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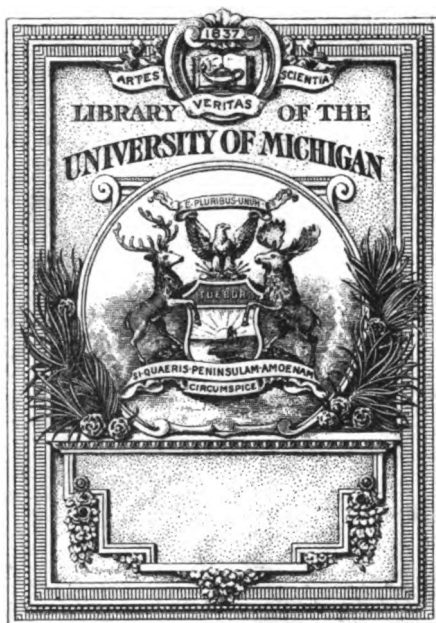
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DEPARTMENT OF THE INTERIOR—U. S. GEOLOGICAL SURVEY  
J. W. POWELL, DIRECTOR

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THE  
POTABLE WATERS  
OF  
EASTERN UNITED STATES

BY  
W J McGEE

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EXTRACT FROM THE FOURTEENTH ANNUAL REPORT OF THE DIRECTOR, 1892-93



WASHINGTON  
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# THE POTABLE WATERS OF EASTERN UNITED STATES.

BY W J MCGEE.

## INTRODUCTION.

### POTABLE WATERS IN THE HUMAN ECONOMY.

Human life depends on the utilization of potential energy stored up in a variety of substances which are consumed as food. These substances include minerals, such as water and salt, which are utilized alike by plants, lower animals, and mankind; vegetal products, comprising fruits and grains as well as leaves, roots, and sometimes stems, which are utilized alike by lower animals and mankind; and a variety of animal products, which are utilized by certain lower organisms as well as by mankind.

While mineral, vegetal, and animal substances yield food for living things, the food substances are not of like value and are not consumed in like proportions by different organisms. The prevailing plant foods are mineral substances which the plants assimilate and transform into higher compounds; excluding water, the prevailing foods of herbivorous animals are these higher compounds of the plant laboratory, which are assimilated and raised still higher; and, again excluding water, the prevailing foods of carnivorous and omnivorous animals are these compounds of the third order which are assimilated and thereby once more raised in the scale of differentiation. Thus, while certain food substances are common to all living things, others differ in degree of differentiation and so in the facility with which they may be assimilated and utilized in the higher stages of vital economy.

There is a differentiation of organisms running parallel with, and doubtless practically dependent on, the differentiation of foods; and viewed broadly the living things of the earth may be classified by the food substances utilized perhaps as justly as in any other way. Under this classification the lowest organisms are those whose food substances are mineral; a higher order includes those organisms whose food substances are predominantly mineral yet in part vegetal; and after several intermediate orders in which the proportion of more and more highly organized food substances varies yet progressively increases, man is found at the head of the series with a higher and more elabo-

rate dietary than any other organism. The reciprocal character of the relation between the organism and its food is well illustrated in this culminating order of the organic series; for while the interdependence of animal and vegetal life began in earlier ages, while, indeed, as early as the Cretaceous of geologic history plant-fertilizing insects and seed-distributing birds initiated the development of fragrant flowers and sapid fruits, most of the foods of modern men are essentially products of human craft. The most useful grains, vegetables, and fruits are vegetal monstrosities, so far modified by cultivation that their original forms are unknown; so far transformed in habit that they can not exist without human aid; so far reconstructed in constitution that their vitality is expended in producing abnormal developments of tissue useless to the organisms themselves and useful only to mankind, for whose behoof they were transformed. And in like manner the chief sources of animal food—cattle, sheep, fowls, and swine—are so completely modified under human will as to be turned into biotic monstrosities, helpless without human aid, whose vitality is expended in producing tissue useless to themselves and useful only as food for mankind. Thus food substances represent a graded series, beginning with undifferentiated minerals and running up to the most highly differentiated animal compounds; and the living things of the earth, with man at their head, represent a parallel series which may be classified by the character of their food. With a single exception there is progressive diminution in the use of mineral foods in the series of organisms followed from the lowest to the highest, the exceptional substance being the mineral compound,  $H_2O$ , or water, which is consumed alike, and nearly always in a large proportion, by all living things.

Human foods are classified in a variety of ways. Thus they are frequently divided into liquids and solids, a division which is measurably indefinite for the reason that the nominal solids are always composed in part, generally in greater part, of water; but even under this classification it is commonly found that considerably more liquid than solid food is consumed. Classified chemically, foods are divided into (1) proteids, or nitrogenous substances, including the most highly differentiated among animal and vegetal compounds; (2) fats or non-nitrogenous substances, in which the proportion of hydrogen and oxygen is unlike that of water and which are second in the inverse order of complexity among animal and vegetal compounds; (3) carbohydrates (sometimes called amyloids) or nonnitrogenous compounds of carbon with hydrogen and oxygen in the proportions required to form water, i. e., relatively simple vegetal and animal compounds, standing third in the inverse order of differentiation; and (4) minerals, including water and various salts. This classification, too, is indefinite in that most articles of food embrace more than one and many embrace all of these constituents—indeed, the best dietary comprises all of these food classes, and none of the food articles in common use are free from the

preponderant mineral constituent, water. Classified by function, human foods may be grouped as (1) nutrients, including meats, fruits, cereals, vegetables etc., whose substance is largely assimilated and absorbed into the system; (2) assimilants, including a variety of condiments which aid in assimilation; (3) paratriptics, or waste-preventers, including tea, coffee, wine and other alcoholic beverages, etc., which in some little understood way retard the waste of tissue and consequent dissipation of energy; and (4) diluents, which modify the consistency of solid foods and thereby facilitate assimilation, besides maintaining the water of the system and perhaps performing other functions. This classification also is indefinite, partly for the reason that many articles used as food perform different functions (e. g., milk is at once a nutrient and a diluent; beer at the same time a nutrient, a paratriptic, and a diluent, etc.); but, like the primary classification by degree of differentiation, the classification by physical condition, and the chemic classification, it indicates the low order of simple liquids among food substances.

So while water occupies the first place among foods in quantity it would appear to occupy a low, perhaps the lowest, place in quality.

The average human adult, in a condition of health and moderate activity, consumes daily about  $4\frac{1}{2}$  pounds of simple liquids and about  $2\frac{1}{2}$  pounds of nominally solid food, really consisting of about equal parts of water and solids, yet so intimately commingled as to demand common treatment; i. e., nearly two-thirds of the average human food is liquid, and barely more than one-third is more or less diluted solids. Now the character of the liquid food consumed by mankind varies from place to place and from time to time with many conditions; but under the social and other conditions obtaining in this country to-day by far the larger part of the liquid food is simple water; and accordingly it is fair to estimate that about one-half of the matter daily taken into the average American stomach is nominally pure water, drawn from spring or river, well or cistern, running brook or city hydrant.

The culinary condition of food substances in this country is not uniform. Most solids are cooked, and thereby any noxious germs or germ products that they may contain are destroyed; many fruits and nuts which are eaten raw are protected by epidermis or shell, so that the danger of contamination is reduced; most beverages are subjected to such treatment in manufacture or cooking as to destroy organic germs (which are now recognized as the cause of most diseases) and thereby rendered innocuous; but water is commonly consumed just as it comes from pump or hydrant, without germicidal treatment, without thought of poisons that may lurk within it. Accordingly, while water may constitute but half of the aliment, the danger of germ poisoning from this substance is, other things equal, much greater than the danger from all others combined.

Solid and liquid foods, even in the uncooked condition, are not alike in danger of contamination. Meats and other animal substances are

highly complex compounds, and therefore, under the law of inverse relation between chemic complexity and stability, they are eminently unstable, so that decomposition is easily initiated and proceeds with great and cumulative rapidity; and in somewhat less degree the same is true of vegetal food substances. Hence, germs which are noxious alike to these substances and to the chemically similar substance of the human body can not long exist without making their presence known; and devices for cooking and preserving foods and systems of food inspection have been developed in order to protect human life from dangers growing out of organic poisons in solid food substances. But water is the common food of animal and plant, microbe and mankind; it is so stable chemically that microbes may exist within it in incalculable numbers without breaking it down or appreciably changing its character; and alone or in combination with other substances it is a favorite, or at least a suitable, medium for the growth and multiplication of germs noxious to mankind. Accordingly, the chance of organic poisoning by potable water is not simply that of the relative proportion of water and other foods, not even the greater probability going with the ratio of danger in raw water to that of cooked foods, but the very much greater probability growing out of the fact that water is a fit and favorite medium for the development of microbe life. This deduction from food character is fully sustained by medical records—indeed it is really an induction from medical observations traced backward, for the infection of typhoid and intermittent fevers and many other germ diseases is so commonly traceable to contaminated waters that the experienced practitioner called to combat such ills at once turns to the well, spring or cistern as the probable source of the disease.

In short, potable water occupies a prominent place in the human economy; it is preeminently *the* food substance of living things, and common to all from the highest to the lowest; it is the most abundantly consumed of all food substances, often more abundantly than all others combined; but at the same time there is a danger in its use much greater than in all other aliments. So it behooves men well to consider their water supply.

#### THE CONQUEST OF THE WATERS.

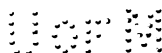
The land of eastern United States is sinking, and the ocean is encroaching on its purlieus. The encroachment has continued for uncounted ages, and the sea waters have backed into the lower reaches of the rivers, converting the valleys into estuaries; and thus the sinking of the land has given character to our coasts and thereby determined the rate and quality of settlement, of the subjugation of the land, and of the conquest of the waters for human weal. This physiographic change, one of the most notable on the globe, may not be neglected in considering the growth of the country.

The first American settlers were invaders of the domain of the red man; they came up from the sea in ships and found havens in the long, narrow, deep, forest-protected estuaries, and the returning mariners carried glowing accounts of fair lands and safe harbors, whereby other adventurers were attracted; and so the ships came up again and again into the deep bayed shores, and cargo after cargo of men and goods were debarked. Plymouth and Jamestown were early points of attack; but the invasion extended along the coast and up the broad estuaries traversing the coastal lowlands until the invaders displaced the aboriginal holders and claimed the land as their own. This was the first stage in the settlement of the country; and it is none the less real that it was not simultaneous from north and south and that it blended with the succeeding stage of internal pioneering.

In the first stage of settlement the invader drank from the fresh streams falling into ocean and estuary, and rejoiced in the sweetness of the waters. When later ships came the invaders, whether Puritans, Knickerbockers or Cavaliers, ascended the tidal canals into which the rivers had been transformed by the sinking of the land, scanning one shore or both for inflowing streams of fresh water; and as the stream mouths were taken by successive communities, or as seaward sites were found unavailable for various reasons, the vessels pushed farther and farther into the interior until they reached the cascades at the termini of the tidal canals; for while the coastwise land is sinking the interior is rising, and the zone of transition from downthrow to upthrow is marked by the line of cascades extending from the Hudson to and beyond the Roanoke (now known as the "fall line"), one of the most trenchant physical and cultural boundaries of the globe. Some settlers in New England, and a few farther southward, indeed, found natural springs; but most of the invaders sought simply for fresh water streams, and the settlements were located at their mouths. In this way the earliest centers of population were fixed, and hundreds of them have grown into towns, and some of them are become commercial marts.

So the dream of the invader of the American soil was a fresh water stream rippling over silvery sands or rushing over rocky bed; long before leaving the fatherland he dreamed by night and queried by day of the tempting flood, and ventured to face the frightsome main only when assured of the verity of the delectable waters in the fair land beyond.

At first the fresh brook water of the new found land was a grateful change from the stale cask water of the ships and even from the polluted streams and wells of the fatherland; and a refreshing expression was coined to indicate the fortunate condition of eastern America—it was said to be a "well-watered country," a land "watered" by many rivers and lesser streams; and the expression took root and followed emigration westward until even the erudite bookmakers came to describe the interior as "watered" rather than "drained" by numerous waterways.



The invaders commonly landed in fair weather, when the brooks were sweet and clear; but storms came and the waters were roiled, the huntsmen with their dogs pushed upstream and the waters were defiled, and anon the spume of marshes spilled into the brooks and the weaker folk fell ill of fevers. Thus little by little the waters of rivers and brooks dropped into disfavor; some sought to store and filter the capricious supply, but they were too few to make this profitable; some made cisterns for storing rain water, but with the limited appliances of primitive culture this involved great labor; and the second generation came to seek for springs and sometimes to dig wells.

So the first stage in the subjugation of the country was invasion by white men from foreign lands; and the first stage in the conquest of the waters began and ended with the beginning and ending of drinking directly from rivers and streams.

The invaders multiplied and the population of the coastwise country grew until the roving hunters on the outskirts found their ranges narrowed, until the farming folk found their acres too few for their families, and then began the stage of pioneering, in which the adventurous sons of hardy sires pushed into the western wilderness toward and finally over and beyond the mountains, slowly displacing the aboriginal landlords who lived on tithes in flesh and blood exacted from bestial tenantry. This was the stage of pioneering, the second stage in the subjugation of the country; and it is none the less real that it was not simultaneous from north to south, and that it merged into the preceding stage of invasion on the one hand and into the succeeding stage of actual settlement on the other hand—for the typical pioneer was a rover, and his race was but the flotsam borne on the breakers of the inflowing tide of population.

A clear cool spring bubbling from moss-covered rocks in a shady dell was the dream of the pioneer. Sleeping and waking, this vision haunted his brain as the brain of one of the first of his class was haunted by the dream of a fount of perpetual youth. From the mysterious sunset land rumors of game-filled woodlands, sparkling trout brooks, and laughing rivers floated away with the west wind and fanned into flame the home-seeking spirit smoldering in a thousand breasts; yet while the home-seeker spoke most of fertile fields and noisy mills and busy water craft, his brightest dreams were of conquest by gun and rod and ax, and the refreshing and health-giving spring was a feature in every picture, often the central feature, about which all others clustered. So the stalwart invader of the red man's domain looked first for a land to his liking and then sought among the hills and valleys for the clear cool spring of his dream; and when he found it, there his household gods were enshrined. His helpmeet shared his quest or soon followed; then children grew up, neighbors came, and the cabin became a house and later the nucleus of a settlement. In this way ten



thousand settlements on both slopes of the Appalachian mountains and in the interior were located; and many hundreds of them have become towns and some of them great cities.

The pioneer accepted the spring as a gift of bountiful providence, or as the meed of patient search, to be enjoyed without profane scrutiny or ingrate question, and the origin of the water was a half-sacred mystery. Ignorant of the source of the crystal flood, he neglected the precaution necessary to preserve its purity, even to prolong its existence; so the fountain was sometimes polluted, often dried up—hundreds of cases of typhoid fever have been traced to the waters of erstwhile healthful springs, and half the springs known to the contemporaries of Daniel Boone and Davy Crockett have ceased to flow. The pioneer dreamed of the spring; his children cherished it until it dwindled away or poisoned their systems; his grandchildren sought the source of the waters, that the supply might be renewed and purified.

So the second stage in the subjugation of the country was that of pioneering; and the second stage in the conquest of the waters began with the search for natural springs and ended when the springs failed.

The pioneer enshrined his Lares and Penates beside the spring, and his followers sought other springs in the same and neighboring valleys, until every natural fountain of the woodland marked a household shrine; and when all were taken later comers crowded around the springs of the early comers and settlements grew up with a well-worn path connecting each house with a nucleal fountain. Yet, even when the springs were utilized to the full, the stream of settlement continued to flow and the pioneers were followed by men of stabler and less adventurous habit, who longed for vine and fig tree rather than gamy sports and flavors, and who sought real homes for themselves and their children. Then it was found that the uplands above the reach of the gurgling spring waters yielded more readily to the plow and produced more abundantly than the steep hillsides bounding the bosky dell, and gradually the sparse population of the pioneer stage spread over the divides and grew into a farming population; later, roads were made, forests were felled, towns were built, and all but the most intractable acres were put to the plow or turned into pasture. This was the stage of actual settlement and the beginning of agriculture, the third stage in the subjugation of the country; and it is none the less real that it was not simultaneous in all parts of the country and that it merged with the antecedent pioneering stage and the subsequent intensive stage.

With the increase in population and the felling of forests the flowing springs became too few and then shrank until a half dried up; so one and another of the settlers, and at last nearly all of the rural householders, were driven to well-digging. At first the failing spring was deepened, and the spring became a well; then other wells were

located on sites whose moisture indicated the proximity of water; still later well sites were chosen at random, and some yielded bounteous supplies of cool, refreshing water, while others were barren. So well-digging went on apace until no homestead was complete without its well, until the son came to dream of the "old oaken bucket" as his sire dreamed of the clear, cool spring; and at length it came about that the water supply of the country was no longer taken from running brooks, no longer dipped from natural springs, but drawn from the artificial well.

The spirit of the pioneer who accepted the spring as a guerdon of the gods clung to his descendants, and some of them, groping blindly for better knowledge, invoked the aid of magic in locating their wells, and the plague of the wizard fell on the land; and from county to county, from settlement to settlement, from house to house, the craze of water-witching spread, deluding thousands and delaying knowledge. Blinded by the glitter of a phantasm, many settlers of the third generation knew even less of the source of the earth-given waters than the pioneer; so they, too, neglected the precautions necessary to preserve the purity and prolong the life of the crystal flood, and the wells were often polluted, sometimes dried up. But when the water wizard failed, and failed again and again until he fell into deserved contempt, when the physician traced the outbreak of typhoid fever to the well, and when the waters dried up in the long summer, many sons of the third generation profited by the experience of their ancestors and more wisely sought to renew and purify the water supply; and thus the nature of wells is becoming known.

So the third stage in the subjugation of the country was actual settlement, actual transformation of woodland and prairie into field and pasture, the appropriation of the land surface for human ends; and the second stage in the subjugation of the waters began with the substitution of artificial wells for natural springs and running brooks and, except in the cities, this stage is not yet ended.

Faculty is the child of exercise in mind as well as in body, in a people as well as in the individual, in the solidarity of terrestrial life as well as in the group of men. Now, so long as fertile and humid lands lay westward, the sons of the settlers sought new homes in the forests and plains of the interior and rested satisfied with a low grade of culture. In soil, as in social condition, their energies were directed toward half-subjugation of the new rather than toward complete subjugation of the old. So, on the Atlantic slope and over the broad interior, settlers multiplied and the population grew to a certain density varying from place to place with fertility of soil and local fashion, when the supposed excess flowed away westward; and the flux continued until nearly all of the fertile and humid lands of the interior, the subhumid lands of the foot slopes rising toward the Rocky mountains,

and the fruitful valleys beyond, were transformed into fields. But when the available lands were taken, the energy born of exercise began to concentrate and seek higher levels, just as the pent-up waters of the walled spring rise; and the farmer boy ceased to dream of reclaiming the distant prairies, which needed only his presence to laugh into bountiful harvests, and sought conquest nearer home. So his hereditary vigor and enthusiasm found outlet first in better methods of farming through the employment of improved farm implements; and the improved implements involved manufacturing, which, in turn, led to the better utilization of forests and the opening of mines of coal and iron, and finally to the development of traffic and transportation; and all these interdependent activities increased cumulatively until human energy came to be expended largely in transforming not only the land surface, but the natural wealth of the forests above and of the earth beneath, until the power controlling the world came to be that of animals and running waters and of steam and electricity, utilized through the craft of the brain rather than the feebler craft of the human muscles.

This is the fourth stage in the subjugation of the country, the stage of intellectual control, in which not only the lands but all things that grow upon them and the resources that lie beneath are appropriated to human welfare; and the stage is none the less real that it is not everywhere simultaneous, but proceeds from nuclei or centers of activity springing into being from time to time and from place to place through the ferment of brain activity; nor is it the less real that it grades out of the earlier stage of subjugation of the surface alone.

The spring of the pioneer was pure and the surface well of the early settler was nearly as pure; but with the increase in settlement and with the manifold attendant transformations of natural conditions the earth beneath barns, houses, gardens, even fields, is gradually charged with noxious by-products of organic activity, and year by year these are washed deeper into the soil and eventually the poison finds its way into spring and well alike. Now in the spring the impurity is diluted and washed away in the flowing waters, while in the well it gathers as a grisly leaven which infects reservoir and contents and changes the healthful flood into festering filth, and curiously—and herein lies the greatest danger to drinkers of well water—as the filth increases the waters become pellucid, sparkling and even brilliant to the eye, sweet and palatably salt to the taste, so that the appetite of the habitual user craves the poison and rejects the pure. How far the surface wells of the country are already polluted no man may say; but certain it is that whole countrysides are annually swept by typhoid fever, that hundreds of towns and villages suffer outbreaks of the same disease every dry summer, and that each epidemic is traceable to the wells; and it may fairly be questioned whether every surface well in city or town is not a source of imminent danger, and whether any such well located hard by village house or country barn is safe. To-day the

groaning sweep and creaking windlass, once beacons of health and the inspiration of the poet, have become signals of danger.

With development of manufacturing, water came to be used in large quantities and for many purposes; with the felling of forests and surface draining most springs failed, and with increasing density of population many wells were polluted or dried up and some rivers were defiled. Thus the problem of potable water supply grew into ever greater importance, and in different localities it was solved in different ways. Utilizing the wisdom inherited from their ancestors and growing out of their own observation, the men of the fourth generation sought potable waters in the deep lying strata of the earth, below the reach of surface contamination, and so artesian wells and deep pump wells were opened; where the underground structure was unfavorable for deep well supply, manufacturers or extensive agriculturists availed themselves of modern devices and made capacious cisterns in which the rain waters were stored; while the urban folk combined interests and forces and made reservoirs and constructed waterworks supplied from rivers, and sometimes adopted devices for filtering or otherwise purifying the waters. All of these solutions of the potable water problem are more or less satisfactory in different regions; and thus the prosaic and practical deep well with rattling windmill or coughing engine or wheezing gauge valves at its head, the underground cement-lined cistern of the North and the overground wood staved and iron-hooped cistern of the South, both filled from carefully cleaned roofs, and the masonry dams diverting river waters into brickwork conduits and through elaborate filters and mains and hydrants to the very hand of the urban user, are all signs of the times and mark a fourth stage in the transformation of nature for human weal.

So the fourth stage in the subjugation of the country is that of complete utilization of natural resources residing in the soil, on the surface of the land, and in the underearth; and the fourth stage in the conquest of the waters began with the making of artesian fountains, or with the diversion of the rains and the control of the rivers, and will end only when the substitution of artificial processes for those of nature is completed.

The progress of civilization in this country may be measured in many ways, but in none more definitely than by the subjugation of the land and the conquest of the waters. The first stage was that of invasion from other lands when men lived largely on the products of the chase and the spoils of the sea, and, like the aboriginal landholders whom they displaced, drank from the running brooks; the second stage and generation was that of hardy pioneers who dreamed of clear, cool springs embowered in primeval forests, and who accepted the flowing water as a guerdon of the gods; in the third stage and generation men were lovers of home and the soil, and in transforming the soil to their uses

destroyed the springs and became well-diggers, and this stage is not yet fully passed; in the fourth generation and stage, which is not yet fully come, men transform not only the soil but all nature, and by cooperation and the utilization of manufactured devices delve deep into the earth or divert the rains and rivers that they may enjoy to the full, without danger of poison, the simple mineral food on which all life depends.

#### THE SOURCES OF POTABLE WATERS.

The immediate sources of potable waters are (1) the rain water collected in cisterns or other reservoirs; (2) running brooks and rivers; (3) springs and wells supplied by ordinary ground water; and (4) deep wells and deep-seated springs supplied by phreatic water. But in the last three cases, as in the first, the ultimate source is the rain falling from the clouds.

While the primary source is the natural rainfall, potable waters are in all cases rendered available by certain natural agencies, or by artificial devices more or less closely simulating the natural agencies; and these agencies and devices give character to the immediate sources.

In the simplest case the waters are collected and stored in cisterns largely or wholly by means of artificial devices. The first device is a catchment area (or drainage basin) which is commonly an artificial roof, though it may be a tract of ground surface of suitable conformation, artificially protected from defilement. The second device is a system of waterways designed to collect the rain waters falling on the catchment area, and these waterways are commonly artificial eaves-troughs, pipes, and conduits; but when the ground surface is employed as a catchment area, natural ravines may be utilized in lieu of a part of the artificial system. The third device, which is not essential to the collection of water for certain purposes, though it is absolutely essential to securing water of sufficient purity for potable uses, is a settling basin, or filter, or both combined, in which the water is strained of mechanical impurities taken up in catchment area and water pipes, and freed (either directly, or indirectly through long storage) from organic impurities gathered from roof or ground surface; and devices designed for this purpose in connection with cisterns are always artificial. The fourth device, which is not a prime requisite but which is requisite for a permanent water supply, is a reservoir of considerable dimensions in which the storm waters are kept against the season of drought; and most reservoirs designed for potable waters in this country are artificial cisterns.

In the second case in the order of complexity, potable waters are drawn from running brooks and rivers. In this case the primary source remains the rainfall, and the catchment area which serves as the agency for collecting the waters is the natural drainage basin of the waterway, while the settling-basin, or filter, is in some measure

replaced by irregularities in the channel,<sup>1</sup> and the body of the stream serves as the reservoir. Now in this case only a part of the rainfall can be utilized; for while a portion of the storm water gathers into rills and rivulets and flows down the slopes and through the main waterways, another portion is absorbed by the porous soil to perform various functions in hydric economy. A fraction remains near the surface of the soil until drawn upward by capillarity and evaporated when the sunshine follows the rain; another fraction is consumed by the plants; while a third fraction percolates slowly downward and remains long at depths determined by the porosity of the soil, the frequency of rainfall, and other conditions, as a simple sheet of moisture known as "ground water;" or under certain conditions it passes into deep-lying strata and is conveyed long distances through subterranean channels or, more frequently, through inclined porous strata as "phreatic water;"<sup>2</sup> and the running brooks and rivers flowing on the surface are supplied only by that portion of the rainfall which flows off on the surface, together with that portion of the absorbed water which is given back through seepage and springs—commonly ground water, rarely phreatic water.

In the third case in the order of complexity, potable waters are drawn from ground-water springs or wells. Now, the ground-water surface is a somewhat indefinite one, and more or less variable in depth from storm to sun, from winter to summer; but in general it is a subterranean surface coinciding fairly with the land surface, save that it is somewhat smoother, its divides lower, its valleys shallower; and when the two surfaces intersect in the deeper valleys, the ground water exudes and perhaps gathers into subterranean streams, appearing in the bottoms or sides of the valley as springs; but in general each surface drainage basin or catchment area has a subterranean double to which the waters are conveyed by percolation vertically downward and along which they slowly move in obedience to gravity. The drainage basin of the land surface therefore constitutes a catchment basin; the porous soil and subsoil serve as an indefinite medium for collecting the waters, which sometimes form for themselves more definite subterranean channels, the whole constituting an agency for water transportation corresponding in function with the artificial system of eaves-troughs and pipes used in connection with the artificial catchment area; the slightly pervious soil and subsoil constitute an agency for freeing the water from impurities analogous in function to—and indeed the model for—the artificial filter; and open caverns, or saturated sand beds and other exceptional porous deposits, serve as natural reservoirs similar in function to artificial cisterns.

<sup>1</sup> As set forth in some detail later, p. 33.

<sup>2</sup> This term was coined by Hay, in the course of the recent artesian and underflow investigation between the ninety-seventh meridian and the foothills of the Rocky mountains, as a convenient designation for "underground waters which can be, or which it is hoped may be, reached by wells or other subground works." Final Geological Report, etc., to the Secretary of Agriculture. Senate Ex. Doc. 41, part 3, Fifty-second Congress, first session, p. 8.

In the fourth and most complex case the waters rise from deep lying strata through natural or artificial openings, and are thus phreatic (called artésian when they flow from artificial openings). Now, in this case, too, there is a catchment area which is, however, only indirectly dependent on the surface configuration and may be remote from the well or spring; the deep lying cavern or porous stratum performs a function analogous to that of the artificial system of waterways used to connect artificial roofs and cisterns; and as in the case of ground water, either open caverns or saturated sand beds—nearly always the latter—replace the artificial reservoirs.

So, whatever the immediate source of potable waters, the ultimate source is the rain distilled from the clouds; and the waters are made available by four more or less clearly defined natural agencies, or four artificial devices of related function. The first of these is always the natural or artificial catchment area on which the waters fall; the second is always the artificial system of eavestroughs and pipes, or the natural drainage system of surface streams, or the natural system of subterranean drainage; the third is the artificial settling basin or filter, the natural pools of surface waterways, or the natural filter afforded by slightly pervious earth matter; and the fourth is always a reservoir whether in the form of artificial cistern, natural cavern, or natural mass of saturated sand or porous rock.

Of the four sources and modes of supply of potable waters, the first—that of cisterns—pertains chiefly to technology, yet is little understood and trenches upon applied geology so far as to demand treatment; the second—that of brooks and rivers—pertains largely to technology and is specially treated by municipalities and other corporations, and hence does not require extended technical discussion here; while the third and fourth sources and modes of supply pertain directly to geology and require somewhat extended treatment.

#### CISTERN WATER SUPPLY.

##### TYPES OF CISTERNS.

A considerable part of the population of the country take their drinking water from underground or overground cistern supplied from the storm water gathered on roofs. Both types of cistern possess merit, and both are, or may easily be made, safer than ordinary wells; yet certain elements of danger inhere in both.

##### UNDERGROUND CISTERNS.

In the northern and middle zones of eastern United States, underground cisterns prevail. The usual type of cistern is a simple excavation in the earth of suitable dimensions, floored and walled with brick

or stone, and covered (except for the neck opening which serves as a manhole and accommodates the inflow and pump tubes) with an arched roof of the materials used for the walls; the entire interior being lined with a coating of hydraulic cement. In the northern zone at least the

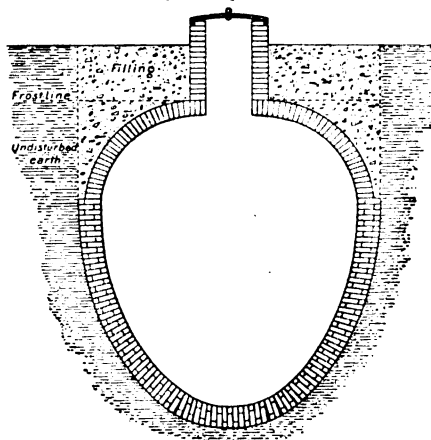


FIG. 1.—Cross-section of jug-shape cistern.

excavation is generally made sufficiently deep to permit the roof to be covered with a thickness of earth greater than the maximum depth of frost. The size of the cistern depends, of course, on the service expected of it, and in some measure the form depends on the size. The ideal form of cistern is that of an egg with the small end downward. A common form in some districts is a modification of this, i. e., a jug shape, with sloping sides, flat or rounded bottom, and

arched roof. A good example of the jug form, with rounded bottom, is shown in Fig 1. A cistern of any such form is, however, somewhat difficult to construct, and its contents, full or partly filled, difficult to determine. A practical form of underground cistern, which well resists internal strains produced by its own contents and the external strains due to ground water under hydrostatic pressure, is a simple segment of a vertical cylinder, with hemispheric arched roof and inverted floor. Such a cistern is shown in section in Fig. 2.

The ideal type of cistern is modified in many ways: Thus, where building stone is abundant and brick expensive stone is frequently employed for the floor, walls, and roof and gives fairly satisfactory results. In fact stone is inferior to brick in cistern-making chiefly in that it is commonly used rough, thereby giving a liability to imperfect joints and to points and lines of weakness either in the main structure or in the lining.

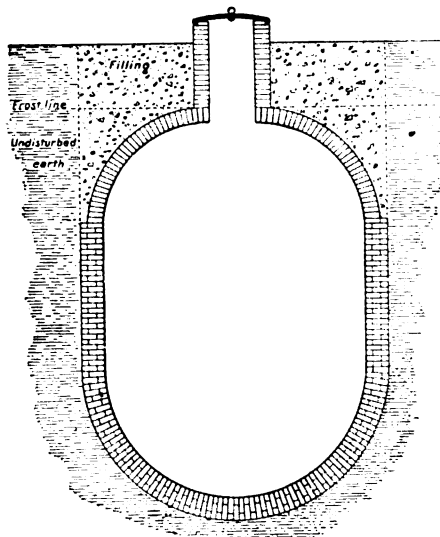


FIG. 2.—Cross-section of underground cistern of simple form.

Again, where the unconsolidated soil is thin and rests on firm and homogeneous rock the reservoir is sometimes excavated therein and the

cement lining applied directly to the rock surface; an arched roof of brick or stone being constructed in the usual way. Where the rock is sufficiently solid and impervious this method is excellent, giving cisterns of great durability; it is objectionable when the rock is porous or penetrated by water-bearing seams, in which case considerable hydraulic pressure may be brought to bear upon a relatively thin wall of cement.

In regions of exceptional homogeneous subsoil or unconsolidated earth matter cisterns are sometimes made by simply excavating the earth and lining the bottom and sides of the excavation with cement applied directly to the earth; when the cistern is commonly roofed with wood, either lined with cement, tarred, charred, or in the natural condition. This method has given satisfactory results in the loess region of the Missouri and lower Mississippi rivers, and sometimes in glacial drift; but it is subject not only to the dangers common to rock cisterns but also to the danger of caving of the little coherent material of the walls.

The excellence of the underground cistern lies (1) in the protection of the waters from organic contamination within the carefully lined reservoir; (2) in the relatively uniform temperature of the water; and (3) in the certainty of supply—for while storms come at irregular intervals,

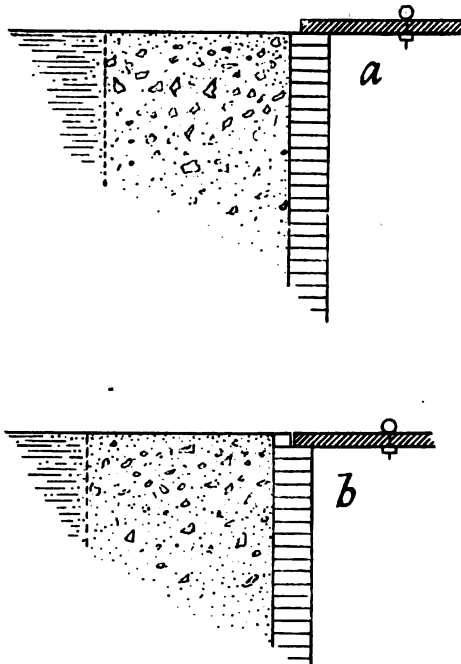


FIG. 3.—Unsatisfactory arrangement of cistern cover.

and while precipitation varies somewhat from year to year, the average annual precipitation is so nearly uniform as to permit calculation of the dimensions of a cistern required to yield a given annual water supply.

The principal sources of danger residing in the cistern itself are (1) the admission of contaminated surface water; (2) direct contamination of the water through the use of unsuitable materials; and (3) cracking of the lining and consequent admission of contaminated ground water.

Surface water may be excluded by suitable construction of the neck of the cistern and by carrying it above the reach of the highest local floods. Frequently the neck of a cistern is made to terminate flush with a cemented floor, and is closed only by a wooden cover laid flat on

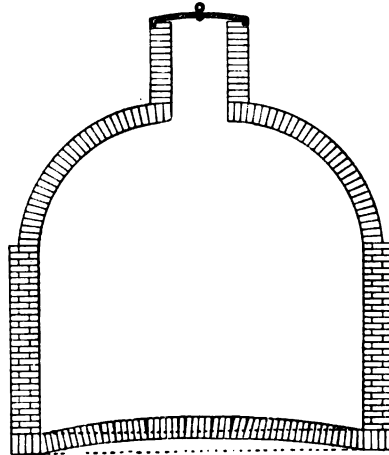
the surface or a cover of wood or iron or terra cotta fitting into a rabbet or depression, as shown in Fig. 3. Such an arrangement is unsatisfactory and a source of danger. Commonly little care is taken to raise the floor above the reach of storm floods or spilled liquids; and even when this precaution is taken dust and other solid matter finds its way under the edge of the cover and into the cistern. The neck should always be carried to a height of at least several inches above the floor and the cover should have an outer flange fitting on the outside of the neck or on the outside of a rabbet made to receive it, as shown in Fig. 1. Equal care in fitting should be bestowed on the pump, which commonly passes through an aperture in the cover. The best material for the cover is terra-cotta ware; the next best iron. If wood is used the interior should be painted with tar or coated with pitch, and it should be frequently examined for fungoid growths and cleaned or renewed.

The direct contamination of cistern waters through materials used in construction is commonly from wood used for roofs and sometimes for walls. Wood should never be used for cistern walls. If the materials in which the excavation is made are such as to require cribbing, wooden cribbing may of course be employed, but it should either be removed on walling or should be thoroughly and completely lined by a water-tight wall of brick or stone laid in hydraulic cement. The use of wooden cistern roofs is also to be deprecated, except, perhaps, when used simply as a support for a lining of cement, which should join and form a unit with the lining of the walls. It is true that wood kept constantly moist endures much longer than when subjected to alternations from wet to dry, commonly longer even than when kept thoroughly dry; but, nevertheless, decomposition begins sooner or later, and certain of the products are poisonous; and, moreover, fungi and other minute organisms are liable to infest wood, hastening decomposition and multiplying the poison.

The chief source of danger in cisterns is cracking of bottom, walls, or roof, and consequent leakage or admission of contaminated water. The cracks are most frequently formed in the bottom; first, because the bottom is carelessly made level, when the floor and lining form a plane which is more easily deformed and broken by external pressure than the curved surfaces of walls and roofs; and second, because most builders neglect the "creep" of more or less plastic earth materials which causes the bottom slowly to bulge upward. Moreover, it is a besetting sin of the cistern-maker not to floor the cistern at all, even when the sides are properly walled, but simply to line it with a thin coating of hydraulic cement. The "creep" of clay beds and even of shale is well known in mines in which the pressure is removed from the portion of the stratum lying immediately beneath the drift and conveyed to the portion lying beneath the side walls; when, partly through the elastic expansion of the materials of the stratum, but chiefly through an

actual viscous movement of the shale or other rock from both sides, the floor of the drift slowly rises and in some cases eventually fills the opening. Now commonly the depth of cisterns is limited, and hence this element of "creep" is much less important than in mines, but it is always to be anticipated; its tendency is to bulge the bottom upward as shown in Fig. 4, and thus to break the floor or crack the cement lining. This element of danger is to be guarded against by constructing the floor of the cistern in the form of an inverted arch, as shown in Fig. 2; or, if this is impracticable, by making the floor so thick and strong as to resist not only the "creep" of materials, but also to compensate for the relative weakness of the plane structure as against the curved structure of walls and roof. It should be noted that the most destructive stress to which the cistern is subjected is commonly that due to external hydrostatic pressure of the ground water.

Cracking of walls and roofs can be guarded against only by the use of good materials in sufficient quantity, and by careful construction. It is to be remembered, particularly when water-bearing seams are encountered in the excavation, that the external water may have considerable "head" or hydrostatic pressure, and when the water in the cistern is low considerable strength of wall may be required to resist this pressure. In some instances, however, the external pressure is less than the internal pressure when the cistern is full.



Rupture of walls or cracking of cement in sides or bottom is sometimes due to the simple weight of water within the reservoir either (1) when the material in which the excavation is made is heterogeneous or incoherent, or (2) when the walls are of inadequate strength. These sources of danger are always to be foreseen and provided against by the use of suitable materials and proper construction.

A serious source of danger in the higher latitudes is expansion and contraction and consequent cracking of the roof through frost action. This evil is best prevented by sinking the reservoir to such depth as to lie beneath the reach of frost; but when this is impracticable the danger may measurably be avoided by use of nonconducting materials, by exceptional strength of roof and thickness of cement, or perhaps by the use of a cement made slightly elastic by the introduction of a fibrous material; or, when asphalt is found available for closed cisterns, by the employment of this somewhat elastic cement.

A self-evident source of contamination is living things, such as frogs, tadpoles, fish, larvæ of mosquitos or other insects, water plants, etc.;

and dead animals or plants are rank poison, their presence demanding the immediate emptying and disinfesting of the cistern.

#### OVERGROUND CISTERNS.

On the Gulf slope, and to some extent on the southern Atlantic slope and in the Mississippi valley, overground wooden cisterns prevail. The chief advantage of this type of cistern lies in its economy; the overground cistern is commonly employed where brick, stone, and cement are expensive, and where, moreover, contaminated "ground water" is exceptionally abundant (e. g., in and about New Orleans), rendering protection therefrom unusually difficult and costly.

Commonly the overground cistern is simply a large, strong, wood-staved cask, tapering upward like an old fashioned churn or fish kit, hooped with iron and floored with a strong bottom fitted into a deep

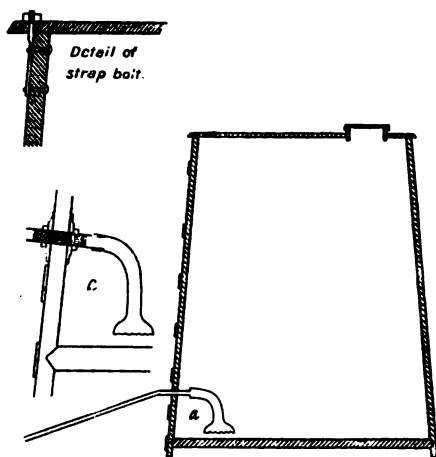


FIG. 5.—Section of overground wooden cistern.

chamfer, the floor commonly requiring the support of external cross beams. Such cisterns should always be covered in order to cut off evaporation and prevent the admission of germ-bearing dust; if of moderate size a movable cover with an external flange fitting over the top will suffice, but if large the cover should be permanently attached and provided with a manhole. The permanent cover may either rest on the ends of the staves and be attached thereto by screws or strapbolts,

as shown in Fig. 5, or it may be chamfered in like the head of an ordinary cask, when apertures should be provided for the escape of water accumulating within the chine. The manhole may be circular or square, with a neck (a hoop, if circular) rising higher than the tops of the staves or other obstruction to the run-off of rain water; and the cover should have an outer flange fitted on or rabbeted into the neck. All joints should be pitched or tarred, and the entire interior should be treated with pitch or other preservative; good results are obtained by charring, though perhaps the best treatment for the interior is coating with silicate of soda or "liquid glass." The exterior should be thoroughly and frequently painted.

Various kinds of wood are used for overground cisterns. The desiderata are (1) freedom from ill taste; (2) durability; and (3) the minimum contraction on drying and consequent freedom from warping. On the whole, cypress is probably the most satisfactory material. The chief source of danger inhering in the overground wooden cistern is contamination of the water from the wood itself, and this is to be pre-

vented only by constant attention to the cover and upper walls of the cistern and by drawing off the water and recharring or recoating the entire interior at intervals of a few years, or whenever the water becomes in the least degree foul. It may be observed that the existence of so-called "water lice" or any other visible organisms in the water affords sufficient warrant for its condemnation; for while the organisms themselves may not be injurious to the system, and while, as frequently held, they tend measurably to purify the water by consuming minute organisms and organic products, their occurrence always indicates the presence of organic impurities, without which, indeed, they could not live.

The wooden overground cistern can hardly be accepted as a sign of the times like the carefully designed underground cistern or the artesian well; it stands rather for the third stage in the conquest of the waters represented by the ground-water well in more favorably conditioned regions. At best the wooden cistern is a primitive affair which is bound to be supplanted by more trustworthy and wholesome devices. It is, indeed, probable that the rain-supplied reservoir will long remain in use in the regions in which overground cisterns now prevail; but it is eminently desirable that some better material should be used in its construction. Probably the best substitute for the easily destructible germ supporting wooden staves and headings will be found to be terra-cotta boards or, perhaps, groups of hollow hexagonal prisms of the same material. There is an extensive area in western Kentucky and Tennessee, northern Mississippi, northern Florida, and parts of Georgia and Alabama in which the lower part of the Lafayette formation contains immense beds of fine siliceous clay, sometimes known locally as kaolin or pipe clay. This material is admirably suited for the manufacture of so-called terra-cotta in boards, tiles, cylinders, prisms, and other forms, and, indeed, is already in use for such purposes. The deposit is one of the most extensive in the world and is bound to be utilized at no distant day, and no better use can be made of the abundant and excellent material than in purifying the water supply of southern United States.

#### ARTIFICIAL CATCHMENT AREAS.

Both underground and overground cisterns are commonly supplied by rain water caught on artificial roofs and collected in gutters and conveyed through pipes directly to the reservoir, or preferably to a filter chamber communicating therewith. Now, the character of cistern water is measurably determined by the materials of the roof on which it is collected. The prevailing roofing material used at the present time is wood, generally in the form of shingles; probably next in extent of use follows metal, usually tin or iron, generally painted; and last in the order of use come slates and tiles. The chief advantage of wood as a material for roofing lies in its cheapness and, if the structure roofed is temporary, consequent economy. It is objectionable from the

hygienic point of view in that unless frequently cleaned or painted the shingles become covered with fungi, lichens, and mosses which eventually cover the greater part of the roof, and in that the wood, howsoever durable or carefully treated, progressively decays. The vegetal growth and decay, and the breaking down of the wood, yield a certain amount of mechanical sediment as well as abundant organic impurities, which are washed from the shingles and are liable to find their way into the cistern. Accordingly, the use of shingle roofs as catchment areas for cisterns can not be recommended, and unless special pains are taken to prevent contamination is strongly to be deprecated.

Metal roofs are preferable to shingle roofs partly in that they may be laid flatter, thereby economizing material. They are preferable also hygienically in that they are much less liable to support organic growths. They are, however, in some measure objectionable in that they readily oxidize, when the oxides are carried into the cistern and affect its contents; the oxides of lead and zinc sometimes used in galvanizing iron or in soldering tin and other materials being especially deleterious. Simple iron oxides are less injurious and, indeed, sometimes beneficial.

Slate roofs are in general nearly as little liable to vegetal growth as metal, and slates are, moreover, practically free from danger of contamination through metallic oxides. Accordingly, slate is an acceptable material for roofs used as catchment areas for cisterns. Glazed tiles are, however, preferable to slates by virtue of their greater freedom from organic growth; indeed, the ideal roof for use in connection with cistern water supply is one of glazed tiles.

Both wooden and metal roofs are frequently painted. If renewed from time to time the paint diminishes the danger from organic growth on wooden roofs and from oxidation on metallic roofs; but the paint itself is gradually worn off under the action of the weather and the beating of the raindrops, and a part is washed into the cistern, either as inert sediment or an active metallic agent, which may be poison to the human stomach, the oxides of lead, which are largely used to give body to mineral paints, being especially injurious.

All roofs, whatever their material, are liable to fouling in a variety of ways. Where coal is used as fuel, and to some extent even where wood is burnt, soot and ashes accumulate during the hours and days of sunshine, and when the storm comes they are carried into the cistern. While these are, perhaps, the least objectionable impurities (soot being even superior to charcoal as a deodorant and disinfectant), they are liable to discolor the water and to affect its flavor. Dust also constantly accumulates on roofs in the intervals between storms, to be swept down the eavestroughs and pipes when the storm begins; and dust is one of the most effective vehicles for the transportation of microbes and spores. Still more dangerous is the pollution of roofs by cats and domestic or semidomesticated birds, chiefly pigeons, while

the most dangerous pest of all is the English sparrow, which not only defiles the roof but nests in and constantly befouls eavestroughs and water pipes. From the point of view of sanitary water supply, cats and pigeons are nuisances and the sparrow is a scourge.

The danger of contamination of cistern water inhering in the conditions of roofs can not, perhaps, be completely removed, but it may be greatly diminished by care and attention. Every roof should be of the best available material and should be cleaned artificially from time to time; and, moreover, the system of pipes connecting roof and cistern should be so arranged as to permit the diversion of the first waters of the storm until roof and eaves troughs and pipes are thoroughly washed.

The catchment area required to supply a given household may easily be computed from (1) the number of persons to be supplied, (2) the daily allowance per capita, (3) the rainfall in the district contemplated, and (4) the frequency of rainfall sufficient to fill the cistern.

The consumption of water in cities and suburban districts has steadily increased for many years. The average consumption for domestic purposes, including drinking, is more frequently over than under 20 gallons per day for each person, but this figure is fair as a basis for computation. When the cistern water is used only for drinking and cooking this allowance may be much reduced, even to a tenth in extreme cases. On the other hand, when stables are supplied, or if water is used freely for baths and closets or in gardens, the allowance should be much increased, even to ten times the average amount.

The rainfall and its distribution throughout the season vary in different districts. The accompanying table, compiled by Mr. Cyrus C. Babb, Secretary of the National Geographic Society, shows the mean rainfall by months in five representative cities of eastern United States:

*Average rainfall for 18 years.*

| Stations.           | Jan. | Feb. | Mar. | Apr. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. | An-<br>nual. |
|---------------------|------|------|------|------|------|-------|-------|------|-------|------|------|------|--------------|
| Portland, Me. ....  | 3.57 | 3.62 | 3.28 | 3.15 | 3.03 | 3.36  | 3.80  | 3.76 | 2.85  | 3.85 | 3.89 | 3.39 | 41.55        |
| Boston, Mass. ....  | 4.56 | 3.88 | 4.49 | 3.95 | 3.30 | 3.58  | 3.57  | 4.26 | 2.72  | 4.12 | 4.86 | 8.50 | 46.79        |
| Philadelphia, Pa. . | 3.42 | 3.29 | 3.21 | 3.01 | 2.99 | 3.50  | 4.36  | 4.80 | 3.20  | 2.90 | 3.08 | 2.75 | 40.51        |
| Washington, D. C.   | 3.41 | 3.26 | 4.21 | 2.95 | 3.48 | 4.40  | 4.52  | 4.38 | 3.71  | 3.15 | 2.85 | 3.11 | 43.43        |
| Augusta, Ga. ....   | 4.63 | 3.71 | 5.39 | 4.01 | 3.34 | 4.42  | 4.77  | 4.63 | 3.40  | 2.55 | 3.49 | 3.86 | 48.20        |

The roof area required to yield a given supply with any rainfall may be determined from the following table, also kindly computed by Mr. Babb. It should be observed that where water is collected from ordinary roofs for drinking purposes a considerable allowance should be made for the washing of roof and pipes by the first waters of the storm, an element always important, and especially so when storms are light and frequent.

*Quantity of water collected on given roof areas from 500 square feet to 10,000 square feet, with given rainfall from 0.5 inch to 5 inches.*

| Roof area.   | 0".5.    | 1".      | 1".5.   | 2".      | 2".5.  | 3".      | 3".5.  | 4".     | 5".    |
|--------------|----------|----------|---------|----------|--------|----------|--------|---------|--------|
| 500 .....    | 155.84   | 311.69   | 467.5   | 623.38   | 779    | 935.06   | 1,091  | 1,246.7 | 1,558  |
| 1,000 .....  | 311.69   | 623.37   | 935.1   | 1,246.7  | 1,558  | 1,870.13 | 2,182  | 2,493   | 3,116  |
| 1,500 .....  | 467.53   | 935.06   | 1,402.6 | 1,870.12 | 2,338  | 2,805.2  | 3,273  | 3,740   | 4,676  |
| 2,000 .....  | 623.38   | 1,246.75 | 1,870.1 | 2,493.50 | 3,117  | 3,740    | 4,363  | 4,987   | 6,234  |
| 2,500 .....  | 779.22   | 1,558.44 | 2,337.7 | 3,116.88 | 3,896  | 4,675    | 5,454  | 6,234   | 7,792  |
| 3,000 .....  | 935.06   | 1,870.13 | 2,805.2 | 3,740.26 | 4,675  | 5,610    | 6,545  | 7,481   | 9,350  |
| 3,500 .....  | 1,090.91 | 2,181.82 | 3,272.7 | 4,363.6  | 5,455  | 6,545    | 7,636  | 8,727   | 10,910 |
| 4,000 .....  | 1,246.75 | 2,493.50 | 3,740.2 | 4,987    | 6,234  | 7,480    | 8,727  | 9,974   | 12,468 |
| 5,000 .....  | 1,558.44 | 3,117    | 4,675   | 6,234    | 7,792  | 9,350    | 10,908 | 12,467  | 15,584 |
| 6,000 .....  | 1,870    | 3,740    | 5,610   | 7,481    | 9,351  | 11,220   | 13,091 | 14,961  | 18,702 |
| 7,000 .....  | 2,182    | 4,364    | 6,545   | 8,727    | 10,909 | 13,090   | 15,272 | 17,454  | 21,818 |
| 8,000 .....  | 2,494    | 4,987    | 7,480   | 9,974    | 12,468 | 14,961   | 17,454 | 19,948  | 24,936 |
| 9,000 .....  | 2,805    | 5,610    | 8,416   | 11,220   | 14,026 | 16,831   | 19,636 | 22,441  | 28,052 |
| 10,000 ..... | 3,117    | 6,234    | 9,351   | 12,468   | 15,585 | 18,701   | 21,818 | 24,935  | 31,170 |

#### EAVESTROUGHS AND WATER PIPES.

In early days eavestroughs, and even the system of pipes by which the roof water was conveyed to the cistern, were commonly of wood, and the water was liable to contamination thereby just as from the wooden roofs. Of late years metallic troughs and pipes are commonly used, and while they are superior hygienically to wood there is a danger of contamination through oxidation of the metal itself and of the solder and paint used in connection therewith. Eavestroughs and water pipes are sometimes made of terra-cotta ware or tiling, and the use of this material is to be commended in the strongest terms, particularly in connection with roofs of tiles or slates.

A common source of danger in eavestroughs and water pipes is found in depressions due to bad designing or workmanship, or to subsequent sagging, by which pools are formed in which the storm water accumulates and lies until it is swept away by the succeeding storm or slowly evaporated. Such pools are particularly objectionable in wooden waterways. Insects flock into them to dwell or drown; birds have recourse to them for drinking and for the insects gathered about them; spores are caught and develop into noisome scum and fungoid growths along the margin, and thus the contents of the pool are quickly converted into reeking filth, a mass of organic poison which too often accumulates only to be washed into the cistern by the next storm. In metallic pipes the organic action soon develops acids which attack the metal and add the poison of metallic oxides, but in such cases the evil soon works its own cure, in that the pipe is oxidized through, forming a leak which must be stopped else the water supply is lost. No system of water pipes should ever be designed or constructed or accepted from the builder that does not show a decided fall in every part, and the pipes and particularly the eavestroughs should be inspected from time to time, and whenever a sag is found it should be remedied at once.

A considerable part of the danger of contamination of cistern waters from roofs and water pipes may be removed by suitable devices for

diverting the earlier storm waters until both roof and pipes are washed. The earliest storm water is itself less pure than that which comes later; for it collects from the lower strata of the air a variety of impurities in the form of dust, smoke, carbonic acid, etc. Then the early waters wash the roof and pipes, collecting thereby a series of mechanical, chemic, and organic impurities which should not be given entrance to the reservoir for potable waters. Accordingly the cistern should never have direct and permanent connection with the roof; but the pipes should be so arranged as readily to be disconnected from the cistern and turned into a waste pipe.

Moreover, it is important that the waste-pipe connection should be habitually maintained, automatically or otherwise, except when the storm waters are deemed sufficiently pure to be admitted into the cistern; and the waters of slight storms and the early waters of all storms should be excluded from the cistern for such time as to permit the thorough washing of roof and pipes.

A common defect in systems of water pipes connecting roofs and cisterns is inadequate capacity. Usually little attention is given to the relation of roof slope and area to size and slope of eavestrough; consequently while the trough may suffice to carry the waters of the light summer shower, it overflows during the heavier shower and allows most of the waters from the storm to run to waste. The serious nature of this defect becomes evident in view of the considerations just mentioned. It is bootless to provide water pipes to carry only the product of light showers when this product is turned into the waste pipe; it is the product of the great storm which quickly washes the roof and then runs pure that it is most desirable to preserve and convey into the reservoir. Accordingly, care should be taken to make eavestroughs and water pipes amply large; if there is any doubt as to the capacity of the former, their slope should be increased to augment their carrying capacity to the desired amount.

#### FILTERS AND RELATED DEVICES.

So many are the ways in which the relatively pure waters falling from the clouds are contaminated on roofs and in water pipes that despite the utmost care cisterns connected directly with roofs are certain to be polluted sooner or later; and if the pollution be that most pervading and insidious of all poisons, germ-bearing organic matter, it will rapidly develop until the entire body of water and the walls by which it is confined will reek with poison. Accordingly, whatsoever the materials of which roofs, eavestroughs, and water pipes are made, whatsoever care is exercised to prevent contamination, no cistern should be used as a source of potable water supply without the further protection afforded by a filter.

Filters used in connection with municipal or other water supply in which the ground surface serves as a catchment basin are commonly

designed to serve several purposes, e. g., (1) to exclude the floating débris, (2) to remove mechanical sediment pushed forward along the stream bottom or held in suspension, and (3) to exclude or destroy organic impurities. Accordingly in such cases it is usual to employ a number of devices including (1) grates or strainers, (2) mechanical filters or settling basins, or both, and (3) devices for securing protection against organic matter. The rain waters collected on roofs or other artificial catchment areas, however, carry little mechanical sediment, and simpler filtering devices suffice.

In most cases the first requisite is a grating or strainer designed to catch leaves, twigs, and other débris that may be blown upon the roof or swept into the eavestroughs during the storm. Such a device is especially necessary when insufficient care is given to diverting the early storm water until the roof and pipes are washed; for in that case there is additional débris of birds' nests and other inter-storm accumulations to be removed. A simple grating, or preferably a strong wire sieve, placed in an enlargement of the pipe immediately below the waste gate, and provided with a movable cover or door, will commonly be found sufficient.

The most important requisite, which is, indeed, absolutely essential to the purification of water taken from ordinary roofs, is a filter for organic matter, which may be so designed as to exclude also any mechanical sediment that may pass the grating. This may consist of alternating layers of gravel, sand, and charcoal, or of a single layer of each of these materials so arranged that the water passes first through the gravel, next through the sand, and last through the charcoal. Other devices are sometimes used with satisfactory results. The Spencer filter, which has been "used in England with great success in connection with sand filtration," employs in lieu of charcoal "the crushed grains of the carbide of iron prepared by roasting red hematite ore mixed with equal parts of sawdust in an iron retort." This material is mixed with the "sand of the lower sand strata of a sand filter and its office is to decompose the organic matters in solution in the water. The carbide is said to perform this office thoroughly several years in succession without renewal."<sup>1</sup>

While this device is especially adapted to use on a large scale in connection with municipal water supply, and has, indeed, been adopted in several of the cities of Great Britain, it is also well suited for use in a small way in connection with cisterns for domestic supply. Another device recently patented in England, but not yet introduced in this country, would seem to be specially applicable for use in connection with household cisterns. This is the Atkins filter, which is designed chiefly or solely for the removal of organic impurities. It consists essentially of charcoal plates, usually a foot square and 3 inches thick, and so firm that their surfaces when foul can be scraped

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<sup>1</sup> Hydraulic and Water Supply Engineering, by J. T. Fanning, 1890, p. 534.

clean. The plates are set in frames as panes of glass are set in the sash, and so arranged that the water must percolate through them in passing from the filter chamber to the main reservoir.<sup>1</sup>

The filter should be so arranged as to be easily accessible for cleaning or renewal, and the conduit opening into the cistern should be provided with a valve or gate, in order that the inflow may be shut off in case of accident to the filter. Various arrangements for filtering have been devised: Thus, the cistern is sometimes divided by a partition into two portions, connected through the filter, the inflow pipe communicating with one compartment, the pump or outflow pipe communicating with the other. Sometimes, also, two cisterns are placed side by side and similarly connected. A more satisfactory arrangement on the whole, however, is a combination of cistern and filter chamber in such manner that the contents of the latter will flow into the larger reservoir through the charcoal plates or other device for filtering. In capacity the filter chamber should suffice to contain the water collected from a single storm; it should be protected from contamination by a manhole cover, etc., like the main cistern; and the filter should be so arranged as to permit inspection of either side. Such a filter chamber should be floored and roofed and lined precisely like the cistern, and provided with a waste or overflow pipe to prevent the water from flowing over the top of the filter, and the conduit opening into the main cistern should always be supplied with a shut-off gate. A filter chamber of this character may be made to perform the functions also of a settling basin by carrying the inverted arch forming the bottom below the level of the filter; and the sediment accumulating in the lower part of the bottom should be removed from time to time.

Filters should be used also in connection with overground cisterns. A simple and evident modification of the filter chamber just described may advantageously be employed.

Various expedients may be used temporarily for the clarification and purification of cistern waters. The most trustworthy is boiling, and no cistern water in which the least trace of organic matter, living or dead, can be detected by the eye, or in which the least trace of foulness can be detected by tongue or nostrils, should ever be used without boiling. Mechanical sediment, which is commonly finely divided clay or mud, may be precipitated by alum when a portion of the organic impurity is commonly carried down at the same time. A saturated solution of alum used in the proportion of 1 part of solution to 50,000 parts of water may be employed for the purpose. The perchloride of iron, in the proportion of 3 or 4 parts by weight to 100,000 parts of water, is especially useful for the precipitation of organic impurities in water, and it has been found by repeated experiments in England and Holland that ordinary iron in the form of filings, turnings, or scraps is a useful purifying agent. All such devices, however, are to be regarded

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<sup>1</sup> Op. cit., p. 535.

only as temporary expedients, makeshift substitutes for the more trustworthy plan of preventing contamination.

To palates accustomed to the water of springs and wells, cistern water is frequently insipid, particularly after long standing. Commonly the staleness and ill flavor of cistern water is due to impurities of such character as to warrant condemnation or demand boiling, but in some cases the difficulty may be remedied by aeration. Many users of cisterns find that the waters are aerated in a satisfactory manner by the use of a chain pump in which the return pipe is fitted to the valves or buckets so that air is pumped into the cistern in quantity equal to that of the water pumped out.

#### STREAM WATER SUPPLY.

##### ECONOMIC CONDITIONS.

In the first stage in the conquest of the waters, the invaders of the red man's domain stooped to quaff from running brooks and dipped water from rivers for domestic uses; but this primitive mode of water supply soon passed away. The waters of running streams are roiled by storms and run dry in droughts, while in populous districts they are contaminated in a multitude of ways. Accordingly stream water can not be made available for drinking and domestic uses without elaborate and costly devices for purification and storage.

The devices for purifying and storing stream waters for drinking and domestic purposes usually comprise a reservoir, which may serve as a settling basin, and some arrangement for filtering; and in addition there are commonly required a dam across the stream yielding the supply, together with intake gates and conduits connecting the stream with the reservoir, and also a system of mains and lesser pipes designed to convey water from the reservoir to the points at which it is needed. Commonly these devices are too extensive and expensive for individual means and can not, accordingly, be installed until the population becomes so dense that individual interests may be united and waterworks constructed for the common use. So a practical requisite for stream water supply is a dense population of united interests. This condition is fulfilled in various parts of the world, and public water supply has been found feasible by municipalities in all civilized countries.

Cooperative water supply from streams, demanding as it does the construction of expensive works, involves a direct or indirect water tax which, like all other institutions designed to distribute benefits, is strenuously opposed by certain individuals and classes. Moreover, there is an undercurrent of opposition to water taxes growing out of the hereditary sentiment that potable water, like the air, like the waters of open ocean, like the land under primitive social conditions, is common property and should be free to all; and for these and perhaps other reasons the installation of waterworks and the imposition of water taxes has

been in the past and is bound to be in the future vigorously opposed in every community, municipality, and state; and this ultra-conservative opposition is a condition which has to be faced whensoever and wheresoever it is proposed to improve the common water supply at the common cost.

Few partisan policies are more prejudicial to human interests than opposition to water taxation. Half the food taken into the human stomach is water, and two-thirds of the preventable disease of modern times arises from the use of impure water. So individuals, communities, municipalities, and states are directly or indirectly taxed, and exorbitantly taxed, in order that individuals may enjoy the inalienable right of consuming poison. Hospitals are maintained, cemeteries are laid out and beautified, and undertakers are supported in consequence of the use of impure water; men and women who should be in the bloom of health are made invalids, children are cut off at the dawn of life, and the aged and infirm are daily swept away by reason of the poison in potable waters; and the average life and working period of man in every country is materially shortened by defective water supply. No municipality or other community can evade certain imposts which grow out of the relations of men among each other and to their environment, and, laying sentiment aside, the questions which communities have to decide are: Is it cheaper to maintain waterworks than hospitals and cemeteries, and is the water tax less burdensome than the impost of the undertaker?

The practical question as to the amount of water tax which a given community is able to bear can not be decided in the abstract by reason of the multiplicity of local and perhaps temporary considerations. The general proposition may indeed be laid down, that no tax is too heavy which secures the health and happiness of the community through permanent immunity from disease; and if the city, town, or village is so unfortunately located that pure water is not obtainable, it should, in common humanity, as well as in the interests of national progress, be abandoned. Practically, however, there is probably no city, town, or populous village in eastern United States which can not secure a trustworthy supply of potable water by collecting the rainfall on artificial roofs or in artificially protected drainage basins, provided natural streams are not obtainable; and so the maximum limit of cost for stream-fed waterworks may be fixed at the minimum cost of rain-fed reservoirs.

The practical question as to the size of town or village required to warrant public water supply is also too complex for solution in general terms, since it depends on a wide variety of local and variable conditions: The character of the population and industries pursued; the cost of waterworks and the tax involved; the character and cost of the present supply, and the preventable death rate depending thereon—all these and many other conditions have to be weighed in solving the

problem as to the expediency of public water supply in city, town, village, or smaller community. In general it may be said that a function of every incorporated city or town should be the supervision and control of water supply; for in this case, as in many others, the thought of the majority is directed elsewhere, so that the few must at least take the lead in thinking for the many. In general it may be said, too, that any community burdened by disease or handicapped by a high death rate is large enough to consider the question of public water supply and to secure pure water in one way or another; and in a desperate case it should be remembered that the actual value of potable water in the human economy, estimated in terms of the quantity consumed, in terms of the beneficence of purity and maleficence of impurity, in terms of physical and mental work determined thereby, or estimated in any other comprehensive way, is fully equal to that of all other foods combined.

So the artificial control of stream waters for common use may be recommended in the strongest terms, and no reasonable per capita tax should be allowed to stand in the way of instituting systems of water-works. This conclusion indeed flows from the logic of events in the settlement of this and other countries, as clearly as from considerations respecting the source and conditions of potable waters in general. Public water supply has long been a subject of municipal legislation and in some cases of legislation by states, and institutions for water supply have grown up in spite of vigorous opposition and have spread wherever men are gathered in such numbers as to profit by cooperation; and this righteous tendency, which has proved stronger than creed or platform or party in the past, is bound to continue until not only the greater cities but the lesser towns and villages are supplied with pure drinking water at the common cost.

#### NATURAL CONDITIONS.

Viewed as sources of potable waters, rivers and smaller streams may be arbitrarily separated into three intergrading classes, viz, (1) storm-fed streams, (2) spring-fed streams, and (3) composite streams.

Streams of the first class serve simply to carry off that portion of the storm water (including the melted snow fall) which is not absorbed into the earth to be consumed by plants or to form ground or phreatic water. Such streams divide into secondary and again into tertiary tributaries, and eventually spread out in fan-like assemblages of rills into which the sheet of fresh-fallen storm water quickly divides; and in humid regions, like eastern United States, streams of this class are nearly always more or less swollen by reason of storms in some part of the drainage basin, though in protracted droughts they run dry. Thus each rain-fed stream represents the accumulation of the storm waters of a definite drainage basin bounded by divides. It is subject to freshets

and great floods produced by vernal snow melting and by heavy storms, particularly when the storms succeed each other in time and place throughout the basin in such order that the floods of all tributaries reach the lower river at the same time. Such rivers, moreover, commonly carry considerable quantities of sediment, for the falling rain-drops, by their impact, dislodge particles of soil and these are carried down the slopes, along the rain-formed rills, and into the ravines and brooks, where a part are deposited by the water, while another part is swept into the lower river. Moreover, such surface streams transport considerable quantities of organic matter swept from the living and dislodged from the decaying vegetation by which the drainage basin is mantled. These characters of surface streams affect their value as sources of supply for potable waters.

The second class of streams is supplied by springs, which may be either of the ground water or of the phreatic type; and they are always less liable to freshets than rain-fed streams, practically uniform in volume when fed by phreatic water. While such streams commonly convey beneficial or injurious mineral salts in greater or less quantity, they usually convey little mechanical sediment derived from the breaking up of the soil and the corrasion of channels; and, in general, they are much freer from organic impurities than rain-fed streams. These qualities affect the value of spring-fed streams and in general the inherent value of spring-fed streams as sources of potable waters.

The third type of stream is supplied in part by storm waters and in part from the outflow of springs, and in general their characteristics are intermediate between those of the distinctive types. Most of the rivers of eastern United States belong to the composite type.

Not only the channels of streams but the valleys in which they run, the hills by which they are bounded, and indeed the entire surface represents the secular work of streams, and there is thus a marvelously harmonious interrelation of parts in each drainage basin. In general the slope of the surface of the stream, or the fall, increases from the lower river to the heads of the tributary streams and confluent brooks, diminishing again toward the divides over the narrow zone representing the sheet of water accumulated during the storm, the zone over which the fresh-fallen rain water flows as a sheet or in ill-differentiated rills too small to form channels. Thus the profile of the waterway from the head of the brook to the mouth of the river is commonly a flattened curve, concave toward the sky, the degree of curvature depending on a variety of conditions, of which one of the most important is the increasing volume of the stream. This curved profile exemplifies the *law of water profiles*,<sup>1</sup> and the degree of curvature affects the rate of deposition of mechanical sediment borne in the stream, and thus the value of the stream as a source of potable waters.

<sup>1</sup> Defined in detail in the Eleventh Annual Report of the U. S. Geological Survey, 1891, p. 246.

The general law of water profiles is affected and measurably antagonized by a subordinate law (the *law of varigradation*),<sup>1</sup> under which the curved stream profile is broken up into alternating pools and rapids. These alternations of relatively still and relatively rapid water are initiated by a variety of causes and conditions, and exert an important influence on the work of the stream in excavating its channel and in fashioning its drainage basin; and they exercise a decided influence on the deposition of matter transported by the stream, and are thus of exceeding consequence in streams used as sources of potable waters.

The rate of stream flow in general depends on slope or declivity; and in general (1) the amount of matter transported in the waters and (2) the activity of the stream in cutting its channel and fashioning its drainage basin depend on the rate of flow and so on the declivity. Other conditions also affect the rate at which sediment is conveyed; i. e., the muddiness of waters. One of these is time distribution of the rainfall. Nearly all of the work of streams in transporting sediment and corradging channels is performed during or in consequence of storms; and other things equal, it may be said that the activity of stream work diminishes with uniformity in precipitation and increases with variable precipitation and culminates where (as in the arid regions of the United States) the precipitation occurs chiefly in infrequent storms. This law finds expression in topographic configuration: Other things equal, regions and districts of gentle slopes and soft contours are regions of uniformly distributed rainfall; other things equal, regions of steep slopes and rugged contours are regions not simply of limited precipitation, as certain masters have held, but of rare storms. Again, the activity of stream work depends on the character of vegetation. When rain falls on a forest the drops are intercepted, and the water percolates slowly down branches and trunk, or drips gently from the leaves, so that the force of the fall is broken, and, moreover, the ground surface is further protected by a carpet of fallen leaves and moss; while on the prairie-land the raindrops are not intercepted, but beat in full violence on the unprotected soil, which is thereby broken up, triturated, and in part carried down the slopes and into the river. Thus, other things equal, the activity of storm work is greater on the prairie than in the forest, and this law, too, finds expression in topographic configuration; for the more active storm waters and streams of the prairie carve the hills into flatter slopes, the waterways into flatter curves, than in the woodland, and there is thus developed a characteristic topography of prairieland and a characteristic topography of woodland which may be distinguished at a glance. All of these conditions affecting the flow of streams and the transportation of sediment therein have an important bearing on the utility of streams as sources of potable waters.

The natural conditions affecting stream water supply are so many and so varied as to render it inexpedient to solve the problem of public

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<sup>1</sup> Op. cit., p. 269.

water supply from this source in the abstract; but they serve to indicate changes and limitations of stream-water supply in concrete cases. Thus it may be said in general that spring-fed streams are superior to storm-fed streams as sources of potable waters; that streams of moderate declivity or gentle (but not too slight) fall are in general superior to streams of high declivity; that other things equal, those streams which are most completely broken up into alternating pools and rapids under the law of varigradation are preferable to streams whose profiles are more uniform; that streams collecting in forest-protected areas are in general freer from freshets and sediment than prairie streams or streams in cultivated districts; and that in general streams are more serviceable as sources of potable waters in regions of uniform precipitation than in regions of variable rainfall.

#### CULTURAL CONDITIONS.

In thinly settled districts the problem of stream-water supply involves consideration only of economic and natural conditions; but the population of eastern United States has already reached such density and such general distribution as to compel consideration of conditions growing out of settlement and industries. The most important cultural conditions are those growing out of (1) cultivation of the soil; (2) the sewerage of cities; (3) the by-products of manufactures; and (4) the waste of mining.

Cultivation of the soil affects materially the volume, rate of flow, and quality of stream water. In regions of high relief agriculturists sometimes endeavor to diminish the rate of run-off of storm waters, either to prevent erosion or to store up ground water against droughts, as in many of the southern states in which contour cultivation has been extensively adopted to serve one or both of these purposes. In regions of low relief, on the other hand, agriculturists resort to open ditches, under drainage, and other devices to hasten the run-off and diminish the ground water, thereby increasing the volume of the stream supply from their acres. But whether the streams are increased or diminished the general effect of agriculture is to increase the transportation of sediment; the plow relieves the beating raindrop of half its task, while the harrow and drill provide rills for the storm water, and the triturated soil is borne off more rapidly than in a state of nature, so that in general agriculture makes muddy streams. But whether mechanical debris is added or not, the effect of cultivation of the soil is to increase the organic impurities; fertilizers are partly absorbed into the ground water to reappear at lower levels, partly washed down the slopes; the annual crop with its enormous waste of root, stalk, leaf, and flower is a more abundant source of organic debris than the natural flora; and, moreover, domestic animals and fowls and even man himself are constantly contributing to the land and event-

ually in part to the streams vast quantities of poisonous by-products of the animal mechanism. So the cultivation of the soil materially affects the value of the stream as a source of potable waters throughout most of the area of eastern United States.

Most cities and many smaller towns secure or seek to secure cleanliness and consequent health by systems of sewerage; and commonly the sewage is conveyed into a neighboring river or on adjacent lands sloping away from the city, to be gradually collected by the waters and conveyed toward the domiciles of their downstream neighbors. In this way the waters of all large rivers are polluted in greater or less degree; sometimes even an important waterway, like the Ohio, is transformed into a great sewer throughout most of its course; and but few rivers, like the Potomac, remain on which the settlements are so few as not to jeopardize the lives of dwellers on the lower reaches compelled to drink of their waters. The contamination of river water by sewage is of great importance in its bearing on the question of stream water supply.

In most cities manufacturing is carried on, and in most manufactories considerable quantities of more or less noxious by-products are formed, and in general these are conveyed either directly or through the sewerage system into the neighboring waterway or on slopes leading thereto. Thus the question of the pollution of rivers through the by-products of manufacturing is connected with that of pollution by ordinary sewage and is of serious import.

Mines and quarries, notably the vast coal mines of the Appalachian region in eastern United States, yields enormous quantities of rock matter, of which a part is thrown into neighboring streams or on tributary surfaces, so as eventually to affect the running waters. A part of the material is organically inert mineral débris, which only adds to the mechanical sediment transported by the streams; but a part comprises mineral salts and various unstable mineral compounds, sometimes of organic origin, which pass into solution, and in some cases befoul and poison the waters. Thus certain mining operations and the disposition of the waste products of mines materially affect the value of the running waters of eastern United States as sources of potable waters.

It is to be observed that to some extent the effects produced on running waters by cultural conditions are compensatory; thus, there is a highly suggestive reciprocal relation between mechanical sediment and organic impurity, evidenced by the facts that sewage is an efficacious precipitant of mechanical sediment and that clay or mud in sufficient volume appears to throw down sewage and other suspended or dissolved organic matter. Thus the mechanical sediment conveyed from plowed lands and the waste heaps of mines into the running streams measurably counteracts the poison of organic matter from farm, factory, and sewer. This inverse relation between chemic and organic impurity

is one of the conditions affecting the value of running streams as sources of potable waters.

#### TECHNICAL CONDITIONS.

Commonly a system of waterworks designed to take its supply from a river or smaller stream requires for its construction a special engineering survey and the construction of dam, intake gates, gauges, conduits, and perhaps other devices which can be successfully installed only under the direction of a hydraulic engineer. Until within a decade it was commonly necessary also to make more or less detailed surveys of the entire area of the drainage basin, designed to show the character of slopes, the presence, absence, or state of vegetal growth, the extent of cultivation, the declivity of the stream and the danger of freshets, the location and probable influence of cities, manufactories, and mines, and in other ways to ascertain the natural and cultural conditions entering into the problem of water supply in the concrete case. During the past decade, however, such progress has been made in the subjugation of the country for human ends that the labor and expense of such general surveys may be spared in many parts of the country.

The U. S. Geological Survey has executed extensive topographic surveys in most of the states and territories; and in the eastern half of the country these surveys are on a sufficiently large scale to meet the general requirements of engineers entrusted with the installation of waterworks. The surveys are made commonly on a scale of 1: 62,500, or about a mile to the inch. They show the configuration of the land, the slopes of streams, the location of lakes and large springs, the distribution of forests; together with roads, railways, cities, towns, villages, and in some cases farmhouses. Several states, acting independently or in cooperation with the national bureau, have made like surveys and published maps of similar character.

Within recent years the operations of the U. S. Signal Service have been extended over a large part of the country, and careful measures have been made of precipitation in the form of rain and snow, so that in almost every district in eastern United States the amount and character of the precipitation may be determined from the published reports of that bureau. Furthermore, the same bureau has instituted a series of hydrographic studies and has established a system of gauging rivers and recording floods, and from this work average natural conditions affecting stream-water supply have been determined and the results of the determinations made public in official reports; and many states maintain weather bureaus or meteorologic offices of related function, either independently or in cooperation with the Signal Service. The Geological Survey has also made extended researches into the hydrography of the country, with the view of ascertaining the extent, character, and frequency of floods in various rivers, and with the view also of determining for various districts what proportion of

the rainfall flows off in surface streams and what proportion is absorbed by the earth to be consumed by plants or perhaps to reappear later in the form of springs.

These researches on the part of the General Government and the wealthier states represent the wholesale method of acquiring knowledge for the public benefit; observations are made by trained men working under definite plans and in accordance with the best known methods; and the results of the work are far more economical and trustworthy than those secured through sporadic effort. Such wholesale researches are preeminently characteristic of the fourth stage in the subjugation of the land for the benefit of human kind. While they are so new that they can hardly be regarded as more than well under way, the results are already of great value; hundreds of cities and towns are to-day in a position to install systems of water supply without the cost of preliminary surveys, and hundreds more are in a position to estimate approximately the cost of public waterworks, and thereby to determine the expediency of cooperative water supply without expensive preliminary examinations.

After the solution of the general problem of water supply there always remains a variety of local and perhaps temporary conditions, giving origin to minor problems which can be solved only by the hydraulic engineer or other technical expert. Similar problems have arisen in various municipalities in different parts of the world, and the experience acquired in solving them has been recorded and crystallized in the art of hydraulic engineering and in a variety of devices and appliances for use in connection with public water supply. So, while such problems are not susceptible of general solution, the present draws on the past for the power of solving them cheaply and well.

In brief, while the problems growing out of the technical conditions affecting stream-water supply are too complex and too varied for general solution, recent progress in scientific work has furnished many of the essential data in such form as greatly to facilitate local solutions, and thus the question of public waterworks no longer remains mysterious and forbidding, no longer transcends the ken of the intelligent citizen, but has become so simple and tangible as to bring cooperative water supply for the common good within the reach of all.

#### GROUND WATER SUPPLY.

##### ACCUMULATION OF GROUND WATER.

When the rain distills from the clouds and falls on the land a part flows away in the form of surface streams and another part is drank by the thirsty soil. Of this part a fraction is consumed by plants, but the remainder percolates downward through the soil and subsoil and perhaps into bed rock, where it may either remain as simple moisture or,

if the substructure is favorable, may flow away through porous strata or in open channels. Immediately after the rain the wettest layer of the earth may be the soil; but as evaporation proceeds at the surface and as percolation proceeds below in obedience to gravity the layer or couche of maximum wetness gradually sinks at an ever-decreasing rate until it is overtaken by the similar couche of moisture derived from a later storm. In this way there is eventually formed a fairly constant layer or couche of moisture at a depth below the surface determined by a variety of conditions, including the slope of the land, and thus the rate of run-off, the porosity of the soil and subsoil, and the frequency of storms. The moisture of this couche or layer is known, colloquially and technically, as "ground water." Ordinary wells are supplied from this layer; many springs flow from it; in sandy tracts perforated pipes—the so-called drive wells—are forced into the earth until they encounter the couche when they are quickly filled, and the water may be pumped out; and when a great earthquake comes, like that of New Madrid in 1811-'13, or that of Charleston in 1886, the shaken earth particles settle into closer contact, and, being heavier than the moisture filling the interstices, squeeze out the water and force it to the surface under hydrostatic pressure so great that the sod may be rent by gushing fountains rising to the height of trees and sweeping out tons of sand to mark for a century the site of the catastrophe. Ordinarily the ground water stream is simply a layer of moisture in permeable soil or rock; yet the disseminated water flows in obedience to gravity, making its way slowly through the interstices of the earth matter just as water exudes from the solid charcoal plates of an Atkins filter.

Commonly the ground water layer is indefinite; the upper limit is simply one of degree of moisture and can only arbitrarily be drawn, perhaps at the horizon at which the moisture is sufficiently abundant to exude more rapidly than evaporation can carry it away, and the lower limit is often more indefinite and of less practical interest. Moreover, the upper limit at least is a variable one, rising with storms and falling with droughts, and so changing from season to season. Yet, albeit indefinite and variable, the ground water layer always forms a surface; and this surface is in general fairly uniform in depth throughout each drainage basin, and thus conforms approximately to the land surface, so that the land surface of each drainage system has a subterranean double which imitates the major features of its model.

Thus in humid lands like eastern United States there is an aqueous circulation within the earth as well as on its surface; that portion of the waters of a given storm absorbed by the earth may exceed the portion which flows away on the surface, and this absorbed water lies long in the earth and a fraction of it at least accumulates in a slowly moving layer of moisture, maintaining approximate parallelism with the surface; and it commonly lies so near the surface as to be intersected by the deeper valleys and is often reached by shallow wells. This layer is

within reach of surface contamination; so while it furnished nectar for the pioneer it distils hemlock for his descendants.

#### GROUND WATER SPRINGS AND WELLS.

While the ground water surface conforms fairly to the superjacent land surface, and while every surface drainage basin has its subterranean double, there is a difference in individuality of the surfaces; the land surface rises into higher and sharper crests and sinks into deeper and sharper ravines than the ground water surface, and accordingly when the land surface is exceptionally rugged it sometimes happens that its deeper ravines intersect the ground water couche when the moisture exudes in the bottom or trickles down the sides of the ravine. This intersection of land surface and moisture surface most commonly occurs when the latter is raised by persistent rains, and is the explanation of the long-continued but gradually decreasing flow of temporary streams as summer advances or as the drought is prolonged. Now, when the ground water horizon is permanently above the level of a surface stream the moisture exuding from the porous rock matter gradually opens passages or channels extending into the hills, and these passages prolong themselves and bifurcate after the fashion of surface streams until they are gradually formed into subterranean waterways with tributaries flowing in from right and left and to some extent from above and below, but all marking approximately the horizon of ground water; and in this way there may be developed a subterranean drainage system, simulating, albeit in vague and variable fashion, the surface drainage system; and the embouchure of the subterranean stream is a spring.

So the ordinary spring, which was accepted as a mysterious dispensation by the pioneer, really derives its supply from the rains which supply also the surface streams of the same drainage basin. When the hills are deforested a larger proportion of the stream water runs off in freshets and a less proportion percolates into the earth, so that the ground water level is lowered and the spring dwindles or fails; so, too, when the land surface is polluted with noxious fertilizers, or when stables or shambles are located on the slopes above the spring, its waters are polluted; and while the percolating waters may be partly purified in their slow passage through the porous soil and subsoil some part of the poison often remains, and the spring, once a source of health and strength, becomes a menace to life.

It follows that the spring fed by a ground water couche is unworthy of trust as a source of potable water. Half the springs of this character known to the pioneers have dried up, and half the remainder have dwindled to the point of failure, and most of the remainder are weakened. Moreover, the ground water spring, like the surface stream, is liable to local contamination. The waters are not distilled from the depths of the earth, but are accumulated rainfall, often gathered within

rifle shot; and while the poison in the spring is diluted in the flowing waters, enough may and often does remain to work mischief—for scores of cases of typhoid and other fevers in different parts of the country have been traced to formerly healthful springs.

The ordinary well is simply an artificial spring of limited flow, and in the laws of its supply, in its evanescence or permanence, in the danger of contamination, it is very like the natural spring gurgling cheerily in the shady dell. Commonly the well is simply a reservoir excavated in the ground water horizon forming the subterranean double of the surface drainage basin; and commonly the reservoir is filled by the exuding moisture from the pervious subsoil, so that, when little used, the water marks the ground water level, though it may easily be pumped out. If the subsoil is exceptionally porous the exuding moisture may gradually open passages through which the water percolates, or even streams, into the reservoir, when the well is a strong one, competent to supply stock as well as human consumers. But, whether weak or strong the ground water well depends for its supply on the rain falling in its immediate vicinity, and thus the supply waxes and wanes with the wetness and dryness of the season and fails when the neighboring hills are deforested. Moreover, the waters are liable to pollution by local poisons coming from ill-used fertilizers, ill-placed barnyards, ill-designed outhouses. The spring of the pioneer was pure and the ground water well of the early settler was nearly as pure, but with increasing population, and with the development of agriculture and manufacturing, and the growth of cities, the very earth is gradually charged with the noxious by-products of organic activity, and year by year these are washed deeper and deeper into the soil, and eventually pervade the ground water horizon. The poison finds its way into spring and well alike; and while in the spring it is in part diluted and washed away, it gathers in the well as a grisly leaven, infecting the reservoir and its contents until the erstwhile healthful flood is changed into noisome filth.

Thus the ground water well, once a source of health and a mark of progress in the subjugation of the land, has in most sections outlived its usefulness and become a source of disease and a mark of social sloth and decadence. How far the ground water wells of the country are already polluted no man may say; but certain it is that whole countrysides are annually swept by typhoid fever, that hundreds of towns and villages suffer outbreaks of the same disease during every dry summer, and that each epidemic is traceable to wells; and while it would be hasty to condemn all wells indiscriminately, it is not too much to say that every well within city limits is a menace to health and should constantly be looked on with distrust, and that every farm well located hard by stable or barnyard is a legitimate object of suspicion.

The pioneer dreamed of the clear, cool spring gurgling from moss-grown rocks in the depths of the dell; the farmer boy dreamed of the picturesque well sweep or creaking windlass and "the moss-covered

bucket that hung in the well;" but both dreams have faded; for the spring is dried up and in the well lurks a poison sweeter than poppies, deadlier than nightshade.

#### PHREATIC WATER SUPPLY.

##### ACCUMULATION OF PHREATIC WATER.

When the rain falls from the clouds and a part is taken up by the thirsty soil, the behavior of the absorbed water depends on the texture and structure of subsoil and bed rock. If soil, subsoil, and bed rock are homogeneous in texture a simple sheet or couche of ground water is formed, but if the subsoil or bed rock is composed of layers of varying porosity, and if these layers are inclined, then the water circulates the more freely in the open textured layers and slowly finds its way down the slope in obedience to gravity. In this way the varying texture of the strata comes to be represented by varying moisture, and each porous bed becomes a phreatic horizon which is measurably independent of surface drainage and closely dependent on structure.

Then, whenever such a porous bed is intercepted by a deep ravine, the waters exude and may gradually form a subterranean channel with tributary channels dividing into seepage passages, and eventually a complete subterranean drainage system; and the embouchure is a spring. The waters of such a spring may come from long distances, and if the distant margin of the inclined porous stratum opens to sun and storm well up among the hills or on the mountain sides the waters may have a strong "head" and gush forth in a natural fountain.

In some cases the inclined porous strata carry the imprisoned waters to considerable depths in the earth, often far below sea level. When the temperature of the water is raised by the proper terrestrial heat, so that if they find or by their increased solvent action make for themselves a passage through the superincumbent less pervious strata, they may appear at the surface as thermal springs; and in this case the waters are commonly charged with mineral salts dissolved by reason of the pressure or the heat of the waters, when they are known as "mineral springs." There are other cases in which the phreatic waters are carried down the inclined strata to fractures (faults) or abrupt flexures in the strata, when they rise to the surface; and if, as frequently happens in mountainous regions, the fault or flexure is undergoing movement (either uniform or spasmodic) and the rocks are thereby heated by friction, the temperature of the water is raised and warm springs are formed which may not come from profound depths; and these thermal springs, like those of deeper origin, may be charged with mineral salts.

In general phreatic waters exist simply as moisture, like that forming the ground water couche, permeating porous beds of sandstone and other rocks; but when limestone or other soluble rocks are permeated

by ground water or phreatic water the material is gradually dissolved along the more pervious lines, and subterranean channels are formed; and these may gradually be enlarged into great channels ever lengthening and bifurcating until the hills are honeycombed with caverns and pitted with sinks, and in some cases (as in the Bluegrass region of Kentucky) subterranean streams take the place of surface drainage, and sometimes these streams burst forth, Juno like, in full-sized rivers, such as the elfin Silver spring of Florida and the enchanting Oklawaha river in which its shining waters are slowly darkened.

So when the subterranean structure and texture are favorable the rain water absorbed by the earth is carried long distances and to profound depths in subterranean drainage systems which are largely independent of surface configuration. Such are the phreatic waters of the country which supply most thermal springs, most mineral springs, all artesian wells, and many deep pump wells; and, in general, the course of the phreatic water from the time of its absorption into the soil to the time of its reappearance in spring or deep well is so long and devious that the mechanical and organic impurities with which it may at first be infected are almost certainly eliminated. Thus the phreatic moisture of the earth is generally a trustworthy source for the supply of potable waters.

#### THERMO-MINERAL SPRINGS.

Some mineral springs are cold and some thermal springs are not abundantly charged with mineral matters in solution, yet in general there is an intimate connection between the thermal condition and the mineral condition; accordingly it is usually inexpedient to separate spring waters into distinct thermal and mineral classes, and for most purposes they may be combined as thermo-mineral waters. In general such waters become impregnated with mineral salts in consequence of the increase in chemic activity due to pressure or augmented temperature, or both combined.

The thermo-mineral character displayed by the phreatic waters appearing in certain springs is produced by a variety of conditions. The prevailing causes are two, viz, (1) contact with rocks heated by faulting, flexure, or other diastrophic movements, or by volcanism; and (2) contact with deep-lying strata whose temperature is raised only by proper terrestrial heat. Accordingly springs of the first class are commonly confined to mountainous regions or regions of volcanic activity, while those of the second class are found in regions of plain surface and simple structure. The first class of springs is accordingly represented by the White Sulphur springs of Virginia, the Warm spring near Asheville, North Carolina, and the Hot springs of Arkansas. The same general class is represented also by many springs distinguished rather for the mineral condition than the thermal condition of the waters, such as those of Saratoga. The second class of thermo-

mineral springs is represented by the deep-seated springs of Florida, of which most are thermal and practically all mineral-bearing.

The thermo-mineral springs of eastern United States are of great and ever-increasing importance as sources of potable waters, for not only the increase in population, but the gradual pollution and abandonment of waters obtained in more primitive ways tends constantly to increase their consumption. Various conditions are, however, combining to regulate and control the distribution of such waters by private enterprises. For this reason and for the further reason that extended publications on the mineral springs of the United States have recently appeared, the thermo-mineral springs of eastern United States do not seem to demand a detailed discussion in this place. They are more fully treated in the following memoir by Dr. A. C. Peale.

#### ARTESIAN WELLS.

Artesian wells (so named from the province of Artois, in France, in which wells of this character were first extensively employed in the present stage in the development of civilization) are usually simple bores tapping deep-seated strata saturated with phreatic water; when, if the tapped stratum is sufficiently porous and the head adequate, the water flows out at the surface. The success of artesian boring depends on a variety of conditions more or less closely analogous to those covering thermo-mineral springs.

In the inverse order of their importance, the requisites for artesian flow of water are, (1) conditions of structure, (2) conditions of texture, and (3) conditions of supply. The most favorable structural condition is an arrangement of the strata in the form of a basin, as in the French province of Artois. The rain water falling on the rim of such a basin percolates through the strata to its center, and there rises through natural or artificial openings to a height depending on the difference in altitude between the area of supply (or catchment area) and the head of the well; but the basin structure is not absolutely essential, and artesian flows are obtained from uniformly inclined strata (such as those constituting the Atlantic coastal plain) when the catchment area is elevated considerably above the wellhead, or when the strata either diminish in permeability in the direction of inclination or extend far beyond the point of outlet, i. e., textural and other conditions may combine with structure to produce flow where structure alone is unfavorable. The most favorable textural condition is found when the porous stratum extends from the catchment area to the part of the basin, trough, or moncline tapped by the drill, and is overlain (excepting in the catchment area) by an impervious stratum. This condition, like the last, is not absolutely essential to artesian flow, since all rocks are more or less pervious, and if the difference in altitude between the catchment area and wellhead is sufficient a slight flow may be obtained almost anywhere; but it is essential to abundant flow, and even

to the slightest flow, unless other conditions are exceptionably favorable. The most favorable condition of supply is found where a porous formation rises from beneath less porous strata and forms the surface over a broad area. It should be borne in mind that on nearly all parts of the land the annual aggregate volume of rainfall largely exceeds the aggregate volume of river flow; that a considerable part of the rainfall not carried directly into the sea by the rivers finds its way thither more slowly by percolation through the rocks in the form of phreatic water; and that in consequence the strata of the earth—at least below the reach of surface evaporation—are more or less completely saturated. Even in desert regions a part of the rain drunk by the thirsty sands during each rare storm reappears in springs, or may be reached by artesian borings to form oases, at lower levels. In short, while the condition of supply is the essential and primary one, it is a fact that the supply is adequate in nearly all parts of the earth, and that artesian flow or its failure are usually determined by local conditions of structure and texture.

Artesian waters, like the naturally escaping phreatic waters, are frequently thermal and also more or less abundantly charged with minerals. The thermal condition, if sufficiently decided, may be utilized, e. g., the warm waters of deep artesian wells may be employed for heating conservatories or residences, as is done to some extent in Florida. The minerals held in solution are sometimes beneficial, sometimes injurious to the human system; and in most sections some wells at least yield waters whose minerals are not so unwholesome as to warrant the condemnation of the water for drinking.

On the whole, artesian wells are to be regarded as a trustworthy source of potable water over large areas in eastern United States. The areas include districts in New England, New York, northern New Jersey, Pennsylvania, western Maryland, West Virginia, eastern Tennessee and Kentucky, northwestern Georgia, and northeastern Alabama, in all of which the phreatic waters represent sublocal rainfall, and in which, with proper precautions, the waters accumulated under local conditions of texture and structure may be considered wholesome. There is another vast area in which artesian waters may be obtained either generally or under favorable local conditions (e. g., in valleys, but not on hilltops), embracing southeastern Minnesota, southern Wisconsin, about half of Iowa, extensive tracts in Illinois, parts of northern Missouri, and some portions of Michigan and Indiana. Throughout this district the waters are slightly thermal and in general exceptionally free from mineral salts, being derived from the extensive sand beds of the Potsdam and St. Peter formations. This district grades southeastward into an extensive area, including portions of the southern peninsula of Michigan, much of Ohio, and parts of Indiana, Connecticut, and Tennessee, in which artesian water may be reached under fair or strong head, but in which the water is commonly too salt

for drinking purposes and is sometimes charged with a variety of mineral constituents. The most extensive area of artesian water supply in eastern United States includes the greater part of the coastal plain fringing the Atlantic and Gulf coasts in a belt from 50 to 250 miles broad. In this district strong flows of water are reached at various depths, e. g., 300 to 700 feet on the New Jersey coast, 400 to 1,000 feet on the eastern shore of Maryland, 1,000 to 1,200 feet in eastern Virginia, about 2,000 feet as well as at lesser depths at Charleston, at different depths up to 1,200 feet at Jacksonville and St. Augustine, and at more variable depths and with somewhat less trustworthy results on the Gulf coast. The waters in general are sufficiently pure for drinking purposes without precipitation of the mineral salts, and are thermal in moderate degree only. Further westward there is a vast area throughout much of which artesian supply is possible, including a large part of the great plains in a zone stretching from the international boundary to the Gulf of Mexico, about  $97^{\circ}$  to  $100^{\circ}$  west longitude.

There are many districts in eastern United States in which artesian water supply is not and never will be possible, by reason of unfavorable conditions of structure and texture. Perhaps the most extensive of these is the Piedmont area of crystalline rocks stretching parallel with the Atlantic coast between the coastal plain and the Appalachian mountains from New York into Georgia and Alabama.

The general conditions of artesian well supply in the coastal plain of the United States have been set forth in considerable detail in the Seventh Annual Report of the U. S. Geological Survey, pages 640-646, and the requisite and qualifying conditions of artesian wells, considered in general, were discussed at length by Prof. T. C. Chamberlin in the Sixth Annual Report, pages 125-173.

#### DEEP PUMP WELLS.

A considerable portion of the phreatic water of eastern United States never reappears at the surface, but is partly consumed in mineral combinations in the depths, partly carried directly into the ocean through seepage and springs. There are unquestionably numerous submarine springs in the Atlantic ocean off the coast of Florida, of which some are so large as to send up strong columns of fresh water to the surface. Now, the phreatic water conveyed into the ocean in these ways is lost to mankind. A part of this supply will eventually be utilized by tapping the water-bearing strata at new points, when, even if the water does not flow at the surface, it will be found to rise within easy pumping distance. Moreover, the principal artesian districts of eastern United States are so conditioned that the waters rise but little above the surface, even when the borings are made in valleys. In such cases the aggregate volume of water may be increased and the water supply

may be extended by tapping the water-bearing stratum at other points, even where it is necessary to use pumps.

In short, the artesian districts of eastern United States can hardly be demarked in sharp lines, since the feasibility of artesian supply depends on local relief, and since, moreover, the head in each district diminishes as the wells are multiplied. But in general the artesian district grades into adjacent districts in which artesian flow can not be secured but in which the waters rise within pumping distance; accordingly the artesian water supply of the country is already extended, and is bound to be still further extended in the future, by deep pump wells fed by the deep-seated phreatic waters, and thereby an important source of potable waters is afforded.







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DEPARTMENT OF THE INTERIOR—U. S. GEOLOGICAL SURVEY  
J. W. POWELL, DIRECTOR

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ON THE  
  
STRUCTURE OF THE RIDGE BETWEEN  
THE TACONIC AND GREEN  
MOUNTAIN RANGES  
IN VERMONT

BY

T. NELSON DALE

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EXTRACT FROM THE FOURTEENTH ANNUAL REPORT OF THE DIRECTOR, 1892-93



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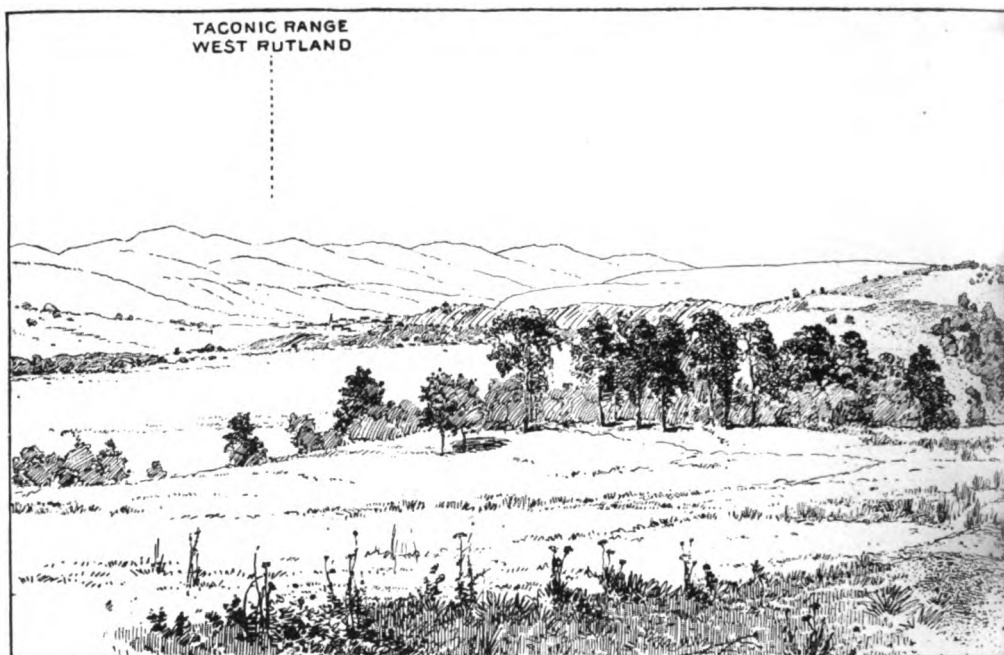
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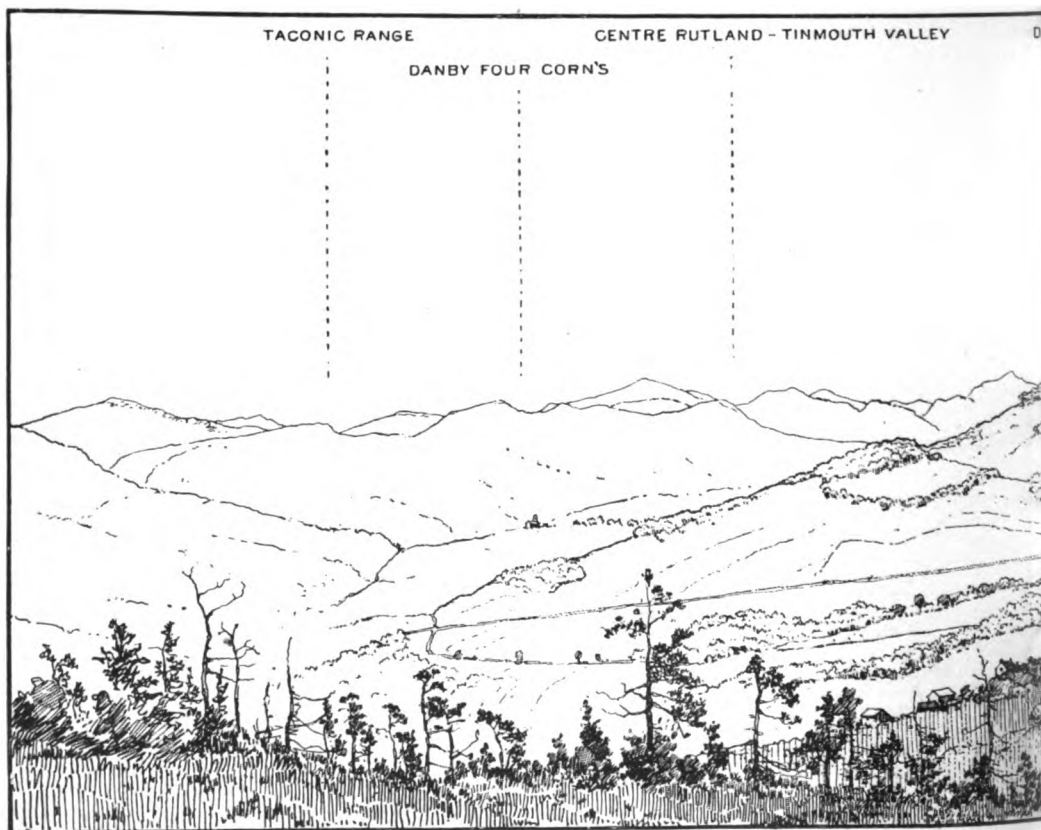




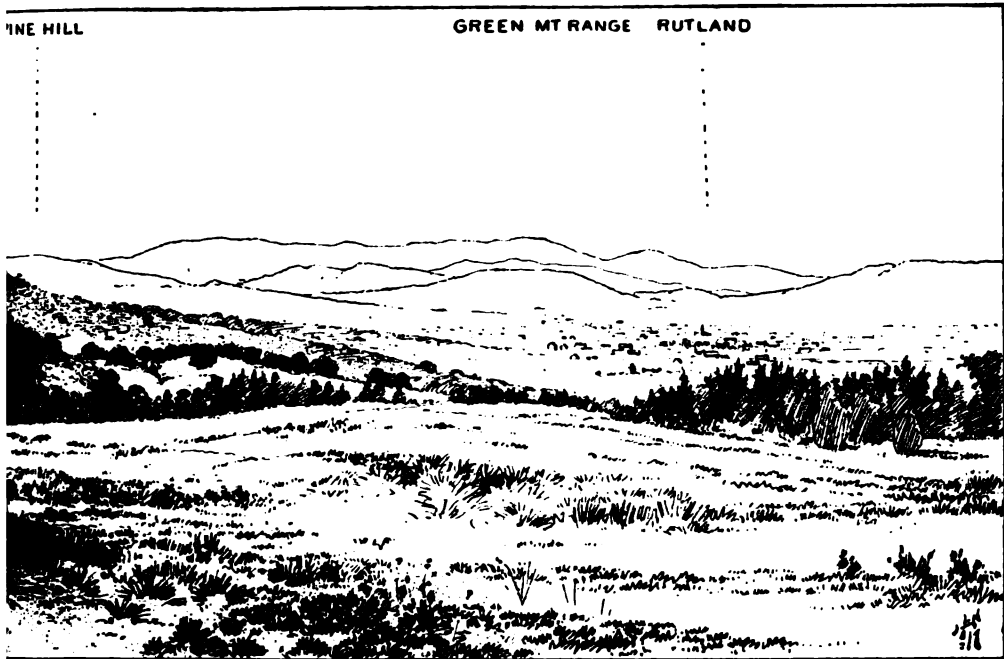
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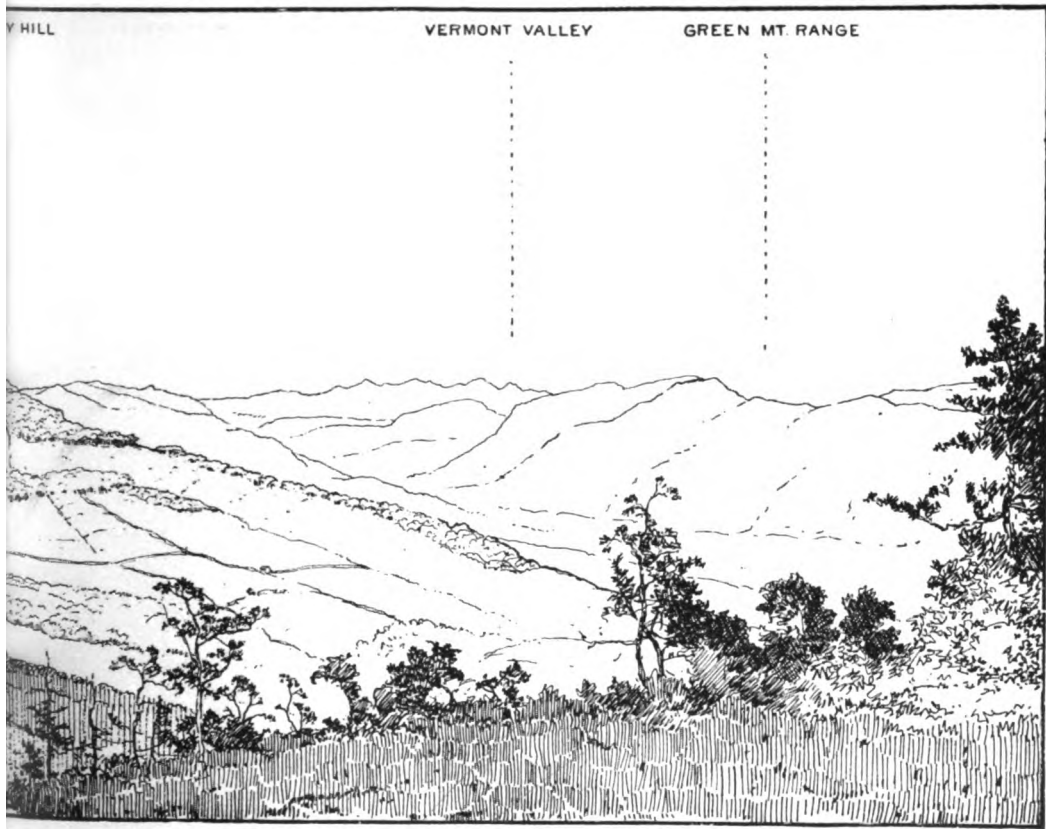
A. THE INTERMEDIATE RANGE AND PINE HILL, FROM THE NO



B. THE INTERMEDIATE RANGE AND DANBY HILL, FROM THE NORTHERN SLOPE OF DORSET



SOUTHERN PART OF THE CLARENDON RIDGE, NEAR LOCALITY 281.



MOUNTAIN, WITH THE TACONIC RANGE ON THE WEST AND THE GREEN MOUNTAINS ON THE EAST.



# ON THE STRUCTURE OF THE RIDGE BETWEEN THE TACONIC AND GREEN MOUNTAIN RANGES IN VERMONT.

BY T. NELSON DALE.

## TOPOGRAPHY.

In the town of Manchester, Vermont, the Taconic and Green mountain ranges are conspicuously distinct. The former, in Mount Equinox, on the west, rises steeply more than 3,000 feet above the valley, while 2 miles east the Green mountain range presents an equally bold but less elevated front.

Three miles northeast of Equinox, Dorset mountain crowds in between the two ranges, leaving narrow valleys on either side. The Dorset mountain mass extends 7 to 8 miles north-northeast, terminating in Danby with a bold east-and-west face; but its northern base, still 500 feet above the Vermont valley, merges in Danby hill, which is the beginning of a series of hills and saddles ranging from 1,500 down to 500 feet above the Vermont valley, and extending 21 miles farther north to the Rutland-Pittsford line, where it dies out. The entire length of this intermediate range, including the Dorset mass, is 32 miles. The general topographic relations of this ridge are shown in Pl. LXVI.

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#### RESULTS OF PREVIOUS INVESTIGATORS.

This intermediate range was described by the geologists of the Vermont survey<sup>1</sup> as an anticline of quartzite flanked on both east and west, in places, by "talcoid schists," in others by "Eolian limestone"; and the schists forming its southern end were represented as cut off from the schists which cap Dorset mountain by an east-west fault. Prof. C. H. Hitchcock<sup>2</sup> omits the anticlinal structure from the quartzite, calls the schists on the east side "Cambrian slates," and the limestone on both sides "Cambro-Silurian."

Mr. J. E. Wolff<sup>3</sup> shows the composition of the northern end of the range to be as follows from east to west: (1) Cambrian limestone, fossiliferous, overlying (2) Cambrian quartzite and its associated conglomerates and gneisses; then (3) schist overlying (4) the lower Silurian limestone of the center Rutland valley. He also shows the continuity at the surface of the quartzite of the ridge with that of the west flank of the Green mountain range. He would explain the abnormal relations between the quartzite of the ridge and the Stockbridge limestone on the west "by a great thrust plane by which the Cambrian is made to overlie the lower Silurian limestone," but of which the Pine hill locality affords no decisive proof.

The bearing of Mr. Wing's discoveries on the subject is that they fixed the age of the upper part of the Stockbridge limestone as lower Silurian. The significance of the paper of the Messrs. Winchell is that from a comparison of the relations of certain limestones and quartzites in the Northwest, and also from a review of Taconic literature generally, they argued that a portion at least, if not all of the Stockbridge limestone must be of Cambrian age.

#### COWORKERS.

The microscopic petrographic determinations were made by Mr. J. E. Wolff, of this Survey, and the paleontological by Mr. C. D. Walcott, then paleontologist of the Survey. Mr. Aug. F. Foerste discovered Trenton-Chazy fossils in Wallingford, and made special collections for determination at the Cambrian locality in West Clarendon.

<sup>1</sup> Op. cit., Vol. I, pp. 350, 353; Vol. II, p. 763; Pl. VIII, fig. 2; Pl. XVI, secs. 4, 5.

<sup>2</sup> Loc. cit., Pl. XVI, secs. 4, 5, 6.

<sup>3</sup> Loc. cit., figs. 1 and 2, and p. 337.

## STRUCTURAL GEOLOGY.

## CLARENDON SECTION.

## TOPOGRAPHY.

A low and broad saddle about 6 miles south of Center Rutland in Clarendon affords access to the structure of the ridge.

The accompanying contour map (Pl. LXVII) shows the topography of about 4 square miles at this interesting point. The summit south of the saddle is 1,120 feet above Otter creek. The double summit north of it, 820 and 880 feet; the saddle itself, 420 feet. The Tinmouth valley here is 140 feet higher than the Vermont valley.

## AREAL AND PETROGRAPHIC GEOLOGY.

The eastern half of the ridge here consists mainly of a quartzite continuous with that which at its north end crosses the Vermont valley to join that along the west face of the Green mountain range,<sup>1</sup> and is now recognized as of lower Cambrian age.<sup>2</sup> This quartzite is commonly interbedded with a very fine grained and finely banded gneiss or schist, consisting of bands of quartz and feldspar (orthoclase, plagioclase, and microcline) alternating with bands of muscovite (sericite) and biotite (see Fig. 59). In places, however, the quartzite is associated with a chloritic muscovite (sericite)-schist, sometimes with thickly disseminated crystals of magnetite. At locality 270 this sericite-schist contains a bed of blue quartz conglomerate 1 foot thick, the pebbles being one-half inch to 1½ inches in diameter. There are also on the eastern side of the ridge (localities 209-212, 220, 222, 279, 312, 315-317) certain coarse chloritic gneisses containing; as at locality 88, small beds of coarse crystalline limestone, rarely hornblende, as at 221. At 265 there is a crushed or brecciated granite, slightly calcareous, and near it is a small well-determined metamorphic basic dike, trending with the ridge. On the map no attempt has been made to separate these gneisses and this granite from the Cambrian rocks proper. Whether they represent the base of the Cambrian or some older series or are extremely altered eruptives must be determined on the Green mountain range, where the outcrops are on a larger scale.

On the western side of the ridge is an irregular area of more or less quartzose, bluish gray and yellowish white, fine grained limestone. It is continuous with that of the Tinmouth and Center Rutland valleys.

<sup>1</sup> See Mr. Wolff's map, loc. cit.

<sup>2</sup> See C. D. Walcott: The Taconic system of Emmons and the use of the name Taconic in geologic nomenclature; *Am. Jour. Science*. Ser. III, Vol. xxxv, 1888, pp. 232-236. Also *The Fauna of the Lower Cambrian or Olenellus Zone*; Tenth Ann. Rept. U. S. Geol. Survey, for 1888-'89, pp. 593-594, 1890.

A small lenticular area of similar limestone occurs in the quartzite on the east side of the ridge. The steep isolated knoll southwest of Clarendon flats consists of such limestone, with a small area of quartzite on its east side. South of this a series of limestone outcrops stretches across the interval to Clarendon falls. The Vermont report represents the limestone areas of the Vermont and Tinmouth valleys as uniting between Dorset and Equinox mountains. We have here to do, therefore, with the Stockbridge limestone, Hitchcock's Eolian limestone.

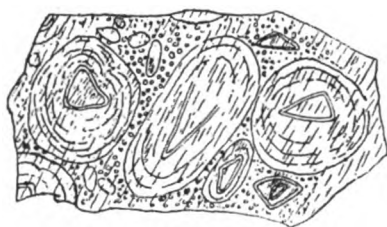


FIG. 54.—Concretionary structure of lower Cambrian limestone at West Clarendon, Vermont, with pteropod shells (*Hyolithes*) as nuclei. The rock also abounds in minute quartz grains.

In the northern part of the western side of the ridge is an area of graphitic sericite-schist much like that which forms the lower part of the schists of the Taconic range, both in Vermont and Massachusetts—the Berkshire schist. South of the saddle a narrow belt of this recurs with a strip of quartzite west of it and the quartzite and fine-banded gneiss east of it. A lenticular limestone area less than a quarter of a

mile long occurs in the schist tract near the road in the northwestern corner of the map. This is the most southerly fossiliferous locality indicated on Mr. Wolff's map.<sup>1</sup> Another much smaller limestone area occurs at 260, about three-quarters of a mile southeast of this one and close to the quartzite.

#### PALEONTOLOGY.

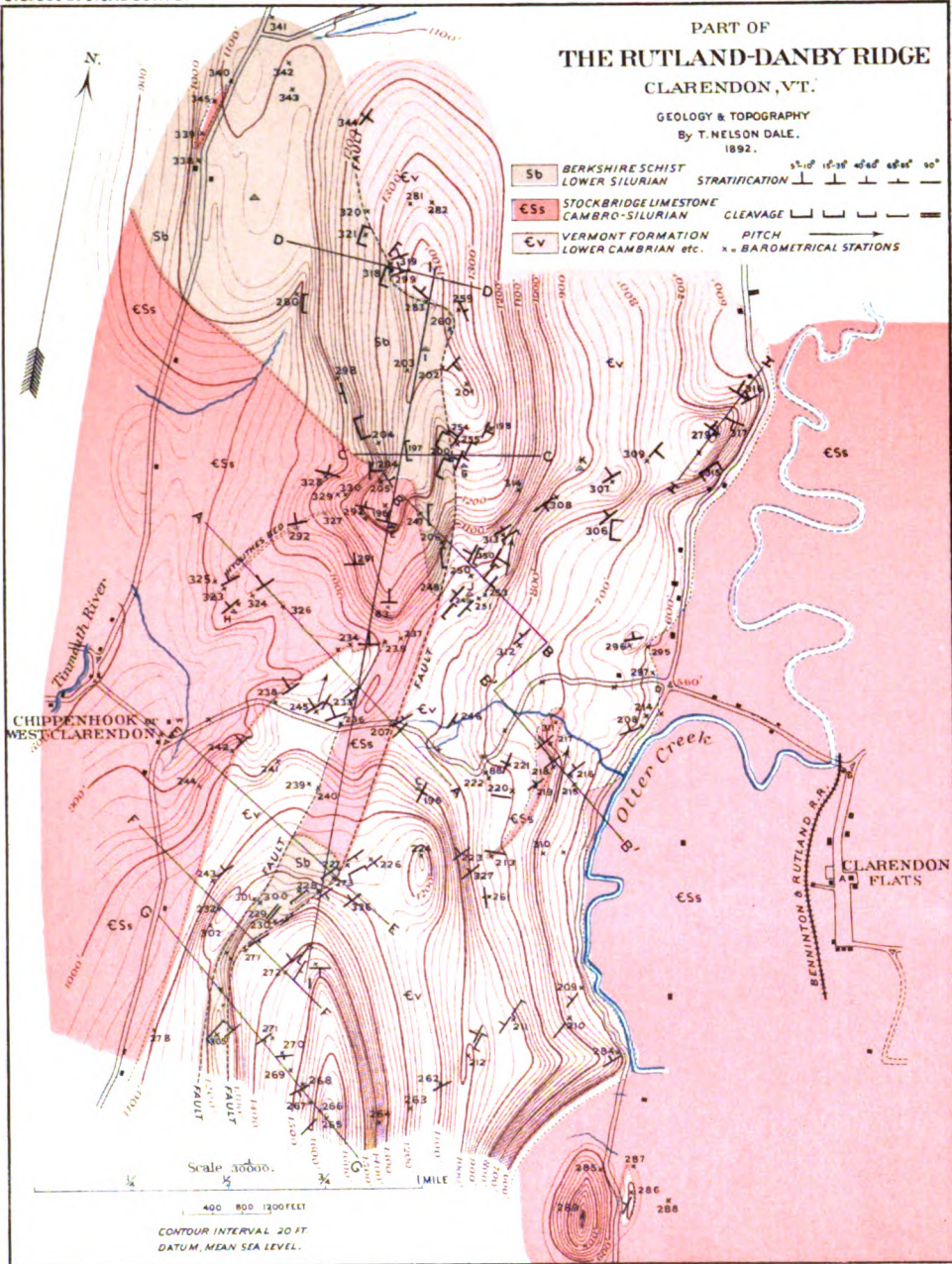
Traces of fossils were observed by the writer near H, on July 9, 1891. On August 4 they were found in abundance at locality 292, and a few were sent to Mr. Walcott for determination. This fossiliferous bed measures about 25 feet in thickness, and crops out, off and on, for 1,600 feet in a northeast and southwest direction, as shown on the map. The rock is made up in many places of spherical or elliptical nodules from one-tenth to eleven-tenths of an inch in diameter. (See Fig. 54).

In structure, the nodules are oolitic, the calcite particles being arranged in concentric rings about the nucleus, and the form of the nucleus generally determining that of the nodule. The nuclei are more or less perfect pteropods (*Hyolithes*) which appear in longitudinal, transverse, or diagonal sections on the surface of the rock. The shells are sometimes partially filled with quartz.

Although, as Mr. Walcott suggests, the concentric arrangement of the limestone in the nodules resembles *Stromatopora*, the sections have not yielded any evidence of their organic origin.

Mr. Walcott's determinations are as follows:

<sup>1</sup> Loc. cit.





*Cambrian fossils.*

|                                                         | Localities.   |
|---------------------------------------------------------|---------------|
| <i>Hyolithes americanus</i> Billings <sup>1</sup> ..... | 292, 323, 324 |
| <i>Hyolithes similis</i> ? Walcott (Newfoundland).....  | 292, 323      |
| <i>Hyolithes impar</i> ? Ford (Troy, N. Y.).....        | 292, 323      |
| <i>Hyolithes communis</i> ? Billings.....               | 292, 324      |
| <i>Salterella pulchella</i> Billings <sup>2</sup> ..... | 324           |

Mr. Walcott adds: "Sections of a round tubular form of *Hyolithes* occur that resemble very closely the transverse sections of the smaller tubes of *Hyolithes communis*. With the exception of *Hyolithes impar*, which is a very doubtful identification, all of the species belong to the upper horizon of the Olenellus fauna. *Hyolithes americanus* has a very wide geographical and vertical range, as also *Hyolithes communis*. *Salterella pulchella* occurs on the Straits of Belle Isle and in Franklin county, northern Vermont, a little below the horizon of *Kutorgina labradorica* var. *swantonensis*."

*Silurian fossils.*—In the small limestone area in the northwest corner of the map Mr. Foerste found in 1890<sup>3</sup> "numerous crinoid stems and occasional plates and rarely a small branching bryozoan with large cells." In the limestone at locality 260 he found in 1891, fragments of crinoid columns and a piece of a coral *Heliolites* ——?, indicating, as Mr. Walcott defines it, "the Trenton fauna, used in a broad sense to include the Chazy-Trenton and Lorraine faunas"—that is, the lower part of the lower Silurian or Ordovician.

## STRUCTURE.

Only at three points in this area are the groups of strata in visible conformity. About a third of a mile north of the Clarendon-Chippenhook road, where it crosses the lowest part of the saddle, between localities 234 and 235, the uppermost layers of the Cambrian quartzite pitch northerly at 10° to 15° under the Stockbridge limestone. The transition is represented by a few feet of calcareous quartzite or quartzose limestone, from which the lime has been dissolved at the surface. About half a mile north of this locality (294) the uppermost strata of the Stockbridge limestone dip 20° easterly under the adjoining schist. There are also conformable contacts between the quartzite and the limestone at localities 218 and 219 on either side of the closed limestone area on the eastern flank of the ridge. This mass seems to be a compressed syncline with a westerly dipping axial plane, and thus represents about 65 feet of the base of the Stockbridge limestone. These and the other structural relations of the quartzite, limestone, schist, and gneiss are shown on the map by symbols and on the sections, Pl. LXVIII.

<sup>1</sup> See E. Billings: On some new species of Paleozoic fossils; Canadian Naturalist, Dec., 1871, reprinted in American Journal of Science, Vol. III, p. 352. 1872. C. D. Walcott: Studies on the Cambrian Faunas of North America; Bull. U. S. G. S., No. 30, p. 132 and Pl. XIII, 1886. Also in Tenth Annual Report of the U. S. Geol. Survey, p. 620, and Pl. LXXV.

<sup>2</sup> Found by Mr. Aug. F. Foerste, Aug. 17, 1891.

<sup>3</sup> J. E. Wolff, op. cit., p. 336, top.

*Section A.*

This passes through the lowest part of the saddle, from the southeast to the northwest. There is an anticline in the quartzite, then a possible fault plane dipping  $70^{\circ}$  to  $80^{\circ}$  west, followed by a strip of limestone 650 feet wide in contact on the west with quartzite strata dipping  $35^{\circ}$  west and a fault plane dipping  $70^{\circ}$  east. The steep easterly face of the quartzite, about 15 feet high, can be followed north of the road for a quarter of a mile, but no farther. The dip of the adjacent limestone can not be determined; the rock is crossed by a fine network of quartz veins. The quartzite continues west in minor folds for 600 feet, here and there with a well-marked northerly pitch. Its most westerly outcrop dips about  $20^{\circ}$  west, but the limestone is covered. The relations of the two rocks are manifest between 234 and 235, already described. A very low westerly dip ( $10^{\circ}$ ) may safely be assumed for the limestone here. At 326 the limestone crops out, but without determinable dip. From 324 to 325 it averages  $30^{\circ}$  west, and the exposed thickness is about 260 feet. Here occurs the Hyolithes bed, with only 15 feet of limestone exposed above it. Allowing a dip of  $10^{\circ}$  for the covered portion and for that between 324 and 326, i. e., a thickness of about 235

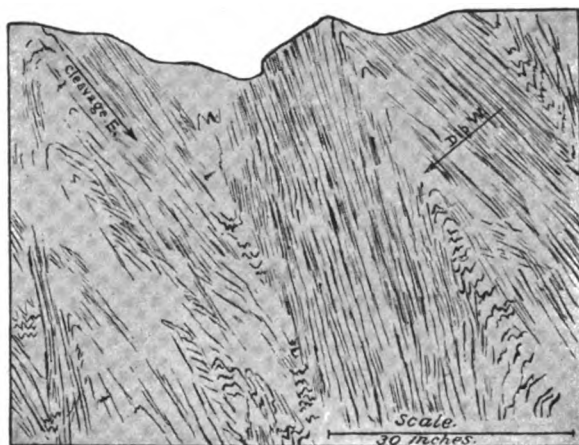


FIG. 55.—Acute folds in the Cambrian quartzite at locality 350, Clarendon, on the east side of the fault.

feet, the entire thickness from the top of the quartzite to the top of the fossiliferous bed would measure about 470 feet, and this much of the base of the Stockbridge limestone would therefore be of lower Cambrian age.

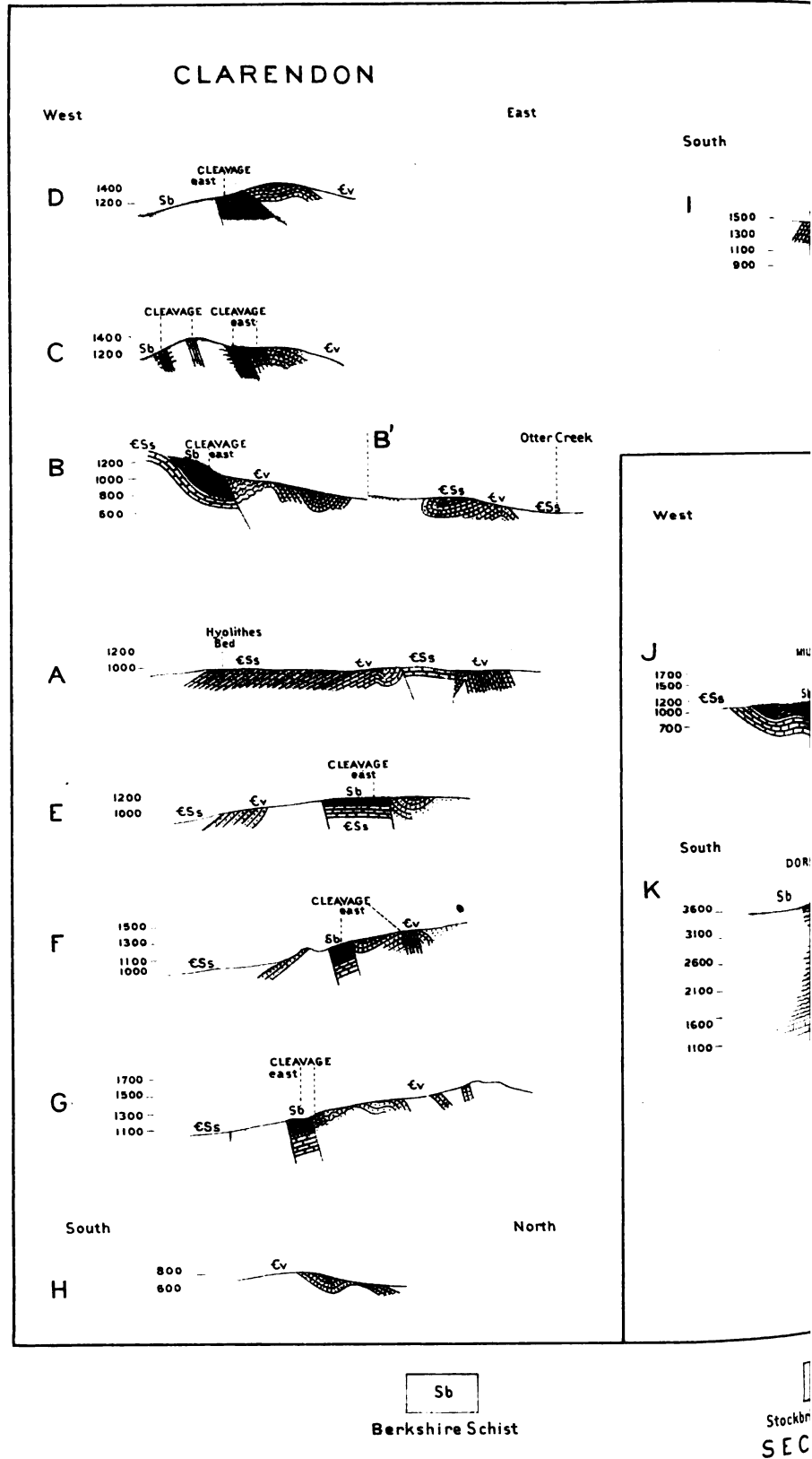
*Section B.*

This begins at the intervalle along Otter creek and follows a northwesterly course, traversing the small limestone syncline. Here the pitch is  $20^{\circ}$  north. On the northwest side of the road is a jog of 900 feet in the section. A syncline followed by an anticline occurs in the quartzite and gneiss. At 249, south of the section line, the fine grained Cambrian quartzite is minutely and extremely plicated, dipping low west with a slip cleavage dipping  $80^{\circ}$  east.

At 350 the sharp compressed zigzags in the quartzite measure several feet in length (see Fig. 55), with the cleavage and the axes dipping  $70^{\circ}$  east, nearly like the cleavage at 249, but there is an actual dip of the stratification to the west.

Then the graphitic sericite schists (Berkshireschist, which overlies the Stockbridge limestone) are reached, here forming a steep hillside. The cleavage foliation dips high east, probably conforming to the hade of the fault, which is here entirely concealed. The position of the limestone in the section is necessitated by its surface relations to the schist and the contours.

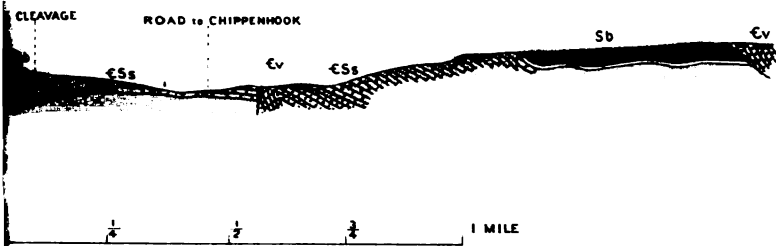




# CLARENDON

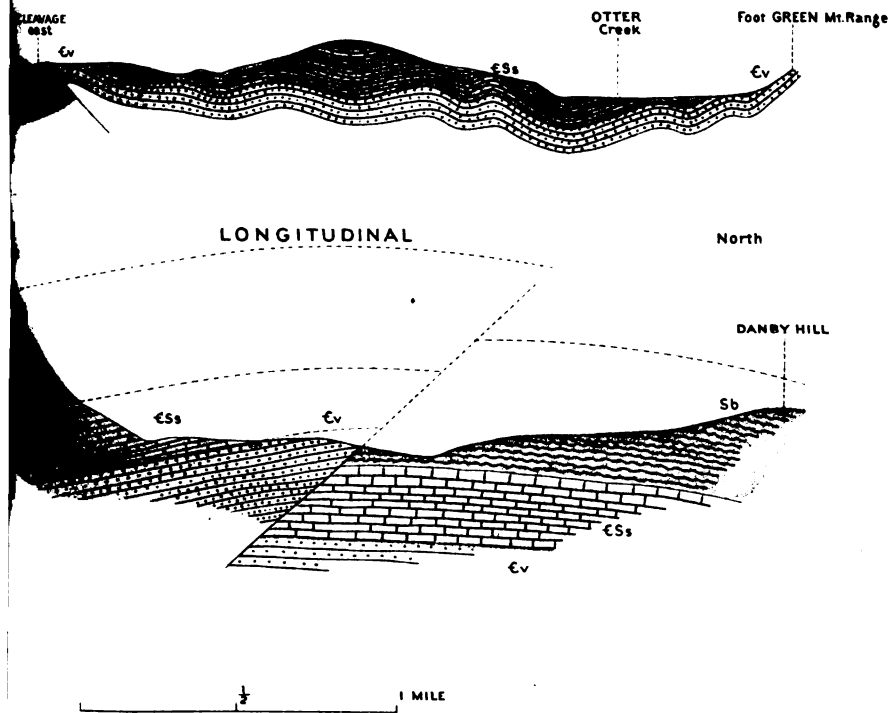
## LONGITUDINAL

North



# DANBY

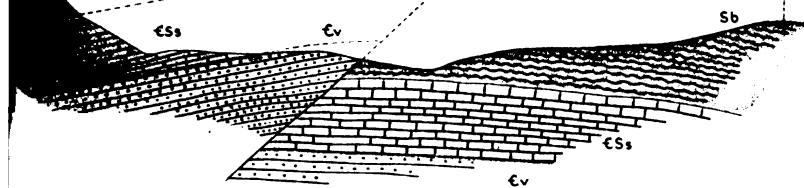
East



## LONGITUDINAL

North

DANBY HILL



$\epsilon v$

Vermont Formation

limestone  
ON S.



## Section C.

In order to cross important outcrops this line has been drawn from east-north-east to west-southwest. There is an anticline in the Cambrian quartzite and gneiss. At 255 (Fig. 56) the westerly dipping stratification meets the fault plane, which dips 60° east. The Silurian schists (sericite, biotite, quartz, and graphite)

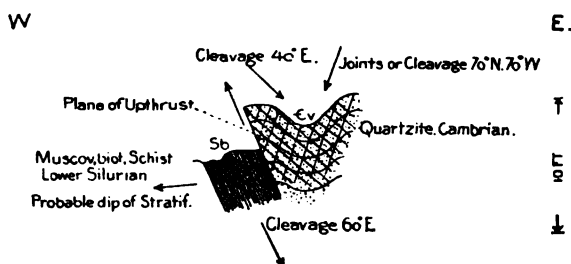


FIG. 56.—Structure of Cambrian quartzite and Silurian schist at the fault, locality 255, Clarendon.

are in contact with the Cambrian quartzite, and have a cleavage foliation parallel to the fault plane. They present an interesting case of a certain type of slip cleavage<sup>1</sup> (Fig. 57). The acute-angled folds of locality 350 (Fig. 55) are repeated here on a microscopic scale, but much more compressed, resulting in extreme slip cleavage.

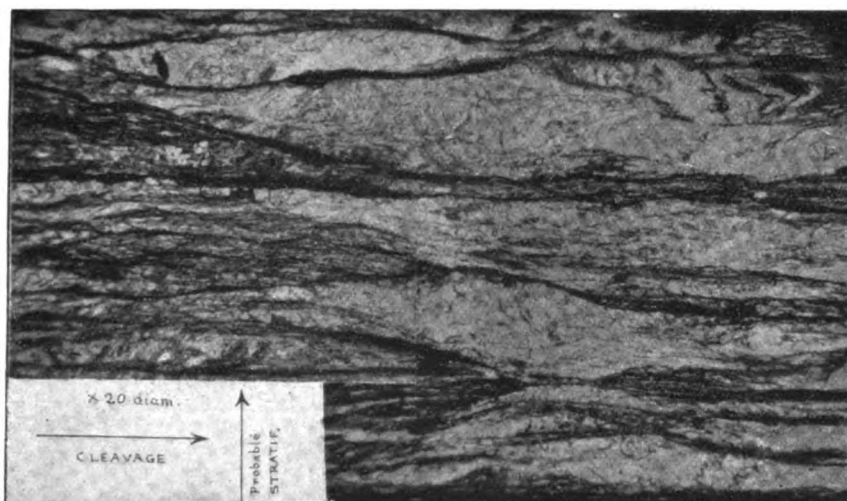


FIG. 57.—Microscopic structure in Silurian muscovite, biotite, quartz, and graphite schist at the fault shown in Fig. 56. The plications have been so compressed as to become extremely acute, then to rupture, and finally to merge into the slip-cleavage foliation thus caused.

Here and there some of the folia of mica have not yet entirely conformed to the cleavage foliation, and thus preserve some indication of the direction of the dip of the stratification, which was probably west or horizontal, i. e., about at right angles to the cleavage.<sup>2</sup> The fault line north of this section is marked by quartz veins. Easterly cleavage foliation pervades the entire mass of schist. On the west side of

<sup>1</sup>See Monograph xxiii, U. S. Geol. Survey, Part III, p. 158.

<sup>2</sup>See Henry Clifton Sorby: On the structure and origin of noncalcareous stratified rocks. Quarterly Journal Geol. Society, London, Vol. xxxvi, 1880, p. 73. Stages of slip cleavage, fig. 3, plication without cleavage; fig. 4, plications faulted. The structure in Fig. 57 above would form the next or third stage. See also J. E. Marr: On some effects of pressure, etc.; Geol. Mag., London, 1888, Vol. v, p. 219, figs. 1-10.

the ridge the Stockbridge limestone dips conformably under the schist, which forms a westerly facing cliff in which there are indications (locality 298) of a westerly dip, and thus of a fold between that point and 294.

*Section D.*

Between sections C and D the fault line makes a sudden bend to the west, with the Silurian schists still on its west and south side. The north-northwest and north-

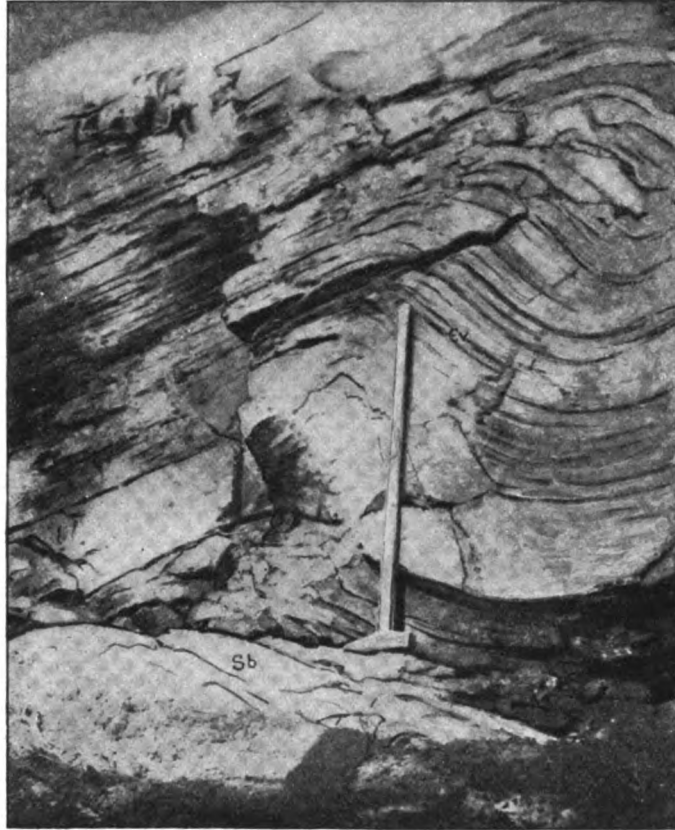


FIG. 58.—The contact of the Cambrian quartzite (Cv) and Silurian schist (Sb) at the overthrust, locality 318, Clarendon, as seen looking east. The sharp edge of the hammer is exactly on the line which divides the two formations. Length of hammer handle, 30 inches. From a photograph.

northeast dip of the quartzite indicates a northerly pitching anticline. At locality 318 the Cambrian quartzite directly overlies the Silurian schists (Fig. 58). The strati-

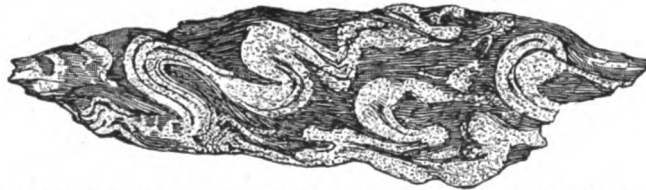


FIG. 59.—The banded Cambrian gneiss or schist near the overthrust, locality 318, Clarendon. The highly plicated light bands consist of a feldspathic quartzite, the dark bands of sericite-biotite schist with slip cleavage.

fication strike of the quartzite is north  $60^{\circ}$  east, and its general dip  $20^{\circ}$  to  $30^{\circ}$  north-northwest, while the cleavage strike of the underlying schist is north  $25^{\circ}$  east, and its

dip  $75^{\circ}$  east-southeast, but decreasing a few feet away. Its stratification is indeterminate. The hade of the fault could not be exactly determined. The whole mass of the quartzite north of the angle in the fault line may have been thrust horizontally over the Silurian schists. The vertical west face of the quartzite (Fig. 58) strikes north to south and is very smooth in places, being either a joint or the vertical upper part of the thrust plane. At 319, 100 feet north of 318, the Cambrian is represented by the fine banded and plicated close grained gneiss described on page 533, dipping  $20^{\circ}$  north-northwest, with a cleavage dip of  $45^{\circ}$  south southeast. (See Fig. 59.) A few feet east this is conformably overlain by a thin-bedded quartzite.

*Section E.*

This is on the south side of the saddle. A syncline is shown in the Cambrian quartzite and gneiss, the west side of which dips nearly if not quite parallel to the



FIG. 60.—Structural character of the gneiss at locality 317, on the east side of the ridge in Clarendon, looking west-northwest. Area 20 by 20 feet. From a photograph.

fault plane and also to the cleavage of the adjoining Silurian schists. The stratification of this schist mass can only be conjectured from its surface relations. The absence of the schists in the deeper part of the saddle between the two fault planes is readily explained by erosion. The schist masses north and south of the road were once continuous, covering the limestone, and therefore necessarily dipping at a low angle east or west.<sup>1</sup> If horizontal the present extreme thickness south of the saddle would be 170 feet, and north of it at least 360 feet.

*Section F,*

A little south of Section E, shows an anticline east of the syncline of F and the narrowing of the schist mass. It probably also increases in depth.

*Section G.*

This section begins at the top of the southern summit at the contact of the Cambrian quartzite and sericite schist with the chloritic gneisses and altered granite. The Cambrian series here may measure about 1,000 feet in thickness. Between F

<sup>1</sup>A half mile south of the most southerly house shown on map, on west side of ridge, the Silurian schists dip west.

and G the fault line bends around to the south and the schist belt becomes still narrower. The easterly fault plane crosses the east line of the syncline shown in F. Here the fine banded schists of the Cambrian dip west in contact with the graphitic schists of the Silurian, which have a high easterly cleavage.

*Section H.*

This passes through the buttress of coarse chloritic gneiss on the east side of the ridge near Otter creek (locality 317). The strikes here are west-northwest to east-southeast, the entire mass of this small spur having apparently been twisted around 90°; or have we here some unconformable pre-Cambrian? Fig. 60 shows the general structural character of the gneiss. The relations on the east side of this mass are covered with drift.

*Section I (longitudinal).*

This section traverses the saddle from south to north, showing the northerly pitch of the quartzite and limestone in the northern part, and affords an approximate measurement of the entire Stockbridge limestone, which amounts to 1,200 feet. At 332, in the southern part, there is an east-to-west strike and southerly dip, possibly due to a southerly pitch. Owing to the curve in the easterly fault line, it is crossed twice by the section.

OTHER LOCALITIES.

Several localities not crossed by sections call for mention: At 295, near the crossroads, on the east side, the coarse chloritic gneisses, with a low easterly dipping foliation, are in contact with a very coarse crystalline limestone veined with quartz. At 215, a half mile south, masses of similar limestone crop out with the coarse gneiss near on the west.

At 337, south of the small limestone syncline on the eastern flank, the Cambrian quartzite and a sericite-biotite-quartz-schist, containing orthoclase, plagioclase, and microcline, stand erect in folds,<sup>1</sup> having been thrown up probably from the east, judging from the synclinal structure of the limestone north of this locality. The cleavage foliation, which traverses only the softer of the two rocks, had probably been formed during the earlier stages of the folding, before the erection of the folds into their present position. The folds of the quartzite are furrowed in a plane striking with the cleavage, but passing around them. (See Fig. 61.) These furrows are what a torsional motion of the folds on each other in a direction at an angle of 45° to their strike might be expected to produce. The data are: Strike of the folds north 40° to 50° east, dip 90° or high west; strike of the joints north 15° west, dip 90°; strike of the cleavage north, dip 20° east; strike of the furrows north.

On the east side of the steep limestone hillock at the southern edge of the map is a small area of westerly dipping quartzite, locality 286, with limestone dipping under it on its east side 25° to 30° west. Unless this quartzite occurs in the Stockbridge limestone, its structure is that of a greatly compressed anticline of the underlying quartzite overturned to the east.

<sup>1</sup>This locality is figured in the 13th Annual Report of the U. S. Geological Survey, The Renaselaer grit plateau, fig. 25, p. 319, as illustrating the occurrence of nearly horizontal cleavage.

The small limestone areas, 339 to 345 and 260, in the schist area, may either be anticlines of the Stockbridge limestone protruding through a thin sheet of the Berkshire schist or may represent local calcareous sediments formed during the Berkshire schist period. The fossils of these areas, lower Silurian, indicate, therefore, the age either of the top of the limestone or of a portion of the schist itself.<sup>1</sup>



FIG. 61.—Specimen of Cambrian quartzite, two-thirds natural size, from locality 337, Clarendon, showing ridges and furrows crossing the fold diagonally. The front edge is a joint face. From a photograph. Size of specimen, 4 by 5½ inches.

#### INFERENCES.

From the foregoing data the following conclusions are drawn:

The ridge at Clarendon consists of the following series:

|                                                       | Feet                                                                                                                                                                                                                                                                                                                                                                                         |
|-------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Berkshire schist (Sb), upper Lower Silurian.....      | 360                                                                                                                                                                                                                                                                                                                                                                                          |
| Stockbridge limestone (ESs) (1,000 to 1,400 feet.)    | <div style="display: flex; align-items: center;"> <div style="margin-right: 10px;">{</div> <div style="margin-right: 10px;">Lower Silurian .....</div> <div style="margin-right: 10px;">{</div> <div style="margin-right: 10px;">Upper and middle Cambrian(?)</div> <div style="margin-right: 10px;">}</div> <div style="margin-right: 10px;">}</div> <div>Lower Cambrian .....</div> </div> |
| Vermont formation, in part (Ev), lower Cambrian ..... | (?) 800                                                                                                                                                                                                                                                                                                                                                                                      |
| <b>Total.....</b>                                     | <b>2,360</b>                                                                                                                                                                                                                                                                                                                                                                                 |

<sup>1</sup> See The Rensselaer grit plateau, loc. cit., p. 312.

## AREAL AND PETROGRAPHICAL GEOLOGY.

The Stockbridge limestone of the Tinmouth and Vermont valleys unite along the north foot of Dorset mountain, and the Silurian schists of Danby hill are bounded on the south by a fault, as shown in the Vermont report.<sup>1</sup> The course of this fault is not due east to west, but forms a zigzag, and there is a triangular area, about one-third of a mile square, of lower Cambrian quartzite, with blue quartz pebbles and sericite-gneiss of the Vermont formation, which on its northwest and southeast sides is by the fault brought in contact with the Silurian sericite-graphite schists of Danby hill, and on its south side is in normal relation to the Stockbridge limestone. At locality 394, in the Silurian schist area and parallel to its strike, is a highly metamorphic basic eruptive with large crystals "of albite, or a soda-lime feldspar near albite." At 429, on the northeast foot of Dorset mountain, near the old stage road, is a small dike of camptonite in marble of the Stockbridge limestone.

## PALEONTOLOGY.

At 443, half a mile southwest of Danby Four Corners, Mr. Foerste found in the Stockbridge limestone sections of a small gastropod, and possibly of a pteropod, *Salterella*, besides crinoid stems, indicating lower Silurian, i. e., the upper part of the limestone.

## STRUCTURE.

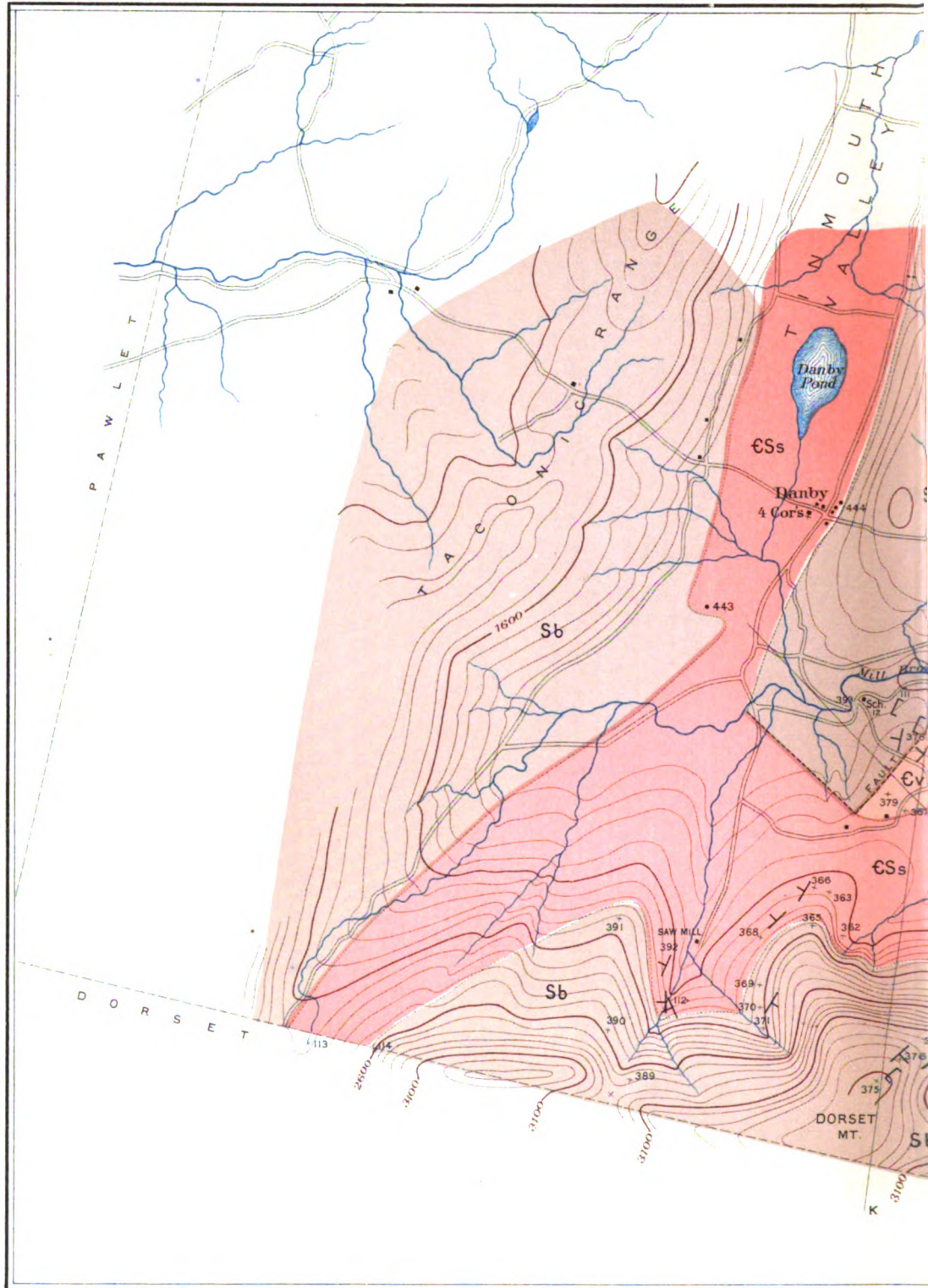
The structural features are shown on the map (Pl. LXIX) and sections J, K (on Pl. LXVIII).

*Section J.*

From the foot of the Green mountain range, east of the top of Dorset mountain, northwest to the Tinmouth valley. At a waterfall in a rugged ravine southeast of School I, and near Benjamin Griffith's sawmill, in Mount Tabor, the quartzite and sericite-gneiss of the Vermont formation (lower Cambrian) are finely exposed for a height of about 80 feet, striking north 50° east and dipping 35° to 45° northwest. Although the Vermont valley is here very narrow, the section has some gaps in it. The outcrops, however, indicate two minor folds in the limestone. The section now crosses the foot of Dorset mountain. Between the Dorset road and the ravine on the northeast side of the mountain there is a syncline. The course of the ravine itself corresponds to the axis of a gentle anticline, and between this point and the quarries there is another syncline. West of this the limestone was not studied. The Cambrian quartzite north of Dorset mountain consists of small folds, more or less sharp, possibly slightly faulted in places along the strike, with a south-southwest pitch of 10° to 15°. Vertical joints strike north 75° west. Cleavage strikes northeast and dips 40° southeast. The general structure is a gentle anticline. The hade of the reversed fault on its west side can only be conjectured from the cleavage dip of the quartzite (40°) and of the adjoining Silurian schists (45° to 50°). The course of this part of the fault is about like that of the strike—northeast—and in line with the notch in Dorset mountain to the southwest; but no evidence of faulting could be found in the few exposures there. The amount of vertical displacement is at least equivalent to the entire thickness of the limestone, besides that of the schist,

<sup>1</sup> Op. cit., Vol. II, Pl. VIII.





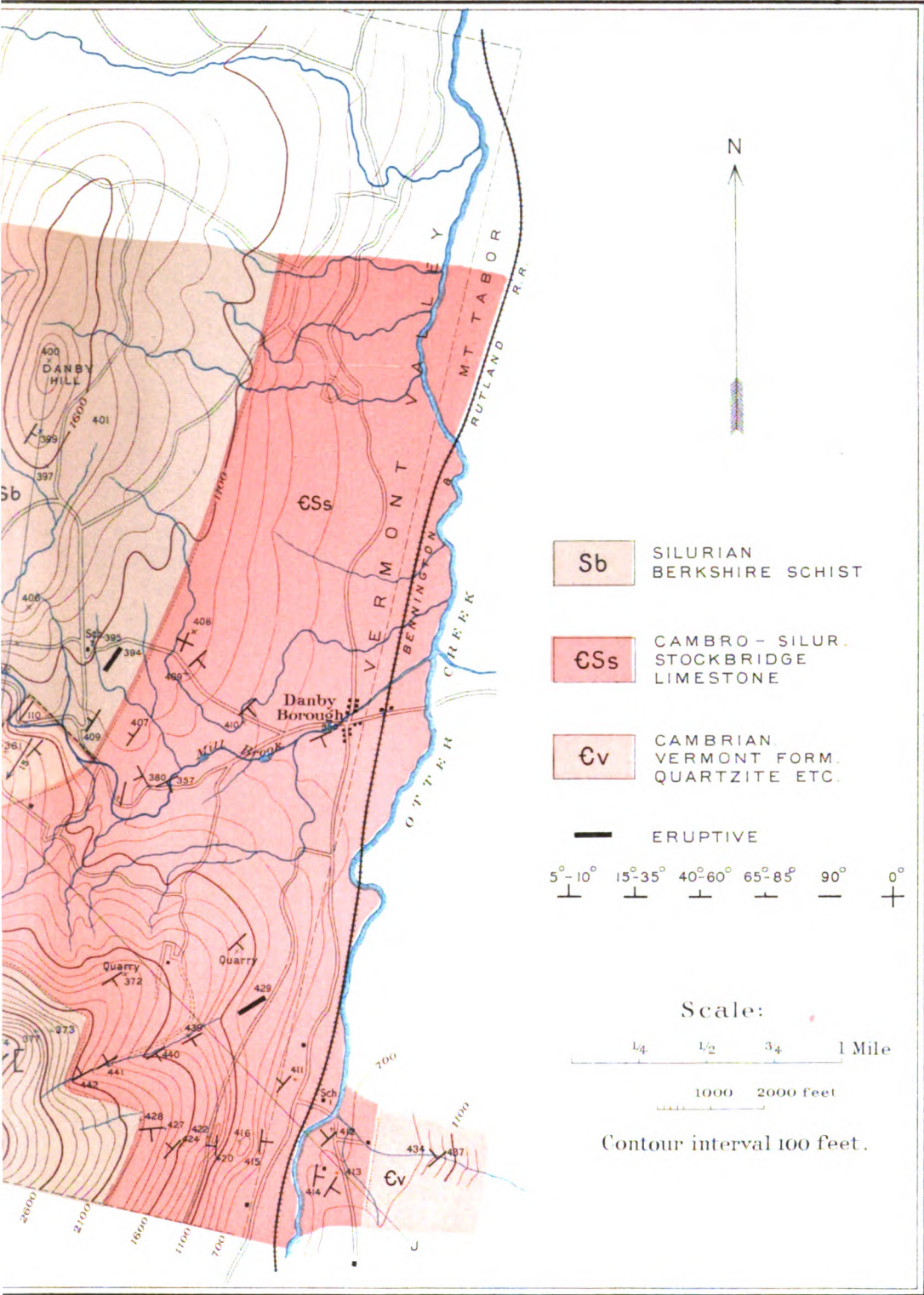
## SKETCH MAP OF DANBY T

FROM BEE

CONTOURS ROUGHLY DRAWN FROM PROFILE

by T. NELS

18



DANBY TOWNSHIP, RUTLAND CO., VT.

US' ATLAS

SKETCHES AND BAROMETRIC OBSERVATIONS

ON DALE.

1912.



near the fault cut by Mill brook.<sup>1</sup> One thousand two hundred feet can be safely taken for the limestone and at least 250 feet for the schist. As the beds south of the fault are in their normal relations—quartzite, then limestone followed by schist—the entire Dorset mountain mass must have been thrown up about 1,450 feet. Neither the exact direction nor the hade of the western and eastern bends of the Danby fault can be observed, but the course of the eastern one is better defined than that of the other.

*Section K (longitudinal).*

This shows the general relations of the masses north and south of the fault to each other. The section should have been drawn at right angles to J and should traverse Dorset mountain just east of the notch, and then cross the eastern bend of the fault and that side of Danby hill, but the relations would not be materially different. Another pitch has been conjectured north of the fault.

INFERENCES.

The probable synclinal structure of the Vermont valley is indicated by the westerly dip in the Green mountain range east of Dorset mountain. The general anticlinal structure of the Danby hill schist mass naturally follows. The complex structure of Dorset mountain is shown by the observations. There is an anticline between the two roads on its east side, a syncline between the old stage road and the ravine on its northeast side, another anticline along that ravine, a syncline between it and the high shoulder near the top, and at least one other anticline between the top and the notch, and west of the notch another syncline, judging from the structure of the west side of Danby hill, which is on the line of strike.

The Silurian schists which cap Dorset mountain, there reaching a thickness of from 1,500 to 2,000 feet, were probably once continuous with those of Danby hill north of the fault. The ravines which now carve the north face of Dorset mountain and the gorge cut in the quartzite by Mill brook, are but insignificant evidences of erosion when compared to those afforded by the general structural relations of the masses on either side of the fault (see section K, Pls. LXVIII and LXIX). The difference in elevation between Dorset mountain and Danby hill is about 1,650 feet, and the vertical upthrust of Dorset mountain about 1,450 feet, so that the original difference in elevation between the two summits, allowing an equal amount of sedimentation and erosion, could hardly have exceeded a few hundred feet. If the erosion of the saddle between Dorset mountain and Danby hill was consequent upon the fault, a mass from 2,200 to 3,000 feet thick must have been removed from the quartzite area in the center of the map.

The structural significance of the bold north face of Dorset mountain (see Pl. LXX) now becomes apparent. It was the result, first, of a fault

<sup>1</sup>If the pitch of 10° observed in the quartzite continues in the limestone south of it, the entire limestone would be about 1,200 feet thick; if 15°, about 1,300 feet. If the limestone is horizontal, it is 700 feet thick. Estimates made on the east flank of Dorset mountain west of the beginning of section J give 700 feet from the level of Otter creek to the base of the schist (there is an anticline below the old stage road which reduces the apparent thickness), but as there may be some sharp folding, if not faulting, in the Vermont valley, this can be taken only as a minimum estimate.

crossing the folds of the intermediate range, and thus of the Green mountain system generally, nearly at right angles, and second, of erosion, perhaps initiated by the fault itself, in the direction of the fault, and then working back onto the masses north and south of it.

#### PINE HILL SECTION.

##### MR. WOLFF'S RESULTS.

These have been referred to on page 532. In crossing the hill from east to west he found the Cambrian quartzite and cement rock just west of the summit in contact, within 2 or 3 feet, with certain schists which farther down on the west side of the hill visibly overlie the upper part of the Stockbridge limestone.

##### ADDITIONAL RESULTS.

There is some difficulty in following the contact between the quartzite and the schist because the quartzite is interbedded with fine banded and close grained gneisses, identical with those of Clarendon (p. 533 and



FIG. 63.—Diagram-section showing the probable structure at the Pine hill overthrust near Rutland. This presents the results of both Mr. Wolff's and the author's studies.

Fig. 59), which in places come in contact with the graphitic sericite-schists and are difficult to distinguish. (See section G, Pl. LXVIII.) The cleavage of the Silurian schist dips east, as does the stratification of the Cambrian gneiss. However, at several points within a few feet of the contact the schists have a westerly stratification foliation crossing the easterly cleavage. Large quartz veins occur here along the contact, and at one point Mr. Wolff found an eruptive which is also in line with the contact. These results substantiate Mr. Wolff's theory that "a great thrust plane exists on the western side of Pine hill, by which the Cambrian is made to lie on the lower Silurian limestone,"<sup>1</sup> which needs only to be amended by adding the words, "and schist." The relations of the schist and limestone on the west side are normal, but a little above the contact westerly stratification crosses the cleavage of the schist.<sup>2</sup> The Silurian schist, which intervenes between the Cambrian quartzite and gneiss and the Stockbridge limestone, has at least one syncline in it. (See Fig. 63.) Mr. Wolff's section with these additions represents the probable structure. Fig. 64 serves to illustrate the topographic relations of the Pine hill overthrust.

The relations between the Stockbridge limestone and the Berkshire

<sup>1</sup> Loc. cit., p. 337.

<sup>2</sup> This structure recurs about one-half mile southwest of center Rutland, on south side of railroad.





U. S. GEOLOGICAL SURVEY



NORTHERN FACE OF THE DORSET



MOUNTAIN MASS, FROM DANBY HILL.



schist were studied at two points—at Proctor (Sutherland Falls) on the west side of the center Rutland valley, and west of the extreme north end of Pine hill. In the most westerly marble quarry the bedding dips  $85^{\circ}$  east for a vertical distance of 100 feet and then below turns west at an angle of  $45^{\circ}$ . The nearest schist at the foot of the ridge west has a cleavage dip of  $55^{\circ}$  to  $65^{\circ}$  east and indications of a westerly dipping stratification, but there is room for minor folds between the limestone and the schist.

At West Rutland, along the foot of the Taconic range and about three-fourths of a mile northwest of the Catholic church, there are some large, conspicuous, sericite-chlorite-schist ledges, with a cleavage foliation dipping  $20^{\circ}$  to  $40^{\circ}$  east and another dipping about  $80^{\circ}$  east, but stratification dipping  $5^{\circ}$  to  $20^{\circ}$  west, and vertical joints striking east to west.<sup>1</sup>

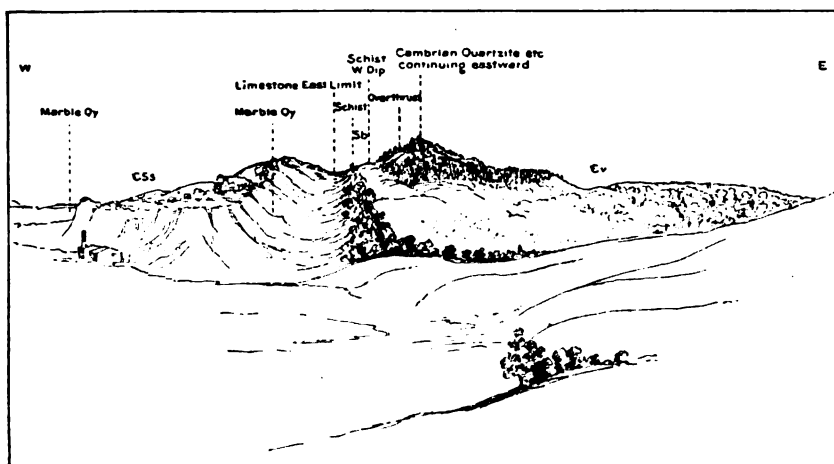


FIG. 64.—Southern side of Pine hill, near Rutland, showing the surface features at the overthrust.

A little farther north, about north-northwest of the Catholic church, the same schists crop out in the meadow east of the road, with a cleavage dip of  $20^{\circ}$  east and stratification dipping rather high west.

Both of these localities indicate, therefore, westerly dips for the limestone and schist on the west side of both the center Rutland and west Rutland valleys; but as those rocks are in minor folds it is quite possible that the contact may occur now on the east and now on the west side of a fold, or that these may be overturned in places.

#### ECONOMIC GEOLOGY.

The structure of the schist ledges on the west side of the West Rutland valley, as thus made out, may possibly prove to have an important bearing on the marble industry of that valley. As the real dip of the

<sup>1</sup> For full description of this interesting locality see Thirteenth Ann. Report U. S. Geological Survey, The Rensselaer grit plateau, p. 321, and Am. Jour. Science, 3d ser., Vol. xviii, April, 1892, p. 317, On plicated cleavage-foliation.

schist is low west, it must form the west limb of some anticline; therefore the marble of the east side of the anticlinal valley may recur much nearer the surface on the west side than would be inferred from mistaking the schist for the west limb of a syncline.

#### INFERENCES.

Upon the basis of Mr. Wolff's general results,<sup>1</sup> thus supplemented, the Pine hill section would be interpreted as follows from east to west: The Vermont valley is a broad, shallow syncline of Cambrian quartzite, pitching southerly under the Cambrian base of the Stockbridge limestone. The eastern and greater part of Pine hill is probably a complex anticline of the Vermont formation (Cambrian quartzite, cement rock, and associated gneisses), ruptured and thrust over the lower Silurian schist (Berkshire schist) syncline, which forms the west side of the hill. The center Rutland and the west Rutland valleys are anticlines of Stockbridge limestone, but with some minor folds.<sup>2</sup> This limestone dips under the more or less complex synclinal ridges of Berkshire schist on both sides of these valleys. The vertical displacement by the overthrust on Pine hill would be at least as great as at Clarendon—some portion of the Cambrian quartzite being brought up the entire thickness of the Stockbridge limestone and about 250 feet of that of the Berkshire schist.

#### RÉSUMÉ.

##### GENERAL STRUCTURE OF THE INTERMEDIATE RANGE.

The foregoing sections establish the general anticlinal structure of this range: it is a complex anticline of the lower Cambrian quartzite and the associated conglomerate "cement rock," sericite-schists, and gneisses of the Vermont formation, overlain by the Cambro-Silurian Stockbridge limestone, followed by a variable thickness of the lower Silurian Berkshire schists, representing a total thickness of at least 2,000 feet and on Dorset mountain probably more than 3,200 feet. This anticline has been faulted in two ways—by a double fracture resulting in letting down a somewhat keystone-shaped block of schist and limestone several hundred feet in width into the anticline, to a depth of about 1,500 feet, and by a reverse fault, which resulted in thrusting some portion of the lower Cambrian quartzite and gneiss westward over the lower Silurian (Berkshire schist), the vertical displacement amounting in this case also to about 1,500 feet.

This fault extends from the Pittsford line south into the town of Wallingford, a distance of at least 12 miles, but not exceeding 18 miles, as it does not reach the town of Danby.

In this town, at a point about  $22\frac{1}{2}$  miles south of the north end of

<sup>1</sup>See his section, *op. cit.*, p. 333, and Fig. 63, herewith.

<sup>2</sup>A rough estimate of the maximum thickness of the Stockbridge limestone at center Rutland gives about 1,250 feet if the structure be a simple anticline.

Pine hill, the ridge is crossed by a zigzag east-to-west reverse fault, by which the Cambrian quartzite is brought up to the level of the Silurian schists, with a vertical displacement of about 1,450 feet. Thus the northern part of the Dorset mountain mass was thrust up to nearly its entire altitude above the next summit of the ridge north of the fault. That this entire range has been subjected to great strain is also manifest from the numerous dikes which traverse it in Rutland, Clarendon, Wallingford, and Danby. It corresponds to a line of both great strain and least resistance. It has also been subjected to such powerful or long erosive influences as to have greatly altered in places its form and its height.

#### RELATION TO THE VERMONT AND TINMOUTH VALLEYS.

The anticlinal structure of the ridge necessitates a syncline in the Vermont valley, and this is also indicated by Mr. Wolff's observations east of Pine hill and by the structure of the west face of the Green mountain range east of the north end of Dorset mountain (p. 544). For similar reasons a syncline must occur along the west side of the intermediate range in the Tinmouth valley. Indications of this are apparent in Clarendon (sections A, E, F), but farther north this syncline is probably continuous with that in the schist mass forming the west side of Pine hill, for the Center Rutland valley is evidently anticlinal.

#### AGE OF THE FORMATIONS.

Mr. Wolff and Mr. Foerste have shown the lower Cambrian age of the base of the Stockbridge limestone on the east side of the north end of the ridge (Pine hill section). The Clarendon section shows the lower Cambrian age of the lower 470 feet of the same limestone on the west side of the ridge (section A). Mr. Wing's discoveries showed the lower Silurian age of the upper part of the Stockbridge limestone in the West Rutland valley.<sup>1</sup> Mr. Foerste's discoveries in 1890 and 1891 showed the same to be true in the Center Rutland and Tinmouth valleys and in Wallingford;<sup>2</sup> and, finally, the lower Silurian (Hudson River) age of the overlying Berkshire schists, long ago insisted upon by the geologists of the New York Survey, has been confirmed by various recent investigations.<sup>3</sup>

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<sup>1</sup>J. D. Dana, loc. cit.

<sup>2</sup>Wolff, loc. cit. and Wallingford sections, p. 543.

<sup>3</sup>Thirteenth Annual Report of the U. S. Geological Survey, pp. 332-333. Also Monograph xxiii U. S. Geol. Survey, p. 190.











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