the other hand, very thin muscles did not consistently have higher Q_{O_2}'s (see *6*). There would seem to be an optimum size, but the data are not conclusive in this respect. When muscles which weighed more than 3 mg (dry wt.) were eliminated from consideration, the Q_{O_2} in 98 percent O_2 was higher ($\bar{X} = 3.6$), and the depression in 25 percent O_2 was slightly greater ($\bar{X} = -55$ percent). The Q_{O_2} of 3.6 is similar to that reported by Lee (*7*) for cat papillary muscles, if the difference in temperature is considered. However, Cranefield and Greenspan (*6*) found considerably higher values for thin muscles and, even if allowance is made for the higher temperature they used, there is no obvious explanation for the different results.

We further examined the data to see if the thinnest muscles had the greatest work capacity per unit of weight, but found they did not (Fig. 1, bottom). The number of very thick muscles was too few to warrant comment on this point (see *8*).

The significance of these results lies not in the fact that the Q_{O_2} was depressed by low pO_2, but that the effect was reversible, and the work capacity was not affected during the time when the Q_{O_2} was depressed. Fuhrman *et al.* (*5*) and others cited by them found that in rat heart slices the depression of Q_{O_2} was irreversible.

We have found no comparable studies in which the work capacity was tested, but Furchgott and Shorr (*9*) did find evidence that the rate of synthesis of high energy phosphate in heart-muscle slices was reduced in 20 to 23 percent O_2. However, the assumption that the contractile mechanism would be correspondingly reduced is, as they said, not necessarily true. Our data suggest that it might not be true.

Our results may help to explain the "stretch response" in muscle, that is, the increase in heat liberation and O_2 consumption when a muscle is stretched (*10, 11*). As suggested by Cranefield and Greenspan (*6*), at least part of the response may be due to the smaller cross-sectional area of the stretched muscle.

In the calculations of the "limiting thickness" for O_2 diffusion through tissues (*12*) it is generally assumed that the Q_{O_2} is independent of the pO_2 as long as a finite amount of O_2 is present. In view of the present results it may be appropriate to re-examine this assumption.

There is additional inferential evidence which seems to support the hypothesis that the pO_2 may limit a heat-generating reaction (see *1*), but speculation at this time seems fruitless. A proof of the hypothesis would demand a complete audit of energy liberation and utilization. We have simply shown that one function of muscle, albeit the primary one, is not deprived of an energy source at a time when the resting respiration is markedly reduced (*13*).

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22 May 1963

Littorina littorea: An Indicator of Norse Settlement in North America?

Abstract. *It is suggested that the originally European species* Littorina littorea *was introduced to North America by Norse settlers about* A.D. *1000. Its subfossil distribution might be used in tracing the extent of Norse travel in this region. Recent archeological finds match very well with the historical records of the Norse exploration and settlements. This activity seems to have been concentrated in Nova Scotia and Newfoundland.*

Clarke and Erskine (*1*) have reported specimens of *Littorina littorea* from a cultural site at Halifax, Nova Scotia. The species, which is widely distributed along the coast of western Europe, was earlier thought to have been introduced by ships from Europe about A.D. 1840. The Nova Scotia material gave a radiocarbon age of 700 ± 225 years ago and Clarke and Erskine concluded that the species must have been native to the Halifax area before the advent of European culture.

This is not supported by the radiocarbon dating, which certainly is "pre-Columbian" but not older than the Norse exploration and settlements which started about A.D. 1000. The history of these activities has mainly been known from the literature, but the recent expeditions of Helge Ingstad have shown a Norse settlement on Newfoundland (Lance aux Meadows) (*2*). This find is the first archeological evidence of Norse activities in North America. One of us (K.H.) took part in last year's expedition, which gave evidence of a highly specialized settlement, probably by the Norse population from Greenland. This is supported both by the archeological data, and by 12 radiocarbon ages all indicating an origin at about A.D. 1000.

Littorina littorea is very common along the coasts of Norway and Iceland, and studies indicate that it was equally common in the period A.D. 1000–1400. It is a hardy species, which can survive for a long time in the bottom water of open boats. It might be introduced into the boats either inadvertently through ballast stones, or purposely because it is edible and is used as bait when fishing. It is frequently found in refuse heaps in archeological sites in Norway, with other mollusks which have evidently been used for food. Experience has shown that it is very difficult to keep Viking ships dry when passing the North Atlantic, and *L. littorea* might therefore easily have survived the transatlantic trip. In fact, it is more likely to do so than most other marine mollusks.

It is therefore possible that the fossil specimens found at Halifax are from a population of the mollusks introduced by the Norse settlers. The present populations along the coast from Nova Scotia to New Jersey might be descendants of this one, or they might be due to a later introduction of the species about A.D. 1840.

It seems less probable that the fossil population should represent a stock native to the area. In that case it would be a relic, isolated from the main area of distribution of *L. littorea*, possibly by the worsening of the climate about 2500 years ago. In Spitzbergen this species existed during the climatic optimum, but now it is no longer found there (see *3*). In Greenland, however, *L. littorea* is not known from the warm period; in its place other species of *Littorina* are found (see *4*).

This makes it likely that *L. littorea* was introduced to North America by man. The fact that the Norse settlers came from Greenland, where the species is not found at present, does not contradict this. The limiting factor for the species in Greenland is probably the winter conditions, and ships arriving in the spring and summer from Norway or Iceland with living *Littorina* specimens on board might easily have carried them to North America the same summer.

There are historical records of Icelandic ships used in the trips from Greenland to North America, and it should also be noted that the shorelines at the Norse settlements in Greenland were submerged after A.D. 1000, so that subfossil specimens of *L. littorea* are not likely to be found at the present shores of Greenland.

The fact that this species presumably was introduced to New England from Nova Scotia by man, and the strong possibility that the fossil specimens were introduced from Europe by man also, indicate that it might be a "guide fossil" for naval exploration and settlements along the eastern coast of North America.

The reason that it was not introduced also into New England by the Norsemen was probably that they mainly visited the northern localities on Newfoundland and Nova Scotia.

It is likely that New England also was visited by the Norse settlers, but probably only by small parties on brief reconnaissance tours. The larger groups of settlers probably did not penetrate that far south. The largest group recorded, which went to North America, consisted of three ships with 160 persons and cattle. It stayed for 3 years.

Most of the Norse settlements were probably of the same type as that found by Ingstad at Lance aux Meadows. This consisted of rather large houses, and evidence is found of iron production from bog iron ore. Studies now under way will show whether these settlements were permanent ones, or whether they were visited intermittently for collecting timber and firewood, and to make charcoal and produce iron, all for the main settlements in Greenland (*5*).

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3 June 1963

Distribution of Atoms in High Chalcocite, Cu_2S

Abstract. *In spite of its simple composition, the structure of chalcocite,* CU_2S*, has long defied analysis. In high chalcocite the sulfur atoms are in hexagonal close-packing, while three varieties of copper atoms, with four-fold, three-fold, and two-fold coordinations respectively, are in disorder in the interstices.*

The investigation by Buerger (*1*) of the phase diagram of Cu_2S-CuS established the general relations between low chalcocite and high chalcocite. The two phases are related by a rapid transformation at about 105°C which appeared to be of the order-disorder variety. In a later investigation (*2*) of the unit cells and space groups of low and high chalcocite the suspected substructure relationship was confirmed.

The high symmetry of high chalcocite ($P6_3/mmc$) and its small hexagonal cell (a = 3.89 Å, c = 6.88 Å, with 2 Cu_2S per cell) made it appear a simple matter to find its structure. Many years ago two attempts were made in this laboratory to do this, but neither succeeded in finding, by straightforward methods, an arrangement of atoms which explained the intensities. Belov and Butuzov (*3*) presented a structure, but this was certainly wrong since it was one of the ones we had

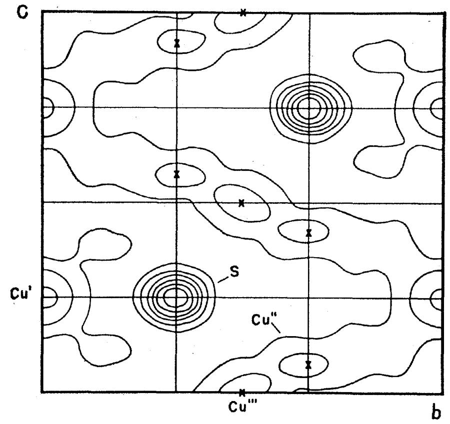

Fig. 1. Electron density section $\rho(0\,x\,y)$ through the orthohexagonal cell for high chalcocite.

already discarded. Ueda (*4*) also found that no simple arrangement of copper atoms provided agreement of computed and observed intensities, and he concluded that the copper atoms were in complete disorder, a conclusion already noted by M. J. Buerger (*5*). The disorder was apparent also from the investigations of Jensen (*6*), who studied the diffusion of Cu in chalcocite; he observed that the diffusion rate increased rapidly in low chalcocite as the temperature approached the transformation temperature, and was much higher throughout the high-chalcocite range. Furthermore, the activation energy for diffusion was about 0.15 ev, an extremely low value compared to the 1 to 2 ev usually found for metal-atom diffusion in close-packed compounds.

The difficulty in finding a structure for high chalcocite has been due to its probably disordered structure, so that the four copper atoms per cell could not be placed merely on a four-fold or two, two-fold equipoints. To find the distribution of disordered copper atoms would require unorthodox methods.

For the present structure investigation we required accurate x-ray diffraction intensities. To allow for absorption we wanted to have a spherical sample and attempted to grind a sphere from the chalcocite obtained from Bristol, Connecticut. We succeeded in obtaining an ellipsoid, but developed a method of allowing exactly for its absorption. The sample was oriented with a precession camera. When oriented, it was maintained at 125°C with a heating attachment, and the full set of three-dimensional reflections were recorded on an integrating cassette on the precession camera. The intensities of these reflections, corrected for Lorentz, polarization, and transmission factors, permit-