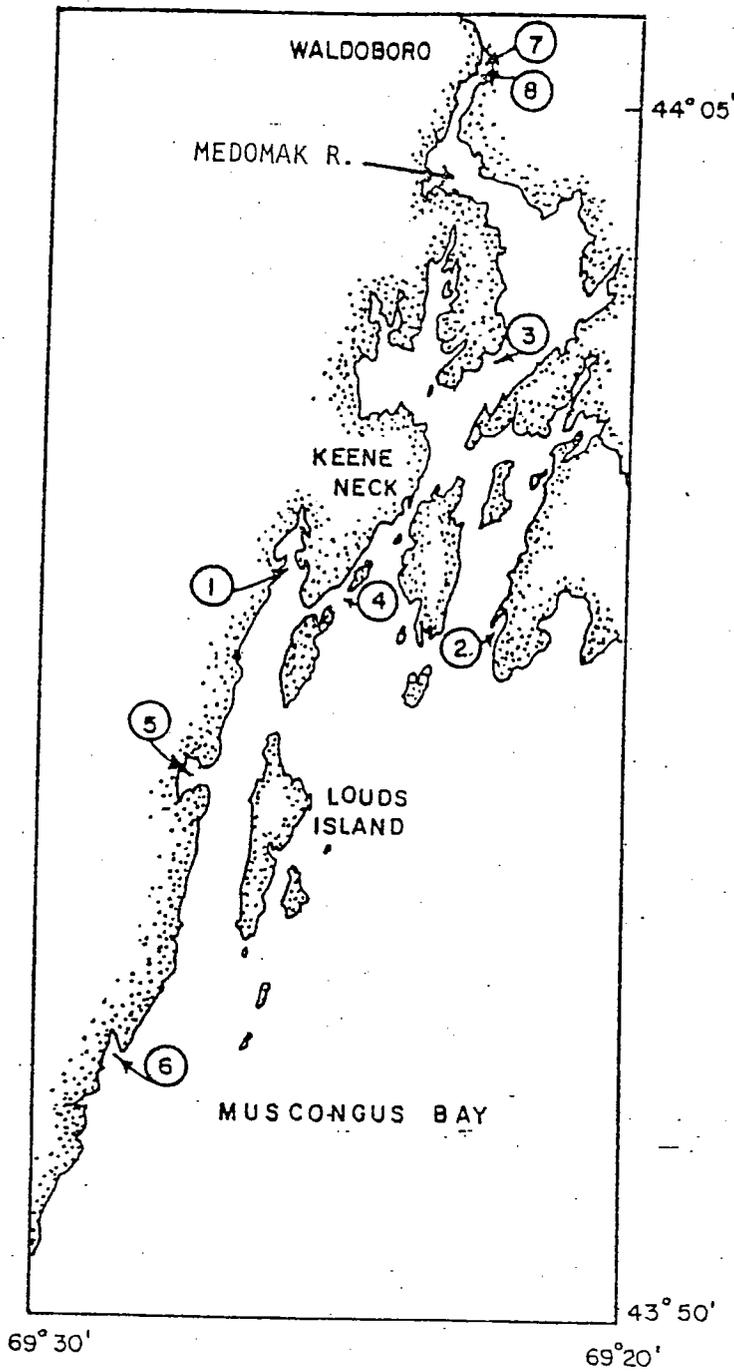
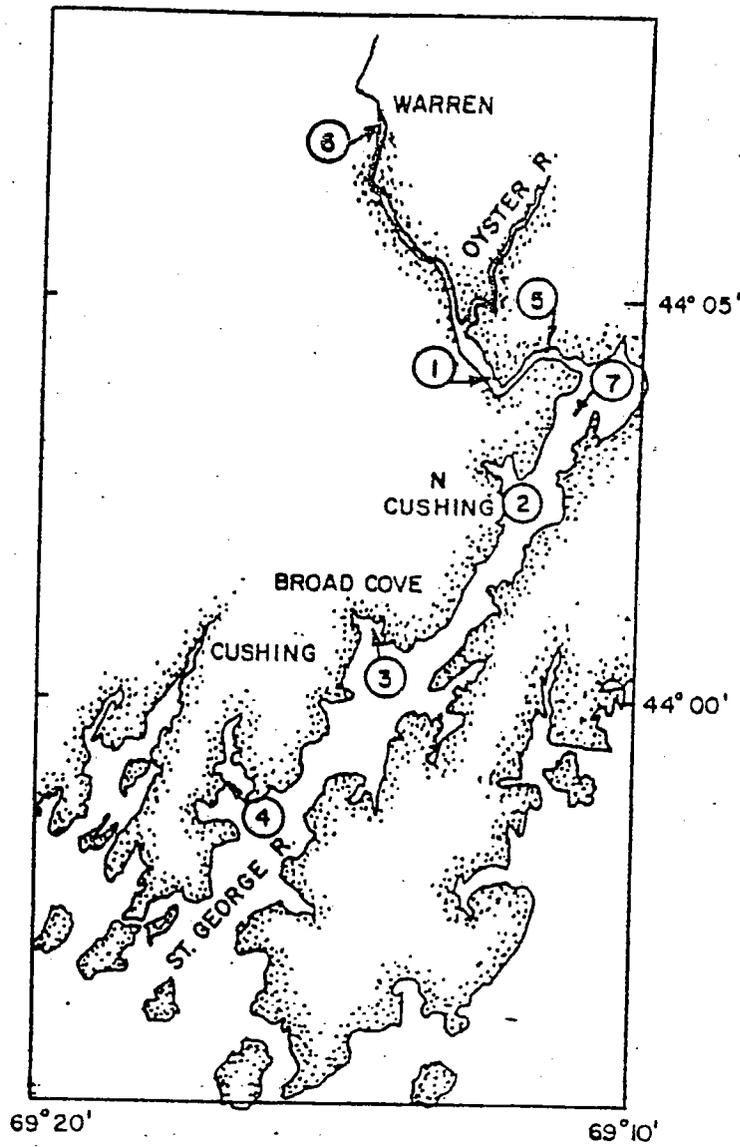


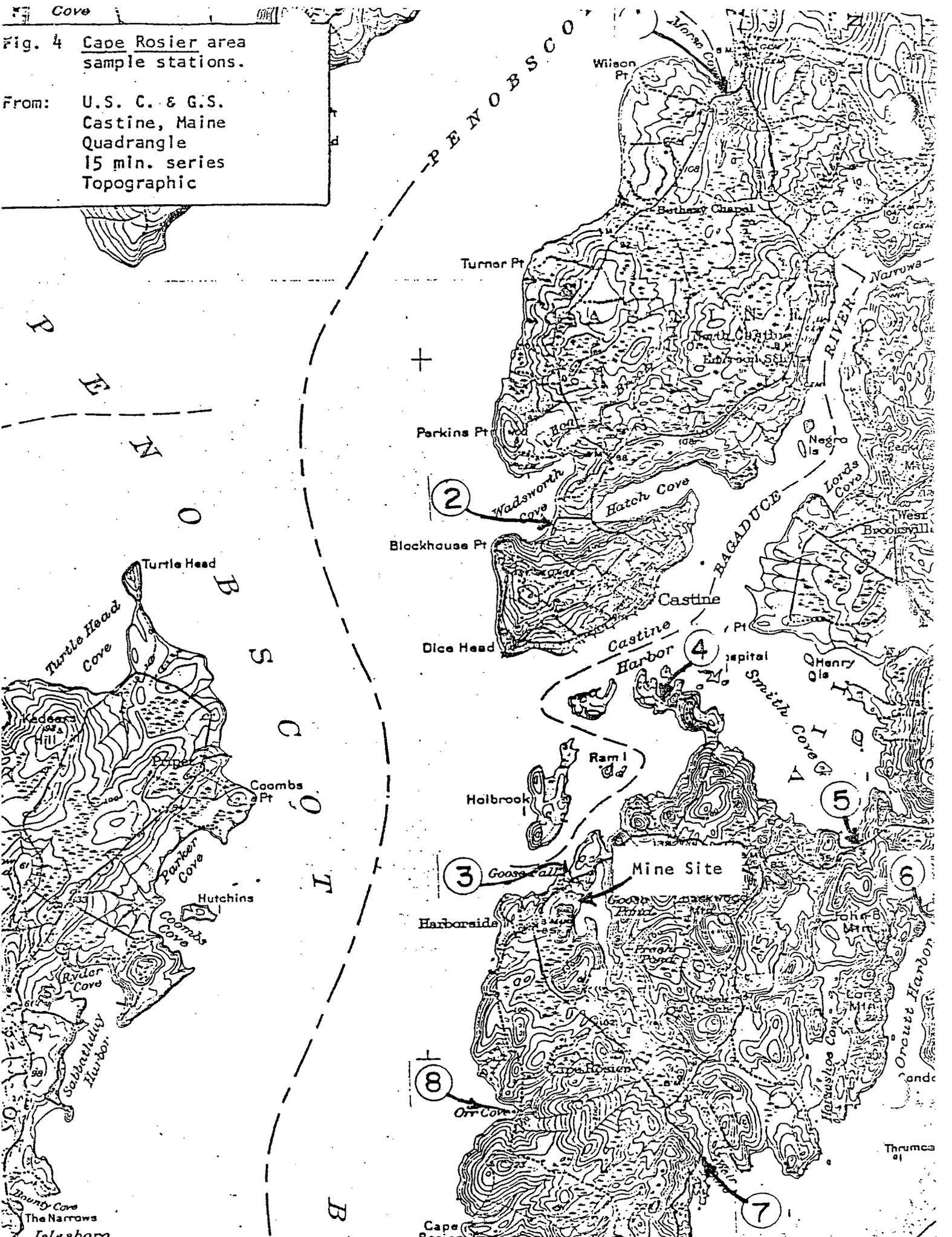
Fig. 3 St. George River Area  
Sample Stations



77 Cove

Fig. 4 Cape Rosier area sample stations.

From: U.S. C. & G.S. Castine, Maine Quadrangle 15 min. series Topographic





Mine Site

5 Blue Hill area sample stations.

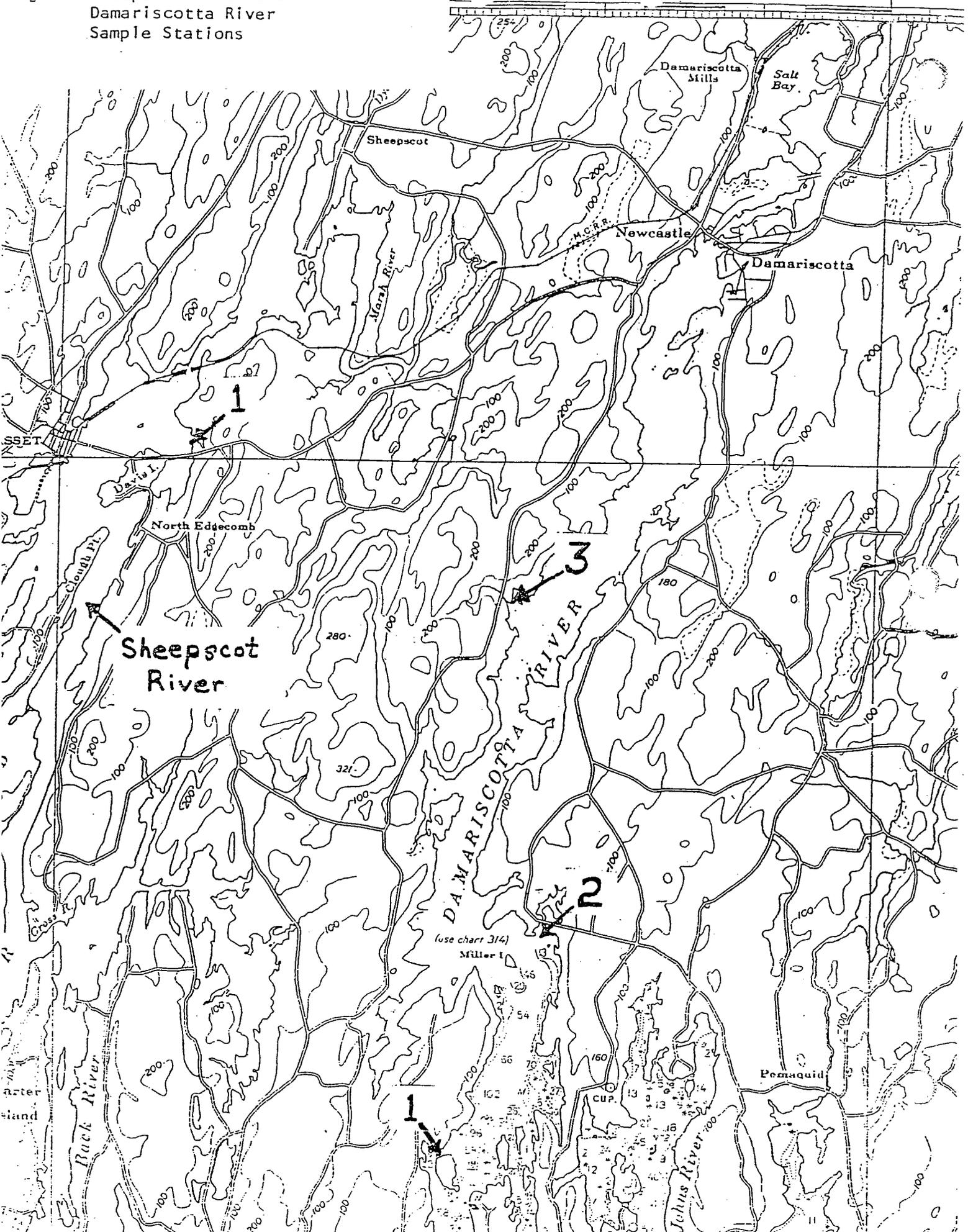
om: U.S. C. & G.S.  
 Blue Hill, Maine  
 Quadrangle  
 15 min. series  
 Topographic

R O O K L I N

ONT

Fig. 6 Sheepscot River and Damariscotta River Sample Stations

69°30'



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DANA'S MANUAL OF  
**MINERALOGY**

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18TH EDITION

CORNELIUS S. HURLBUT, JR.

Professor of Mineralogy  
Harvard University

Reference 32

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**Name.** The name diamond is a corruption of the Greek word *adamas*, meaning *invincible*.

### GRAPHITE—C

**Crystallography.** Hexagonal;  $6/m2/m2/m$ . In tabular crystals of hexagonal outline with prominent basal plane. Distinct faces of other forms very rare. Triangular markings on the base are the result of gliding along an undetermined second-order pyramid. Usually in foliated or scaly masses, but may be radiated or granular.

$C6_3/mmc$ .  $a = 2.46$ ,  $c = 6.74 \text{ \AA}$ .  $Z = 4$ .  $a:c = 1:2.740$ .  $d's: 3.36(10)$ ,  $2.03(5)$ ,  $1.675(8)$ ,  $1.232(3)$ ,  $1.158(5)$ .

**Physical Properties.** *Cleavage.* {0001} perfect. H 1–2 (readily marks paper and soils the fingers). G 2.23. *Luster* metallic, sometimes dull earthy. *Color* and *streak*, black. *Greasy* feel. *Folia* flexible but not elastic.

**Composition.** Carbon. Some graphite impure with iron oxide, clay, or other minerals.

**Diagnostic Features.** Graphite is recognized by its color, foliated nature, and greasy feel. Distinguished from molybdenite by its black color (molybdenite has a blue tone), and black streak on glazed porcelain. Infusible, but may burn to  $CO_2$  at a high temperature. Unattacked by acids.

**Occurrence.** Graphite most commonly occurs in metamorphic rocks such as crystalline limestones, schists, and gneisses. It may be found as large crystalline plates enclosed or disseminated in small flakes in sufficient amount to form a considerable proportion of the rock. In these cases, it has probably been derived from carbonaceous material of organic origin which has been converted into graphite during metamorphism. Metamorphosed coal beds may be partially converted into graphite, as the graphite coals of Rhode Island and in the coal fields of Sonora, Mexico. Graphite also occurs in hydrothermal veins associated with quartz, biotite, orthoclase, tourmaline, apatite, pyrite, and sphene, as in the deposits at Ticonderoga, New York. The graphite in these veins may have been formed from hydrocarbons introduced into them during the metamorphism of the region and derived from the surrounding carbon-bearing rocks. Graphite occurs occasionally as an original constituent of igneous rocks as in the basalts of Oviyak, Greenland, in a nepheline syenite in India, in a granite pegmatite in Maine. It is also found in some meteorites.

The principal countries producing natural graphite are: North and South Korea, U.S.S.R., Mexico, Austria, China, Malagasy Republic, and Ceylon. The chief deposits in the United States are in the Adirondack region of New York, in Essex, Warren, and Washington counties, particularly at Ticonderoga.

**Artificial.** Graphite is manufactured on a large scale in electrical furnaces using anthracite coal or petroleum coke as the raw materials. The use of artificial graphite in the United States is considerably in excess of that of the natural mineral.

**Use.** Used in the manufacture of refractory crucibles for the steel, brass, and bronze industries. Flake graphite for crucibles comes mostly from Ceylon and Malagasy Republic. Mixed with oil, graphite is used as a lubricant, and mixed with fine clay, it forms the "lead" of pencils. It is employed in the manufacture of protective paint for structural steel and is used in foundry facings, batteries, electrodes, generator brushes, and in electrotyping.

**Name.** Derived from the Greek word meaning *to write*, in allusion to its use in pencils.

### SULFIDES

The sulfides form an important class of minerals which includes the majority of the ore minerals. With them are classed the similar but rarer selenides, tellurides, arsenides, and antimonides.

Most of the sulfide minerals are opaque with distinctive colors and characteristically colored streaks. Those that are nonopaque, as cinnabar, realgar, and orpiment, have high refractive indices and transmit light only on thin edges.

The sulfides can be divided into small structural groups, but no broad generalizations can be made regarding their structure. Many of the sulfides have ionic bonding, whereas others, displaying most of the properties of metals, have metallic bonding at least in part. Sphalerite has a structure similar to diamond and like diamond has a covalent bond.

The general formula for the sulfides is given as  $A_mX_n$  in which  $A$  represents the metallic elements and  $X$  the nonmetallic element. The order of listing of the various minerals is in a decreasing ratio of  $A:X$ .

#### Sulfides

|                |               |                |                        |
|----------------|---------------|----------------|------------------------|
| Argentite      | $Ag_2S$       | ✓ Cinnabar     | HgS                    |
| ✓ Chalcocite   | $Cu_2S$       | ✓ Realgar      | AsS                    |
| ✓ Bornite      | $Cu_5FeS_4$   | ✓ Orpiment     | $As_2S_3$              |
| ✓ Galena       | PbS           | ✓ Stibnite     | $Sb_2S_3$              |
| Sphalerite     | ZnS           | Bismuthinite   | $Bi_2S_3$              |
| ✓ Chalcopyrite | $CuFeS_2$     | ✓ Pyrite       | $FeS_2$                |
| Stannite       | $Cu_2FeSnS_4$ | Cobaltite      | (Co,Fe)AsS             |
| Greenockite    | CdS           | ✓ Marcasite    | $FeS_2$                |
| ✓ Pyrrhotite   | $Fe_{1-x}S$   | ✓ Arsenopyrite | FeAsS                  |
| ✓ Niccolite    | NiAs          | ✓ Molybdenite  | $MoS_2$                |
| Millerite      | NiS           | Calaverite     | AuTe <sub>2</sub>      |
| ✓ Pentlandite  | (Fe,Ni)S      | Sylvanite      | (Au,Ag)Te <sub>2</sub> |
| ✓ Covellite    | CuS           | Skutterudite   | (Co,Ni)As <sub>3</sub> |

### ✕ Argentite—Ag<sub>2</sub>S

**Crystallography.** Isometric,  $4/m\bar{3}2/m$  (above 179°C); monoclinic,  $2/m$  (acanthite) at ordinary temperatures. Crystals, paramorphs of the high-temperature form, commonly show the cube, octahedron, and dodecahedron but frequently are arranged in branching or reticulated groups. Most commonly massive or as a coating.

Argentite:  $Im\bar{3}m$ ;  $a = 4.89 \text{ \AA}$ ,  $Z = 2$ .

Acanthite:  $P2_1/m$ ;  $a = 4.23$ ,  $b = 6.93$ ,  $c = 7.86 \text{ \AA}$ ,  $\beta = 99^\circ 35'$ ,  $a:b:c = 0.610:1:1.134$ ,  $Z = 4$ .  $d$ 's: 2.60(10), 2.45(8), 2.38(5), 2.22(3), 2.09(4).

**Physical Properties.** H 2–2½. G 7.3. Very sectile; can be cut with a knife like lead. Luster metallic. Color black. Streak black, shining. Opaque. Bright on fresh surface but on exposure becomes dull black, owing to the formation of an earthy sulfide.

**Composition.** Ag 87.1, S 12.9 per cent.

**Diagnostic Features.** Argentite can be distinguished by its color, sectility, and high specific gravity. Fusible at 1½ with intumescence. When fused on charcoal in the oxidizing flame it gives off the odor of sulfur dioxide and yields a globule of silver.

**Occurrence.** Argentite is an important primary silver mineral found in veins associated with native silver, the ruby silvers, polybasite, stephanite, galena, and sphalerite. It may also be of secondary origin. It is found in microscopic inclusions in argentiferous galena. Argentite is an important ore in the silver mines of Guanajuato and elsewhere in Mexico; in Peru, Chile, and Bolivia. Important European localities are Freiberg, Saxony; Joachimsthal, Bohemia; Schemnitz and Kremnitz, Czechoslovakia, and Kongsberg, Norway. In the United States it has been an important ore mineral in Nevada, notably at the Comstock Lode and at Tonopah. It is also found in the silver districts of Colorado, and in Montana at Butte associated with copper ores.

**Use.** An important ore of silver.

**Name.** The name argentite comes from the Latin *argentum*, meaning silver.

### ✕ CHALCOCITE—Cu<sub>2</sub>S

**Crystallography.** Orthorhombic;  $2/m2/m2/m$  (below 105°C); above 105°C, hexagonal. Crystals are very rare, usually small and tabular with hexagonal outline; striated parallel to the  $a$  axis (Fig. 291). Commonly fine grained and massive.

$Abm2$ ;  $a = 11.92$ ,  $b = 27.33$ ,  $c = 13.44 \text{ \AA}$ .  $a:b:c = 0.436:1:0.492$ ,  $Z = 96$ .  $d$ 's: 3.39(3), 2.40(7), 1.969(8), 1.870(10), 1.695(4).

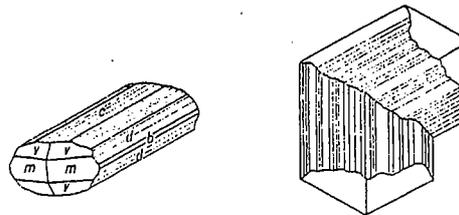


FIG. 291. Chalcocite crystals.

**Physical Properties.** Cleavage  $\{110\}$  poor. Fracture conchoidal. H 2½–3. G 5.5–5.8. Luster metallic. Imperfectly sectile. Color shining lead-gray, tarnishing to dull black on exposure. Streak grayish black. Some chalcocite is soft and sooty.

**Composition.** Cu 79.8, S 20.2 per cent. May contain small amounts of Ag and Fe.

**Diagnostic Features.** Chalcocite is distinguished by its lead-gray color and sectility. Fusible at 2–2½. When heated on charcoal it gives odor of sulfur dioxide and is easily reduced to metallic copper. Roasted mineral, moistened with HCl, gives azure-blue flame.

**Occurrence.** Chalcocite is one of the most important copper-ore minerals. Fine crystals are rare but have been found at Cornwall, England and Bristol, Connecticut. Chalcocite may occur as a primary mineral in veins with bornite, chalcopyrite, enargite and pyrite. But its principal occurrence is as a supergene mineral in enriched zones of sulfide deposits. Under surface conditions the primary copper sulfides are oxidized; the soluble sulfates formed move downward reacting with the primary minerals to form chalcocite and thus enriching the ore in copper. The water table is the lower limit of the zone of oxidation and here a "chalcocite blanket" may form. Many famous copper mines owe their greatness to this process of secondary enrichment as: Rio Tinto, Spain; Ely, Nevada; Morenci, Miami, Clifton, Arizona; and Butte, Montana.

Much of the world's copper is today produced from what is called "porphyry copper" ore. In these deposits primary copper minerals disseminated through the rock, usually a porphyry, have been altered, at least in part, to chalcocite and thus enriched to form a workable ore body. The amount of copper in such deposits is small, rarely greater than 1 or 2 per cent and may be as low as 0.50 per cent. The largest copper producer in the United States, is a porphyry copper deposit at Bingham, Utah.

**Use.** An important copper ore.

**Similar Species.** Digenite, Cu<sub>9</sub>S<sub>4</sub>, is blue to black, associated with chalcocite. Stromeyerite, (Ag,Cu)<sub>2</sub>S, is a steel-gray mineral found in copper-silver veins.

### ✕ BORNITE— $\text{Cu}_5\text{FeS}_4$

**Crystallography.** Isometric;  $4/m\bar{3}2/m$ . Rarely in rough cubic and less commonly in dodecahedral and octahedral crystals. Usually massive.

$Fd\bar{3}m$ .  $a = 10.93 \text{ \AA}$ .  $Z = 8$ .  $d's$ : 3.30(8), 3.17(8), 2.74(8), 1.93(10), 1.37(8).

**Physical Properties.** H 3. G 5.06–5.08. *Luster* metallic. *Color* brownish-bronze on fresh fracture but quickly tarnishing to variegated purple and blue (hence called *peacock ore*) and finally to almost black on exposure. *Streak* grayish-black.

**Composition.** Cu 63.3, Fe 11.2, S 25.5 per cent. Microscopic admixed blebs of other minerals cause the composition of what appears to be bornite to vary considerably, but analyses of pure material agree with the above formula.

**Diagnostic Features.** Bornite is distinguished by its characteristic bronze color on the fresh fracture and by the purple tarnish. Fusible at  $2\frac{1}{2}$ . When heated on charcoal it gives off the odor of sulfur dioxide and becomes magnetic. If, after roasting, it is moistened with hydrochloric acid and heated, it gives an azure-blue flame.

**Alteration.** Bornite alters readily to chalcocite and covellite.

**Occurrence.** Bornite is a widely occurring copper ore usually found associated with other copper minerals in hypogene deposits. It is much less frequently found as a supergene mineral, in the upper, enriched zone of copper veins. It is found disseminated in basic rocks, in contact metamorphic deposits, in replacement deposits, and in pegmatites. Bornite frequently occurs in intimate mixtures with chalcopyrite and chalcocite. It is not as important an ore of copper as chalcocite and chalcopyrite.

Good crystals of bornite have been found associated with crystals of chalcocite at Bristol, Connecticut, and at Cornwall, England. Found in large masses in Chile, Peru, Bolivia, and Mexico. In the United States it is found at Magma mine, Pioneer, Arizona; Butte, Montana; Engels mine, Plumas County, California; Halifax County, Virginia; and Superior, Arizona.

**Use.** An ore of copper.

**Name.** Bornite was named after the German mineralogist von Born (1742–1791).

### ✕ GALENA— $\text{PbS}$

**Crystallography.** Isometric;  $4/m\bar{3}2/m$ . The most common form is the cube, sometimes truncated by the octahedron (Figs. 292 and 293). Dodecahedron and trisoctahedron rare. Galena has a NaCl type of structure with Pb in place of Na and S in place of Cl.

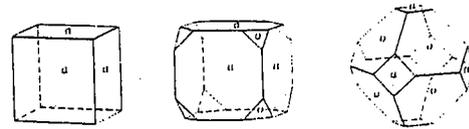


FIG. 292. Galena crystals.

$Fm\bar{3}m$ ;  $a = 5.936 \text{ \AA}$ ;  $Z = 4$ .  $d's$ : 3.44(9), 2.97(10), 2.10(10), 1.780(9), 1.324(10). **Physical Properties.** *Cleavage* perfect  $\{001\}$ . H  $2\frac{1}{2}$ . G 7.4–7.6. *Luster* bright metallic. *Color* and *streak* lead-gray.

**Composition.** Pb 86.6, S 13.4 per cent. Silver is usually present, probably as admixtures of silver minerals such as argentite or tetrahedrite. Inclusions probably also account for the small amounts of zinc, cadmium, antimony, arsenic, and



FIG. 293. (a) Galena crystals, Joplin, Missouri. (b) Galena on sphalerite and dolomite crystals.

bismuth that may be present. Selenium may substitute for sulfur and a complete series from  $PbS$ - $PbSe$  has been reported.

**Diagnostic Features.** Galena can be easily recognized by its good cleavage, high specific gravity, softness, and lead-gray streak. Fusible at 2. Reduced on charcoal to lead globule with formation of yellow to white coating of lead oxide and odor of sulfur dioxide.

**Alteration.** By oxidation galena is converted into the sulfate, anglesite, and the carbonate, cerussite.

**Occurrence.** Galena is a very common metallic sulfide, found in veins associated with sphalerite, pyrite, marcasite, chalcopyrite, cerussite, anglesite, dolomite, calcite, quartz, barite, and fluorite. When found in hydrothermal veins galena is frequently associated with silver minerals; it often contains silver itself and so becomes an important silver ore. A large part of the supply of lead comes as a secondary product from ores mined chiefly for their silver. In a second type of deposit typified by the lead-zinc ores of the Mississippi Valley, galena, associated with sphalerite, is found in veins, open space filling, or replacement bodies in limestones. These are low temperature deposits, located at shallow depths and usually contain little silver. Galena is also found in contact metamorphic deposits, in pegmatites and as disseminations in sedimentary rocks.

Famous world localities are Freiberg, Saxony; the Harz Mountains; Westphalia and Nassau; Pflibram, Bohemia; Cornwall, Derbyshire, and Cumberland, England; Sullivan mine, British Columbia; and Broken Hill, Australia.

In the United States there are many lead-producing districts; only the most important are mentioned here. In the Tri-State district of Missouri, Kansas, and Oklahoma centering around Joplin, Missouri, galena is associated with zinc ores and is found in irregular veins and pockets in limestone and chert. It is found in a similar manner but in smaller amount in Illinois, Iowa, and Wisconsin. The deposits of southeast Missouri where galena is disseminated through limestone are particularly productive. In the Coeur d'Alene district, Idaho, galena is the chief ore mineral in the lead-silver vein deposits. Lead is produced in Utah at Brigham and from the silver deposits of the Tintic and Park City districts; and in Colorado, chiefly from the lead-silver ores of the Leadville district.

**Use.** Practically the only source of lead and an important ore of silver. Metallic lead is used chiefly as follows: for conversion into white lead (a basic lead carbonate), which is the principal ingredient of many white paints, or into the oxides (*litharge*,  $PbO$ , and *minium*,  $Pb_3O_4$ ) used in making glass and in giving a glaze to earthenware; as pipe and sheets; and for shot. It is a principal ingredient of several alloys as solder (lead and tin), type metal (lead and antimony), and low-fusion alloys (lead, bismuth, and tin). Large amounts of metallic lead are used in storage batteries and as shielding in working with uranium and other radioactive substances.

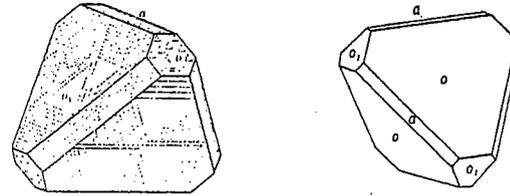


FIG. 294. Sphalerite crystals.

**Name.** The name galena is derived from the Latin *galena*, a name originally given to lead ore.

**Similar Species.** *Altaite*,  $PbTe$ , and *alabandite*,  $MnS$ , like galena, have a NaCl type of structure.

### ✕ SPHALERITE— $ZnS$

#### Zinc Blende

**Crystallography.** Isometric;  $\bar{4}3m$ . Tetrahedron, dodecahedron, and cube common forms (Fig. 294), but the crystals, frequently highly complex and usually malformed or in rounded aggregates, often show polysynthetic twinning on  $\{111\}$ . Usually found in cleavable masses, coarse to fine granular. Compact, botryoidal, cryptocrystalline.

The sphalerite structure is similar to that of diamond with one-half of the carbon atoms of diamond replaced by zinc and the other half by sulfur. Each zinc atom is surrounded by and bonded to four sulfur atoms and in turn each sulfur atom is bonded to four zinc atoms (Fig. 295a).

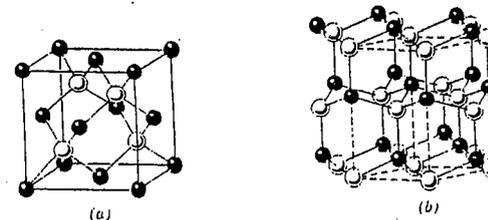


FIG. 295. Structure of  $ZnS$  dimorphs. (a) Sphalerite. (b) Wurtzite.

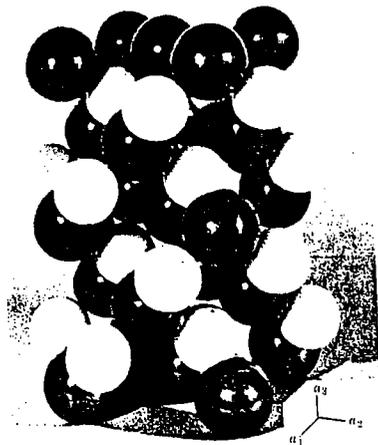


FIG. 296. Sphalerite,  $ZnS$ , packing model. Zn (black) and S (white) are both in 4 coordination. Note sheets of atoms parallel to (111). If they are rotated  $180^\circ$  alternately, the wurtzite structure results.

$F\bar{4}3m$ ;  $a = 5.41 \text{ \AA}$ ;  $Z = 4$ .  $d's$ : 3.12(10), 1.910(8), 1.631(7), 1.240(4), 1.106(5).

The dimorphic form of  $ZnS$ , wurtzite, is hexagonal,  $6mm$  (Fig. 295b).

**Physical Properties.** *Cleavage*,  $\{011\}$  perfect but some sphalerite is too fine grained to show cleavage.  $H$   $3\frac{1}{2}$ –4.  $G$  3.9–4.1. *Luster* nonmetallic and resinous to submetallic; also adamantine. *Color* white when pure, and green when nearly so. Commonly yellow, brown to black, darkening with increase in iron. Also red (ruby zinc). Transparent to translucent. *Streak* white to yellow and brown.

**Composition.** Zn 67, S 33 per cent when pure. Nearly always contains iron with the amount of iron dependent on the temperature and environment. If iron is in excess as indicated by the presence of pyrrhotite, FeS can reach nearly 50 mole per cent (see Fig. 269). If sphalerite and an iron sulfide crystallize together, the amount of iron is an indication of the temperature of formation, and sphalerite becomes a geologic thermometer. Manganese and cadmium are usually present in small amounts in solid solution.

**Diagnostic Features.** Sphalerite can be recognized by its striking resinous luster and perfect cleavage. The dark varieties (black jack) can be told by the reddish-brown streak, always lighter than the massive mineral. Pure zinc sulfide is infusible; it becomes fusible, with difficulty, with an increase in the amount of

iron. When heated on charcoal it gives the odor of sulfur dioxide and with the reducing mixture, gives a coating of zinc oxide (yellow when hot, white when cold).

**Occurrence.** Sphalerite, the most important ore mineral of zinc, is extremely common. Its occurrence and mode of origin are similar to those of galena, with which it is commonly found. In the shallow seated lead-zinc deposits of the Tri-State district of Missouri, Kansas, and Oklahoma these minerals are associated with marcasite, chalcopyrite, calcite, and dolomite. Sphalerite with only minor galena occurs in hydrothermal veins and replacement deposits associated with pyrrhotite, pyrite, and magnetite. Sphalerite is also found in veins in igneous rocks and in contact metamorphic deposits.

Zinc is mined in significant amounts in over 40 countries. Although in a few places the ore minerals are hemimorphite and smithsonite and at Franklin, New Jersey willemite, zincite, and franklinite, most of the world's zinc comes from sphalerite. The principal producing countries are: Canada, U.S.S.R., United States, Australia, Peru, Mexico, and Japan. In the United States nearly 60 per cent of the zinc is produced east of the Mississippi River with Tennessee, New York, Pennsylvania, and New Jersey the principal producing states. In western United States, Idaho, Colorado, and Utah are the chief producers. The mines in the Tri-State district, formerly major zinc producers, are now largely exhausted.

**Use.** The most important ore of zinc. The chief uses for metallic zinc, or *spelter*, are in galvanizing iron; making brass, an alloy of copper and zinc; in electric batteries; and as sheet zinc. Zinc oxide, or zinc white, is used extensively for making paint. Zinc chloride is used as a preservative for wood. Zinc sulfate is used in dyeing and in medicine. Sphalerite also serves as the most important source of cadmium, indium, gallium, and germanium.

**Name.** Sphalerite comes from the Greek meaning *treacherous*. Blende because, although often resembling galena, it yielded no lead; from the German word meaning *blind* or *deceiving*.

### ✕ CHALCOPYRITE— $CuFeS_2$

**Crystallography.** Tetragonal;  $\bar{4}2m$ . Commonly tetrahedral in aspect with the disphenoidal  $p\{112\}$  dominant. Other forms shown in Fig. 297 are rare. Usually massive.

*Angles:*  $p(112) \wedge p'(1\bar{1}2) = 108^\circ 40'$ ,  $c(001) \wedge z(011) = 63^\circ 06'$ ,  $c(001) \wedge p(112) = 54^\circ 20'$ ,  $c(001) \wedge e(102) = 44^\circ 34'$ .

$\bar{4}2d$ ;  $a = 5.25$ ,  $c = 10.32 \text{ \AA}$ ,  $a:c = 1:1.966$ ;  $Z = 4$ .  $d's$ : 3.03(10), 1.855(10), 1.586(10), 1.205(8), 1.074(8).

**Physical Properties.**  $H$   $3\frac{1}{2}$ –4.  $G$  4.1–4.3. *Luster* metallic. *Color* brass-yellow; often tarnished to bronze or iridescent. *Streak* greenish black. Brittle.

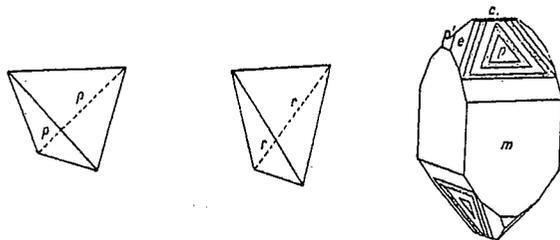


FIG. 297. Chalcopyrite crystals.

**Composition.** Cu 34.6, Fe 30.4, S 35.0 per cent. Analyses often show variations from the percentages given because of mechanical admixtures of other sulfides, chiefly pyrite.

**Diagnostic Features.** Recognized by its brass-yellow color and greenish-black streak. Distinguished from pyrite by being softer than steel and from gold by being brittle. Known as "fool's gold," a term also applied to pyrite. On charcoal it fuses at 2 to a magnetic globule, and gives off the odor of sulfur dioxide. Deceptritates and gives sulfur in the closed tube. After roasting, and moistening with HCl, gives the azure-blue copper chloride flame.

**Occurrence.** Chalcopyrite is the most widely occurring copper mineral and one of the most important sources of that metal. Most sulfide ores contain some chalcopyrite but the most important economically are the hydrothermal vein and replacement deposits. In the low-temperature deposits as in the Tri-State district, it occurs as small crystals associated with galena, sphalerite, and dolomite. Associated with pyrrhotite and pentlandite, it is the chief copper mineral in the ores of Sudbury, Ontario and similar high-temperature deposits. Chalcopyrite is the principal primary copper mineral in the "porphyry-copper" deposits. Also occurs as an original constituent of igneous rocks; in pegmatite dikes; in contact metamorphic deposits; and disseminated in schistose rocks. It may carry gold or silver and become an ore of those metals. Often in subordinate amount with large bodies of pyrite, making them serve as low-grade copper ores.

A few of the localities at which chalcopyrite is the chief ore of copper are: Cornwall, England; Falun, Sweden; Schemnitz, Czechoslovakia; Schlaggenwald, Bohemia; Freiberg, Saxony; Rio Tinto, Spain; South Africa, Zambia and Chile. Found widely in the United States but usually with other copper minerals in equal or greater amount; found at Butte, Montana; Bingham, Utah; Jerome, Arizona; Ducktown, Tennessee; and various districts in California, Colorado, and New

Mexico. In Canada the most important occurrences of chalcopyrite are at Sudbury, Ontario and at Rouyn district, Quebec.

**Alteration.** Chalcopyrite is the principal source of copper for the secondary minerals malachite, azurite, covellite, chalcocite, and cuprite. Concentrations of copper in the zone of supergene enrichment are often the result of such alteration and removal of copper in solution with its subsequent deposition.

**Use.** Important ore of copper.

**Name.** Derived from Greek word meaning *brass* and from *pyrites*.

### Greenockite—CdS

**Crystallography.** Hexagonal;  $6mm$ . Crystals rare and small, showing prism faces, and terminated usually below with pedion and above with pyramids. Usually pulverulent, and as powdery incrustations.

$P6_3mc$ ;  $a = 4.15$ ,  $c = 6.73 \text{ \AA}$ ,  $a:c = 1:1.622$ .  $Z = 2$ .  $d's$ : 3.59(8), 3.167(10), 2.071(8), 1.900(8), 1.764(8).

**Physical Properties.** *Cleavage*  $\{11\bar{2}2\}$ ,  $\{0001\}$  poor.  $H$  3–3½.  $G$  4.9. *Luster* adamantine to resinous, earthy. *Color* various shades of yellow and orange. *Streak* between orange-yellow and brick-red. Greenockite containing zinc shows a strong orange-yellow fluorescence.

**Composition.** Cd 77.8, S 22.2 per cent. Wurtzite, ZnS, and greenockite are isostructural, and a complete solid-solution series exists between the two minerals (see Fig. 295b).

**Diagnostic Features.** Characterized by its yellow color and pulverulent form and association with zinc ores. Infusible. Yields odor of sulfur dioxide when heated in the open tube, and a reddish-brown coating of cadmium oxide when heated with sodium carbonate on charcoal.

**Occurrence.** Greenockite is the most common mineral containing cadmium but it is found only in a few localities and in small amounts, usually as an earthy coating on zinc ores, especially sphalerite.

Found in crystals at Bishopton, Renfrew, Scotland; Tsumeb, South-West Africa; and also in Bohemia and Carinthia. In the United States it is found with the zinc ores of the Tri-State district, in Arkansas, and in small amounts at Franklin, New Jersey.

**Use.** A source of cadmium. Cadmium is used in alloys for antifriction bearings and low-melting alloys. Small amounts, less than 1.5 per cent, will harden copper and silver. The largest use is in electroplating other metals to form a coating resistant to chemical attack. Cadmium is also used in many pigments and chemicals.

**Name.** Named after Lord Greenock (later Earl Cathcart). The first crystal was found about 1810. It was over one-half inch across and was mistaken for sphalerite.

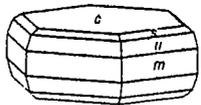


FIG. 298. Pyrrhotite.

### ✕PYRRHOTITE— $Fe_{1-x}S$

#### Magnetic Pyrites

**Crystallography.** Hexagonal;  $6/m2/m2/m$ . Crystals usually tabular, in some cases pyramidal (Fig. 298). Usually massive with granular or lamellar habit.

*Angles:*  $c\{0001\} \wedge s\{10\bar{1}2\} = 45^\circ 8'$ ,  $c\{0001\} \wedge u\{20\bar{2}1\} = 76^\circ 0'$ .

*$C6/mmc$ :*  $a = 3.44$ ,  $c = 5.73 \text{ \AA}$ ,  $a:c = 1:1.666$ ;  $Z = 2$ .  *$d$ 's:* 2.97(6), 2.63(8), 2.06(10), 1.718(6), 1.045(8).

**Physical Properties.** **H** 4. **G** 4.58–4.65. *Luster* metallic. *Color* brownish bronze. *Streak* black. Magnetic, but varying in intensity; the greater the amount of iron, the lesser the magnetism. Opaque.

**Composition.** Most pyrrhotite has a deficiency of iron with respect to sulfur, as indicated by the formula  $Fe_{1-x}S$ , with  $x$  between 0 and 0.2. The mineral troilite is close to  $FeS$ .

**Diagnostic Features.** Recognized usually by its massive nature, bronze color, and magnetism. Fusible at 3. When heated on charcoal, it gives off the odor of sulfur dioxide and becomes strongly magnetic.

**Occurrence.** Pyrrhotite is commonly associated with basic igneous rocks, particularly norites. It occurs in them as disseminated grains or, as at Sudbury, Ontario, as large masses associated with pentlandite, chalcopyrite, or other sulfides. At Sudbury vast tonnages of pyrrhotite are mined principally for the copper, nickel, and platinum that are extracted from associated minerals. Pyrrhotite is also found in contact metamorphic deposits, in vein deposits, and in pegmatites.

Large quantities are known in Finland, Norway, and Sweden; in Germany from Andreasberg in the Harz Mountains; at Schneeberg, Saxony; and Bodenmais, Bavaria. In the United States in crystals from Standish, Maine; at the Gap mine, Lancaster County, Pennsylvania; and in considerable amount at Ducktown, Tennessee.

**Use.** It is mined for its associated nickel, copper, and platinum. At Sudbury, Ontario it is also a source of sulfur and an ore of iron.

**Name.** The name pyrrhotite comes from the Greek meaning *reddish*.

### ✕Niccolite— $NiAs$

**Crystallography.** Hexagonal;  $6/m2/m2/m$ . Rarely in tabular crystals. Usually massive, reniform with columnar structure.

*$C6/mmc$ :*  $a = 3.61$ ,  $c = 5.02 \text{ \AA}$ ;  $a:c = 1:1.391$ ;  $Z = 2$ .  *$d$ 's:* 2.66(10), 1.961(9), 1.811(8), 1.328(3), 1.071(4).

**Physical Properties.** **H** 5–5½. **G** 7.78. *Luster* metallic. *Color* pale copper-red (hence called *copper nickel*), with gray to blackish tarnish. *Streak* brownish-black. Opaque.

**Composition.** Ni 43.9, As 56.1 per cent. Usually with a little iron; cobalt, and sulfur. Arsenic frequently replaced in part by antimony.

**Diagnostic Features.** Characterized by its copper-red color. Fusible at 2. When heated on charcoal it yields a white sublimate and a garliclike odor is given off. Gives nickel test with dimethylglyoxime.

**Alteration.** Quickly alters to annabergite (green nickel bloom) in moist atmosphere.

**Occurrence.** Niccolite, with other nickel arsenides and sulfides, pyrrhotite, and chalcopyrite, frequently occurs in, or is associated with, norites. Also found in vein deposits with cobalt and silver minerals.

Found in Germany in the silver mines of Saxony, the Harz Mountains, in Hessen-Nassau; and at Cobalt, Ontario.

**Use.** A minor ore of nickel.

**Name.** The first name of this mineral, *kupfernichel*, gave the name *nickel* to the metal. Niccolite is from the Latin for nickel.

**Similar Species.** Breithauptite, NiSb, is isostructural with niccolite with similar occurrence and association.

### Millerite— $NiS$

**Crystallography.** Hexagonal— $R$ ;  $\bar{3}2/m$ . Usually in hair-like tufts and radiating groups of slender to capillary crystals (capillary pyrites). In velvety incrustations. Rarely in coarse cleavable masses.

*$R3m$ :*  $a = 9.62$ ,  $c = 3.16 \text{ \AA}$ ;  $a:c = 1:0.328$ ;  $Z = 9$ .  *$d$ 's:* 4.77(8), 2.75(10), 2.50(6), 2.22(6), 1.859(10).

**Physical Properties.** *Cleavage*  $\{10\bar{1}1\}$ ,  $\{01\bar{1}2\}$  good. **H** 3–3½. **G** 5.5 ± 0.2. *Luster* metallic. *Color* pale brass-yellow; with a greenish tinge when in fine hairlike masses. *Streak* black, somewhat greenish.

**Composition.** Ni 64.7, S 35.3 per cent.

**Diagnostic Features.** Characterized by its capillary crystals and distinguished from minerals of similar color by nickel tests. Fusible at 1½–2 to a magnetic globule. Gives odor of sulfur dioxide when heated on charcoal.

**Occurrence.** Millerite forms as a low-temperature mineral often in cavities and as an alteration of other nickel minerals, or as crystal inclusions in other minerals.

Occurs in various localities in Saxony, Westphalia, and Hessen-Nassau and in Bohemia. In the United States, it is found with hematite and ankerite at Antwerp,

New York; with pyrrhotite at the Gap mine, Lancaster County, Pennsylvania; in geodes in limestone at St. Louis, Missouri; Keokuk, Iowa; and Milwaukee, Wisconsin. In coarse cleavable masses it is a major ore mineral at the Marbridge Mine, Lamotte Township, Quebec.

**Use.** A subordinate ore of nickel.

**Name.** In honor of the mineralogist, W. H. Miller (1801-1880), who first studied the crystals.

### ✕ Pentlandite—(Fe,Ni)<sub>9</sub>S<sub>8</sub>

**Crystallography.** Isometric;  $4jm\bar{3}2/m$ . Massive, usually in granular aggregates with octahedral parting.

$Fm\bar{3}m$ ;  $a = 10.07 \text{ \AA}$ ;  $Z = 4$ .  $d's$ : 5.84(2), 3.04(6), 2.92(2), 2.31(3), 1.781(10).

**Physical Properties.** Parting on {111}.  $H$  3½-4.  $G$  4.6-5.0. Brittle. *Luster* metallic. *Color* yellowish-bronze. *Streak* light bronze-brown. Opaque. Nonmagnetic.

**Composition.** (Fe,Ni)<sub>9</sub>S<sub>8</sub>. Usually the ratio of Fe:Ni is close to 1:1. Commonly contains small amounts of cobalt.

**Diagnostic Features.** Pentlandite closely resembles pyrrhotite in appearance but can be distinguished from it by the octahedral parting and lack of magnetism. Fusible at 1½-2. On heating gives odor of sulfur dioxide and becomes magnetic. Gives nickel test with dimethylglyoxime.

**Occurrence.** Pentlandite usually occurs in basic igneous rocks where it is commonly associated with other nickel minerals, pyrrhotite, and chalcopyrite, and has probably accumulated by magmatic segregation.

Found at widely separated localities in small amounts but its chief occurrences are in Canada where, associated with pyrrhotite, it is the principal source of nickel at Sudbury, Ontario, and the Lynn Lake area, Manitoba. It is also an important ore mineral in similar deposits in the Petsamo district of U.S.S.R.

**Use.** The principal ore of nickel. The chief use of nickel is in steel. Nickel steel contains 2½-3½ per cent nickel, which greatly increases the strength and toughness of the alloy, so that lighter machines can be made without loss of strength. Nickel is also an essential constituent of stainless steel. The manufacture of Monel metal (68 per cent nickel, 32 per cent copper) and Nichrome (38-85 per cent nickel) consumes a large amount of the nickel produced. Other alloys are German silver (nickel, zinc, and copper); metal for coinage—the 5-cent coin of the United States is 25 per cent nickel and 75 per cent copper, low-expansion metals for watch springs and other instruments. Nickel is used in plating; although chromium now largely replaces it for the surface layer, nickel is used for a thicker under-layer.

**Name.** After J. B. Pentland, who first noted the mineral.

### ✕ Covellite—CuS

**Crystallography.** Hexagonal;  $6/m2/m2/m$ . Rarely in tabular hexagonal crystals. Usually massive as coatings or disseminations through other copper minerals.

$P6_3/mmc$ ;  $a = 3.80$ ,  $c = 16.36 \text{ \AA}$ ;  $a:c = 1:4305$ ;  $Z = 6$ .  $d's$ : 3.06(4), 2.83(6), 2.73(10), 1.899(8), 1.740(5).

**Physical Properties.** *Cleavage* {0001} perfect giving flexible plates.  $H$  1½-2.  $G$  4.6-4.76. *Luster* metallic. *Color* indigo-blue or darker. *Streak* lead-gray to black. Often iridescent. Opaque.

**Composition.** Cu 66.4, S 33.6 per cent. A small amount of iron may be present.

**Diagnostic Features.** Characterized by the indigo-blue color, micaceous cleavage yielding flexible plates, and association with other copper sulfides. Fusible at 2½. Gives off the odor of sulfur dioxide in the open tube, and much sulfur in the closed tube. The roasted mineral, moistened with HCl and ignited, gives the blue copper chloride flame.

**Occurrence.** Covellite is not an abundant mineral but is found in most copper deposits as a supergene mineral, usually as a coating, in the zone of sulfide enrichment. It is associated with other copper minerals, principally chalcocite, chalcopyrite, bornite, and enargite, and is derived from them by alteration. Primary covellite is known but uncommon.

Found at Bor, Serbia, Yugoslavia; and Leogang, Austria. In large iridescent crystals from the Calabona mine, Alghero, Sardinia. In the United States covellite is found in appreciable amounts at Butte, Montana; Summitville, Colorado; and La Sal district, Utah. Formerly found at Kennecott, Alaska.

**Use.** A minor ore of copper.

**Name.** In honor of N. Covelli (1790-1829), the discoverer of the Vesuvian covellite.

### ✕ CINNABAR—HgS

**Crystallography.** Hexagonal— $R$ ;  $32$ . Crystals usually rhombohedral, often in penetration twins. Trapezohedral faces rare. Usually fine granular massive; also earthy, as incrustations and disseminations through the rock.

$P\bar{3}_121$ ;  $a = 4.146$ ,  $c = 9.497 \text{ \AA}$ ;  $a:c = 1:2.291$ ;  $Z = 3$ .  $d's$ : 3.37(10), 3.16(8), 2.87(10), 2.07(8), 1.980(8).

**Physical Properties.** *Cleavage* {10 $\bar{1}$ 0} perfect.  $H$  2½.  $G$  8.10. *Luster* adamantine when pure to dull earthy when impure. *Color* vermilion-red when pure to brownish-red when impure. *Streak* scarlet. Transparent to translucent. *Hepatic cinnabar* is an inflammable variety with liver-brown color and in some cases a brownish streak, usually granular or compact.

**Composition.** Hg 86.2, S 13.8 per cent. Frequently impure from admixture of clay, iron oxide, bitumen.

**Diagnostic Features.** Recognized by its red color and scarlet streak, high specific gravity, and cleavage. Wholly volatile before the blowpipe. In the closed tube it yields (1) black sublimate of HgS when heated alone, and (2) globules of metallic mercury when heated with sodium carbonate.

**Occurrence.** Cinnabar is the most important ore of mercury but is found in quantity at comparatively few localities. Occurs as impregnations and as vein fillings near recent volcanic rocks and hot springs and evidently deposited near the surface from solutions which were probably alkaline. Associated with pyrite, marcasite, stibnite, and sulfides of copper in a gangue of opal, chalcedony, quartz, barite, calcite, and fluorite.

The important localities for the occurrence of cinnabar are at Almaden, Spain; Idria, Yugoslavia; Huancavelica in southern Peru; and the provinces of Kweichow and Hunan, China. In the United States the important deposits are in California at New Idria in San Benito County, in Napa County, and at New Almaden in Santa Clara County. It also occurs in Nevada, Utah, Oregon, Arkansas, Idaho, and Texas.

**Use.** The only important source of mercury. The most important use of mercury has been in the amalgamation process for recovering gold and silver from their ores, but other methods of extraction have lessened its demand for this purpose. It is used in thermometers, barometers, and various scientific and electrical equipment, including the mercury cell, in drugs, and in the form of an amalgam with silver for dental work and with tin in "silvering" mirrors. Several plants in the United States utilize mercury vapor instead of steam for the generation of power. This is a great potential use for mercury. Important military applications include the manufacture of fulminate of mercury for detonating high explosives and of paint for ship bottoms.

**Name.** The name cinnabar is supposed to have come from India, where it is applied to a red resin.

**Similar Species.** Metacinnabar is a black isometric polymorph of HgS.

### ✕REALGAR—AsS

**Crystallography.** Monoclinic;  $2/m$ . Found in short, vertically striated, prismatic crystals (Fig. 299). Frequently coarse to fine granular and often earthy and as an incrustation.

*Angles:*  $b(010) \wedge m(110) = 56^\circ 36'$ ,  $b(010) \wedge l(120) = 37^\circ 10'$ ,  $c(001) \wedge m(011) = 24^\circ 56'$ ,  $c(001) \wedge z(101) = 29^\circ 25'$ .

$P2_1/m$ ;  $a = 9.29$ ,  $b = 13.53$ ,  $c = 6.57 \text{ \AA}$ ;  $a:b:c = 0.687:1:0.486$ ,  $\beta = 106^\circ 33'$ ;  $Z = 16$ .  $d's$ : 5.40(10), 3.19(9), 2.94(8), 2.73(8), 2.49(5).

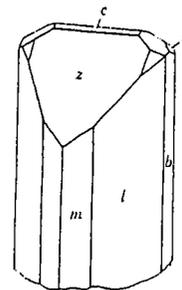


FIG. 299. Realgar.

**Physical Properties.** *Cleavage*  $\{010\}$  good.  $H 1\frac{1}{2}$ -2.  $G 3.48$ . Sectile. *Luster* resinous. *Color and streak* red to orange. Translucent to transparent.

**Composition.** As 70.1; S 29.9 per cent.

**Diagnostic Features.** Realgar is distinguished by its red color, resinous luster, orange-red streak and almost invariable association with orpiment. Fusible at 1. When heated on charcoal it yields a volatile white sublimate with a garlic odor. In the open tube it gives a volatile crystalline sublimate of arsenious oxide and the odor of sulfur dioxide.

**Alteration.** On long exposure to light disintegrates to a reddish-yellow powder.

**Occurrence.** Realgar is found in veins of lead, silver, and gold ores associated with orpiment, other arsenic minerals, and stibnite. It also occurs as a volcanic sublimation product and as a deposit from hot springs.

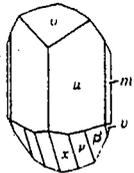
Realgar is found associated with silver and lead ores in Hungary, Bohemia, and Saxony. Found in good crystals at Nagyág, Transylvania; Binnenthal, Switzerland; and Allchar, Macedonia. In the United States realgar is found at Mercur, Utah; at Manhattan, Nevada; and deposited from the geyser waters in the Norris Geyser Basin, Yellowstone National Park.

**Use.** Realgar was used in fireworks to give a brilliant white light when mixed with saltpeter and ignited. Artificial arsenic sulfide is used for this purpose at present. It was formerly used as a pigment.

**Name.** The name is derived from the Arabic, *Rahj al ghar*, powder of the mine.

### ✕ORPIMENT—As<sub>2</sub>S<sub>3</sub>

**Crystallography.** Monoclinic;  $2/m$ . Crystals small, tabular or short prismatic, and rarely distinct; many pseudo-orthorhombic. Usually in foliated or columnar masses (Fig. 300).



Allchar, Macedonia FIG. 300. Orpiment.

Angles:  $b(010) \wedge m(110) = 39^\circ 59'$ ,  $b(010) \wedge u(210) = 59^\circ 12'$ ,  $b(010) \wedge v(311) = 73^\circ 27'$ .

$P2_1/m$ ;  $a = 11.49$ ,  $b = 9.59$ ,  $c = 4.25 \text{ \AA}$ ;  $a:b:c = 1.198:1:0.443$ ,  $\beta = 90^\circ 27'$ ;  $Z = 4$ .  $d's$ : 4.78(10), 2.785(4), 2.707(6), 2.446(6), 2.085(4).

**Physical Properties.** Cleavage  $\{010\}$  perfect; cleavage laminae flexible but not elastic. Sectile.  $H 1\frac{1}{2}$ -2.  $G 3.49$ . Luster resinous, pearly on cleavage face. Color lemon-yellow. Streak pale yellow. Translucent.

**Composition.** As 61, S 39 per cent.

**Diagnostic Features.** Characterized by its yellow color and foliated structure. Distinguished from sulfur by its perfect cleavage. Gives the same tests as realgar.

**Occurrence.** Orpiment is a rare mineral, associated usually with realgar and formed under similar conditions. Found in various places in Rumania, Kurdistan, Peru, Japan, etc. In the United States it occurs at Mercur, Utah, and at Manhattan, Nevada. Deposited with realgar from geyser waters in the Norris Geyser Basin, Yellowstone National Park.

**Use.** Used in dyeing and in a preparation for the removal of hair from skins. Artificial arsenic sulfide is largely used in place of the mineral. Both realgar and orpiment were formerly used as pigments but this use has been discontinued because of their poisonous nature.

**Name.** Derived from the Latin, *auripigmentum*, "golden paint," in allusion to its color and because the substance was supposed to contain gold.

## X STIBNITE— $Sb_2S_3$

**Crystallography.** Orthorhombic;  $2/m2/m2/m$ . Slender prismatic habit, prism zone vertically striated. Crystals often steeply terminated (Fig. 301). Crystals sometimes curved or bent (Fig. 302). Often in radiating crystal groups or in bladed forms with prominent cleavage. Massive, coarse to fine granular.

Angles:  $b(010) \wedge m(110) = 45^\circ 12'$ ;  $b(010) \wedge n(210) = 63^\circ 36'$ ;  $s(111) \wedge m(110) = 64^\circ 17'$ ;  $p(331) \wedge m(110) = 34^\circ 42'$ .

$Pbmm$ ;  $a = 11.22$ ,  $b = 11.30$ ,  $c = 3.84 \text{ \AA}$ ;  $a:b:c = 0.993:1:0.340$ ;  $Z = 4$ .  $d's$ : 5.07(4), 3.58(10), 2.76(3), 2.52(4), 1.933(5).

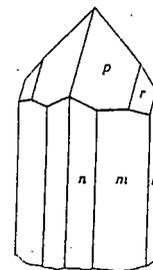


FIG. 301. Stibnite.

**Physical Properties.** Cleavage  $\{010\}$  perfect, showing striations parallel to  $[100]$ .  $H 2.0$ .  $G 4.52$ -4.62. Luster metallic, splendid on cleavage surfaces. Color and streak lead-gray to black. Opaque.

**Composition.** Sb 71.4, S 28.6 per cent. May carry small amounts of gold, silver, iron, lead, and copper.

**Diagnostic Features.** Characterized by its easy fusibility, bladed habit, perfect cleavage in one direction, lead-gray color, and soft black streak. Fusible at 1. When heated on charcoal it gives a dense white coating and the odor of sulfur dioxide. When roasted in the open tube it gives a nonvolatile white sublimate near the bottom of tube and a white volatile sublimate as a ring around tube.

**Occurrence.** Stibnite is found in low-temperatures hydrothermal veins or replacement deposits and in hot spring deposits. It is associated with other antimony minerals which have formed as the product of its decomposition, and with galena, cinnabar, sphalerite, barite, realgar, orpiment, and gold.

The finest crystals of stibnite have come from the province of Iyo, Island of Shikoku, Japan. The world's most important producing district is in the province of Hunan, China. It occurs also in Algeria, Borneo, Bolivia, Peru, and Mexico.



FIG. 302. Curved stibnite crystal, Ischinokowa, Japan.

Found in quantity at only a few localities in the United States, the chief deposits being in California, Nevada, and Idaho.

**Use.** The chief ore of antimony. The metal is used in various alloys, as antimonial lead for storage batteries, type metal, pewter, babbitt, britannia metals, and antifriction metal. The sulfide is employed in fireworks, matches, percussion caps, vulcanizing rubber and in medicines. Antimony trioxide is used as a pigment and for making glass.

**Name.** The name stibnite comes from an old Greek word that was applied to the mineral.

**Similar Species.** Bismuthinite,  $\text{Bi}_2\text{S}_3$  is a rare mineral isostructural with stibnite with similar crystallographic and physical properties.

### X PYRITE— $\text{FeS}_2$

**Crystallography.** Isometric;  $2/m\bar{3}$ . Frequently in crystals (Fig. 303). The most common forms are the cube, the faces of which are usually striated; the pyritohedron and the octahedron. Figure 303f shows a penetration twin, known as the *iron cross* with  $[011]$  the twin axis. Also massive, granular, reniform, globular, and stalactitic.

$P_{a3}$ ;  $a = 5.42 \text{ \AA}$ ,  $Z = 4$ .  $d's$ : 2.70(7), 2.42(6), 2.21(5), 1.917(4), 1.632(10).

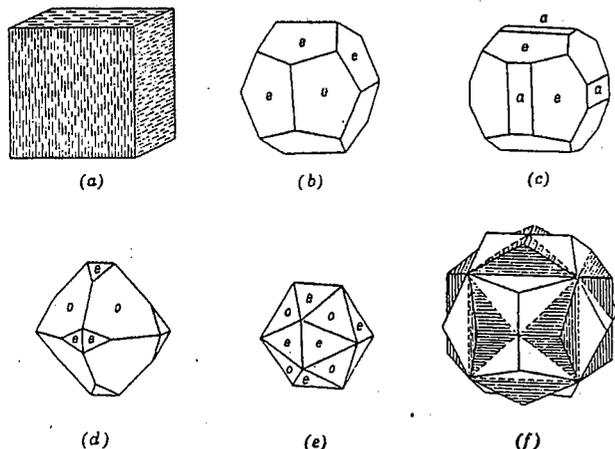


FIG. 303. Pyrite crystals. (a) Striated cube. (b) Pyritohedron (210). (c) Cube and pyritohedron. (d) and (e) Octahedron and pyritohedron. (f) Twinned pyritohedrons, iron cross.

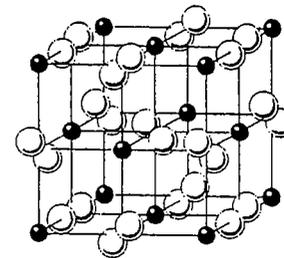


FIG. 304. Pyrite structure.

Pyrite has a modified type of NaCl structure (Fig. 304) with Fe occupying the position of Na and with  $\text{S}_2$  groups occupying the position of Cl. The sulfur pairs are joined along the 3-fold axes, and each sulfur of a pair touches three iron atoms. Each iron atom is surrounded by six sulfur atoms. It will be noted that only one sulfur pair in four lies along a given 3-fold axis (Fig. 305).

**Physical Properties.** *Fracture* conchoidal. Brittle.  $H$  6–6½ (unusually hard for a sulfide).  $G$  5.02. *Luster* metallic, splendent. *Color* pale brass-yellow; may be darker because of tarnish. *Streak* greenish or brownish black. Opaque. Paramagnetic.

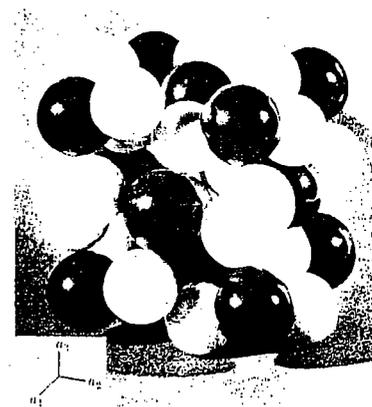


FIG. 305. Pyrite,  $\text{FeS}_2$ , packing model. Fe black; S white. Note that the sulfur pairs are aligned along the 3-fold symmetry axes.

**Composition.** Fe 46.6, S 53.4 per cent. May contain small amounts of nickel and cobalt. Some analyses show considerable nickel, and a complete solid-solution series exists between pyrite and *bravoite*,  $(\text{Ni, Fe})\text{S}_2$ . Frequently carries minute quantities of gold and copper but presumably as microscopic impurities.

**Diagnostic Features.** Distinguished from chalcopyrite by its paler color and greater hardness, from gold by its brittleness and hardness, and from marcasite by its deeper color and crystal form. Fusible at  $2\frac{1}{2}$ –3 to a magnetic globule. Yields much sulfur in the closed tube, and sulfur dioxide when heated in the open tube.

**Alteration.** Pyrite is easily altered to oxides of iron, usually limonite. In general, however, it is much more stable than marcasite. Pseudomorphic crystals of limonite after pyrite are common. Pyrite veins are usually capped by a cellular deposit of limonite, termed *gossan*. Rocks that contain pyrite are unsuitable for structural purposes because the ready oxidation of pyrite would serve both to disintegrate the rock and to stain it with iron oxide.

**Occurrence.** Pyrite is the most common and widespread of the sulfide minerals. It has formed at both high and low temperatures, but the largest masses probably at high temperature. It occurs as a magmatic segregation, as an accessory mineral in igneous rock, and in contact metamorphic deposits and hydrothermal veins. Pyrite is a common mineral in sedimentary rocks, being both primary and secondary. It is associated with many minerals but found most frequently with chalcopyrite, sphalerite, galena.

Large and extensively developed deposits occur at Rio Tinto and elsewhere in Spain and also in Portugal. Important deposits of pyrite in the United States are in Prince William, Louisa, and Pulaski counties, Virginia, where it occurs in large lenticular masses which conform in position to the foliation of the enclosing schists; in St. Lawrence County, New York; at the Davis Mine, near Charlemon, Massachusetts; and in various places in California, Colorado, and Arizona.

**Use.** Pyrite is often mined for the gold or copper associated with it. Because of the large amount of sulfur present in the mineral it is used as an iron ore only in those countries where oxide ores are not available. Its chief use is a source of sulfur for sulfuric acid and *copperas* (ferrous sulfate). *Copperas* is used in dyeing, in the manufacture of inks, as a preservative of wood, and as a disinfectant.

**Name.** The name *pyrite* is from a Greek word meaning *fire*, in allusion to the brilliant sparks emitted when struck by steel.

#### COBALTITE— $(\text{Co, Fe})\text{AsS}$

**Crystallography.** Isometric;  $2/m\bar{3}$ . Commonly in cubes or pyritohedrons with the faces striated as in pyrite. Also granular.

$P_{2,3}$ ;  $a = 5.57 \text{ \AA}$ ;  $Z = 4$ .  $d's = 2.78(5), 2.48(10), 2.27(7), 1.676(9), 1.488(5)$ .

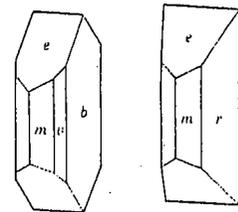


FIG. 306. Marcasite crystals.

**Physical Properties.** Cleavage  $\{001\}$  perfect. Brittle. H  $5\frac{1}{2}$ . G 6.33. Luster metallic. Color silver-white, inclined to red. Streak grayish black.

**Composition.** Usually contains considerable iron (maximum about 10 per cent) and lesser amounts of nickel. *Gersdorffite*,  $\text{NiAsS}$ , and *cobaltite* form a complete solid-solution series, but intermediate members are rare.

**Diagnostic Features.** Although in crystal form *cobaltite* resembles pyrite, it can be distinguished by its silver color and cleavage. Fusible at 2–3. On charcoal it gives a volatile white sublimate and characteristic garlic odor. In the oxidizing flame in borax bead it gives deep blue color (cobalt).

**Occurrence.** *Cobaltite* is usually found in high-temperature deposits, as disseminations in metamorphosed rocks, or in vein deposits with other cobalt and nickel minerals. Notable occurrences of *cobaltite* are at Tunaberg, Sweden, and Cobalt, Ontario. The largest producer of cobalt today is the Congo, where oxidized cobalt and copper ores are associated.

**Use.** An ore of cobalt.

#### X MARCASITE— $\text{FeS}_2$

**Crystallography.** Orthorhombic;  $2/m2/m2/m$ . Crystals commonly tabular  $\{010\}$ ; less commonly prismatic  $[001]$  (Fig. 306). Often twinned, giving cockscomb and spear-shaped groups (Fig. 307). Usually in radiating forms. Often stalactitic,

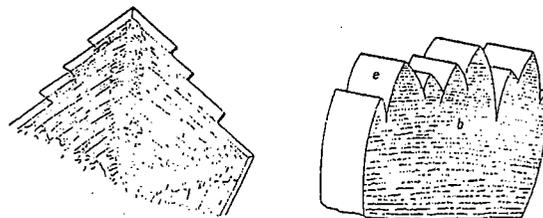


FIG. 307. "Cockscomb" marcasite.