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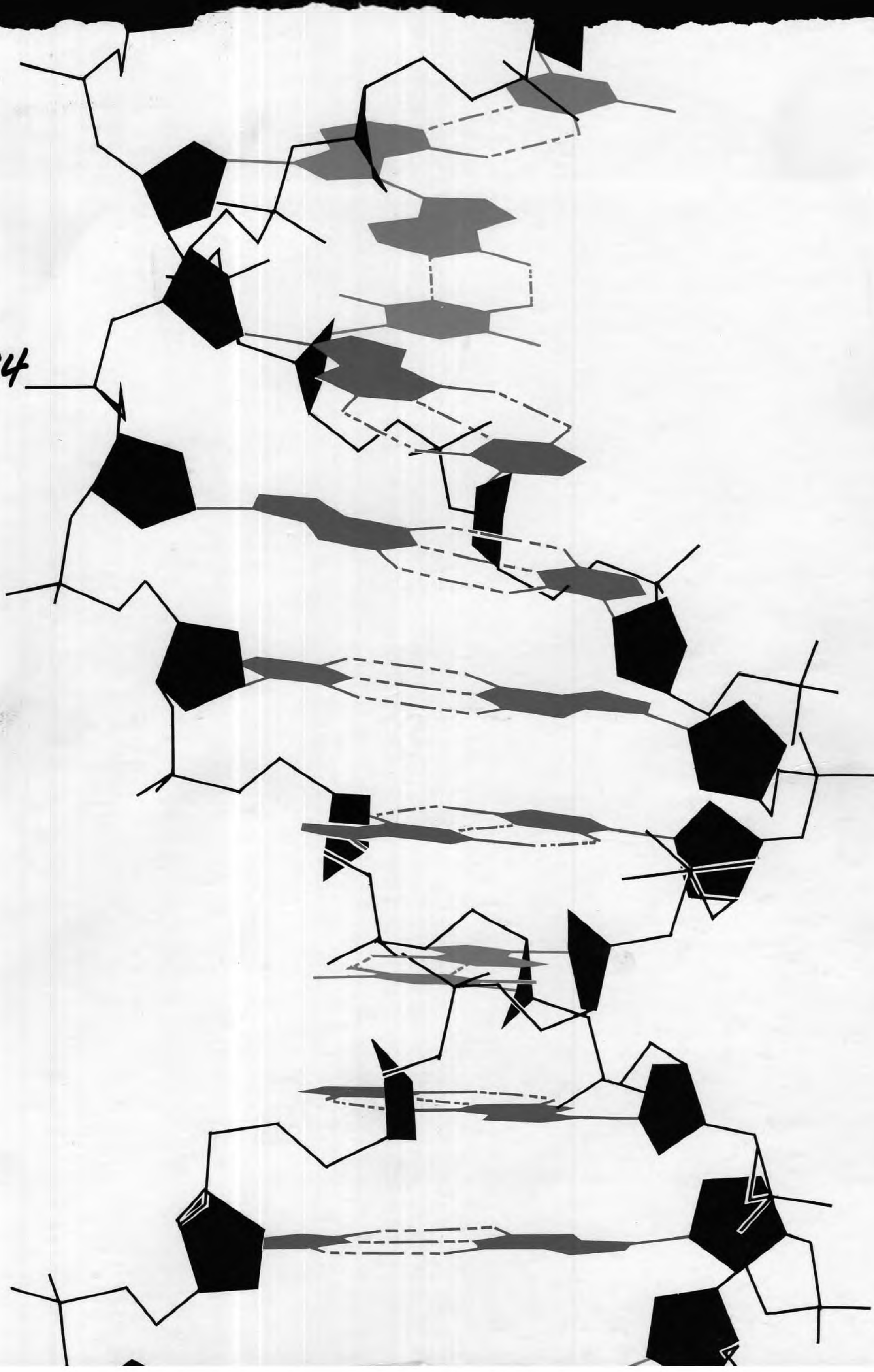
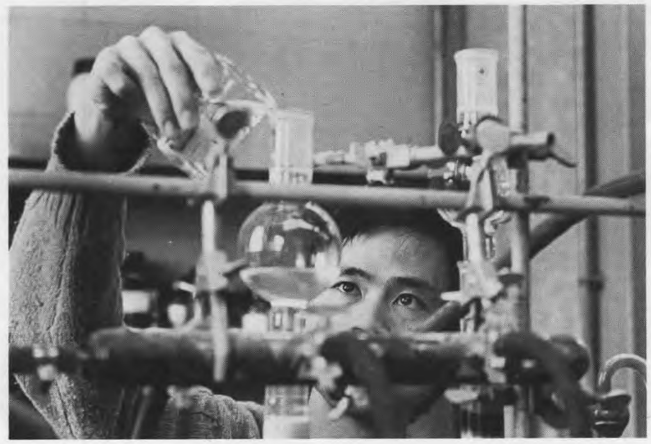
October 1984

EXPLORATIONS

A JOURNAL OF RESEARCH AT THE UNIVERSITY OF MAINE AT ORONO





Welcome to the first issue of EXPLORATIONS, A Journal of Research at the University of Maine at Orono. Join us as we explore a representative selection of the pure and applied research of our faculty. At UMO, we believe that research can capture the imagination and invigorate the mind, as well as contribute directly to the quality of life of the citizens we serve.

In this first issue, we have selected four areas of research that span the disciplines of biological and environmental sciences and the arts. This is but a small part of the research conducted by the faculty at UMO where research, teaching and public service activities support baccalaureate degree study in more than 85 fields and graduate study at the master's and doctoral levels in more than 50 fields.

EXPLORATIONS

A JOURNAL OF RESEARCH AT THE UNIVERSITY OF MAINE AT ORONO

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THE DNA MOLECULE
Mapping its Mysteries

Clues to an organism's ancestral past can be found in the DNA molecule. Modifications in the species, the cell, and the genome (the complete set of genes in the organism) are demonstrably etched in DNA sequences. Exploration of these sequences suggests that DNA, while expressing itself, gravitates toward certain habit patterns: specific shortcut ways of performing, which show the DNA molecule acting as if drawn to a special kind of efficiency, and once finding the most efficient, locking on to it. The more of a specific product a cell needs, the more often its DNA produces it, and the more tightly and efficiently the process is encoded in the sequences, the further it becomes locked into habit. Analyzing the DNA's codon preferences, its habit patterns, by computer also serves to show just where genes lie. This visually charted information looks to the efficient synthesis of hormones and other medically important substances: "Genetic engineers might find that it would pay in the long run to translate the mammalian codon pattern to that of the bacterium" . . . (and proceed) "by established organic chemical techniques."

BY R. D. BLAKE

The subject of our research is the DNA molecule, "a long slimy small wriggly thing that keeps copying itself and somehow has knotted onto it a plan of the animal it lives in"(1). While its diameter is a slim 1/12.5 billionths of an inch, its length reaches an extraordinary 72 inches in a single human cell, where it has the capacity to code for more than five million different genes. "The human body is, in point of fact, infested with the stuff." A major quest of our research is the nature of the different structures presumed to be adopted by this complex molecule at various times during the performance of its two principal biological roles (2). Studies currently in progress by Gary Day, Susan Helek and me involve an investigation of the relationship between segments of genes encoded in the DNA sequence, and the ability or energetic cost to these segments of forming alternate spacial configurations. An incidental goal of this work is to determine whether local stability may not be a factor in providing temporal control over staging of the differentiation process.

DNA is a biopolymer of just four repeating monomeric units or bases denoted simply as A, T, G and C, (adenine, thymine, guanine, cytosine), and arranged in sequences that are specific for each gene and each organism. It is also double stranded, with the As in one strand bonded weakly to Ts in the other, and similarly, with Gs bonded to Cs. The two strands wrap around one another to form the familiar double helix, with the A-T and G-C base-pairs more or less sequestered in the center. It is of vital importance to the survival of the organism that these bonds between strands always be between As and Ts, and Gs to Cs, and that they be weak. Minor changes (mutations) in the genetic plan encoded in the sequence of As, Ts, Gs and Cs can sometimes lead to dramatic changes in the character of the cell. For example, spontaneous and cumulative changes of sequence may be manifest as senescence or cancer. When changes occur in germ cell DNA, they may be passed along to future generations, which if not fatal or deleterious, may eventually be seen in the evolution of the species.

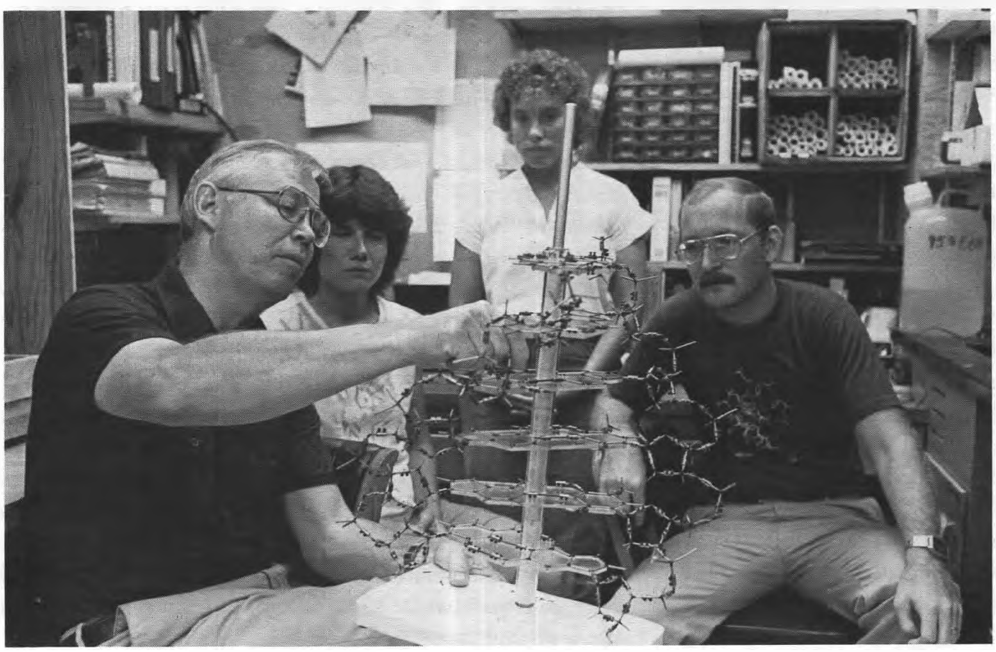
The reason bonding between strands must be weak is so

R. D. Blake is Professor of Biochemistry at the University of Maine. His thesis work at Princeton (1967) was on the kinetics of helix formation in nucleic acids. His current interest continues to be with nucleic acid structure, with a special focus on the evolution of nucleic acid sequences, as well as on mechanisms of gene expression, order-disorder processes of nucleic acids, and on the interactions of ions, drugs and solvent with nucleic acids.

they may more readily undergo local separation, enabling the sequence of specific genes to be exposed for expression according to the requirements of the cell. A second reason is so the two strands may be later separated and copied from one end to the other, for dissemination to the daughter cells during cell division. The former process is referred to as transcription; the latter is replication. We and others have measured the strengths of bonds holding the two strands together, and we find the G-C (or C-G) base-pairs to be almost 12 percent stronger than the A-T (or T-A) base-pairs (3,4). This means the slightest preference of one or the other pair over a short segment of the double helix should lead to variations in the local stability of DNA, and indeed that is what we observe, (Figure 1) using a high-resolution physical method developed by Weber Yen, Thomas Hydorn, Stephen Lefoley and me in 1977-80 (3,5-7). However, the effect is significantly more pronounced than anyone had anticipated, reflecting our considerable ignorance about the energetic and structural dynamics of the molecule. Susan Helek, Karin Ost and I continue to work on this problem with cloned DNAs of defined sequence. Results with such specimens seem to provide the best indications yet of factors determining the local polymeric chain dynamics of DNA, particularly those partially dissociated forms that may specially relate to the biological functions of this molecule. A detailed knowledge of such structures will be essential for the development of suitable structural models for intermediates during replication and transcription, two processes that require DNA adopt different local structures from the familiar double helix.

Studies with DNAs of defined base sequence became possible only quite recently with the development in 1975-77 (8-10) of rapid and efficient methods for determining the base sequence of DNAs. The Nobel Prize was awarded to W. Gilbert and F. Sanger (his second) in 1980 for their independent contributions to the methodology of sequencing. The importance of a base sequence library is that it opens up a totally new and direct approach to those age-old questions of gene expression and control, and this fact is undoubtedly responsible for the extraordinary exponential growth rate of the library, which increases tenfold each year. We estimate (11) that almost five million base-pairs will have been sequenced by mid-1985, which is equivalent in length to an entire bacterial genome. (The human genome is some one thousand times longer, and therefore will take a proportionately longer effort to complete). Most laboratories conducting analyses on DNA sequences obtain a computer tape containing an up-to-date listing of the growing base sequence library from the Los Alamos National Laboratory in New Mexico.

From studies of this large sequence database, a number of investigators have demonstrated recently that the nonrandom variations in stability we have observed show a weak statistical correlation with genetic *functional units* in the DNA sequence (12-14). While we find these results exciting, since they would appear to offer new justification for our high resolution studies of stability, we do so for very different reasons. We believe the cause and effect relationship between DNA base sequence and stability is just opposite that which has been proposed, and that the correlation is the consequence of decidedly nonrandom sequences in functional DNAs (15-19). By coincidence these studies intersect with those of a computer analysis study of sequences that has been underway in our



Professor Blake, graduate student Susan Heleck, undergraduate Karin Ost, and graduate student Philip Hinds examine a model of part of the familiar double helix.

laboratory since 1979, shortly after the development of DNA sequencing methodology. Recent results of Philip Hinds, Gary Day, Scott Early and mine working on the latter study have come up with a different, more mundane explanation for the correlation phenomenon (18-20).

Beyond the development of a large number of computer programs and statistical criteria for the analysis of sequences, our initial objectives in this study were naively phenomenological (11,18). There was almost no literature base from which to work on the analysis of DNA sequences before 1979. Through access to the growing Los Alamos sequence library, our first efforts quickly led us in a search for vestiges of the evolutionary past in different segments of DNA sequence (19). We had indications that such archeological remnants might provide clues of the involvement of specific molecular components in bringing about evolutionary-level modifications of the genome, and thereby, of the cell and species. These remnants are in the form of short codons, used during the expression of genes to produce protein molecules. Whereas DNA is a more or less passive molecule with structural monotony over exceedingly great lengths (much as a large cookbook), proteins exhibit far more structural variability and are often quite active in the cell (much like Julia Childs). The synthesis of proteins is prescribed by the sequence of bases in DNA by a rather complex process (2). Like DNA, proteins are also biopolymers, the difference being that the monomeric unit is an amino acid, of twenty different types. Thus, a protein of 100 amino acids in length has the potential for 100^{20} different sequences, providing far more than enough variability to satisfy all the complex needs of a cell. Proteins are not as constrained as DNA in their ability to assume different spacial configurations, and we see them taking up all sorts of different shapes to meet the hundreds of different specific needs of the cell. Each shape is, of course, dictated by the specific amino acid sequence of the protein.

During gene expression, the relationship between DNA and protein is as follows: a gene prescribing the synthesis of a specific protein, for example, the globin of hemoglobin, is first delineated in the DNA molecule, and then transcribed into an RNA molecule. This RNA is absolutely identical in base sequence with one strand, the *sense* strand of DNA, over the length of the gene. (The average gene is about 1000 base-pairs in length.) The next few steps involve movement of the RNA copy into association with a large number of other factors to form a complex assembly ready to produce a protein. Components of this assembly then look for a sequence of three bases in the RNA transcript that specifies *start*, a unique signal telling the assembly to begin protein synthesis. Amino acids are then joined one after another into a growing chain according to the sequence of bases in the RNA. Each amino acid is coded for by three bases, designated a codon. The RNA, therefore, is ratcheted through the protein synthesis assembly three bases at a time until the *stop* signal appears, completing the synthesis of the protein. Since there are four different bases in DNA (or RNA) there are 4^3 or 64 possible codons for just 20 amino acids. Obviously there are several codons for each amino acid, but the distribution is not haphazard. There is one triplet for some amino acids and as many as six for others, in rough proportion to their occurrence in proteins. With minor exception the code is universal.

Focusing on the large number of sequences that were available on our computer tape for the common colon bacterium, *E. coli*, Philip Hinds and I sought to determine the level of codon usage in this popular laboratory organism (19,20). We found that codons were used in a

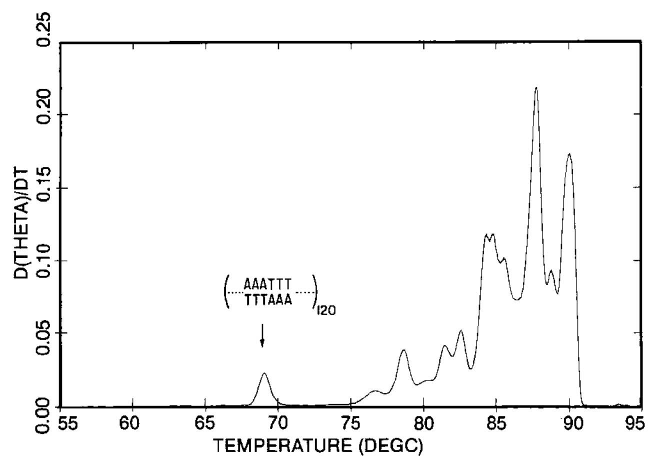


Figure 1. A stability profile of pA-T120 DNA. This plasmid is only 4,483 base-pairs in length, yet it contains (genetic) instructions sufficient for efficient self-replication when slipped inside the bacterium E. coli, *plus it contains both tetracycline and ampicillin resistance genes for ready identification of recipient cultures. The DNA replicates in the form of a closed circle, and also contains a synthetic insert of A-T base-pairs, prepared by standard recombinant techniques (2). Susan Heleck has isolated several subcultures containing plasmid with various discrete lengths of A-T base-pairs at the site of original insertion. The specimen in this figure has been determined to have 120 A-T base-pairs in the approximate middle of the linearized plasmid DNA. Since the A-T base-pair is significantly weaker than the G-C, this insert dissociates at relatively low temperatures to form a bubble between two helical segments, seen in this figure as a well-isolated band at about 69 degrees C. Other studies indicate this A-T insert to dissociate at 63 degrees C., when located at the end of the plasmid DNA. The dependence of stability on location provides information about the physical dynamics of the DNA chain. The complex profile above 75 degrees C. represents the dissociation of the remaining helix, and shows that the dissociation process occurs by unraveling of domains of differing discrete stabilities. (Reference: S. Heleck (1984) M.S. thesis (in preparation), Department of Biochemistry, University of Maine at Orono.)*

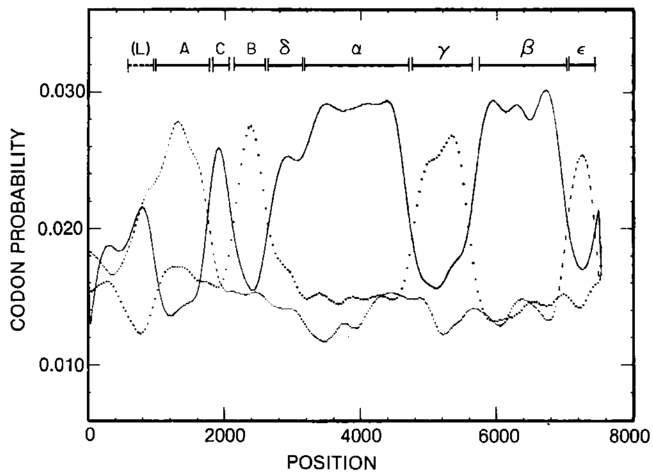


Figure 2. Example of the graphic identification of codon reading frame sequences in DNA (20,23). The sequence of this example is the 7,540 base-pair gene cluster from E. coli *known as the* pap operon, *coding for all eight subunit proteins making up the large proton translocating ATPase enzyme* (a, b, c, d, e, *A, B and C). A computer program (23) assigns a probability to each triplet equal to the frequency of occurrence as a codon in the total* E. coli *database, and returns the codon probability for each triplet in a window as the sequence moves past. The complete sequence is passed before the window three times, once for each of the three possible reading frames. The eight genes of the* pap operon *are clearly delineated in this figure where codon probabilities rise and fall by 80-100 percent. A random probability of triplet occurrence corresponds to a value of 0.0156 (1/64) on the left-hand vertical scale, while values for coding frame regions are seen to rise to an average of 0.028, corresponding to the use of only 36 codons. Such high values (low codon use) reflect a highly preferred codon pattern in these genes. There is perfect correspondence between segments delineated graphically by a sharp rise or fall and those assigned in the literature on the basis of* start *and* stop *punctuation codons, and indicated in the top of this figure by heavy horizontal lines. Changes in reading frame between different genes along the length of the operon are also quite evident. The efficacy of this program in delineating reading frame sequences is equally as good for almost every* E. coli *gene sequence examined, yet we found it was unable to delineate reading frame segments in selected sequences from other bacterial species. (Reference: P. Hinds (1984), M.S. thesis (in preparation) Department of Biochemistry, University of Maine at Orono.*

distinctly nonrandom fashion, confirming the earlier results on a smaller sampling by a French group (15-17). We found this bacterium to use an average of only 35-45 codons out of a possible 64, and that this preference pattern was rather uniformly distributed throughout all *E. coli* sequences. We then demonstrated a strong correlation between the 64 codon frequencies and all overlapping triplet base frequencies, and this allowed us to extend our analysis to all sequences, not just those coding for proteins. We found a surprisingly high degree of correlation between triplet frequencies everywhere in the genome indicating the ubiquitous presence of primordial coding remnants (19). We concluded from these results that during the early evolutionary life of this bacterium, the codon usage pattern showed more and more preferences, and eventually became thoroughly *frozen in* by the inertial barrier to any further change due to the overwhelming complexity of the protein synthesis assembly. That we find remnants of this ancient codon pattern throughout the genome then indicates that the evolution of the genome involves processes of gene duplication with rearrangement and slow divergence of those sequences that are free of selective pressures. Such a mechanism for the origin of new genes during the evolution of higher, multicellular species is now widely accepted (21). In bacteria, however, the pressures for genomic *streamlining* apparently eliminate most burdensome noncoding segments (22), and, therefore, the usual telltale signs of the duplicative-divergence mechanism seen in higher species are missing. A further result of this study is that the codon preference pattern in genes of certain viruses that infect this bacterium show an extraordinarily high correlation with their host (19). These high levels of correlation contrast with the zero levels we see for sequences from other species, even related bacteria.

In our most recent computer analyses of *E. coli* sequences, Philip Hinds and I have obtained results that appear to have uncovered a very primitive and basic mechanism of control of gene expression (20). We characterized 53 different gene sequences according to the level of average codon preference, ranging in usage from a low of just 33 codons to a high of 58. We then found an excellent correlation between the level of preference in DNA, the level of specific components that recognize each codon in the protein synthesis apparatus, and the abundance of protein product, indicating that codon patterns of preference are exploited by the cell for the production of widely different levels of gene product. We suspect this mechanism of control over gene expression is much more pervasive than that of more elaborate, classical regulatory mechanisms involving specific gene repressors and activators (2).

An incidental aspect of this latter study is the utility of the preference codon pattern for identifying coding regions in otherwise undistinguished stretches of DNA. We have written a small computer program that reads in the DNA sequence three times, beginning each time with the next base in from the end (20,23). The program then simply assigns a probability that each triplet of bases is a codon according to the frequency that that triplet is observed to occur in our analysis of the 53 sequences. This assignment is made on all three sequences with different frame shifts for each triplet. The results are best seen in a graphic output; the example seen in Figure 2 is for a large sequence of 7,540 bases in length coding for a gene cluster of eight different proteins. The broken horizontal bar in the figure indicates the positions of coding regions assigned in the literature, while the three undulating lines indicate variations in coding probability. The eight genes are clearly delineated where probabilities abruptly increase and decrease, in perfect correspondence with assigned regions. Changes in reading frame among the different genes are also quite evident in this figure.

This type of graphic analysis will be useful for locating partial genes in DNAs isolated in fragments (the usual case), and for translating the genetic information of one species to that of another. Despite the oft-quoted *universality* of the code, genes from mammalian species often show reduced activity when inserted into a bacterium, for example, for the synthesis of a medically or commercially important hormone or other protein. One reason for a lower level of synthesis is that all the components of the bacterial protein synthesis machinery, essential for reading specific codons in the DNA transcript from the mammalian gene, are simply not present in the most favorable concentrations for the unusual codons it encounters. Genetic engineers might find that it would pay in the long run to translate the mammalian codon pattern to that of the bacterium, and then to synthesize the translated sequence by established organic chemical techniques. Needed for this will be tables of preferred codon frequencies for both bacterium and mammalian species. We have established the codon pattern for *E. coli*, the most popular bacterium for genetic engineering work, and have also published the human DNA pattern (20). We are presently working to establish the patterns in other mammalian DNA gene sequences. However, Philip Hinds and I believe a simpler, more direct approach to this problem is by the development of a computer program that will provide a translated codon table for any species, based on reasonable theoretical assumptions. Our current efforts are focused on this possibility.

Should you wish to explore the molecular biology of the cell, our author recommends selection number 2 as a starting point: *Molecular Biology of the Cell*, by Alberts, Bray, Lewis, Raff, Roberts and Watson.

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THE LARCH

averting a critical shortage

The forest is the foundation of Maine's economy. A renewable natural resource, the forest demands careful attention and professional management to assure a continuous supply of the multiple benefits the forest can supply and people need. About seventy years ago, a severe spruce budworm outbreak caused problems which Maine's pulp and paper industry will face fully in a very short time. The problem rears immediate; the solution rests with research.

BY KATHERINE CARTER

Forests have long been an important part of Maine's economy, from the days when towering white pines provided masts for England's sailing ships to the current emphasis on pulpwood and paper production. Today, with six million acres of timber for raw material, Maine pulp and paper manufacturers employ more than 18,000 workers at 21 mill locations. Seventy-six paper machines, with a capacity to produce 11,500 tons of paper per day, turn out goods valued at more than 2.8 billion dollars annually.

More than 90 percent of the logs processed in Maine's mills are grown in this state, and the industry's future depends on a steady supply of wood, wood which can be used successfully by the industry. A severe spruce budworm epidemic struck Maine forests in 1913-1919, and that destructive moment in history is expected to cause a gap in forest productivity during the years 2000 to 2020. Because fewer than needed native spruce and fir will be reaching a marketable size during that period, pressure is intense to solve the problem. New management methods may allow foresters to reduce the gap by planting trees

Katherine Carter is Assistant Professor of Forest Biology in the University of Maine at Orono's College of Forest Resources. She received her Ph.D. from West Virginia University, where she first became acquainted with the growth potential of larches. Since coming to UMO, her research has centered on the genetics of forest trees, especially white spruce, black spruce, and native and exotic larches.

The larch

which grow quickly and may be used at a younger age than native spruce and fir.

With the support of the Maine Agricultural Experiment Station and the Cooperative Forestry Research Unit (a voluntary association of Maine forest landowners), we have been evaluating several species of larch trees from around the world to assess their potential for large-scale plantations. All these larch species are closely related to our native tamarack (also known as eastern larch or hackmatac) but are generally straighter and faster-growing on good sites. Early indications are that many of these exotic larches reach a harvestable size in twenty to thirty years, as opposed to sixty years or more for native spruce and fir. Consequently, certain larches planted now could be harvested during the critical period of 2000-2020. In addition, larches are seldom attacked by the destructive spruce budworm, and their rapid early growth reduces or eliminates the need for herbicide treatment of planted areas.

Although older, slower-growing larches have a high extractive content which interferes with pulp production, younger trees can be pulped satisfactorily. Investigations of larch wood qualities in Ontario and the Lake States indicate that these fast-growing exotic larches often have higher wood density (0.38 to 0.43) than do mature jack pine (0.39) or white spruce (0.37). Exotic larch fiber

Larch branch and its cones; this particular variety is indigenous to Maine.

lengths are in the range of 2.7 to 3.1 mm, slightly shorter than jack pine and white spruce. Kraft pulping studies of 18- to 23-year-old European, Japanese, and hybrid larches compared to pulp from 50-year-old jack pine indicate that the larches give yields 1 percent to 4 percent greater than the jack pine. European larch pulps were comparable to jack pine in strength properties, while Japanese and hybrid larch pulps had somewhat lower breaking length. In general, the quality of the larch Kraft pulps was sufficiently similar to allow for its use in place of jack pine. In Ontario, larch is currently being mixed successfully with black spruce for the production of bleached Kraft pulp. Canadian studies have also shown that Japanese and European larch are well suited to the production of waferboard material.

A few older plantations of exotic larches in the Northeast provide estimates of potential yields. In New Hampshire, Japanese larch planted at a 7 by 7 foot spacing on a sandy loam soil produced an average of 1.6 cords per acre per year through age 29, as compared to an average production of approximately 0.5 cords per acre per year produced by natural unmanaged spruce-fir stands. Somewhat younger stands of hybrid larch in eastern Maine

Katherine Carter holds a 2½" larch steckling.

have grown at a similar rate, 1.7 cords per acre per year. While these figures demonstrate the productive potential of larches, they provide little relevant information about the expected performance of particular species or seed sources of larch under a range of climatic conditions.

The objective of our current research is to determine which species of larch grows best in Maine. Since there is often considerable variation among trees within each species, we also want to identify individual seed sources that have outstanding growth characteristics and to develop efficient means of propagating these selected trees.

Seeds for this study were obtained from trees in Japan, Denmark, Germany, Czechoslovakia, and Poland, and from some second-generation European and Siberian larches in the United States and Canada. A total of 37 seedlots was collected, representing 11 sources of European larch, 20 sources of Japanese larch, five European-Japanese hybrids, and one Siberian larch source. One-year-old seedlings from each seedlot were planted in 1977 at each of two locations, near Milo in Central Maine and in northern Maine near Ragmuff Stream, 30 miles west of Baxter State Park. These planting sites were chosen because they are located in climatic zones typical of Southern Interior and Northern Maine, respectively. During the years after planting, survival and height growth at both sites have been recorded periodically to detect differences among seedlots and to determine the effect which the planting site has on the growth of different seedlots. (See comparison graph.)

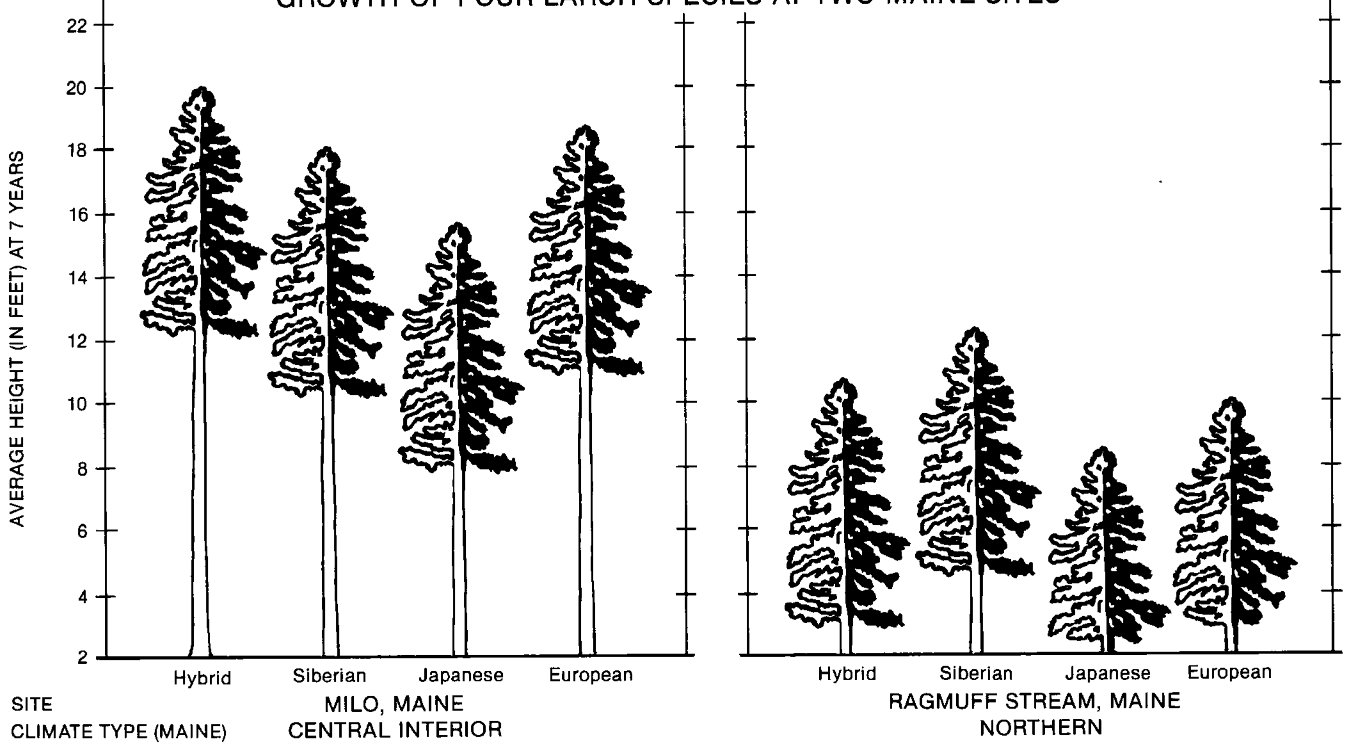
After seven growing seasons, large differences in growth and survival are evident at these two sites. At Milo, survival has been good for all species and growth is excellent, with heights averaging 17.4 feet at the end of seven years. As a group, the hybrid larch are tallest at this site and average 20.4 feet in height. European and Siberian larch at Milo average 19 and 18.5 feet, respectively, and Japanese larch are shortest, with an average height of 16.2 feet. There is also considerable variability between different seedlots of each single species, with some individual seedlots of each species averaging as much as 1.5 to 2 feet above or below the average for their species. This variability would translate into 10 percent to 15 percent gains in growth, simply through the selection of appropriate seedlots within species.

For European and hybrid larches, these differences in growth rate are related to the geographic origin of the seedlots. European larches that originated in seed orchards in Germany and Czechoslovakia grew much faster than trees from other locations. Among the hybrids, the best trees originated from a cross between Japanese larch fathers and female European larches from the Sudetan Mountains near the Polish-Czechoslovakian border. Trees from this cross were taller than any others and averaged 22.5 feet in height at Milo.

Growth patterns in the northern Maine plantation were very different. The colder climate and shorter growing season at that site resulted in reduced growth, and trees averaged only 9.1 feet in height at age seven. In addition, almost half of the Japanese and hybrid larches at this site died, probably as a result of the harsh climate. Japanese and hybrid larches are known to be susceptible to injury and dieback from late spring and early fall frosts. Siberian larch outgrew all other species at this site, averaging 12.5 feet tall. The European larch also survived and grew well, averaging 10.2 feet in height, but the best European seed sources at Ragmuff Stream are from different regions than are the superior European seed sources at Milo. The best European larch at Ragmuff Stream were from seed sources in Denmark, Poland, and plantations in Quebec and Wisconsin. Among the hybrid larches, only one cross survived and grew well (11.3 feet) in northern Maine. This was the same Sudetan-Japanese cross which performed well at Milo. For the pure Japanese larch seedlots, average height at Ragmuff Stream was 8.3 feet and none of the individual seedlots equaled the performance of the European, Siberian, and hybrid larches at that site.

This research indicates that the proper choice of larch species and individual seed sources is critical to the success of planting operations in Maine. For example, the best seed source at Ragmuff Stream is more than twice the height of the poorest seed source, while at Milo the tallest seed source is 50 percent taller than trees from the shortest seedlot. It also illustrates the necessity of experimentation under local conditions prior to the formulation of seed source recommendations. In other larch

GROWTH OF FOUR LARCH SPECIES AT TWO MAINE SITES



Rooting in the greenhouse, larch clones represent potential acres of exotic larch trees.

species trials located in New Hampshire, New York, and New Brunswick, Japanese and hybrid larches have usually outgrown their European cousins. Our research demonstrates that these species are not necessarily the best planting choices in Maine, especially in the Northern climatic zone, where survival of Japanese and hybrid larches is greatly reduced.

Selection of the best seed sources within a single species such as European larch will also be influenced by the climatic zone in which they are to be planted. These plantations included only seven seed sources of European larch, yet the four tallest European seedlots were entirely different at each of the two sites. It is most likely that separate planting recommendations should be made for the different climatic areas of Maine.

In order to sample more of the genetic variability within and among larch species, we have established two more test plantations during 1984. These plantations, located near Topsfield and Kokadjo (Kokadjo is located about 20 miles north of Greenville), include 82 different seedlots of European, Japanese, Siberian, and hybrid larches, plus our native tamarack and Dahurian larch, a previously untried species from central Asia. Data from these new plantations will allow us to refine the results drawn from earlier studies, and to test the performance of these larches in the eastern and western regions of the state. The inclusion of many new seedlots which were not represented in the earlier plantations should lead to the identification of more individual seed sources that can be recommended for specific planting regions. Tamarack has been included in these tests because there is much genetic variability in this species and several of these native larches have been found which have growth rates approaching that of exotic larches. In addition, tamarack is very frost-hardy and it is capable of growing on poorly-drained sites where the exotic species do not grow well.

After superior larch seed sources are identified, they can be propagated by seed or by rooted cuttings to produce large numbers of seedlings for operational plantings. Traditionally, branchlets of superior trees have been grafted into a central area, called a seed orchard, and managed exclusively for the production of seed. The State of Maine and several forestry companies have recently established such seed orchards for the production of superior seed of tamarack, European, Japanese, and hybrid larch. For many larches, however, seed production is sparse and the small cones are difficult to harvest and process efficiently. Seed production also involves sexual recombination, and consequently, the seedlings produced from seed orchards will not have exactly the same genetic characteristics as their parents. This is a particular problem when trying to produce hybrid larch seed.

Clonal propagation of larches is being investigated as a means of circumventing these problems. Clonally propagated material retains the exact genetic makeup of its parents: particularly favorable gene combinations can be maintained. At this time, the use of rooted cuttings is the most promising means of clonal propagation for larches, since cuttings taken from young seedlings root readily. Dozens or even hundreds of rooted cuttings called stecklings can be produced from one seedling during the course of a year. The two and one half inch cuttings are treated with rooting hormone and placed under an automatic misting system in the greenhouse. Roots begin to form in about six weeks, followed by shoot growth of the cutting. After several more weeks, the rooted cuttings are ready to be planted in the field.

Since the idea of planting rooted cuttings of larch is relatively new, many unanswered questions need to be addressed. How will the growth rate and form of the stecklings compare to that of regular seedlings? Will the stecklings survive field planting as well as seedlings do? How much variability will there be among stecklings that share a clonal origin from the same seedling? For large-scale plantations, should stecklings of different clones be intermixed or planted in patches of pure clonal composition? Research addressing some of these questions is now underway in cooperation with Dr. E. K. Morgenstern at the University of New Brunswick, and two research plantations of these clonal stecklings are expected to be established next year.

By its very nature, forestry research involves long-term studies. The larch species trials established in 1977 are now providing important information about juvenile growth relevant to species and seed source selection. As a rule of thumb, however, results are not considered fully reliable until trees have reached half of their expected rotation age. For larches to be grown on a 25-year rotation, this means that twelve years of data are needed to make final decisions regarding seed source recommendations. Until then, the seven-year results may serve as a general guide to seed source selection for larch plantations in Maine. As research on seed source selection and clonal propagation progresses, its implementation should result in greater productivity and more efficient use of Maine's forest resources.

THE MEDIEVAL OLIPHANT

Its Function and Meaning in Romanesque Secular Art

This article is a revision of a paper given during the Fourth Symposium on Literature and the Arts: The Medieval Court in Europe, held at the University of Houston, March 2-5, 1983.

BY DAVID MacKINNON EBITZ

Art historians have emphasized the religious arts of the pre-Gothic Middle Ages in Western Europe to the exclusion of all but the most imperial of the secular arts.(1) The Middle Ages are still viewed as Christian centuries, just as the Renaissance was once characterized as pagan. This neglect of the secular arts, though unfortunate, is understandable for several reasons. First, little secular art survives, whether in architecture, painting and sculpture, or in the minor arts, because such arts did not have the aura of sacredness that served to preserve much religious art until the ravages of the Reformation and Revolution. A second reason to ignore the minor arts of secular origin in particular is that so little is known of their provenance, and therefore of the contexts in which they were manufactured and initially used. Being portable and readily exchangeable, they migrated all over Europe. So few having survived and these so poorly documented, they are now difficult to group, characterize, and adequately explain. Finally, since the time of Emile Mâle and Charles Rufus Morey, medieval sculpture, painting and the minor arts have been most extensively studied in terms of their iconography, the meanings that they bear. In this respect, the secular arts have seemed unrewarding, lacking as they do the contexts of theology, liturgical practice, and piety embodied in the numerous religious texts that have been preserved from the Middle Ages to explain the religious

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Figure 1. Oliphant. London, Victoria and Albert Museum (photo: author).

arts, sometimes in quite specific terms. Secular meanings seem vague in comparison. But in a religious age, medieval men and women could also be profane, and products of their secular art do survive.

I want to consider here one of the more prominent and intriguing of these neglected products of secular art, that is, the oliphant, a horn carved from the ivory tusk of an elephant. About seventy-five of these horns survive from a brief period of production during the eleventh and first half of the twelfth centuries. An examination of church inventories indicates that there were once many more of these horns in existence. The majority of the horns were manufactured in Italy. By the beginning of the twelfth century references to ivory horns in inventories, clerical and lay chronicles, and *chansons de geste* and romances show that they were known from France to Germany and England. The focus of my discussion is on the secular function and meaning of these oliphants, but first a few words about when and where the horns were made.

The largest group of surviving oliphants consists of about twenty horns in a style whose closest parallels are with the eleventh-century art of Fatimid Egypt. I illustrate a horn from this group in the Victoria and Albert Museum, London (Figures 1, 2). These horns are associated with four caskets and a writing case. They were first systematically discussed by Ernst Kühnel in an article in 1959, and then catalogued in the posthumous publication of his *Die islamischen Elfenbeinskulpturen* in 1971.(2) Despite the Fatimid sytle of the ivories, there is good reason to believe that they were carved in Venice around 1100.(3) A second group of oliphants was identified by Hans Swarzenski in 1962.(4) Among the more elaborately decorated of the eight horns in this group is one in the Bibliothèque Nationale, Paris (Figures 3, 4). These horns were probably carved in Amalfi, near Naples, also around 1100, in a style related to that of the so-called Salerno ivories, originally part of an alter antependium or door, perhaps, in the cathedral of Salerno.(5) In the following discussion of the function and meaning of the oliphant, I shall limit my consideration to these two groups of horns as being representative of the whole.

The function and meaning of the oliphant are revealed in two kinds of evidence: first, the internal physical and iconographic evidence of the horns themselves, and, second, the external evidence of visual representation of horns and references to horns in written documents. Taken together, these two kinds of evidence tell us of the use, and of the associations attached to the use of these horns during the Middle Ages. It also indicates directions to be explored in considering other kinds of medieval secular art.

The internal evidence is contained in the physical nature of the horns and in the subject matter of their decoration. The horns are fashioned from ivory tusks.

Figure 2. Detail of oliphant. London, Victoria and Albert Museum (photo: author).

These are ordinarily hollow, so that it requires little effort to remove an extra growth ring or two from the interior and to bore out the tip. The resulting horn can be blown, albeit with some difficulty, by pursing and vibrating the lips, as one does with a trumpet. The sound obtained is deep and limited to one, two, or at most three tones. The horns are large, often two feet long, and quite heavy. Thus they are neither musically flexible nor convenient to use. But they are ostentatious. Their effect was enhanced by metal strips mounted around the rim of the mouth and at the tip of many of the horns, and by fastenings at each end attached to a strap that facilitated carrying the horns and hanging them when not in use. These various mounts have long since disappeared, but discoloration, grooves and holes indicate their original presence, as on the Paris horn (Figure 4).(6) In some instances, the mounts, fastenings and hanging strap were later replaced, as done in part on the London horn (Figure 1).(7) An occasional horn remains plugged at the tip, the ivory never having been bored all the way through.(8) These were probably used for drinking, though the opening at the mouth of an oliphant is so broad that is must have been difficult not to spill the drink.

Most of the horns are remarkably well preserved, showing little wear attributable to handling. This suggests that they were rarely used, which is not surprising when we consider how little practical satisfaction they offered the person blowing or drinking from them. Perhaps they were largely for ceremonial show. This may explain why production of the horns ceased almost completely during the course of the twelfth century and so many of them were given to churches,(9) disposed of like previous, but useless, white elephants whose functions and meaning were no longer of interest in a changing society.

The decoration of the horns tells us something of this meaning and its relation to the possible functions of the horns. Both groups of horns are decorated with animals, birds, fantastic creatures, and a few humans. Though no horn may be said to have a developed iconographic program, the decoration is nevertheless meaningful. But it derives its meaning from metaphorical associations and analogies rather than from the precise symbols we look for in religious art.

On several of the Fatimid style horns, a man is shown holding a sword and shield,(10) presumably referring thereby to prowess in hunt or battle, during which the oliphant could have been blown to signal and stir the hearts of hunters or combatants. The variety of animals on the London and related group of horns (Figures 1, 2), taken mostly from the repertory of Fatimid art, may be divided into two types: predators, including lions, wolves and eagles, and their prey, including rabbits, ibexes, antelope, deer, and birds. Occasionally the predator attacks its prey, but more often there is just the potential of attack as each creature remains within its roundel. These animals refer to the hunt. In hunt or battle, the imagery enhanced the prowess of the owner of the horn with respect to his prey, whether animal or human.

These possible meanings are more concretely stated on the other group of horns, on which humans and animals are rendered in a more active mode. The hunt is explicitly represented on the Paris and one other horn as a hunter, on horseback on the Paris horn (Figure 4) and on foot on the other,(11) drives his spear into the rump of a deer while a snake curls out of the deer's mouth in turn to menace the hunter. On two other horns, indirect reference is made to hunting in Classical images of Hercules struggling with the Hind and Nemean Lion.(12) Eighteen of the thirty-five or so figures on the Paris horn are locked in struggle, as the hunter, hounds, eagles, a lion and griffon attack deer and other prey. The outcome of the struggles is foregone: the hunter, whether human or animal, has his way.

The fact that these images were with few exceptions not based on actual scenes of the hunt, but instead copied from one visual tradition or another—from Classical, Byzantine, and Islamic art, or from the indigenous medieval art of Italy—mattered little with respect to the meaning of the images.(13) These attacks of predator on prey, of the strong on the weak, could allude by association, rather than by direct depiction, to the prowess and power of the owner of the horn during the hunt or in battle, and afterward. To understand this visual language and how it worked through a process of association, we can turn to another group of equally traditional, but still meaningful images, the innumerable literary similes and metaphors used to characterize heroes in medieval chronicles and epic literature. For example, in the twelfth-century French epic poem, the *Chanson de Roland*, Roland's effect on the enemy is described by the following simile: "Just as deer run before dogs, / So the pagans flee before Roland" (1874-75, translation mine). This literary simile has potentially the same general meaning as a visual metaphor, or simile if such it was intended, of two

Figure 3. Oliphant. Paris, Bibliothèque Nationale (photo: Bib. Nat.).

dogs chasing a deer on the Paris and another horn.(14) As Roland is characterized by the simile, so potentially are the owners of these horns characterized by the visual metaphor in their decoration. Images of predatory lions and eagles (Figure 3) carry similar meanings, finding a parallel for example in the description by William of Apulia, in the late eleventh-century *Gesta Roberti Wiscardi*, of Greeks fleeing from his hero, Robert Guiscard, like birds and hares from an eagle.(15) Inactive, heraldic images of lions (Figures 2-4) and eagles (16) could be equally significant of prowess and power, in the same manner that the name given to Richard Lion-Heart signified his qualities. The lion and eagle were for such reasons among the most powerful images soon to be commonly adopted on coats of arms.

The imagery on the horns alludes to their potential use as hunting and war horns, and it has the additional or perhaps primary function of signifying the owner's prowess while not actually engaged in these activities. In fact, as already mentioned, the horns must have been awkward to use in hunt or battle, and in practice may have been generally limited to ceremonial occasions.

It may be impossible for us today to understand exactly how this visual imagery was associated with the person who used the horn, but we do have a contemporary analogy which may shed some light on how such metaphorical associations work. This lies in our infatuation with the car.

We can ride a Mustang or a Bronco, restrain a Bobcat or Jaguar, have a "tiger in the tank" and "treads that claw the road." The difference is that in the Middle Ages one actually did and saw such things, and so the similes and metaphors were correspondingly that much more alive and snarling.

A few horns, left plugged with ivory at the tip, were designed for nothing more strenuous than drinking. Other horns could have been put to the same use at times with the judicious placement of a finger or temporary plug. The vine and grape decoration of the Paris and related horns may reflect this function. In this context, too, special meaning may be attached to an image of two birds drinking from a chalice-shaped fountain on the Paris (Figure 4) and two other horns.(17) This is a common image in Christian medieval art, in which the fountain was sometimes understood as the fountain of life.(18) Drinking wine from these secular horns, one was reminded perhaps not only of the pleasures of the drink, but also of the consecrated wine one drank from the Communion chalice. But this possible exception aside, the meaning of the imagery on these horns was not religious.

Some of the animals that appear on both groups of horns, like the lion, were largely foreign to the experience of the carvers and users of the horns. These unusual animals, and such mythical creatures as the winged lion (Figures 2, 3) griffon, sphinx, harpy, and unicorn (Figure 4) together composed a metaphorical world not only of prowess and aggression, but also of strangeness and magic, probably both entertainingly foreign and also frightening. These creatures enhanced the foreign, perhaps magic quality of the horns themselves, as they, the material out of which the horns were carved, and the elephants that provided the tusks all originated in some marvelous foreign land. Indeed, elephants are represented on five of the Fatimid style horns including the horn in London (Figure 1).(19) In like manner, few of us have ever seen a Jaguar, and the Thunderbird exists only in our imagination, so that driving them as cars becomes something special—at least car manufacturers hope so.

We now turn to the second broad category of information available on the function and meaning of the oliphant: the external evidence of visual representations of such horns and references to ivory horns in texts. This evidence will serve to corroborate and extend hypotheses based on the internal evidence of the horns themselves. It is important at the outset to limit our consideration to those visual representations and textual references that actually or at least probably involve ivory horns, because horns made of ivory are quite different from instruments made out of the horns of cattle, metal or other materials. This Ernst Kühnel failed to do in compiling an otherwise impressive collection of visual representations of horns and references to horns in documents, published in *Die islamischen Elfenbeinskulpturen*.(20) While his examples are useful as a source of information on the popularity and use of horns in general, many of the references and a majority of the visual representations are not sufficiently specific to warrant Kühnel's assumption that ivory horns are in fact mentioned and depicted. Thus it is hardly likely that an oliphant would have been used as a musical instrument by a musician, as Kühnel suggests, or as a horn by a huntsman on foot to roust game and signal hunters.

The very nature of the oliphant, large and awkward to handle, ornately carved and costly, and its association with the noble and heroic, would seem to preclude its use in any but the most noble contexts. Such a context might be the scene of the chase of the legendary King Theodoric in the twelfth-century sculpture by Niccolò, on the right side of the portal of S. Zeno in Verona, Italy. (Figure 5) (21) According to a legend popular in Italy and Germany, the king was the son of the Devil, who is shown on the far right. Theodoric sent to his sire asking for the gift of a horse and hound. These gifts arrived while he was in the bath. Too impatient to dress, he sprang on his horse and started out on a wild hunt that took him off to Hell, never to return. He is shown on the portal wearing only a cape flying in the wind, and blowing what could well have been intended to represent an ivory horn. The theme of the hunt is restated between the two halves of the scene representing Theodoric's chase, in terms of the visual simile of an eagle with an animal in its claws, a motif often encountered on the horns.

Another example of what seems an appropriately noble context for the presence of an oliphant is in one of seven large miniatures in the Spanish, so-called *Libro* de los *Testamentos* in Oviedo Cathedral, executed between 1126 and 1129 for Bishop Pelayo of Oviedo. In the miniature representing King Bermudo II in the formal act of giving his testament to an archbishop (Figure 6), the king's armiger carries a sword, shield and horn, presumably the king's own.(22) Here, as in Theodoric's chase, the shape and size of the horn in relation to the human figure support the evidence of context to suggest that what we see is an oliphant.

What also may be oliphants put to other uses are represented on the Bayeux Tapestry, commissioned in the 1070's by Bishop Odo of Bayeux to commemorate the events culminating in the Norman Conquest of England by his half-brother William the Conqueror. In the scene of a feast at Harold's manor house at Bosham, toward the beginning of the visual narrative, one guest drinks from what may be an ivory horn while another guest holds his horn to the table.(23) The Normans were familiar with oliphants by the last quarter of the eleventh century when the tapestry was embroidered. William the Conqueror (d. 1087) himself bequeathed his own ivory horn, *cornu eburneum*, to Rochester Cathedral. Osmund, bishop of Salisbury from 1078 to 1099, gave two ivory horns to his cathedral. Slightly later, King Henry I (d. 1135) confirmed tenure in a grant of land in Inglewood Forest to Carlisle Cathedral through a certain ivory horn, *per quoddam cornu eburneum*.(24) These horns no doubt came from Italy, where other Normans had just completed the conquest of Southern Italy and Sicily, including Amalfi where a number of the horns were probably carved. Therefore the horns depicted on the Bayeux Tapestry may well have been meant to be ivory horns, stopped up at the tip for drinking like the Boston horn.

Another horn is shown on the tapestry being blown by the figure decorating the sternpost of one of William's boats crossing the Channel to England.(25) If this horn was not meant to be an oliphant when the tapestry was made, it soon came to be regarded as one. In an anonymous life of William the Conqueror written during the

Figure 4. Detail of oliphant. Paris, Bibliothèque Nationale (photo: Bib. Nat.).

first half of the twelfth century, a similar figure is described blowing an ivory horn, made for William's flagship at the order of his wife: "In the prow of this same ship this Matilda had made a little figure out of gold, pointing to England with its right forefinger, and with its left hand pressing an ivory horn to its mouth."(26) The figure seems to have served as a source of inspiration and good luck charm, and the oliphant, with those heroic qualities of power and prowess already alluded to, must have been thought to reinforce this effect.

Horns resembling oliphants also appear in noble contexts in the art of France. In the twelfth-century church of St.-Lazare at Autun, for example, a large horn figures prominently on the second capital to the right supporting one of the archivolts over the central portal. The horn appears there as an attribute of St. Eustace, martyred during the time of Hadrian.(27) It hangs suspended over the saint's horse along with his spear, as the saint himself falls to his knees converting to Christianity before the apparition of a crucifix between the antlers of a stag he has been hunting. This horn, too, associated as it is with a noble saint, may have been intended as an oliphant.

Oliphants may enter the realm of theophany at Autun if the angels sounding the Last Judgment on the tympanum above St. Eustace are blowing ivory horns.(28) The horns depicted certainly resemble oliphants. Given the increasing number of ivory horns donated to churches during the twelfth century and the general aura of strangeness and magic we have seen in the decoration of these horns, we should not be surprised to find them raised thus from the human to the angelic sphere, transformed from secular into sacred instruments.(29)

We come finally to the second kind of external evidence for the function and meaning of the oliphant, the evidence found in the written documents. Some of these I have already mentioned. The key document, however, is the *Chanson de Roland*, in which the ivory horn is first given the name *olifan or olifant*,(30) thereby extending through synecdoche the application of a word that in other contexts originally signified elephant and ivory.(31) The *Chanson* purports to describe a rearguard action at Roncevaux in the Pyrenees as Charlemagne was leaving Spain in 778. It gained substance during the course of the eleventh century, and was written down in Anglo-Norman by the mid-twelfth century. What better source can there be for an understanding of the context of medieval secular art than medieval secular literature? Yet it is a source generally overlooked by art historians dealing with the early Middle Ages. Let us listen to what the *Chanson de Roland* has to say about the oliphant. As we may expect, the following scenes in which Roland uses his famous horn are represented in the art of the twelfth and thirteenth centuries throughout Western Europe.(32)

Fighting at Roncevaux to the rear of Charlemagne's

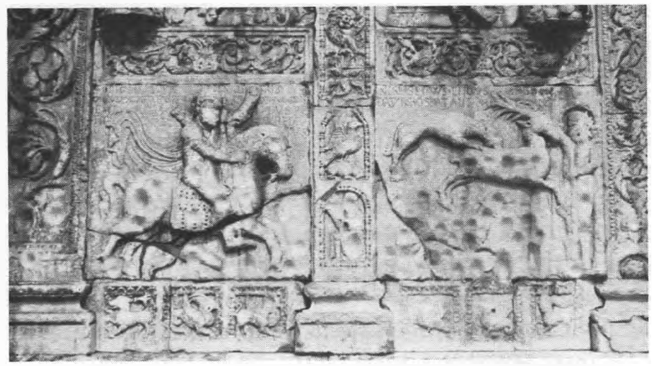


Figure 5. Theodoric's Chase. Verona, S. Zeno, façade to right of portal (photo: author).

army for Christianity and his master against the pagan Saracen, sore-pressed and facing the end, the great hero of the *Chanson* finally winds his oliphant to recall Charlemagne so that his lord might come to avenge his death and that of his companions and bury the dead. And so:

> The County Roland with pain and anguish winds
> His Olifant, and blows with all his might.
> Blood from his mouth comes spurting scarlet-bright
> He's burst the veins of his temples outright.
> From hand and horn the call goes shrilling high:
> King Carlon hears it who through the passes rides,
> . . .
> Quoth Charles: "I hear the horn of Roland cry!
> He's never sound it but in the thick of fight"
> (1761-66, 1768-69).(33)

If we look for prosaic information in the midst of this poetry, we learn that the oliphant takes great effort to blow, but that its sound carries. It is here used as a signal horn in battle. But the horn has other functions as well. Indeed, the villain of the *Chanson*, Count Ganelon, takes advantage of the multiple potential functions of the horn in making fun of Charlemagne for having thought that Roland was blowing his horn in battle, saying:

> For one small hare he'll blow from morn till night;
> Now to the Peers he's showing-off in style
> (1780-81).

So the oliphant could also be used in hunting.

Meanwhile, Roland and his valiant few drive the Saracens from the field. Surrounded by his dead and dying companions, Roland faints. Seeing him, the Archbishop Turpin tries to help:

> He reaches out; he's taken Roland's horn up.
> In Ronceval there runs a stream of water;
> Fain would he go there and fetch a little for him
> (2224-26).

Thus the writer of the *Chanson* was presumably accustomed to seeing such horns used to hold liquid. But the archibisop dies before accomplishing his errand of mercy.

Roland revives, takes his sword in one hand and his oliphant in the other, and falls again into a faint. One of the treacherous Saracens, having feigned death, now approaches to steal the sword. Roland awakens to the tugging and:

> Opens his eyes and speaks this word alone:
> "Thou'rt none of ours, in so far as I know."
> He takes his horn, of which he kept fast hold,
> And smites the helm, . . .
> He breaks the steel and the scalp and the bone,
> And from his head batters his eyes out both,
> And dead on the ground he lays the villian low;
> Then saith: ". . .
> Lo, now! the mouth of my Olifant's broke;
> Fallen is all the crystal and the gold" (2285-92, 2295-96).

In an emergency, the otherwise awkward weight and solidity of the oliphant made it an effective weapon. This excerpt suggests that the mounts on the horn and perhaps the horn itself could be decorated with gold and precious and semiprecious stones.

Roland finally dies. Charlemagne comes, mourns, and then leads the Franks against the Saracens to the sound of Roland's oliphant reverberating above all the other horns, an image often repeated in the epic poems and courtly romances of the later twelfth and thirteenth centuries. The battle won, Charlemagne returns to France with his army.

> They storm Narbonne and leave it by the way,
> And reach Bordeaux, a city of great fame.
> There, on the altar of Sev'rin the good saint,
> Filled with gold mangons, the Olifant they lay,
> (Pilgrims may see it when visiting the place)
> (3683-87).

And so, in the *Chanson*, Roland's horn is given in the end to a church, as often happened in practice during the twelfth century. The *Chanson* focused on a horn actually in St.-Seurin in Bordeaux, for the presence of Roland's ivory horn in the church is corroborated by the famous *Pilgrim's Guide* to Santiago de Compostella, written in Latin around 1139.(34) We can only guess at how the church actually acquired such a horn and how it came to attract pilgrims along with the church's other relics, but it was not Roland's horn in more than legend.

We do not know what happened to this so-called horn of Roland in St.-Seurin in Bordeaux, but just as the relics of a saint could multiply, so did the hero's horns. There is a horn related to the Paris horn in the Musée Paul Dupuy in Toulouse that according to legend was also Roland's horn, given to the church of St.-Sernin in Toulouse by Charlemagne after the hero's death.(35) Then there is the so-called horn of Charlemagne himself in the Palatine Chapel at Aachen, supposedly given to him by the Abbasid Caliph Harun al-Rashid,(36) a foreign origin for

Figure 6. Testament of King Bermudo II, Libro de los Testamentos. *Oviedo, Cathedral Archives (photo after Bordona).*

the horn matching the strange character of its Fatimid style decoration.

It was common practice to give oliphants to churches as costly gifts, sometimes with money or containing relics, or as horns of tenure. These transactions are recorded in inventories and church and lay chronicles. The earliest reference to this practice is in the German *Chronicon Hugonis,* which records the gift by Emperor Henry II (d. 1024) of two ivory horns containing relics to St. Vincent of Verdun, *cornua 2 eburnea idemtidem reliquiis conferta.* Speyer Cathedral possessed one ivory horn in 1051 and received six more in 1065. In 1127 there were three ivory horns in Bamberg Cathedral.(37) I believe that a number of these horns were made in Venice.

Ivory horns were equally popular among the Normans in newly conquered England, as we have seen, and there, as in Germany, the horns passed into church treasures in increasing numbers during the course of the twelfth century. Bishop Henry of Blois (d. 1171), for instance, gave nine ivory horns to his cathedral of Winchester.(38) He may have acquired these horns during one of his trips to Italy, perhaps in Amalfi.

The church had no trouble absorbing such secular gifts and transforming them to her purpose. Occasionally, the horns may have been recarved to add an appropriately Christian element to the decoration. Such is the case with a horn in the Musée de Cluny in Paris (Figure 7).(39) Originally the horn was decorated solely around the mouth and tip with a Fatimid style frieze of animals and narrow strips of arabesque, basket weave, and pierced bead ornament. The middle zone was left blank. But once acquired by a church, the horn was Christianized by the addition of an image of the Ascension in the middle zone, carved in an entirely different style. Thereby the predominant meaning of the decoration was changed to be in keeping with the horn's new function, perhaps to hold relics or to blow during processions. This treatment of the Cluny horn is unusual, however, as the secular decoration of most of the ivory horns acquired by churches was left intact.

As fewer oliphants were carved during the twelfth century, and as they were put aside among the possessions of the nobility or given to churches, the origins, functions and meanings of these horns were gradually forgotten or transformed in legend. They became curiosities, and their inherent foreign and magical qualities increased, qualities for which they were valued in the same way as the elephant tusk still hanging suspended from the vaulting over one of the portals to the cathedral of Seville is valued, keeping company there with an equally strange crocodile and the supposed bridle of El Cid's horse.

Roland's oliphant in the *Chanson* served the sort of practical, albeit heroic needs recognized by an audience that was itself making use of ivory horns. But by the end of the twelfth century the oliphant had become in some instances a magical instrument in secular literature,(40) as secular literature itself was dwelling increasingly on the make-believe. Such is the ivory horn in the *Lai du Cor*, a poem written by an Anglo-Norman author, Robert Biket, during the third quarter of the twelfth century, and repeated in other versions throughout Western Europe during the following century.(41) The story takes place on Absolution Day at Carlion where 30,000 knights have gathered with their ladies at King Arthur's court. While they are waiting for the feast to begin, a beautifully clad youth arrives on horseback bearing a gift for King Arthur from his master, King Mangons de Moraine. The gift is a wonderful ivory horn made by a fairy. Before receiving his reward the youth departs hurriedly. Arthur orders his chaplain to read aloud the inscription which the horn bears. Reluctantly the latter makes known that no man whose wife has ever been faithless or has even harbored a faithless desire may drink from the horn without spilling its contents. Arthur immediately takes the test, and spills the wine with which the horn is filled. Angrily he threatens the queen with a knife, but his knights restrain him. Thereupon he makes all of them take the test, and they too all fail, with one exception. Caradoc, after his beautiful wife has encouraged him, drinks without spilling a drop. He is awarded the horn, and all guests take leave and return to their homes.

About fifty years after the *Lai du Cor*, a similar, but shorter version of this horn story occurs in the first, anonymous continuation of Chrétien's *Perceval*, at the end of the story of Carados.(42) It too features an ivory horn, "*un cor / D'yvoire a riches bendes d'or / Plaines de pierres prescïeuses*" (8535-37). This horn has the additional property of transforming water into wine. Another ivory horn appears slightly later in an equally magical setting at the beginning of the second continuation of *Perceval*, in the story of the Castle of the Ivory Horn.(43) Perceval comes to a castle and finds its portal closed. But an ivory horn hangs by a strap of gold-embroidered cloth from a gold ring in the center of the door. He blows the horn three times until the Knight of the Horn comes forth. A fight ensues and Perceval emerges victorious.

We find reminiscences in these poems of the original functions and meanings of the oliphant. But as the oliphant was put aside in favor of more practical instruments,(44) its origins were forgotten and its spirit escaped into the magic world of the romance. Some of this magic lingers on.

Figure 7. Oliphant. Paris, Musée de Cluny (photo: Réunion des Musées Nationaux).

For further reading on the so-called minor arts of the Middle Ages, and on secular objects in particular, I recommend the book and articles by Lasko and Shapiro cited in my first footnote. The most useful of what little has been written on oliphants is cited in notes 2 and 4. Two useful and readily accessible general surveys of medieval art are Robert G. Calkins, *Monuments of Medieval Art* (New York: Dutton, 1979); and George Zarnecki, *Art of the Medieval World* (Englewood Cliffs, N.J.: Prentice-Hall, and New York: Abrams, 1975). Neither mentions oliphants.

(1)Thus the volume by Peter Lasko in the Pelican History of Art devoted to the minor arts of the earlier Middle Ages is typically, and too narrowly, titled: *Ars Sacra: 800-1200* (Harmondsworth, Middlesex: Penguin Books, 1972). There are occasional exceptions to this neglect of the secular in art, most notably the exploration of secular themes by Meyer Schapiro in articles such as "On the Aesthetic Attitude in Romanesque Art" (1947) and "The Bowman and the Bird on the Ruthwell Cross and Other Works: The Interpretation of Secular Themes in Early Mediaeval Religious Art" (1963), conveniently republished in idem, *Selected Papers*, I: *Romanesque Art* (New York: Braziller, 1977), 1-27, and III: *Late Antique, Early Christian and Mediaeval Art* (1979), 177-86 and 192-95. What secular objects survive from the earlier Middle Ages have never received the attention given the secular arts of the Gothic period, for example in New York, The Metropolitan Museum of Art, *The Secular Spirit: Life and Art at the End of the Middle Ages* (New York: Dutton, 1975).

(2)"Die sarazenischen Olifanthrner," *Jahrbuch der Berliner Museen*, I (1959), 33-50; and *Die islamischen Elfenbeinskulpturen, VIII.-XIII. Jahrhundert* (Berlin: Deutscher Verlag für Kunstwissenschaft, 1971), pp. 14-19, the text of which largely duplicates the above article, 52-59, 61-67, and, with a comprehensive bibliography on all the oliphants in general, 99-103; cat. nos. 52-55, 59-62, 66-70, and 76-86; and pls. XLIV-XLIX, LIV-LIX, LXIV-LXX, and LXXIV-XCI.

(3)See David MacKinnon Ebitz, "Two Schools of Ivory Carving in Italy and Their Mediterranean Context in the Eleventh and Twelfth Centuries," Diss. Harvard (1979), pp. 129-395; and idem, in New York, The Metropolitan Museum of Art, *The Vatican Collections: The Papacy and Art* (New York: Abrams, 1982), cat. no. 43, pp. 106-07.

(4)"Two Oliphants in the Museum," *Bulletin, Museum of Fine Arts, Boston*, 60 (1962), 27-45.

(5)See Ebitz, "Two Schools," pp. 9-127; and Robert P. Bergman, *The Salerno Ivories, Ars Sacra from Medieval Amalfi* (Cambridge, Mass.: Harvard Univ. Press, 1980).

(6)Cf. evidence of original mounts on the Fatimid style horns in Kühnel, *Elfenbeinskulpturen*, e.g., cat. nos. 59, 62, 69, and 78, pls. LIV, LVIII, LXVIII, and LXXVII.

(7) Cf. later mounts on two other of the Fatimid style horns: ibid., cat. no. 61, pl. LVII, p. 56 (English, sixteenth century); and cat. no. 81, pl. LXXXI, p. 63 (seventeenth century?). When the so-called horn of Ulph, one of the Amalfitan group, was restored to York Minster in 1675, the grateful dean and chapter of the church commissioned new silver mounts for the horn as an inscription on the mounts informs us (Swarzenski, "Two Oliphants," figs. 10-11; and T. D. Kendrick, "The Horn of Ulph," *Antiquity*, 11 (1937), 278-82, pls. I-V). Some indication of what ostentatious effect hanging straps might originally have given the oliphants is provided by the late fourteenth-century German belt attached to the so-called horn of Charlemagne, in the treasure of the Palatine Chapel at Aachen (Ernst Günther Grimme, *Der Aachener Domschatz (Aachener Kunstblätter*, 42), 2nd ed. (Düsseldorf: L. Schwann, 1973), cat. no. 11, pp. 17-18, fig. on p. 18).

(8)Swarzenski, "Two Oliphants," fig. 3.

(9)See the convenient, though too uncritical, appendix of excerpts from church inventories and other medieval documents referring to ivory horns in Kühnel, *Elfenbeinskulpturen*, pp. 85-88.

(10)Ibid., cat. nos. 67, 77 and 81, pls. LXV, LXXVI and LXXXI. These and the other subjects carved on the Fatimid style horns and caskets are indexed ibid., pp. 19-23, pls. XCIV-XCVI.

(11)Swarzenski, "Two Oliphants," fig. 13.

(12)Ibid., figs. 18-20, which also include two nudes of Classical origin on one of the horns carrying game strung from poles.

(13)See Ebitz, "Two Schools," pp. 25-40.

(14)Swarzenski, "Two Oliphants," figs. 5-6.

(15)William of Apulia, *La Geste de Robert Guiscard*, ed. and trans. Marguerite Mathieu (Palermo: Istituto Siciliano di Studi Bizantini e Neoellenici, 1961), V, 180-83, p. 246.

(16)Two heraldic eagles appear on the outer curve of the Paris horn, barely visible in fig. 3. For other examples of eagles, see Swarzenski, "Two Oliphants," figs. 14 and 21-23; and Kühnel, *Elfenbeinskulpturen*, pl. XCV; and for lions, Swarzenski, figs. 3, 10, 21, and 24

(17)Swarzenski, "Two Oliphants," figs. 5 and 21.

(18)See Paul A. Underwood, "The Fountain of Life in Manuscripts of the Gospels," *Dumbarton Oaks Papers*, No. 5 (1950), pp. 43-138, passim, especially pp. 78-79, 88 and 114.

(19)Kühnel, *Elfenbeinskulpturen*, cat. nos. 61, 67, 79, and 81, pls. LVII, LXV, and LXXIX-LXXXI.

(20)*Elfenbeinskulpturen*, pp. 6-15 and 85-88, figs. 8-30.

(21)Arthur Kingsley Porter, *Lombard Architecture*, III (1917; rpt. New York: Hacker, 1967), 531; and IV (1915; rpt. 1967), pl. 229, fig. 2, and pl. 230, fig. 2. See also Rita Lejeune and Jacques Stiennon, *La Legende de Roland dans l'art du moyen age* (Brussels: Arcade, 1966), I, 72, and II, pl. 46.

(22)J. Domínguez Bordona, *Spanish Illumination* (New York: Harcourt, Brace and Co., n.d.), I, 26-27, pl. 73.

(23)Frank Stenton, ed., *The Bayeux Tapestry* (London: Phaidon, 1957), pl. 4.

(24)For excerpts and sources, see Kühnel, *Elfenbeinskulpturen*, appendix no. 20, p. 87 (William); no. 22, p. 87 (Osmund); and no. 6, p. 85 (Henry I).

(25)Stenton, *Tapestry*, pl. 43 and detail.

(26)*Brevis Relatio de Origine Willelmi Conquestoris*. Translation here of excerpt in Otto Lehmann-Brockhaus, *Lateinische Schriftquellen zur Kunst in England, Wales und Schottland vom Jahre 901 bis zum Jahre 1307*, III (Munich: Zentralinstituts für Kunstgeschichte, 1956), no. 5836, p. 186.

(27)Denis Grivot and George Zarnecki, *Gislebertus, Sculptor of Autun* (New York: Orion, 1961), p. 79, pls. B and 52b. Cf. the horn blown by St. Eustace on a contemporary nave capital in La Madeleine at Vézelay (Francis Salet, *La Madeleine de Vézelay* (Melun: Lib. d'Argences, 1948), p. 120, pl. 32).

(28)Grivot and Zarnecki, *Autun*, pls. C, K, M, and N.

(29)See the review of the "rich fund of horn symbolism in theophanic, messianic, and Apocalypse texts (which) equates the horn with revelation and deliverance," discussed in relation to the ivory horn of Roland, in Stephen G. Nichols, Jr., *Romanesque Signs, Early Medieval Narrative and Iconography* (New Haven: Yale Univ. Press, 1983), pp. 180-91.

(30)Or, once each, *oliphan* and *olifans*. For the variant spellings and their occurrence in the text of the Oxford manuscript of the poem, see Joseph J. Duggan, *A Concordance of the Chanson de Roland* (Ohio State Univ. Press, 1969), p. 277.

(31)In the *Chanson* (609 and 2653), for instance, *olifan* and *olifant* are each used once to signify ivory as the material out of which a throne, *faldestoed*, is made. The absence in the poem of further examples of the use of the word to signify anything other than an ivory horn may be an indication of the author's fascination with the use and dramatic possibilities of the new word to designate a newly popular accouterment of contemporary nobles and knights. See Joseph Bédier, *La Chanson de Roland, Commentaires*, 2nd ed. (Paris: H. Piazza, 1927), p. 438, s.v. *olifan*; Adolf Tobler and Erhard Lommatzsch, *Altfranzösisches Wörterbuch*, VI, pt. 2 (Wiesbaden, 1964-65), cols. 1063-66, s.v. *olifant*; and Fritz Brücker, *Die Blasinstrumente in der altfranzösischen Literatur*, Giessener Beiträge zur Romanischen Philologie, No. 19 (Giessen, 1926), pp. 7-9.

On the thematic significance of Roland's horn in the *Chanson*, see C. Minis, "Über Rolands Horn, Burgers Passio Rotolandi und Konrads Roland," *Annales Universitates Saraviensis Philosophischen Facultät*, 6 (1957), 439-53; and Nichols, *Romanesque Signs*, pp. 143-47, 155-57, 162, 166-70, 180-91, and 199.

(32)See Lejeune and Stiennon, *Legend de Roland*, I and II, passim.

(33)I excerpt here and below from the translation in *The Song of Roland*, trans. Dorothy L. Sayers (Baltimore: Penguin, 1957), checked for accuracy against the definitive edition of the Oxford manuscript in *La Chanson de Roland, Edizione critica*, ed. Cesare Segre (Milan, 1971).

(34)*Le Guide du pèlerin de Saint-Jacques de Compostelle*, ed. and trans. Jeanne Vielliard (Macon: Protat Frères, 1938), p. 78: "Tuba vero eburnea scilicet scissa aput Burdegalem urbem, in basilica Beati Severini habetur . . . ." The *Guide* comprises the fifth book in the *Liber Sancti Jacobi*, the fourth book of which is an early twelfth-century Latin prose version of the legend of Charlemagne and Roland, the *Historia Karoli Magni et Rotholandi* by the so-called pseudo-Turpin. Related to the *Chanson de Roland*, the *Historia* gives a somewhat more complicated account of the final disposition of Roland's horn which seems to reconcile two different traditions (*Historia Karoli Magni et Rotholandi ou Chronique du Pseudo-Turpin*, ed. C. Meredith-Jones (Paris: Droz, 1936), XXIX, pp. 212-13). Roland's horn and sword were brought with his body to St. Romain in Blaye. Later the horn was removed to St.-Seurin in Bordeaux, just across the Gironde.

(35)The legend seems relatively modern. See, for instance, Henry Howard, "The Hunting Horn of Charlemagne, The Hunting Horn Roland, Hunting Horn at Greystoke Castle," *Archaeologia*, 29 (1842), 370; and Hanns Swarzenski, "L'Olifant de Toulouse: Les Olifants," *Les Monuments Historiques de la France*, 12 (1966), 7-11.

(36)See above, n. 7; and Kühnel, *Elfenbeinskulpturen*, cat. no. 55, pp. 53-54, with additional bibliography.

(37)For excerpts and sources, see ibid., appendix no. 28, p. 87 (Henry II); nos. 24-25, p. 87 (Speyer); and no. 1, p. 85 (Bamberg).

(38)Ibid., appendix no. 29, p. 88.

(39)Ibid., p. 19, fig. 34; David MacKinnon Ebitz, "Letter to Editor," *Art Bulletin*, 55 (1973), 163; and idem, abstract of "Two Italian Fatimid Style Oliphants and Their Later Recarving," *Proceedings of the Third Medieval Forum* (Plymouth, N.H.: Plymouth State College, 1982), pp. 26-27.

(40)For examples, see Tobler and Lommatzsch, *Wörterbuch*, VI, pt. 2, cols. 1063-66, s.v. "*olifant*"; and Brücker, *Blasinstrumente*, pp. 8-9.

(41)H. Dörner, *Robert Biquet's Lai du Cor mit einer Einleitung über Sprache und Abfassungszeit*, Diss. Strassburg 1907 (1907); and Edmund Kurt Heller, "The Story of the Magic Horn: A Study in the Development of a Mediaeval Folk Tale," *Speculum*, 9 (1934), 38-50.

(42)*The Continuations of the Old French Perceval of Chrétien de Troyes*, ed. William Roach, I: *The First Continuation* (1949; rtp. Philadelphia: American Philosophical Society, 1965), lines 8493-734, pp. 231-38.

(43)*Continuations*, Roach, IV: *The Second Continuation* (1971), lines 19654-936, pp. 7-29.

(44)In representations of Roland from the mid-thirteenth century on, for example, his horn often does not resemble an oliphant despite its specific identification as such. See Lejeune and Stiennon, *Legend de Roland*, I and II, passim; and also Brücker, *Blasinstrumente*, passim; E. Buhle, *Die musikalischen Instrumente in den Miniaturen des frühen Mittelalters*, I: *Blasinstrumente* (Leipzig, 1903), passim; and Bernhard Brüchle and Kurt Janetzky, *Kulturgeschichte des Horns, Ein Bildsachbuch* (Tutzing: Schneider, 1976), passim, with comprehensive bibliography on pp. 291-93.

From time to time, one is happily surprised to find a research story which begins with simple contingency; demonstrates the scientific mind making quick, yet complex, connections, and evolves through collegial cooperation to the point where its results make a distinct and crucial impact on human life. Most research studies embody some of these characteristics; the study of radon conducted at the University of Maine at Orono embodies all of them. Special thanks to Professor Stephen A. Norton for telling us the story and guiding us through the retelling.

RADON: noble gas?

BY CAROLE J. BOMBARD
ASSISTED BY STEPHEN A. NORTON

IN THE BEGINNING Radioactive transformations are present all around us: uranium, the parent of many radioactive decays, was present when the earth was formed. The radioactive transformations spawned by uranium produce radium, and as it decays radon is formed. During each transformation, radioactive decay produces alpha, beta or gamma radiation, and it is that radiation which affects living organisms. Radon is part of the decaying process, with attendant radioactive radon progeny. (See Figure 1.)

Found in low concentrations almost everywhere on earth, radon is a naturally occurring gas, colorless, odorless, chemically inert, and fairly soluble in water. It is the propensity to be soluble in water that makes the presence of high radon concentrations critical to humans.

In the course of a study of the distribution of naturally occurring radionuclides in the Wiscasset area, physics professor Charles T. Hess discovered some extraordinarily high levels of radon in groundwater. When combined with previously known information, that incidental discovery led to new and nagging questions.

Personally conscious of cancer and its relationships with radioactivity, C.T. Hess was also aware of the high incidence of cancer in uranium miners; the relationship of cigarette smoking and cancer; the carcinogenic effects of radon by itself, and the synergistic relationship between tobacco smoking and radon. With statistical evidence of high rates of tobacco smoking in Maine and a cancer incidence higher than the national average, the discovery of Maine's high radon levels suggested to Hess a clear, in-

UMO faculty members, graduate students and others who have contributed to the ongoing studies of radon in Maine include Charles T. Hess, Professor of Physics; Stephen A. Norton, Professor of Geological Sciences; Willem F. Brutsaert, Professor of Civil Engineering; Jerry D. Lowry, Associate Professor of Civil Engineering; Conrad Weiffenbach, Assistant Professor of Physics; John K. Corsah, Assistant Professor of Electrical Engineering; Anne L. Hess, Clinical Associate Professor of Psychology; graduate students John Wadach, Cecelia Einloth, Robert E. Casparius, Edward G. Coombs, Jeffrey E. Brandow, Thomas Menerney, and Cindy Molk. Members of the current investigative team involved in the epidemiological study of radon and cancer may be found on page 25.

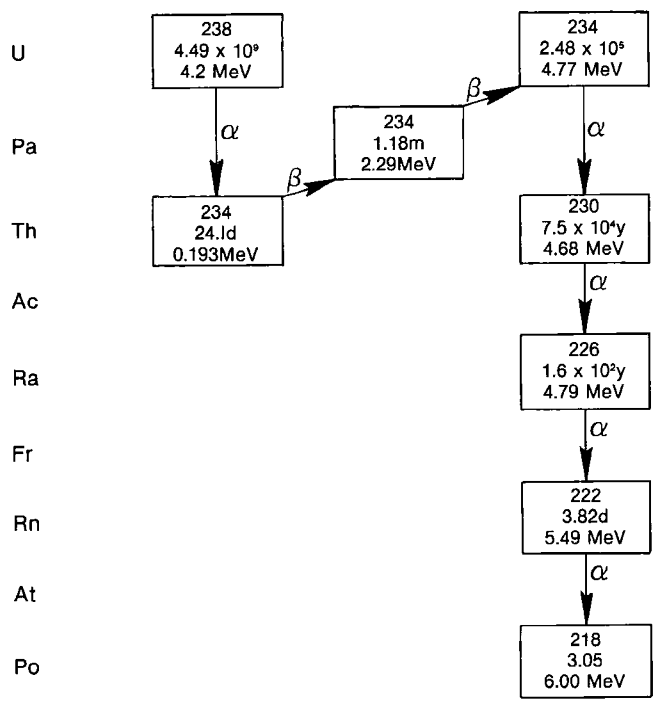
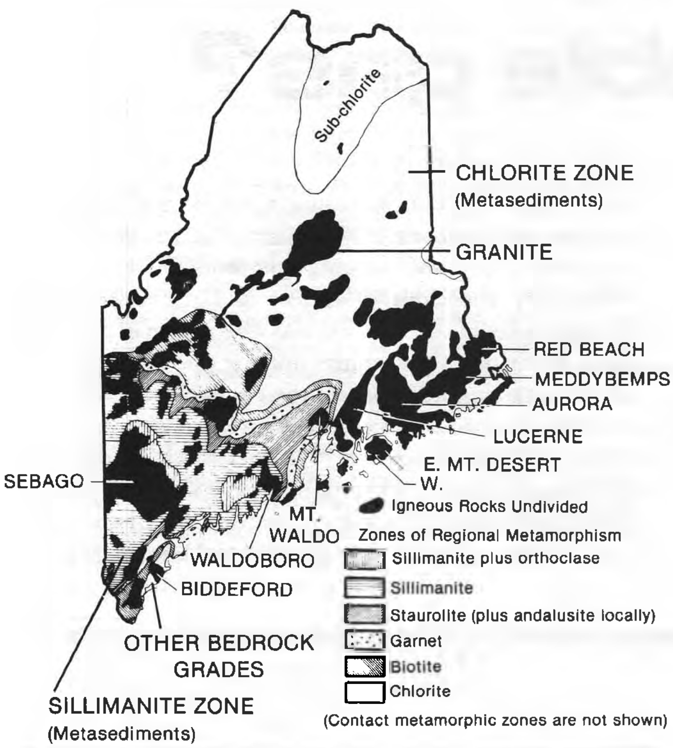


Figure 1
Decay for U^{238} to Po^{218}. Within each block are atomic weight, half life, and energy of the decay.

deed imperative, need for further study. Because rocks are the source of radon's parent uranium, and because water moves uranium byproducts, Hess knew that he needed to involve a geologist and an hydrologist in projected studies. He turned to his colleagues, Stephen A. Norton, professor of geological sciences; Willem F. Brutsaert, professor of civil engineering, and Anne L. Hess, clinical associate professor of psychology, who was interested in health statistics and was instrumental in the initial proposal writing.



	Number of wells Tested	Average Radioactivity of Well Water (pCi/L)
CHLORITE ZONE (Metasediments)	56	1,100
GRANITE	136	22,000
SILLIMANITE ZONE (Metasediments)	35	13,600

Figure 2

Generalized geologic map of Maine showing metamorphic zones and granites.

THE GEOLOGY AND THE HYDROLOGY

Since both geological activity and water move the radioactive products of uranium decay, Norton and Brutsaert needed to determine whether the presence of radon (^{222}Rn) in water was primarily controlled by geologic or hydrologic considerations.

The way into the problem consisted of measuring the radon in water samples from many groundwater sources in Maine and relating the geology of the areas from which the water samples were taken to the radon values. Samples of drinking water from across Maine were tested to measure the radon present, and maps from the Maine Geologic Survey allowed Norton to determine the types of bedrock underlying the water samples' sources. Norton determined that a strong relationship exists between the radon levels in water and the types of host rock. By correlating results from water testing and existing bedrock, Norton demonstrated that some types of rock can be characterized as carrying certain levels of radon. This result produced a useful tool: predictability.

Correlations between the levels of radon in groundwater and the host rock indicated that granites in general yielded the highest radon levels. (See Figure 2.) Further studies indicated that appreciable variations exist among different types of granite. (See Figure 3.) Please note the unit of radioactivity, pCi/L, (picocuries per liter), is the unit of measure for radiation in water. The prefix pico means a multiplication factor of a millionth of a millionth of a Curie.

The general relationships between the levels of radon and bedrock geology and groundwater chemistry were established. Granites typically have groundwater with the highest radon levels, normally ranging from 5,000 to 100,000 pCi/L. High grade metamorphic terranes (sillimanite or higher) have water with radon values in the range of 5,000 to 30,000 pCi/L. (These values are thought to be the result of metamorphic pegmatite development and associated uranium mineralization.)

Metasedimentary rock units at metamorphic grades less than stillimanite have groundwater with radon levels ranging from 1,000 to 10,000 pCi/L. (Each rock unit has a somewhat characteristic radon range for groundwater, but these ranges overlap.) Further testing pursued the possible relationships between radon and other elements, but results indicated no relationship between radon levels and levels of dissolved potassium, magnesium, calcium, zinc, copper, or iron, and a weak inverse relationship between radon levels and sodium. It was concluded that the levels of sodium, calcium and magnesium in domestic water wells are governed by human activity rather than natural groundwater processes.

FOUR QUESTIONS Emerging from the conclusions found in the studies of radon and its relationship to drinking water and the geology of the water's sources were four basic questions, each of which is important to humans:

1. Is the problem of high radon levels unique to Maine?
2. How does the radon get from the water to the human body?

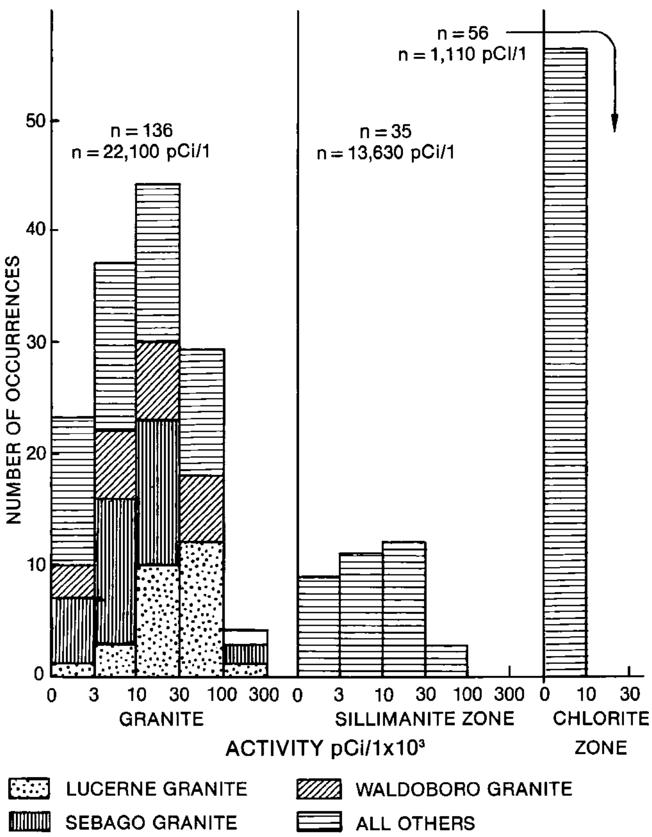


Figure 3 ^{222}Radon activity as a function of rock types
In general, chlorite grade metasedimentary rocks (and on up to staurolite grade) have low radon values which are characteristic of the rock, not the metamorphic grade. But, at sillimanite grade and above, metasedimentary rocks yield higher radon than their lower grade equivalents. This change coincides with the development of pegmatites within the rocks and presumably uranium mineralization. The ultimate source of the uranium is probably intrusive igneous rocks, primarily granites.

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3. What are the health effects of elevated radon levels in water?
4. Can high levels of radon be controlled? Can they be removed?

The first question. Geological formations do not stop at state boundaries. As one sees in Figure 2, the structural trend of metasedimentary rocks continues southwesterly, and the metamorphic isograds trend northwesterly with no regard for human imposition of political boundaries.

If the geological model worked in Maine (and it did), it should be a viable prediction model out of state. Water samples were evaluated from New Hampshire, Massachusetts, Vermont and Rhode Island, and the model worked. Norton was able to predict *hot spots*, areas of high radon, from geological maps. The problem of significant radon levels is not unique to Maine.

The second question. Given the presence of high levels of radon in water, how does that substance make its way into the human body where it can affect human health? It is generally believed that health problems arise from airborne radon.

The distribution of radon has been measured in the sixteen counties of Maine: water samples from more than 2,000 public and private wells have been analyzed; 350 of the sampled wells have been characterized for geology and hydrology. In addition, airborne radon has been measured in 70 houses with grab samples (which are just what they sound like) and in 18 houses for five to seven days each, with continuously recording radon detectors. The variations in airborne radon in measured houses was significant (see figure 4) from house 7's low level to the very high range found in house 13.

Conrad Weiffenbach, assistant professor of physics, found airborne radon usually increased shortly after water use in a home: a radon burst would shadow the use of a shower, dishwasher, washing machine, etc., indicating that aerating water released significant amounts of radon and radon progeny into the air. When this aeration takes place out-of-doors, the process is harmless; if it takes place in certain types of houses, radon can become abundant in the air. Airborne radon in houses may also result from radon's presence in soil gas.

The study indicated the importance of house ventilation rates, as well as the types of foundations under houses, or their lack, and building materials such as gypsum wallboard used in house construction. In summary, domestic *radon sources* included groundwater which acquires radon as it seeps through cracks in bedrock and soil and enters the house in well water; soil gas infiltrating the air of a house, and construction materials. The key factors influencing *airborne radon levels in a home* include radon levels in the soil gas, the type of construction where the house and earth come together, and ventilation in the house. (Currently, soil gas as a radon source is a matter of intense interest: the scientific exploration of one question has led to another question.)

As radon in houses is either airborne or waterborne, the basic ways for it to enter the human body are through inhalation or ingestion. What is relevant to individual humans is what happens (or doesn't happen) when these common practices occur. Radon is chemically inert, so radon which is inhaled is exhaled. But the radon progeny, which are constantly being produced in the air, are another story. Progeny such as polonium, bismuth and lead are chemically active metals, and they will stick to particulates with which they come in contact in the air. When inhaled, the particulates (with radon progeny attached) come in contact with air passageways in the lungs and adhere to their surfaces. Radiation from these progeny can strike and break molecules in living cells.

Radon progeny ingested with water can affect the stomach and other organs, but food and liquid in the stomach usually absorb the radon. Compared to inhaled radon, ingested radon's effects are much smaller.

The risks to living cells posed by radon progeny rest with the alpha, beta or gamma radiation given off as the radon decays to produce its progeny. These radiation particles can travel through living DNA molecules and cause breaks in the molecular structure. While DNA can and does repair itself under certain condition, (for example, if lesions in one strand of the DNA are a certain critical distance apart, and if the second strand in the double helix is uninjured, certain enzymes can use the uninjured strand as a template from which to build a replacement part), that repair capacity is limited and easily stressed. When DNA can *not* repair itself, its basic functions will be deleteriously affected.

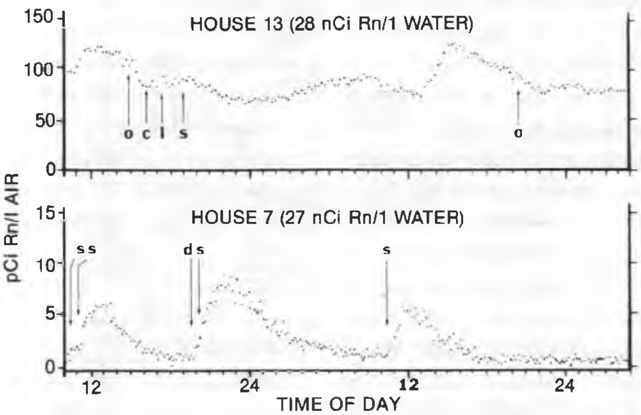

Figure 4
Time variations of radon in two houses, measured with an electrostatic diffusion alpha detector. Events of interest are labeled: (o) opened window to outside; (c) closed window; (1) laundry machine used; (s) shower; (d) dishwasher used.

The third question. Numerous studies link radioactivity with cancer, and as radon has a relatively short halflife of 3.8 days producing radioactive progeny, exploration of the possible health effects of high radon levels in water was an essential problem.

As a beginning, A.L. Hess obtained cancer rates for each of Maine's sixteen counties, and she found the correlations between the levels of radon in the water by estimating the percent of radon-bearing granite rock formations underlying each county and correlating it with the county's cancer rate. While the study used only sixteen counties (Maine's total) resulting in only sixteen numerical comparisons, the population base stood at almost one million people and covered a period of twenty years. Figure 5 shows a weak correlation between radon levels in water and cancer incidence.

While the correlation between radon levels and all types of cancer is significant, when cancer in general is broken down into several different types, A.L. Hess found that radon would correlate with some types of cancer and not others. Radon levels correlated significantly with lung cancer and with reproductive cancer in males; it correlated moderately, but not significantly, with connective tissue cancer in both men and women, and with brain cancer for women.

It was clear to A.L. Hess that even though a strong relationship had been demonstrated between radon and cancer, radon is not the only factor associated with the cancer rate in Maine. Other variables relating to cancer and radon and an on-going study of the radon-cancer link were required.

In pursuit of the relationships between radon and cancer, C.T. Hess came up short realizing that he did not have all of the tools necessary to study the detailed health data required to take the study further. He resolved the situation by taking a year's sabbatical leave from UMO to go to the University of Texas School of Public Health in Houston, where he worked with Professor Thomas Gesell, sharpening his skills studying radon in water measurements and epidemiology. He is currently conducting an epidemiological study of radon and cancer in cooperation with Peter Rand, MD, Director of the Department of Research at Maine Medical Center in Portland, and Gregory Bogdan, Doctor of Public Health, an epidemiologist and assistant director of the Division of Disease Control, Maine Department of Human Services.

The fourth question. As the studies in radon in Maine water progressed, and as findings indicated strong correlation between radon and cancer, methods of controlling the problem became one focus of investigation.

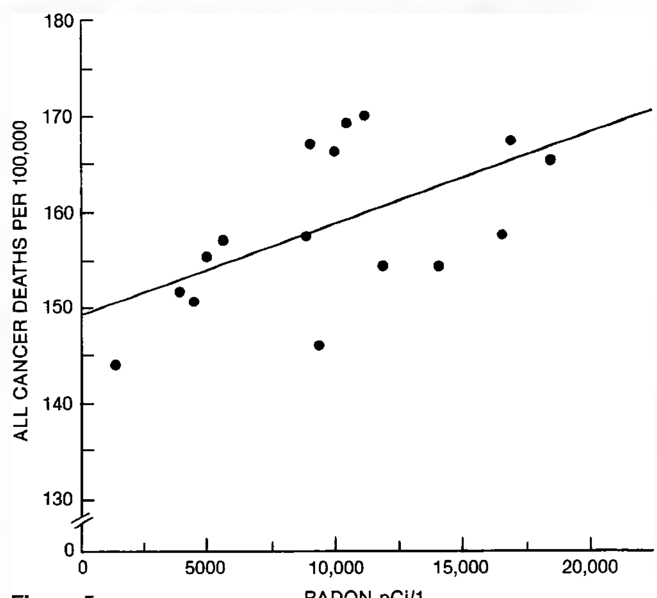

Figure 5
The Relationship of Radon Levels to all Cancer Deaths
Males and Females

Testing by Brutsaert indicated that radon may be removed from well water by aeration. Just as the domestic uses of water (showering, running dishwashers, etc.) release radon into the air in a home, controlled aeration of water can be used to release radon harmlessly into the air outside the house. A second method of removing radon from well water was developed by Jerry D. Lowry, associate professor of civil engineering. Using granulated activated charcoal (GAC) Lowry demonstrated that when used in a continuous flow process, the GAC continues to remove radon beyond the point at which saturation would be expected, and a steady-state removal occurs. Carbon filters also remove uranium salts which may be chemically toxic. Both systems for water aeration and granulated charcoal filters to remove radon from domestic water are now commercially available.

Airborne radon may be controlled with changes in the ventilation of both houses and crawlspaces; air-to-air heat exchangers can be used to improve ventilation while controlling heating costs, and a number of methods exist for caulking and sealing basements to prevent the entry of radon which will make its way into a house's living space.

THE DISCOVERY COMES FULL CIRCLE What began as the incidental discovery of high radon levels being recognized as a potential health problem for Maine people, has led, over several years' interdisciplinary study, to means of controlling the problem. In short, UMO scientists recognized a problem; studied it, and helped solve it.

Currently, C.T. Hess continues with work on two radon projects, the medical epidemiological study of radon effects, and a study of the effects of weather conditions on radon in houses, conducted with John K. Corsah, assistant professor of electrical engineering, and graduate student Cecelia Einloth. He also serves as a nationally respected source of information on radon safety levels.

People are benefitting from what C.T. Hess noticed and pursued:

> The Department of Human Services Public Health Laboratory provides radon testing for well water.
>
> The Cooperative Extension Service conducts training sessions, educational workshops and informational conferences for Maine people.
>
> Flyers, pamphlets and digests have been prepared from information gleaned in the studies and have been made available to the public.
>
> An epidemiological study of radon's causal relationship to cancer is underway, led by C.T. Hess, Dr. Peter Rand of Maine Medical Center, and Doctor of Public Health Bogdan.

As of June, 1984, radon programs had been conducted for citizens in four of Maine's sixteen counties, and programs were planned for at least four more counties.

Extension Service leaders have followed the bedrock model of predictability established by geologist Norton, using Maine Geological Survey maps to determine specific areas of granitic bedrock, to find potentially affected population centers to target for programs.

Extention Service leaders have also used research results to determine that specific residents need *not be* actively involved. (Camp owners, for example, may reside in areas of granitic bedrock, but the buildings are not well insulated; drinking water comes from open, and therefore aerated sources; the camps have no foundations and no cellers, and the camps are used seasonally when air exchange rates are high. These conditions mean that camp residents are not affected by any local radon problem.)

The programs have received a great deal of attention in the news media, including attention from the Public Broadcasting Service's McNeil-Lehrer Report. The news has spread and echoed: the Health Engineering Division of the Department of Human Services in Augusta reported a more than 20 percent increase in water testing for radon in the January to June 1984 period, compared to the same period in 1983. Actually the requests for water tests have been even higher, but the laboratory has not been able to analyze the water to keep pace with the requests. In June, 1984, there was a six week waiting period for water testing.

In a relatively short time, scientists at the University of Maine at Orono have discovered a problem; studied it, and taken steps to solve it.

Radon in Water and Air, a 12-page informational digest prepared by the Land and Water Resources Center at UMO, as well as other publications, are available from Maine county Cooperative Extension Service offices. Procedures for well water testing may be obtained from the Public Health Laboratory, Department of Human Services, State House Station 10, Augusta, Maine, 04333.

The problem of radon and cancer is international and recognized with concern in Finland, Norway, Denmark, West Germany and Japan, but only three countries (Sweden, Italy, the United States) are conducting epidemiological studies to determine the causal relationship of radon and cancer. And in the United States, Maine is the only state involved in such epidemiological studies.

Conducting the study are C.T. Hess, Professor of Physics, UMO.; Peter W. Rand, MD, Director of the Department of Research at Maine Medical Center in Portland; Gregory F. Bogdan, Doctor of Public Health and epidemiologist and assistant director of the Division of Disease Control, Maine Department of Human Services; E. Melanie Lanctot, Department of Conservation; Donald Hoxie, Director of the Division of Health Engineering in the Department of Human Services' Bureau of Health.

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