who would get their training, if possible, from experienced specialists in this class of work. Computers of orbits would be aided in the same way, and their work might thus be greatly improved in quality and increased in quantity. Directors of observatories could get most valuable advice and help from the committee, and when a new observatory was established its plan for work could thus be greatly improved. The Harvard Observatory would gladly welcome and profit by such advice.

The committee should not stop with existing problems. When a new line of research, like measuring the heat of the stars, is proposed, they should at once investigate it and, if the results are promising, test it. If it prove successful, they should carry it as far as present means permit. In this, as in securing the cooperation of existing observatories for any of the great problems now before us, there seems to be no limit to the results obtainable by a wise administration.

The donor, as well as the astronomer, must be asked to consider first the interests of science. His name would necessarily always be associated with his gift, and would he not prefer a world-wide, to a local, immortality? There must now be many wealthy men trying to find some good use for the money they can not take with them out of this life. The hardest problem will be to find an active committee with no taint of selfish dross. This taint exists even among astronomers. There is no more permanent, economical and efficient trustee than a great university with long continued and honorable traditions. As with any other wish of the donor, it could secure and enforce unselfish management, as well as efficiency.

Industrial enterprises half a century ago were in nearly the same condition that science is in to-day. May we not expect in astronomy the same advance by cooperation and organization? If donors, trustees and astronomers can thus be led to work for scientific results alone, regardless of country or personal considerations, it will be the best return I can make for the great privilege of addressing the Harvard Chapter of Phi Beta Kappa.

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SOME ASPECTS OF THE PANAMA CANAL.[1]

AFTER approximately six years of investigation, the selection of both route and type for a ship canal across the Isthmus of Panama is nearly completed. Although the report of the board of consulting engineers already made public is not final, it leads to the final consideration of the question in congress so that on the conclusion of congressional consideration work can be promptly begun under the adopted plan. Whether the final plan be that of a lock or a sea-level canal, the route will be the same, practically that of the Panama Railroad running between Colon on the Caribbean side of the isthmus and a point called La Boca on the Pacific side, a mile and a half west of the city of Panama.

The length of the Panama Canal is about 49 miles between 40-foot contours at low water at its termini, but the length between shore lines will be not more than 42 miles.

The topography of the Isthmus at the Panama crossing is well adapted to the construction of this ship canal, the original summit of the divide on the line of the canal being but about 330 feet above sea level. This has now been reduced to about 170 feet above mean sea level by the French excavation at Culebra. About one half of the length of the canal lies along low marshy ground on either side of the

[1] Read at the Ithaca, N. Y., meeting of the American Association for the Advancement of Science, June 30, 1906, before Section D, Mechanical Science and Engineering.

isthmus, making two natural sea-level sections, one about eighteen miles long on the northerly side of the isthmus, and the other about seven miles long on the southerly side; that on the northerly side running for the greater part of its length generally along the course of the Chagres River. This river has been one of the main features in the consideration of the canal work since the beginning of operations by the old Panama Canal Company in 1881. It is not a large river, as it has not more than about 800 square miles of watershed above Bohio, where in its flow toward the sea it leaves the rising ground and enters what may be termed the coastal plain, through which it meanders along a sinuous course to the ocean. It has even changed its course in the past at various locations in this marshy ground.

That portion of the canal route lying in the higher ground of the divide is but about 24 miles long, and but little more than three quarters of a mile of it had an original surface elevation exceeding 200 feet. The surface material is largely clay of ordinary character, slippery and easily moved when wet, but holding well in place when protected from the entrance of water. Below this covering of clay lies material of irregular character, as the entire isthmus is of volcanic origin. In the continental divide, at a depth varying from twenty to forty or fifty feet below the surface, an indurated clay, classed for purposes of excavation as soft rock, is found. This material gives place irregularly to hard rock at greater depths. Much of the rock of the isthmus is soft, although there is hard basalt in a number of places and, in one locality on the Panama slope of the divide, columnar basalt is found.

The work performed by the old and new Panama canal companies amounted in the aggregate to not far from eighty million cubic yards of all classes of excavation, of which possibly forty million cubic yards at most will be found available for the American construction of the canal, whether a lock plan or a sea-level plan be adopted. This work extends practically over the entire canal route, with the exception of the approach channels in the two terminal harbors, and it is nearly continuous. Over considerable stretches of the higher ground it is little more than shallow cuts through the softer surface materials, but at the great Culebra cut the material which has been excavated varies from the surface clay, readily removed by steam shovels, to hard basaltic rock, requiring blasting by high explosives before it can be removed. All the material, even the indurated clay, below the softer covering, requires blasting before it can be excavated, although the softer portions need the action of black powder only.

Except the deep cutting at Culebra, through the summit of the continental divide, the most marked work done by the old French company was the dredging through the low marshy lands from Colon to Bohio. There is at present a strip of partially completed canal about 14 miles long with a bottom width of seventy-two feet, which may be navigated by vessels drawing twelve to fourteen feet, with the exception of a short distance near Colon. Indeed, so much excavation was completed in this portion of the canal, intersecting the Chagres at a number of places, that the waters of that river have abandoned the old bed and now flow through the partially completed canal prism.

In the execution of any plan of canal one of the principal problems involved is the control of the Chagres River during seasons of flood. This problem has been considered so formidable in the past that some experienced engineers have hazarded the opinion that the Panama Canal could never be successfully completed in consequence of the uncontrollable destruction that would be caused by the Chagres floods. The regimen of that river in connection with the rainfall on the isthmus has been a subject of such extensive and careful investigation that the elements entering the problem of control are now comparatively well known. Instead of the floods of the Chagres playing such a destructive part in the history of the canal, there have now been devised a number of methods of effective control, so that it can be actually demonstrated that such floods are not to be feared in any respect whatever. Indeed, if a lock plan should be adopted for construction, it would be impossible to feed the locks with sufficient water for navigation were it not for the supply offered by the Chagres River. In other words, the Chagres would play the part of a friendly agent rather than that of a vicious enemy in the maintenance and operation of the canal. While this river is subject to rapid variations of discharge, so that within a period of twenty-four or forty-eight hours it may change its character from that of a quiet, inoffensive mountain stream to a literally raging torrent, the range between low water and flood elevations is much less than in many of our American rivers. Nor are the extreme floods so formidable in character as they have sometimes been supposed. While many small floods occur every season, a high flood is a rarity, as but five have occurred within fifty years, and in no case have these high flood effects lasted more than about forty-eight hours. One of the prominent characteristics of the Chagres floods is the rapidity with which they rise, the short period of highest water and the short time required for recession to the condition before the flood began.

Records of accurate daily observations, both self-recording and otherwise, of the discharge of the Chagres under all conditions of flow have been kept for nearly twenty years, and more or less complete observations for a much longer period, so that what may be reasonably expected of the river at all seasons of the year is now fairly well known.

In addition to the discharge observations along the Chagres River, accurate rainfall records have for many years been kept for all portions of the isthmus. The amount of rainfall varies greatly both from certain portions of the year to other portions, and from one year to another. The isthmian year is divided into two parts, the wet season and the dry season. The former begins about the latter part of December and usually extends to the latter part of April, the remainder of the year constituting the dry season. During the dry season but very little rain falls; sometimes none at all for long periods. An erroneous impression may easily be received from the term wet season, which does not mean that rain falls daily, or that it often rains all day. In reality, some of the most enjoyable weather of the entire year is found in the rainy season, when there is no dust and the general temperature is agreeable. The rain falls mostly in showers, although there are continuous rain storms extending over several days. The latter, however, are not common. The average annual rainfall is not far from 130 inches at Colon and on the Caribbean side of the isthmus, but on the Pacific side at Panama the annual precipitation is only about one half as much.

These excessive rainfalls and the proximity of the two oceans produce at nearly all times an atmosphere of high humidity. The trying character of the isthmian climate is due chiefly to this feature. The temperature usually runs from 70° to 75° F. in the morning, and to 82° to 86° F. in the hottest part of the afternoon. Occasionally the temperature rises to 96° or 98°

F., but such periods of extreme heat are rare.

During the greater portion of the year the northeast trade winds blow steadily across the Caribbean Sea, so that Colon receives the benefit of the resulting winds. In fact, during the greater part of the year strong breezes are of daily occurrence in the vicinity of Colon, although these are interrupted during some portions of the rainy season.

The winds are much more gentle and far less in amount in Panama than on the northerly side of the isthmus. There are periods of gentle breezes from the north and also from southerly directions, but they are never high winds. The Bay of Panama, on which is located the city, and into which the canal will lead from the north, is so free from high winds that shipping at anchor in it never needs the protection of breakwaters or similar structures. A real wind storm of high intensity in that vicinity is practically unknown. This condition is so strongly characteristic of the Bay of Panama that many of the opponents of the Panama route have strongly argued against it for the reason that the prolonged calms and general absence of winds would make it difficult for sailing vessels either to approach that end of the canal or to leave it after having passed through the waterway.

The harbor of Colon, completely open to the north, is of a radically different character. While it is frequently visited by breezes and winds of ordinary intensity, there are not, on the average, more than three or four days at most in the year when winds are high enough to be troublesome to shipping lying there. During those three or four exceptional days, however, wind storms of great violence, called 'northers,' may blow. At such times no ship can safely lie at anchor in Limon Bay, on which Colon is located, nor can they lie berthed alongside of the piers. In both cases they are in grave danger of being wrecked. It is the universal custom during the period of 'northers'—November, December and January—for every ship fitted with power quickly to leave the Bay of Limon and either put to sea while the storm lasts or seek the small naturally protected harbor of Porto Bello, about eighteen miles to the northeast from Colon. This characteristic of the harbor of Colon will make necessary the construction of great breakwaters or other similar works, in order to transform it into a suitable terminal harbor for the Panama Canal.

The report of the board of consulting engineers discloses a radical divergence in the views of its members. A majority of eight of thirteen members, including the five foreign members, have reported unqualifiedly in favor of a sea-level canal, having a bottom width not less than 150 feet in ordinary section, a minimum depth of water of 40 feet, and a top width in ordinary section of 270 feet except for a distance of seven miles in the great Culebra Cut, where the canal prism would be in rock with a width of 200 feet. All sides in rock excavation would be vertical. Inasmuch as the maximum range of tide in the Bay of Colon is never more than about two feet no tidal lock would be required at the Caribbean entrance of the canal. In the Bay of Panama the maximum range of tide may reach nearly twenty-one feet. The board, therefore, assumed that a tidal lock would be required, or at least should be planned and estimated for at or near the Panama end of the canal. This lock is to be located near the easterly side of Sosa Hill, not more than one half mile from the shore of Panama Bay. It is designed to have a usable length of 1,000 feet and a usable width of 100 feet.

The control of the floods of the Chagres River would be effected in, the majority plan by a dam across the Chagres River at Gamboa, about thirty-one miles from Colon, near the point where the Chagres River in its downward course first cuts the canal line. At that point bed rock is about fifty-five feet below the surface of the water in the river, affording a comparatively easy masonry construction resting directly upon bed rock, and thus securing an undoubted foundation for a dam. The maximum elevation of water surface in this lake would be about 120 feet above the present surface of the water in the river at Gamboa, or about 170 feet above mean tide. The dam would be fitted with suitable controlling gates of sufficient capacity to meet the requirements of the highest floods. The available storage volume created by this lake would be sufficient to take in quick succession two of the greatest floods which have ever occurred in the Chagres River, so far as is known either by exact records or by reliable report.

It would be the purpose in this system of control to allow flood waters of the Chagres River to escape through the controlling gates into the canal prism at a maximum rate not exceeding 15,000 cubic feet per second, producing a current in the canal, if all flow should be in one direction only, of about one and one quarter miles per hour, a negligible quantity as far as its effects on navigation are concerned. It would require but two or three days after high floods in the Chagres to depress the surface of water in the lake so as to be in readiness for another flood whenever it might occur.

The only other stream of magnitude, discharging into the Chagres River within limits affecting the canal, is the Gatun River, which joins the Chagres near the little native town of Gatun, seven miles from Colon. The discharge of this river, however, would be carried into Manzanillo Bay entirely outside of the canal in an independent artificial channel on which much work was done by the old Panama Canal Company. The other and much smaller streams intersecting the canal line throughout its entire course would be either kept out of the canal altogether by dams high enough to reverse their flow into other drainage basins than their own, or received into settling basins outside of the canal and quietly discharge their small flows into the canal prism over wiers in the usual manner. All streams of this latter class, however, are extremely small. By these means all sensible amounts of silt or other heavy material carried in floods would practically be kept out of the canal, thus reducing the cost of maintenance in this respect to a small annual amount.

A minority of five of the consulting board reported their judgment in favor of a lock canal with two terminal lakes and with a summit level eighty-five feet above the mean level of the ocean. In this plan it is proposed to construct a great earth dam 135 feet high across the Chagres River at Gatun. This dam would retain a large lake backing the water in the river up to Alhajuela, a point over thirty miles from the site of the dam. The surface of the water in this lake constitutes the summit level of the lock plan. Three locks in series or flight, each with a clear length of 900 feet and a clear width of 95 feet, would be built at the site of the dam, each with a lift between 28 and 29 feet to pass vessels up from the approach channel leading to the locks from the harbor of Colon to the summit level. The southern extremity of the summit level of this plan would be at Pedro Miguel on the southerly side of the continental divide where the channel issues from the Culebra cut. At this point, between thirty-nine and forty miles from Colon, there would be located a lock with a lift of about thirty feet, connecting with the terminal lake at the

Panama end of the canal, which would have a water level of about fifty-five feet above mean tide in Panama Bay. This terminal lake would extend to another earth dam, or rather two earth dams in the vicinity of the present railroad terminus at La Boca and one embankment easterly of this location. That portion of the dam at La Boca would be built directly across the mouth of the Rio Grande River, which is chiefly a tidal estuary. A hill known as Sosa Hill would separate the two earth dams already alluded to, and in this hill would be two locks in series connecting the terminal lakes with tide water in Panama Bay. All the locks required by this plan would be built on the twin system, so that one set would always be in use if the other should be disabled or be out of use for repairs. All ships passing across the isthmus in such a canal would have to be lifted up to an elevation of 85 feet at one end of the canal and dropped down the same amount at the other.

The control of the Chagres River in the lock plan would be effected by the lake formed by the dam at Gatun. Its volume would be so large that the waters of the highest floods could be received into it and discharged through suitable controlling gates constructed in the dam without varying the elevation of the lake more than two or three feet at most. Also, the lake would act as a reservoir for the water required to feed the locks during their operation.

There are at present being built ocean steamers for the traffic between Liverpool and New York about eight hundred feet long. This fact coupled with the rapid increase in ocean steamship dimensions during the past fifteen or twenty years caused the board by an almost unanimous vote to record its judgment that locks proposed for the isthmian canal should have a usable length of not less than one thousand feet and a usable width of not less than one hundred feet, but the minority abandoned this position in their plan and recommended the smaller locks which have already been mentioned.

The total estimated cost of the sea-level canal is about $247,000,000, including a twenty-per-cent. allowance for contingencies, administration and engineering. The estimated cost of the lock plan with the reduced size of locks is about $140,000,000, including the same twenty-per-cent. allowance found in the above estimate of cost of the sea-level plan.

In the recent examination before the Senate Committee on Interoceanic Canals, however, it was brought out that the minority allowance for the cost of lands submerged by the terminal lakes of its plan was entirely inadequate. It was shown that on the basis of prices already paid by the United States government, and by the new Panama Canal Company for somewhat similar lands, and in view of the claims already made by alleged owners, this amount of land damage might reach an additional sum of $15,000,000 to $18,000,000, and that if the excess of annual cost of maintenance and operation of the lock plan over the sea-level plan be capitalized at prevailing rates of government interest the real cost of the lock plan might approximate not less than $175,000,000 to $180,000,000.

The question of the selection of ultimate type of canal to be adopted for construction has been submitted by the President to Congress, and the Senate Committee on Interoceanic Canals has been conducting an extended examination of the entire question. That committee has called for evidence in detail from the advocates of both types of canals, but its report has not yet been made.[2]

The advocates of the sea-level plan con-

[2] Since preparing the MSS. for this article the Senate Committee has reported in favor of the sea-level plan, but Congress has adopted the lock canal.

tend that the only suitable canal across the Isthmus of Panama, commensurate with the great interests involved, especially those of the United States, is one which will permit the safest and freest passage of traffic. It is contended that there should be practically no obstruction to a free transit across the isthmus; that any canal now constructed should accommodate conveniently and freely the greatest ships afloat, and be of such a character as to admit of the easiest and most economical enlargement in the future if it should ever be required, and that the sea-level plan only fulfills all these fundamental requisites. Although there would be a tidal lock at the Panama end of the canal, inasmuch as the range of neap tides may not exceed seven or eight feet, the gates of that lock would be wide open at least one half of the time. There are hydraulic engineers of repute, who even believe that this lock would not be necessary. The majority of the board further contends that the operation of three locks in series would be a source of grave danger, indeed, a continual menace to the safety of the large ships passing them. Serious accidents caused by ships ramming the gates of both the Manchester Canal in England and at Sault Ste. Marie, Mich., show that it would be possible, and even probable, that some ship approaching the upper of these gates might ram them out of position and plunge down through the entire series.

Although the minority claim an annual capacity of sixty to seventy million tons of traffic for its lock plan, this elaim has been strongly contested, and evidence brought out before the senate committee indicated that it would be more reasonable to place the maximum annual capacity at one half that amount or less.

Again the safety or stability of the earth dams, on which the very existence of the minority plan is based, has been most seriously questioned. A considerable number of borings made into the material on which it is proposed to place the Gatun dam show that the maximum depth of that material is not less than 258 feet; that it is largely sandy, and in some places gravelly and freely water bearing, *i. e.,* permeable at various depths from thirty-two feet below the surface down to nearly two hundred and fifty. These conditions, it is alleged, might lead to dangerous percolation under the dam, and so bring its stability into grave question. Somewhat similar criticisms have been made regarding the earth dam across the tidal estuary of the Rio Grande.

Although the capacity of the sea-level canal has been also criticized or questioned, that capacity was shown to be practically unlimited. Although most serious congestions of ships arriving in groups or fleets at either end of the lock canal might lead to long delays in some cases with a lock canal, it was shown that no such congestion could occur with the sea-level canal, even at the Panama end, for the half of any tidal period would permit any group of ships to pass into the canal while the gates were open.

The one hundred and fifty feet bottom width of the sea-level plan exceeds the width of even the turning out or passing places in the Suez Canal. In other words, the Panama sea-level canal would be a continuous passing place throughout its entire line. The total curvature of the sea-level plan was also shown to be less than that of the lock plan, and but little different from the total curvature of the Suez Canal. The lock plan with the large terminal lakes has the further serious disadvantage of possessing a minimum adaptability to transformation to a sea-level canal in the future. While this transformation is a possibility, the great difficulties attending it, and the excessive cost of that transformation, were considered by the board as a whole to make transformation of this plan essentially not feasible.

Again, inasmuch as the canal would probably not be completed and opened within less than ten years on any plan the locks of the minority plan would not be large enough to accommodate ships then afloat if the rate of increase of ships' dimensions during the past ten years should be nearly reached during the next ten.

The time estimated by the majority to be required for the building of the sea-level canal is from twelve to thirteen years after making the most abundant allowances for the effects of climate, of the rainy seasons, of the necessary repairs and renewals of plant, of the eight-hour labor day, of the low efficiency of available labor, and without working more than one shift of labor within twenty-four hours. It is believed that the investigations of the majority show, however, that there is a reasonable probability of a sea-level canal being opened in from one to two years less time than their estimate.

The time estimated by the minority as necessary for the construction of their lock plan was ten to eleven years. As the construction of this plan involves a much higher grade of labor, and a far larger amount of so-called works of art, such as the locks, involving the making and putting in place of about 3,500,000 cubic yards of concrete, than the sea-level plan, the writer believes that a lock plan with a summit level eighty-five feet above mean tide can be executed in little if any less time than a sea-level plan.

The recent dreadful earthquake disaster at San Francisco constitutes the gravest warning in human experience of the advisability of constructing this canal in such a way as to give it the greatest degree of immunity from the results of any convulsion of nature. The isthmus of Panama is a region of rather frequent earthquakes, but they are not often severe. It would be an act of folly, however, to ignore the lesson of such an appalling catastrophe. The canal which is to be constructed across the Isthmus of Panama should be of such a type as to give the minimum of obstruction, either natural or artificial, the greatest degree of safety not only in operation, but from the effects of earthquakes, against the severity of which there is absolutely no insurance whatever, and the sea-level is the only type which fulfills these imperative requisites.

Wm. H. Burr.

SCIENTIFIC BOOKS.

Archeological Researches in Costa Rica. By C. V. Hartman. Stockholm, Ivar Haeggströms Boktryckeri, A.B., 1901. 4°, 195 pp., 488 text illus., 1 map and LXXXVII pls.

Museum collections and special publications derive their value from the character of the field-work on which they are based. It is with such material as Mr. Hartman has furnished and by means of the methods he employed that we may hope to raise American archeology to the dignity of a real science.

In the growth or decay of art, industry, customs, religion, there must of necessity enter the time element. For this reason, systems of relative chronology play a most important part in prehistoric archeology. A careful, intelligent, thorough study, therefore, of the contents of graves is absolutely indispensable. 'Archeological Researches in Costa Rica' is by no means confined to a study of burial places, yet it describes fully more than 400 graves.

Mr. Hartman's field investigations were carried on during the years 1896–97. He began his researches on the east coast with the great mound and walled enclosure at Mercedes. The mound is about 300 meters west of Rio Novillo; is truncated, with diameters at base and top of 30 and 20 meters, respectively. The height, 6.5 m., is the same as that of the surrounding wall. The purpose of the mound 'seems to have been to serve as a platform, or temple, for the large statues, which were