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Changing Perspectives of the Quaternary Surficial Geology of Maine

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ABSTRACT

The major historic publications reporting research on the surficial geology of Maine are reviewed to illustrate significant changes in scientific thinking that have led to the present understanding of Quaternary events and history.

The earliest research attributed the surficial geology of Maine to the biblical flood. By 1862, although the biblical flood concept still held scientific sway in Maine, glaciation started to gain importance as a factor; and by 1899 glaciation as the cause of the surficial geology of Maine had entirely replaced the flood theory in the scientific community. During the twentieth century, the collection and interpretation of geological data has rapidly expanded in Maine and adjacent parts of New England, Quebec, and New Brunswick. This progress in turn has allowed researchers to refine our understanding of the geological processes and history related to the surficial geology of Maine. However, although we know a great deal about the geological events of the late Pleistocene Epoch, almost nothing is known of early Pleistocene or Holocene events.

THE ICE-AGE THEORY

Louis Agassiz, a young Swiss naturalist from the University of Neuchatel, Switzerland, in his presidential address before the Swiss Society of Natural Sciences in 1837, revealed his revolutionary new theory that advocated the existence of a large glacier of continental proportions that had covered northern Europe and the Alps in the recent past. This glacier was said to be responsible for most of the erosional and depositional features previously attributed to the biblical flood, also referred to as the great deluge. Subsequently in 1840, in his monumental publication "Studies on the Glaciers," Agassiz provided the evidence for his conclusions. This was largely derived from his own observations in the Alps, integrated with and building upon the observations and conclusions of earlier and contemporary researchers in Europe such as Bernhardi in 1832, and Charpentier in 1834. Not only did Agassiz visualize an ice sheet covering northern Europe and the Alps, he also realized that the growth and demise of such an ice sheet would be directly related in a cause-and-effect manner to global changes of major magnitudes, including climatic cooling and warming, shifts in the distribution of plants and animals, and major sea-level changes. In addition, he predicted contemporary ice sheets on other continents. Hence, in total, the holistic concept of an Ice Age was born. Subsequently, Agassiz devoted his career to both researching his speciality, (modern and paleo ichthyology) and to compiling field data to support the concept of a global ice age. In 1846 Agassiz joined the faculty of Harvard College in Cambridge, Massachusetts with the charge to develop programs in the natural sciences. During the next 30 years, until he died in 1873, he did just this. He became a major influence on American science, and in his own right continued to be a leader in the field of ichthyology and an advocate of the Ice Age theory. In addition to his extensive research travels around North America and abroad, he came to Maine on several occasions, where he documented a variety of Ice Age phenomena (Agassiz, 1867, 1876). Although

Agassiz arrived in the United States in 1846, T. A. Conrad (1839) was the first American to accept the glacial theory, having been stimulated by Agassiz's 1837 paper.

THE BIBLICAL FLOOD VS. ICE AGE THEORY IN MAINE

Quaternary researchers in Maine (which was part of Massachusetts until 1821) prior to the proclamation of the Ice Age theory generally considered the unconsolidated glacial and glacial-marine sediments and bedrock erosional features to be the products of the biblical flood. The flood theory also included the concept of drifting icebergs as active participants in the processes of deposition and erosion. Sediments deposited by the flood were collectively called "diluvium." The persistence of the biblical flood/drifting iceberg origin for surficial deposits continued in Maine long after Agassiz's announcement of the global Ice Age theory in 1837. However, a growing number of workers presented an expanding body of data and conclusions which attributed these phenomena to the work of glaciers.

In the First and Second Reports on the Geology of Maine, Dr. Charles T. Jackson, the first State Geologist, continued to adhere to the popular biblical flood origin for the surficial sediments and modified bedrock surfaces that we currently attribute to glaciation (Jackson, 1837, 1838). Jackson synthesized his rather uncritical observations concerning the origin and distribution of various sediments and erosional features, including the emerged fossiliferous marine sediments of coastal and central Maine, the northwest-southeast trending eskers, the northwest-to-southeast transport of erratics, the trend of striae on bedrock surfaces, and the elevational distribution of both striae and erratics. He assigned the origin of these phenomena to the biblical flood coupled with the concept of iceberg drift. In doing so, Jackson concluded:

(1)A cold sea had completely covered the state to a minimum depth of 5,000 feet, at least equal to the height of the highest point in Maine, Mt. Katahdin.

(2)A great oceanic current flowed over Maine from northwest to southeast, causing icebergs to drag on and striate bedrock surfaces and to distribute erratic boulders to all elevations on the landscape. Within this sea the eskers were formed by the current as longitudinal sand bars, and the sizes of boulders that they contain reflect the high velocity attained by this ocean current.

It should be noted that the Jackson reports predate the wide dissemination of Agassiz's glacial theory, and Jackson's conclusions reflect the generally held geological views of his day.

During one of Agassiz's early forays into Maine in search of glacial features, he observed a well-developed, extensively smoothed and striated roche moutonnée, which is still observable adjacent to US Route 1A in Ellsworth Falls (Agassiz, 1876). This observation led him to proclaim for the first time that this region had, like northern Europe, been covered by a great ice sheet in the recent past. This may be the first such proclamation in the United States, but in any event provides one of the benchmarks in Maine science.

It is interesting to note that the general view, held by theologians and other scholars of the time, held that the "great deluge" was God's punishment of mankind for its sins. However, Jackson questioned this theology in part, by noting that the flood had in fact caused changes that were often beneficial rather than detrimental to mankind, at least in Maine.

> Although we are informed in the scriptures, that the deluge was ordained for the punishment of wicked men, it is certain, that there was mercy mingled with this dispensation, for the soils were comminuted, transported, and mixed in such a manner, that their qualities were improved, and rendered more suitable for the growth of plants, so that new and more fertile soils were prepared for coming generations, who literally reap advantage from the deluge. -- C. T. Jackson (1838).

Charles H. Hitchcock's subsequent reports on the geology of Maine (1861, 1862) are more scientifically sophisticated than the reports of C. T. Jackson. The geology is more thoroughly described and is systematically organized into a simple stratigraphic framework. In his classification scheme Hitchcock placed all (superficial) surficial deposits under the inclusive heading of "alluvium." He indicated that they constituted a geological formation and that the study of these deposits should be called surface geology. In addition, he reduced the number of terms for the superficial deposits from a confusing plethora of terms such as drift, diluvium, Pleistocene, Post-Pleistocene, and alluvium, used by previous authors, to the terms alluvium and drift. Hitchcock used "alluvium" as an inclusive term equivalent to drift and relegated drift to subdivision status. However, other workers used alluvium not only to denote the deposits as a whole, but also to denote the time period when the original deposition took place. Their "drift" comprised the deposits resulting from the modification of alluvium as well as the period when this modification was accomplished. Faced with this confusion Hitchcock divided drift as shown in Table 1. This classification simply appears to have added more confusion to an already confusing array of terms and usages.

Hitchcock's theory of the origin of surficial geologic features was still fundamentally based upon the concept of the biblical flood. However, relative to the conclusions of C. T. Jackson (1837, 1838), he added substantially more critical observations to the regional data base and was therefore able to reach more valid conclusions than Jackson concerning regional

TABLE 1. HITCHCOCK'S CLASSIFICATION OF QUATERNARY SEDIMENTS.

I. DRIFT	II. MODIFIED DRIFT
1. The Drift Period	2. The Beach and Sea Bottom Period 3. The Terrace Period 4. The Historic Period

events. In this regard he visualized that all of Maine and possibly the rest of northern North America were submerged beneath the sea, with currents flowing across the area from the north and northwest during the Alluvial period. Hitchcock further believed that the now-emergent "marine clay" of coastal Maine was deposited in the sea, and that most of the bedrock striae, including those on high mountains, were formed by drifting icebergs. He concluded, as had C. T. Jackson, that the sea was much colder than it is presently along the coast, judging from the assemblage of cold-water fossils contained in the emerged clay. Furthermore, he believed that icebergs were primarily responsible for the sea's coldness.

Hitchcock's definitions, coupled with the basic characteristics of the alluvial deposits, allowed him to partition the drift into the two general categories and four subdivisions mentioned above. This classification reflects the differences he visualized between alluvial sediments deposited at the stage of maximum submergence and those resulting from their reworking, first by marine action, subsequently by estuarine action, and finally by fluvial processes as the land emerged from the sea. In this scheme he visualized that icebergs, both large and small, became grounded throughout the region. Melting of the icebergs was responsible for the formation and deformation of sediments deposited against them, and ultimately for depressions left by their final melting.

Although Hitchcock clearly felt that the biblical flood was ultimately responsible for the surface geology of Maine, he conceded that small glaciers may have been present before the maximum submergence, as well as during the emergence, and coexisted with the icebergs. He reasoned, probably based upon his image of valley glaciers following Agassiz's research in the Alps, that the glaciers on our landscape must also have been confined to valleys. He further reasoned that numerous striae would be found confined to valleys and would indicate flow through the valleys. Hitchcock also concluded that markings left by valley glaciers would be similar to those left by drifting icebergs, but felt that they would be more consistent in their implications of flow directions than would those striae caused by randomly drifting icebergs. While glacier striae would be restricted to valleys and essentially parallel to their axes, striae produced by drifting icebergs would be found everywhere, including the tops of formerly submerged mountains in Maine.

As an example of glacial action, Hitchcock (1861) cited the great numbers of striae and their parallelism within the upper portion of the St. John River valley as the only evidence found to date. However, he predicted that similar evidence would be found in the mountains of Oxford and Franklin Counties, and indeed he presented such field evidence in the following year (Hitchcock, 1862).

In summary, it should be noted that Hitchcock (1861) reported the first evidence in any major geological report on Maine to support the concept of glaciers on the landscape. It is also clear in his report that the great deluge explanation for the origin of surficial deposits was still preeminent in his mind as well as in the scientific community. However, here for the first time in Maine, some credence was given to the possibility that glaciers, albeit valley glaciers, could possibly have played a role in forming the surface geology of Maine. This apparently was in deference to the growing acceptance of the Ice Age theory.

In retrospect, the evidence Hitchcock presented does indeed indicate glaciation, but of a style and magnitude beyond his experience and perhaps comprehension. Features of the surface geology of Maine were being increasingly attributed to glacial action, and in general Agassiz's Ice Age theory was being tested and accepted by the broad scientific community.

Dr. John De Laski, a physician and naturalist, in a letter (1854) to C. H. Hitchcock, reported on the distribution of striae in central coastal Maine (Hitchcock, 1862). He concluded that the striae were produced by glacier flow towards the south, which was inconsistent with the generally held view of iceberg-produced striae indicating flow towards the southeast over the entire state. In 1862 De Laski sent a solicited letter to Mr. George L. Goodale which was subsequently published in the Report of the Scientific Survey of the State of Maine (Hitchcock, 1862). In his letter De Laski carefully pointed out and documented the "gigantic system of sculpturing" reflected in the streamlined, elongated hills of the central coastal region. He observed that these hills are smooth on the sides and tops, but have bold, rough southerly ends, and noted that these characteristics are present at all elevations. These, along with many other critical observations of geological features, led De Laski to question their great deluge origin and to suggest alternatively that glacial action was responsible. Expanding on his analysis, he visualized that the bedrock sculpturing could not have been done by a small glacier confined to a valley, but rather "a glacier that filled the basin between the Camden Hills on the west to those of Mt. Desert on the east, was 40 miles wide, extended to a great distance north, involving several hills besides those mentioned, of a thousand feet high and certainly was not less than three thousand feet thick." This benchmark presentation of excellent observations and conclusions, although regionally limited, provided critical evidence for the major shift from the great deluge to the glacier theory as being responsible for the surficial geology of Maine.

In a later publication (De Laski, 1864) on glacial action in Penobscot Bay, in which he presented considerable field evidence, De Laski concluded that the glacier was not limited to this "great fjord of Maine." He alternatively reasoned that it must have extended far to the east and west and indeed was probably part of the universal glacier that covered the northern part of the continent in areas wherever striae had been observed (De Laski, 1864). In summary, Dr. John De Laski was the first worker in the region to conclude that a continental ice sheet had not only covered Maine, but areas far beyond.

THE NEW GLACIAL CONCEPT

In addition to De Laski, a growing number of contemporary researchers of Maine geology invoked glacial action as the cause for the features previously attributed to the flood. For example, A. S. Packard, Jr. (1866), in studying drift phenomena from Labrador southward along the Atlantic coast, including all of northern New England, clearly believed in their glacial origin. The first modern comprehensive work devoted to the glacial geology of Maine was that of G. H. Stone. He did most of the field work for his monumental pioneering publication, The Glacial Gravels of Maine (1899), in the 1870's and 1880's, only a decade after the publication of C. H. Hitchcock's Geology of Maine (1862). We see in Stone's and Packard's publications a complete change from the biblical flood to nearly unconditional acceptance of widespread glaciation to account for the surficial geology of Maine.

Significantly, Stone (1899) was the first to produce a geographic map of ice-margin retreat in Maine. His map (Fig. 1) displays retreatal positions of the ice margin progressing from southeast towards the northwest. It is based upon his very careful and insightful observation and correlation of ice-marginal deposits and directional indicators of ice flow. Subsequent research has expanded his area of interpretation, but has only slightly modified his conclusions over much of the state.

It is worth noting that Stone recognized in his introduction to The Glacial Gravels of Maine (1899) the need to study the activities of modern glaciers in order to more adequately understand the results of past glaciers.

> The investigation made slow progress, not only because there were several thousand miles to be carefully explored, but especially because the nature of the subject renders such an investigation exceedingly difficult. The scout of the Western frontier who undertakes to guide a body of troops in pursuit of hostile Indians--to follow the trail, and, from the traces left behind, to give a history of the enemy's performances from day to day--has a difficult task before him: but in thus reconstructing history he has the advantage of knowing, from direct observation, the habits of the Indians. In his study of glacial deposits the glacialist labors under the disadvantage of not knowing, by observation, the exact nature of the geological work going on beneath and with an ice-sheet. It is comparatively easy to theorize regarding the probable behavior of such a body of ice, and, if properly held in check, imagination is of the greatest use in such an investigation, but the chances for error are very great. The method here adopted has been to collect as large a body of facts as possible, and then carefully to test various hypotheses by the facts, rejecting or holding in abeyance all theories not supported by positive field evidence. Glacialists are exploring a comparatively untrodden field, and it behooves them to proceed cautiously and to avoid dogmatism and denunciation. -- G. H. Stone (1899)

By 1935, when Leavitt and Perkins published their Glacial Geology of Maine, the first major study after that of Stone (1899), there was complete acceptance of the former continental glaciation of Maine within the scientific community. The major purpose of their study was to locate and characterize the gravels of Maine as potential road-building materials. In addition, they also produced a surficial geologic history. They reported a variety of equivocal evidence for periods of glaciation earlier than the last episode which we now assign to Late Wisconsin time (Leavitt and Perkins, 1935). It should be noted that considerable differences in time and effort went into the coverage of different areas of the state, which resulted in variations in the quality of results from various areas. Stone's coverage of Maine appears to have been more uniform by comparison.

Leavitt and Perkins proposed two provisional models for dissipation of the last ice sheet. In the first model, a generally east-west trending ice margin receded northward with a continuous but irregular front, progressively uncovering the state like a window shade going up, and continuing into the St. Lawrence Lowland. Final dissipation of the glacier occurred in central Canada. This view was generally held by workers in New England up until about 15 years ago, when a new model started to evolve.

Leavitt and Perkins' alternative model called for simultaneous widespread stagnation of the ice followed by melting downward and inward until the ice sheet separated into irregular masses and ice-tongues in the lowland basins and valleys. Their less-than-critical evidence documents both marginal recession in some areas and separation and stagnation in others. This dichotomous conclusion reflected a major controversy raging in New England at the time concerning which of these methods, marginal retreat or downwasting, was the major mode of glacier dissipation. The same argument persists today, but in a far less polarized and rigid manner.

Regardless of this controversy, Leavitt and Perkins did report observations from which a sequence of geological events was established. In turn, this allowed them to correlate glacial events in Maine with events in the Great Lakes region. The latter area served for many years as a "type section" for the glacial history of North America primarily because of the early and intensive research done in the Midwest by pioneers in the field of glacial geology in the United States.

The interpretations and correlations of Leavitt and Perkins were based upon relative chronology and therefore suffered from the lack of absolute dates. However, they assumed that the sequence of Late Wisconsin deglacial events established in the mid-continent would be the same all along the southern margin of the Laurentide ice sheet in terms of sequence and timing. This was a generally held view at the time. Hence they correlated, without much success in retrospect, the sequence of events as they saw them in Maine with events of the mid-continent. This task has subsequently proven to be much more complex than was imagined in 1935. In addition, they visualized that Maine was totally deglaciated for the last time by 25,000 years ago. Again, this conclusion was based upon correlation with interpretations from the mid-continent, but with no absolute chronological data available from either region.

Following the state-wide study of Leavitt and Perkins, there were a number of studies on the surficial deposits of Maine which provided considerable data on a variety of local topics. Some of these studies contributed to the analysis of major glacial events. For example, beginning with C. T. Jackson (1837), there are scattered discussions in the literature of the glacial-marine

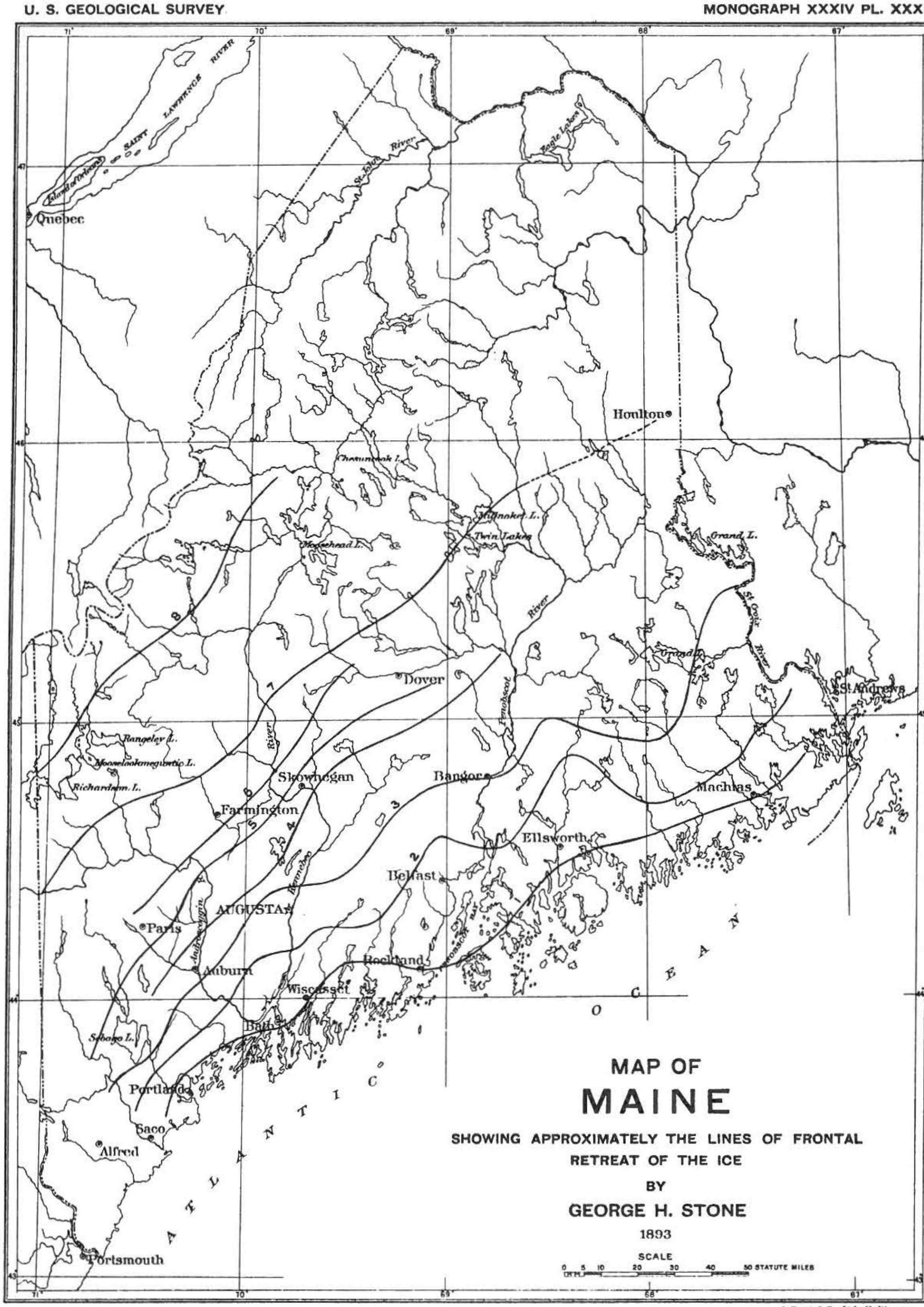

Figure 1. A map of Maine showing approximately the lines of frontal retreat of the Late Wisconsin ice sheet (from Stone, 1899).

sediments that are found throughout the lowlands of coastal and central Maine. Contemporary scientific questions focused on the origin of these sediments, first in the context of the great deluge, and later their relationship to glaciation and related land and sea-level changes. In addition, many published papers reported the nature of the marine macro-fossil assemblage within these sediments, and not only described the taxonomy of the fossils, but reported on their paleoenvironmental significance. Throughout all of these studies there was a thread of general concern about the age of the deposits and their relationship to the margin of the receding glacier and isostatic crustal and sea-level adjustments. In this regard Leavitt and Perkins (1935) were first to compile a map contouring the elevations of emerged glacial-marine features (Fig. 2).

The first significant studies of the emerged fine-grained marine sediments were published in the Report of the State Geologist for 1943-1944 (Trefethen, 1945; Trefethen et al., 1947). This was followed by a series of "clay reports" (e.g. Goldthwait, 1949) for several years, which addressed the geographic distribution as well as mineralogical and grain-size characteristics of the "clay" in regard to possible industrial uses such as lightweight aggregate. Modern studies of the late-glacial to early postglacial submergence and emergence of central and coastal Maine began with Bloom's work in southwestern Maine (1960). In studying the glacial geology, he defined the "clay" unit and named it the Presumpscot Formation. He was the first to critically discuss its relationship to land and sea-level changes and to the receding Late Wisconsin glacier margin. Stuiver and Borns (1975) expanded this style of modern research to include the entire area of late-glacial submergence in Maine. They reported that the Presumpscot Formation was entirely deposited between about 13,500 and 12,300 yr B.P. and applied their chronological data to an existing crustal rebound model. This study produced approximately 40 radiocarbon dates on fossil marine shells and on plant remains from bog bottoms, all of which were analyzed with state-of-the-art methods. Until that time there were fewer than five randomly distributed and poorly controlled radiocarbon dates, all from fossil marine shells collected at scattered locations in central and coastal Maine.

These two studies set the stage for expanded research. H. W. Borns, Jr., in a series of papers, reported and defined an extensive complex of marine grounding line moraines and ice-marginal marine deltas and fans. Borns' work focused on the central and eastern coastal zone (e.g. Borns, 1967, 1973; Borns and Hughes 1977; Borns et al., 1983). This style of work was expanded into the western coastal zone by G. W. Smith and W. B. Thompson, who examined the distribution and chronology of grounding line deposits and their implications for styles of deglaciation (e.g. Smith, 1981, 1985; Smith et al., 1982; Thompson, 1979, 1982). These and other field investigations were carried out as part of the surficial geologic mapping programs of the Maine Geological Survey. W. B. Thompson and co-workers further expanded the research on the marine transgression with studies of ice-marginal deltas throughout the entire

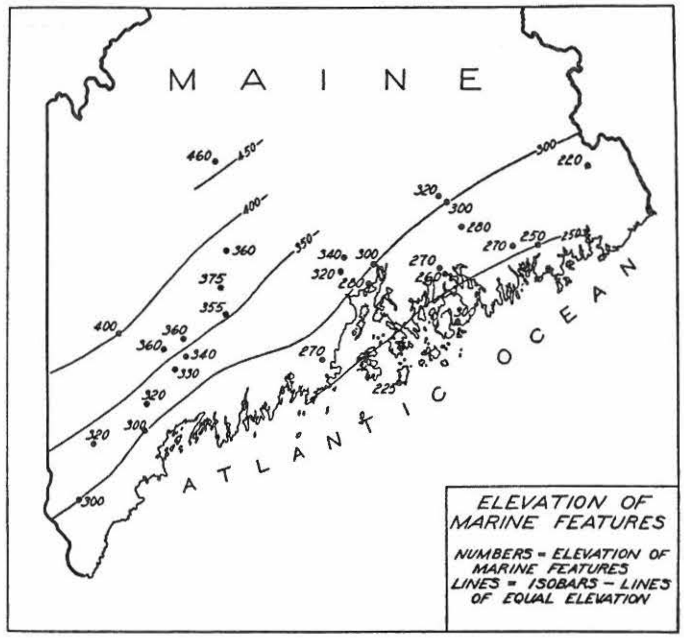

Figure 2. A map of Maine showing contoured elevations of emerged late-glacial deltas and other indicators of the upper marine limit (from Leavitt and Perkins, 1935).

area of submergence and used these data to contour the postglacial rebound pattern (Thompson et al., in press).

In addition to many topical and geographically local studies, increasing attention has been given to defining the former extent of the Laurentide ice sheet in the Gulf of Maine. Clearly, most researchers long ago agreed that the last ice sheet had flowed generally towards the southeast, across the present coastal zone of Maine, and terminated to the southeast at some unknown position on the continental shelf. Shepard et al. (1934) were the first to quantitatively address the question of the extent of the glacier on the continental shelf. In their paper on the geology of Georges Bank they determined that the last ice sheet reached that position after expanding across the entire Gulf of Maine.

Since the work by Shepard et al. (1934), a number of Canadian and American studies have been done in the different areas of the Gulf of Maine. These studies have yielded two opposing ideas on the former extent of the glacier (e.g., Borns et al., 1983; Dyke and Prest, 1987; Mayewski et al., 1981; Stone and Borns, 1986). In summary, there is little doubt that ice extended to the edge of the shelf; the question is during which ice advance. Presently, the evidence is ambivalent as to whether the Laurentide ice sheet terminated just off the Maine coast or on the edge of the shelf. However, accumulating evidence favors the latter hypothesis (Stone and Borns, 1986).

MULTIPLE GLACIATION

Leavitt and Perkins (1935) were the first to present data in an organized manner that suggested the possibility of multiple phases of glaciation in Maine. These data consist of regional variations in glacial ice-flow directions determined by striae, coupled with localized observation of crossed sets of striae, and stratigraphic interpretations of readvances at various locations in Maine. All of these interpretations suffer from a general lack of rigorous understanding of glacier dynamics, a lack of absolute chronology, and limited stratigraphic exposures. However, Leavitt and Perkins' field observations were good, worth consideration, and certainly suggestive.

The first stratigraphic evidence for multiple glaciations in Maine, in contrast to Late Wisconsin glacier fluctuations, was reported from New Sharon in central Maine by Caldwell (1959). At this location he reported two tills separated by a forest litter zone. This was subsequently examined by Borns and Calkin (1977) who reported a radiocarbon date from wood collected at New Sharon at greater than 52,000 yr B.P. (Y-2683). Borns and Calkin also reported other sites displaying undated multiple-till sections. However, recent detailed work by Weddle (this volume) on the exposures at New Sharon shows no evidence of pre-Late Wisconsinan glaciation.

Schafer and Hartshorn (1965), in their synthesis of Quaternary geology of New England, indicated that there had been at least two extensive glaciations of the region based upon their interpretation and that of others of two tills exposed at several locations, largely in southern New England. Koteff and Pessl (1985) extended this till stratigraphy to northern New Hampshire; two equivalent till units representing separate glaciations are believed to occur in southwestern Maine (Thompson and Borns, 1985b). The observations reported in these papers document multiple tills and strongly suggest that there were at least two major episodes of extensive glaciation, the last being of Late Wisconsin age, but a clearer definition of these and possibly other glacial events awaits future research.

LATE WISCONSIN DEGLACIATION

Earlier workers beginning with Stone (1899), and continuing with Leavitt and Perkins (1935), visualized that Maine was last deglaciated from south to north by progressive retreat of the glacier margin. Shafer and Hartshorn (1965) likewise concluded, based upon older as well as some new evidence accumulated since the work of Leavitt and Perkins, that the margin of the last glacier retreated progressively to the north and northwest across New England and into Canada. In addition, they felt, along with Koteff and Pessl (1981), that this was accomplished by "stagnation-zone retreat," a process in which they visualized the progressive development of a stagnation zone of varying widths at the margin of the retreating glacier. Their model was based upon interpretations of the local geology, largely from southern New England, and studies of modern glaciers in Alaska, in particular the Malaspina Glacier. However, there was little new pertinent data available for Maine beyond that presented in 1935 by Leavitt and Perkins and, hence, the marginal retreat model originally suggested by Stone (1899). The regional model of stagnation-zone retreat presented by Shafer and Hartshorn (1965) was indirectly addressed by Borns (1973), who added new field evidence from Maine and re-evaluated the stratigraphic significance of existing radiocarbon dates from the northeast. His interpretation supported the view of a progressive retreat of the glacier margin towards the north and northwest, at least through coastal and central Maine and into Canada. However, the validity of a marginal stagnation zone was still in question. In his conclusion, Borns (1973) cited modern glaciological thinking and pointed out the inadequacy of attempting to correlate glacier margin positions over great distances along the southern and eastern margins of the Laurentide ice sheet.

The long-held "rising window shade" concept of marginal retreat implying progressive retreat of the active ice margin to the north and northwest through New England, the St. Lawrence Lowland, and into central Canada, was generally advocated into modern times (Schafer and Hartshorn, 1965; Borns, 1973). However, an alternative and very different view was expressed by Chalmers (1890, 1899), based upon his work in adjacent southeastern Quebec. He correctly observed evidence that led him to conclude that during the last glaciation, ice flowed from Maine into southeastern Quebec. This indicated for the first time that a local ice sheet occupied the highlands of southeastern Quebec, Maine, and probably New Brunswick. Chalmers named this ice cap the Appalachian Glacier. Unfortunately, his conclusion was not widely accepted and became all but lost with time.

G. H. Stone, working in Maine, certainly had the opportunity to discuss with R. Chalmers the evidence for late ice flowing from Maine into adjacent southeastern Quebec. Apparently with this knowledge Stone (1890) expanded on these ideas, along with his own evidence, and presented his hypothesis for the late-glacial history of the region as follows:

> The above stated hypotheses are consistent with the opinion of Mr. R. Chalmers of the Geological Survey of Canada that from the highlands south of the St. Lawrence River in Quebec the ice flowed north and eastward. This hypothesis would make the valley of the St. John River in Maine the area of accumulation from whence glaciers radiated north, east and south. In a paper on Glacial Erosion in Maine (published in the Proceedings of the Portland Society of Natural History in 1882), I dwelt at some length on the fact that the glaciation of Maine is less intensive in the northern part of the State. This indicates neve-like conditions prevailing over northern Maine for a large part of the glacial period. This conclusion would be consistent with the hypothesis that the radiating flow discovered by Mr. Chalmers continued throughout the whole of the glacial age, or with the hypothesis that it was only a feature of the last days of the ice-sheet. For even if we suppose with Prof. Dana that the highlands near Hudson's Bay were the radiating area during the time of maximum glaciation, it is as yet permissible to suppose that in late glacial time the rising Champlain sea melted its way up the valley of the St. Lawrence, thus isolating the portion of the ice-sheet lying south of that valley. If so, the ice would for a time flow northward from the water-shed of the St. John and from the Notre Dame hills. In other words, late in the ice age northern Maine and the adjacent

territory would for a time be the area of accumulation from whence the ice-flow radiated, no matter what may have been the earlier history of the region. -- G. H. Stone, 1890

The origin of this residual ice cap hypothesis in terms of the contributions from both researchers is not clear. However, it is obvious that their combined observations, conclusions, and experience produced the concept presented in the above quote as early as 1890. Unfortunately, the observations of Chalmers and the hypothesis advocated by Stone for the region were not widely accepted. This concept of a late-glacial residual ice cap over Maine was revived by H. W. Borns (1963) in a paper in which he stated that radiocarbon dates on ice-marginal features in coastal Maine were essentially the same as those for the Champlain Sea. This fact led him to conclude that a remnant ice cap probably existed between the St. Lawrence Lowland and the coast of Maine approximately 13-12,000 years ago. At that time Borns had not discovered the earlier works of Chalmers and Stone on this matter.

Subsequently, workers in Canada (e.g. Chauvin et al., 1985; David and Lebuis, 1985) and in Maine (Kite et al., 1982; Borns, 1985; Lowell, 1985; Newman et al., 1985) have focused upon this "new" ice cap concept, and their work has led to the current understanding of the framework of deglaciation. The greatly increased activity in surficial geological mapping since 1963 and a large body of radiocarbon dates now available from both Maine and Quebec clearly demonstrate that at the time the late-glacial marine invasion had reached the Ottawa River valley, perhaps as early as 12,600-12,800 years ago (Richard, 1978), a residual ice cap in central and northern Maine coexisted with the receding ice-sheet margin lying along the north slope of the St. Lawrence Lowland (Borns, 1985). Thus it is clear that the older "rising window shade" concept for deglaciation at least cannot be applied to the entire northern Appalachian region.

The current model representing the deglaciation of Maine, for example Figure 3, has been presented in publications by Mayewski et al. (1981); Hughes et al. (1985); Jacobson and Davis (1984); and Thompson and Borns (1985a).

ALPINE GLACIATION

Integral with the history of the ice-sheet glaciation of Maine is the associated history of alpine glaciation. As early as 1900 Tarr reported glacial cirques on Mt. Katahdin. He and subsequent workers concluded that these basins were most probably occupied by glaciers during or after the dissipation of the last ice sheet, and since then there has been general acceptance that the basins of Mt. Katahdin are indeed cirques. However, the time of their formation and occupation by alpine glaciers is in question. Caldwell (1966) reported that these cirques held alpine glaciers following retreat of continental ice from the mountain. Davis (1976), the first researcher to produce a surficial geologic map of the mountain, argued that there is no evidence to firmly support Caldwell's conclusions. In 1951, based upon a model of late-glacial climate in the northeast, Flint reported that the highlands of western Maine, including the Boundary Mountains, and also the White Mountains of New Hampshire were probably late-glacial centers of radial ice flow.

However, the work of Borns and Calkin (1977) has clearly demonstrated that the highlands of western Maine did not support either an ice cap or cirque glaciers in late-glacial time, based upon the lack of evidence for post-ice-sheet occupation of the cirques. These authors showed that the cirques were overrun by the last ice sheet, and the mountains emerged first from the ice as deglaciated nunataks. Similar conclusions were reached concerning the White Mountains (Goldthwait, 1970). Clearly, cirques exist in Maine on Mt. Katahdin, Sugarloaf Mountain, and possibly on other mountains (Borns and Calkin, 1977) above the elevations of approximately 800 m. However, the accumulating evidence indicates that these cirques were developed prior to overriding by the Late Wisconsin Laurentide ice sheet and not reoccupied during or after dissipation of the ice sheet. This suggests that by the time these mountains emerged as nunataks the regional snowline had risen to elevations of about 1,500 m or more. This concept has been expanded on a regional basis by Mayewski et al. (1981).

SURFICIAL GEOLOGIC MAPS

The first comprehensive, albeit very limited, surficial geologic map of Maine was compiled by Leavitt and Perkins (1935). Since that time there has been an accelerated program of surficial geologic quadrangle mapping by the Maine Geological Survey, especially during the last two decades. This activity has resulted in the Survey's publication of a new, second-generation Surficial Geologic Map of Maine, co-edited by Thompson and Borns (1985a) and based upon the work of many researchers.

CONCLUSION

The distribution and history of the surficial geology of Maine evolved from a model totally embracing the biblical flood origin, as in C. T. Jackson's First Report on the Geology of Maine in 1837, to a hint of the possibility of some glaciation associated with the flood, in C. H. Hitchcock's report on the Geology of Maine in 1862. However, Dr. John De Laski (1864) was the first researcher who clearly saw and documented that glaciation, and not the great deluge, was responsible for the surficial geology of Maine. Subsequently, origins based upon the flood rapidly disappeared from the literature, and research concentrated upon the regional nature and distribution of glacial processes involved in both sedimentary and erosion features. These studies have led us into modern times, when similar work has continued and provides the data base for modern interpretations of the glacial history and processes that have been active in Maine. Although much is known, there is much yet to learn about the pre-Late Wisconsin history, the maximum extent of ice sheets, the geography and chronology of the last deglaciation, and the nature and

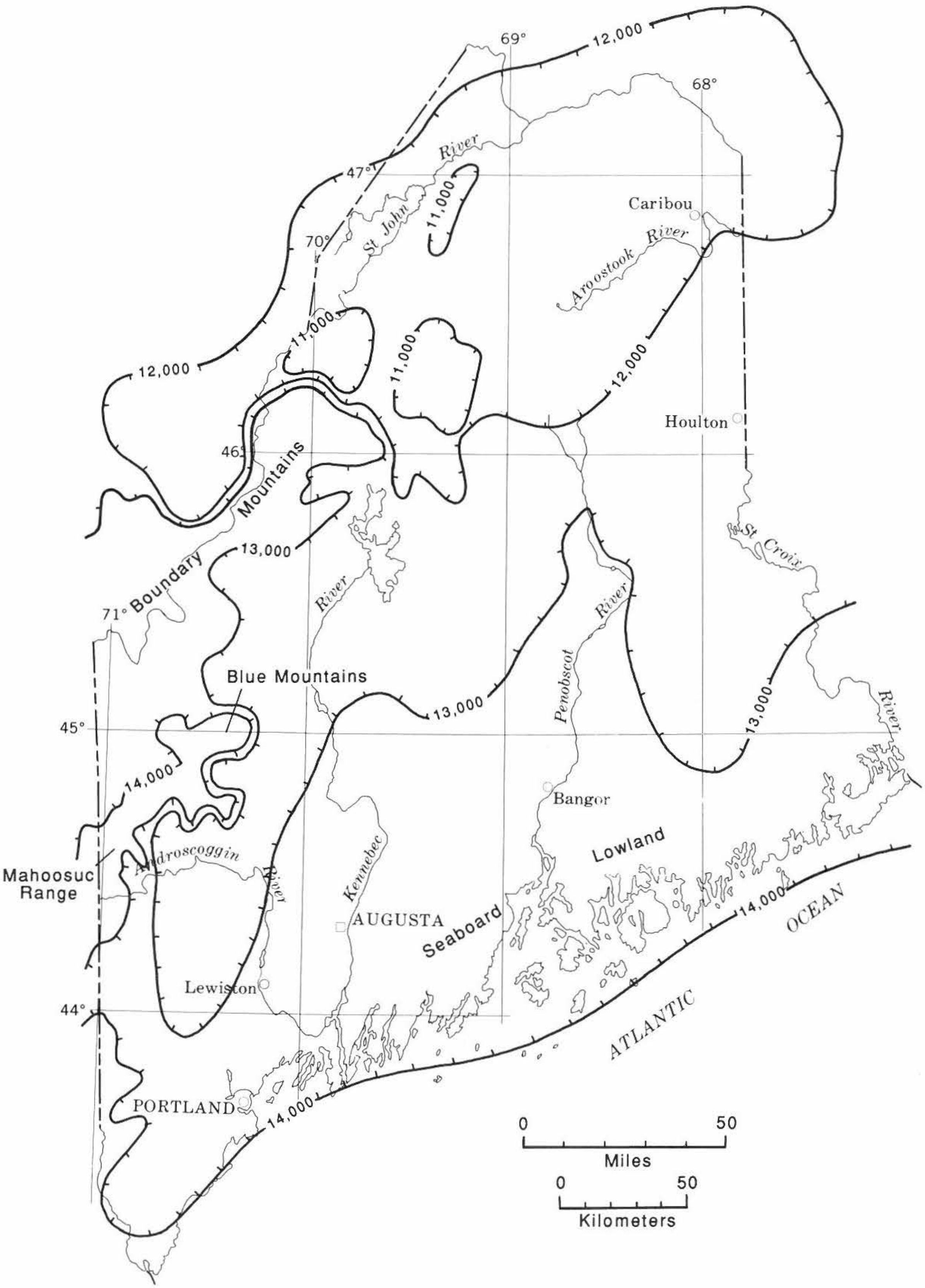

Figure 3. Ice-margin positions during the last deglaciation (from Thompson and Borns, 1985a).

distribution of glacial and glacial-marine sediments. New data, coupled with reconstructions drawn from other Quaternary sciences, will eventually allow the development of a much clearer history of changing late-glacial and postglacial environments which eventually allowed the human occupation of Maine.

To extend our current understanding of the history of the Quaternary Period in Maine, attention should be focused upon expanding the basic knowledge of the sedimentary and stratigraphic record, especially that of pre-Late Wisconsin time, integrating modern glaciological theory into understanding glacial-geological processes in Late Wisconsin time, refining the prevailing but largely generalized deglacial model, and beginning in a concerted way to identify and map the Holocene sediments with the goal of integrating the glacial and non-glacial surficial geology record to understand the entire Quaternary history of Maine.

In total, this data base is becoming an increasingly valuable and necessary tool in making proper environmental decisions in Maine and will provide input into the international effort to predict future global environmental change associated with our current Ice Age.

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