HAWAIIAN VOLCANIC AGGREGATES

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SYNOPSIS

The island of Hawaii is a volcanic island that is still in the process of being built up Recent lava flows can be observed side by side with ancient flows and also one on top of another.

Varying conditions at time of eruption give rise to different types of erupted material such as lava rock, cinders, ash etc. Also variations in climate and rainfall cause differences in weathering and in soil formation.

This paper describes the various types of volcanic material found on the island of Hawaii and their use as aggregates and material for the building of highways

The Hawaiian Archipelago is a group of islands, reefs, and shoals, the summit parts of a 2000-mile range of marine volcanic mountains. Its capital, Honolulu, lies 2,100 miles southwest of San Francisco

TABLE 1
AREA AND POPULATION OF PRINCIPAL ISLANDS OF HAWAIIAN GROUP

Island	Area	Population		Principal City
		1940 Census[a]	1949 Estimate[b]	
	sq mi.			
Niihau	72	182	213	None
Kauai	555	35,636	36,840	Lihue
Oahu	604	257,664	360,085	Honolulu
Molokai	260	5,840	5,384	Kaunakakai
Lanai	141	3,720	3,078	Lanai City
Kahoolawe	45	1	0	None
Maui	728	46,919	48,778	Wailuku
Hawaii	4,030	73,276	76,513	Hilo
Totals	6,435	422,738	530,891	

[a] According to U S Federal Census 1940
[b] Estimated by Territorial Board of Health

From an economic point of view, only the eight principal islands lying east of longitude 161 deg. west are of any importance. The names, area, and population of these eight principal islands are given in order from west to east in Table 1.

The islands lying to the west of longitude 161 deg. west are known as the Leeward Islands and consist of about fifteen small islands. A few consist of volcanic rock; the remainder are composed of coral reef rock and sand (*1*)[1]. Formerly of no economic value and somewhat of a menace to navigation, these tiny islands have recently acquired strategic value as sites for air strips as a result of World War II and the present world situation.

Governmentally the eight principal islands are divided into four counties, each county consisting either of a single island or a principal island and its neighboring smaller islands. The City and County of Honolulu includes not only the whole of the island of Oahu, but its jurisdiction extends over hundreds of miles to the west and south to cover all the other tiny islands and islets not included in Table 1, making it one of the world's great cities, at least in geographical extent.

Although some historians claim that Spanish ships under Juan Gaetano visited the Hawaiian Islands in 1555, their existence was not made known to the world generally until the 1778 voyage of Captain James Cook (*2*). He named the islands the "Sandwich Islands" in honor of his patron, the Earl of Sandwich The name has gradually fallen into disuse.

From practically all points of view, except size, Oahu is the most important of the Hawaiian Islands. In size, as can be seen from Table 1, the island of Hawaii, from which the Territory[2] of Hawaii as a whole takes its name, is by far the largest. Moreover, it is the only island of the group having live volcanoes. In geologic age, its rocks extend from the present to the remote past, presenting the engineer with an interesting variety of highway and other building materials. This paper is confined mainly to the volcanic aggregates of the island of Hawaii.

[1] Figures in parentheses refer to the list of references at the end of the paper

[2] The Hawaiian Islands were annexed to the United States in 1898 and a territorial form of government established in 1900

THE ISLAND OF HAWAII

The island of Hawaii is roughly triangular in shape (See Fig 1). The Kohala mountains, elevation 5,505 ft, form the northern tip Mauna Kea, elevation 13,784 ft, lies on the eastern side, while Hualalai, elevation 8,251 ft, and Mauna Loa, elevation 13,680 ft, lie on the western side

The northern or Kohala end is the oldest part of the island and at one time according to geologic theory, it existed as a separate island before the other volcanoes forming the island built up sufficiently to cause coalescence above sea level

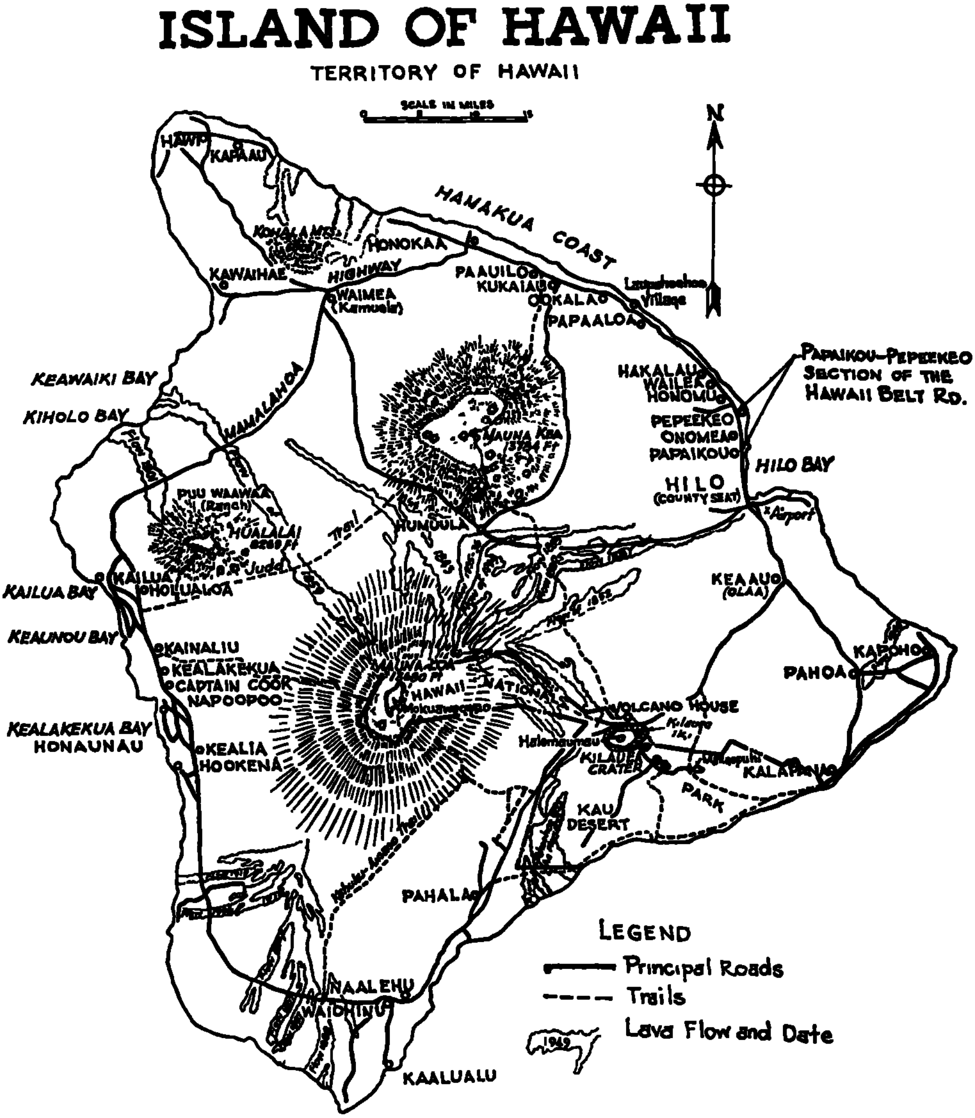

Figure 1

Both the Kohala mountains and Mauna Kea have long been extinct, the former becoming inactive first. The last volcanic activity of Mauna Kea is estimated to have taken place some time after the last glacial epoch. Because of their age, both the Kohala mountains and Mauna Kea exhibit highly eroded surfaces in areas of heavy rainfall (*3*).

Hualalai has been active in historic time, its last eruption having occurred in 1801. Mauna Loa is still very active, periodically sending out great streams of molten lava either from its summit crater or from rifts in its flanks. To the east of Mauna Loa lies the famous volcano of Kilauea, which appears to be a secondary summit on Mauna Loa's flank, but it is actually a separate mountain, elevation 4,090 ft. Formerly this volcano of Kilauea was continuously active, but in recent years it has been mostly quiet with only short spurts of activity, although at all times steam may be observed issuing from its crater and from cracks in the surrounding ground.

Although there have been a few explosive ash eruptions from Kilauea, Hawaiian volcanoes are not classed as of the explosive type. The product of eruption is almost always lava. The great deposits of ash found along the Hilo and Hamakua coasts and inland to the Waimea plains, Mountain View, Glenwood, and Pahala are believed to have originated from Mauna Kea, now long since extinct (*4*).

The prevailing moisture-laden winds blow inland from the northeasterly direction. Accordingly, the windward slopes of the Kohala mountains, Mauna Kea, and Mauna Loa receive an abundance of rainfall. The lavas of Kohala and Mauna Kea, because of their age and the heavy rainfall, are in many places highly weathered. The lavas of Mauna Loa are less weathered because of their youth when compared with the Kohala and Mauna Kea lavas. The rainfall, in general, increases with elevation up to about the 1,800- to 2,000-ft. contour, above which it begins to decrease.

The Wailuku River in Hilo is the dividing line between the lavas of Mauna Kea and Mauna Loa. To the south are the Mauna Loa lavas, relatively recent with very little soil cover. To the north are the Mauna Kea lavas, highly weathered, with a thick cover of soil formed from volcanic ash, measuring as much as 25 to 30 ft. in places.

Except for very minor amounts of coral limestone and other sedimentary rocks along the shoreline, formed subsequent to its volcanic growth, the entire mass of the island of Hawaii consists of lava flows bedded one on top of another.

TYPES OF LAVA

The ancient Hawaiians distinguished two basic types of lava, the aa, or rough surface lava, and pahoehoe, or smooth surface lava. Since there are no corresponding terms in English, these Hawaiian words have been adopted by geologists, engineers, and others dealing with the subject as their use does away with the cumbersome phrases that would otherwise be necessary to express the same idea.

Figure 2. Advancing Aa Flow—Mauna Loa Eruption of 1935
(Photograph by U. S. Geological Survey)

Aa flows are extremely rough surfaced. Figure 2 shows an advancing aa flow. In such flows the surface is broken up into fragments and masses of clinker, the latter resembling blast furnace clinker. In fresh flows the fragments are sharp and spiny. Under continued weathering, these sharp edges break off and the particles become somewhat rounded.

Pahoehoe flows, in contrast, show a smooth ropy surface (See Fig. 3). A relatively unweathered pahoehoe flow exhibits a glassy sheen, which is distinctly noticeable even at a distance if the light conditions are favorable. It is comparatively easy to hike across a pahoehoe flow but to do so over an aa flow is extremely difficult, even with pack animals, as the sharp fragments cut up the animals' feet.

Whether a lava flow turns out to be of the aa type or of the pahoehoe type depends upon a number of factors. To begin with, the molten lava[3] as it comes up from within the earth contains a lot of entrained gas, mostly steam. The gas acts as a flux to lower the melting point. Thus, if the molten lava contains much gas, it will remain liquid longer than lava with little gas, other factors being equal.

The great historic lava flows of Hawaii have usually originated from rifts or cracks along the flanks of Mauna Loa in one or more lava or fire fountains (See Fig. 4). At the source the lava is naturally very fluid and flows readily. As long as it maintains sufficient liquidity it tends to flow and spread out into a relatively thin-layered pond or stream of molten lava, with a smooth surface. Thus, flows start out initially as pahoehoe lava.

As the flow advances, the forward end begins to cool, the gasses escape, and the mass becomes more viscous. Decrease in the slope of the land, obstructions, increase in viscosity, and cooling of the mass all tend to decrease the velocity of flow at the forward end. This slowing down causes the lava stream to pile up. The pressure exerted by the upstream end causes the piled up lava, by now partially solidified, to break up into a tangled mass of lava debris. The flow becomes an aa, or rough surfaced flow. Figure 2 shows this well. At times the transition from pahoehoe to aa takes place near the source. At other times the flow continues as pahoehoe to the end. The reverse transition from aa to pahoehoe has never been observed. Aa flows are thicker than pahoehoe flows and move more slowly.

Pahoehoe lavas, because of their manner of formation, occur as broad sheets and are comparatively thin-layered. Also as a result of entrapped gasses such lavas contain numerous gas holes or vesicles, approximately spherical in shape. Such rocks are known locally as puka-puka rock, meaning "full of holes."

Because of their occurrence as relatively broad sheets, a pahoehoe formation is difficult to handle even with power grading equipment. In general bulldozers and rooters are ineffective. Blasting has to be used. But here there is another difficulty. Beneath the surface of a pahoehoe flow are numerous cracks and hollows where the still molten interior lava continued to flow after the surface solidified. Such a hollow is known as a lava tube (See Fig. 5). The result is that in blasting a part of the force of the explosive is dissipated through the cavities. It is obvious that great care must be exercised and the sub-surface exploration work thoroughly done if a heavy structural foundation is to be placed on a pahoehoe formation.

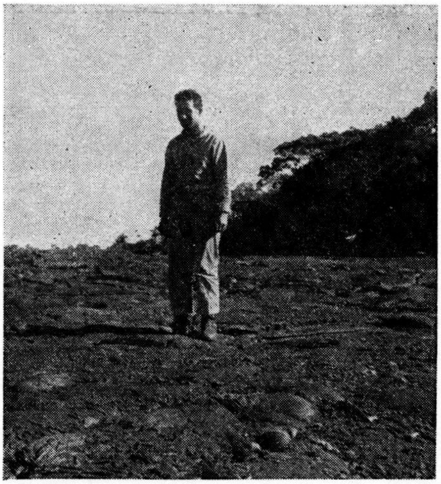

Figure 3. Pahoehoe Lava

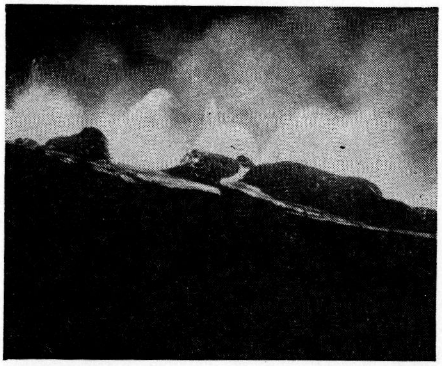

Figure 4. Fire Fountains at Source of Flow —Mauna Loa Eruption of 1935
(Photograph by U. S. Geological Survey)

On the other hand, aa lava because of its fragmental nature is easily broken up and moved around by bulldozers. Thus, with modern grading machinery to do the work, where

[3] Molten lava emerging from the interior of the earth is termed "magma" by geologists. But this term is not used in this paper.

a choice is possible, it is preferable to locate a highway near an aa flow, which in addition to its easier handling, will serve as an economical source of select material for sub-base, or even base. In the latter case it is preferable to crush the material so as to have fractured faces, since the sharp, spiny sides and edges of aa lava particles tend to round off under the roller, resulting in an unstable layer. Of course only hard and relatively unweathered particles are suitable for crushing.

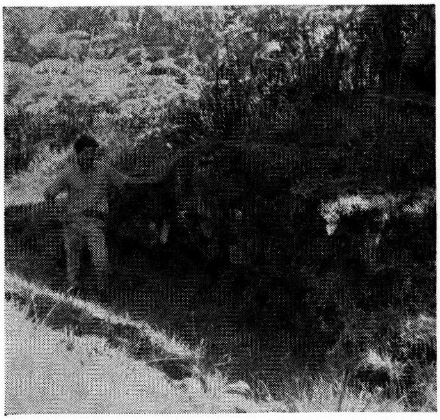

Figure 5. Lava Tube in Pahoehoe—Road Cut on Volcano Road

ROCK QUARRIES

Because of their thin-layered nature, good ledges of dense rock are not found in pahoehoe flows. Figure 6 shows a quarry in a pahoehoe flow. Note the thinness of the top pahoehoe layer. Below the top layer are the clinkers, cinder-like material, and broken-up fragments of an older aa flow. Such materials are usually somewhat weathered and are not suitable for crushing.

Beneath the fragmental, clinkery top of an aa flow is a part that is more dense. This is known as the dense core of an aa flow. The lava, here protected by the broken fragmental top and also subject to its weight, remains liquid longer, and thus has a chance to cool more slowly with less cracking. Also because of escape of entrapped gasses, the lava becomes more viscous and thus there is less tendency for it to flow out from under as in a pahoehoe flow. Also because of viscosity, a tangential, differential sliding movement of one layer over another takes place. This tangential motion tends to flatten the vesicles or eliminate them, resulting in the type of rock usually referred to in local engineering specifications as "dense blue lava rock."

From the foregoing it can be inferred that the most suitable grade of quarry rock is found in the dense core of an aa flow. A good thick ledge of dense unweathered rock is desirable for economical production. This is difficult to find in mountainous areas, contrary to what one would naturally expect. Many ridges can be seen with exposed faces of good quality rock, but experience shows that the latter

Figure 6. Quarry in Pahoehoe Lava

peters out a short distance in from the face. This is so because such ridges are probably the result of a very tumultuous flow or flows, both aa and pahoehoe, and much loss is caused in quarry operations by the necessity for handling large quantities of unsuitable clinkery material, usually weathered, lying between the dense cores of successive flows. On the exposed sides of the ridges, the clinkery mass falls as talus material during the weathering process, exposing a face of apparently solid ledge rock.

The best quarry sites are found where an aa flow had come to rest in fairly level country, where its viscous core had a chance to pond out. Also the level ground allows the lava to pond out in a thick layer. An example is the flat land of Waiakea, suburb of Hilo, where the airport is located. The fragmental top is only slightly weathered and measures but five to ten feet in thickness, below which is the dense core of the flow measuring thirty feet or so to the quarry floor and in addition probably many feet below that.

For high grade pavement rock, both penetration and asphalt concrete, and aggregates for portland cement concrete, dependence is placed on crushing the above mentioned dense core of aa lava flows

CONCRETE AGGREGATES

Hawaiian lava rock, when crushed, tends to flatness with sharp sliver edges In fine aggregate gradation, there is a deficiency in the particle sizes passing the No. 30 to No. 100 standard sieves. To reduce the percentage of flat and elongated particles in crushed aggregates, it has been found best to open the primary crusher as wide as possible and then to crowd the secondary. Opening the primary tends to lessen the shattering effect of the first crushing, which is responsible for most of the flat and elongated particles. Crowding the secondary then causes the particles of rock to rub against one another, breaking off the sliver ends and rounding off the sharp edges by abrasion. By this procedure the percentage of flat and elongated particles is substantially reduced.

In order to reduce the deficiency in particle sizes passing the No. 30 to No. 100 standard sieves, sand rolls have been tried, but these have not proved successful. Better results have been obtained by equipment such as cone crushers which produce fines by abrasive action. Even then results are not altogether satisfactory. The deficiency at the No. 30 sieve is reduced but, generally, there is too much material passing the No. 200 sieve. Some specifications, therefore, require this dust to be screened out.

In common with the other islands of the Hawaiian group, there are no deposits of gravel or of river sand of commercial importance on the island of Hawaii, despite the vigor of coastal erosion and numerous flowing streams.

On the other major islands of the group, Oahu, Maui, and Kauai, it has been standard practice to use calcareous beach sand as part of the fine aggregate in concrete work. The use of this calcareous beach sand with its water-worn rounded grains, gives added workability to the mix, since the exclusive use of crushed coarse and fine aggregates results in a very harsh concrete, more so if the percentage of flat and elongated particles is large. As a rule, the calcareous sand is mixed with an equal volume of rock sand, produced by crushing lava rock, the combination making up the fine aggregate. Actually the optimum proportion of calcareous sand for maximum compressive strength depends on the richness of the mix. According to Austin (*5*), the optimum proportions are as follows:

1 1:1½:2½—a rich mix such as is used in concrete piles, 75 percent calcareous beach sand, 25 percent crushed rock sand
2. 1:2½:4—standard mix for structural concrete, 50 percent calcareous beach sand, 50 percent crushed rock sand.
3 1:3½:5—a lean mix for footings and mass concrete, 33⅓ percent calcareous beach sand, 66⅔ percent crushed rock sand.

Experience shows that the calcareous beach sand, to be effective, must be a coarse sand with approximately 40–65 percent of the particles retained on a No 30 standard sieve.

On the island of Hawaii, calcareous beach sand is not available, at least not on a commercial scale But there are a number of beaches of black sand formed by wave action from lava rock Such a sand adds to the workability of concrete in the same manner as calcareous sand, provided the grains are rounded. Some of these black sands have been found to be too sharp and angular to add anything to the workability of concrete.

A note of caution should be sounded Lava ledge rock, even of the dense aa core, is usually fissured with generally columnar jointing. In rainy regions with thin overburden and dense vegetation, these fissures become coated with a white substance, which when examined casually appears to be rock dust. If the rock is much fissured so that the blocks are small, the proportion of this coating to the whole becomes appreciable. It has recently been brought to the author's attention that fine aggregate made by crushing such rock slows up or even prevents the concrete from hardening.

Most of the lavas occurring on the island of Hawaii are basalt These make excellent crushed aggregates for both portland cement concrete and road surfacing. When tested in the Los Angeles abrasion machine by A A S H O method T-96, the percentage of wear after 500 revolutions varies from below 20 percent to slightly over 30 percent, depending on the source. The apparent specific gravity, A.A.S H O. method T-85, varies from slightly below 2.8 to slightly over 3.0, with absorption ranging from 2 percent to 4 percent. In the poorer quarries, where the original flow had not been massive, the rock from various parts of the same quarry is apt to vary erratically in specific gravity and absorption, which adds to the difficulty in mix proportioning.

Along the eastern and northern coast, north of Papaikou to beyond Honokaa and inland to Waimea many of the lava flows have been andesitic, which are more acid than basaltic lavas. Andesitic lavas tend to the fragmental, clinker type (i.e. the aa type) of flow more readily than the basaltic lavas. They are, in general, more massive and harder than basalts.

Trachyte lava, which is characterized by a relatively high silica content, is found occasionally. This type of lava rock is interesting chiefly because of its use in the past on other islands of the group in the manufacture of hydraulic cement.

WEATHERED AA LAVAS

In rainy regions, a fresh lava flow is quickly covered by moss, lichen, and similar plant life. Within a few years, larger plants take root, forming the beginning of a forest cover. Thus soil formation is rapid in such localities. Figure 7 shows the almost jungle growth over that part of the 1881 flow near the city of Hilo. On the other hand, in arid regions the lava remains bare of plant life and soil for years, probably centuries.

The fragmental top of a recent and unweathered aa flow is composed of jagged, fragile masses of clinker and easily breaks up, when bulldozed, into predominantly coarse particles. Because of a lack of fines to fill the voids and bind the surface, such unweathered aa material tends to washboard if used as base or surface course. If used as a temporary surface in stage construction, the fragile clinker particles are abraded by traffic producing some fines to partially fill the voids. However the surface will still be loose and the results will generally not be wholly satisfactory.

Weathered aa lavas are more suitable than the unweathered aa for sub-base, for base course in stage construction, and for surface course. Such a material occurs in great quantities in the Kulani and Mountain View areas. These are very rainy regions and are covered by thick jungle growth. The weathering process results in a large percentage of plastic, clay-like fines so that the material looks like a gravel-clay mixture. When first laid down, the frequent heavy rains of the region cause it to turn extremely muddy (See Fig. 8). In this state the material appears unsuitable for road purposes. However, after about a month of traffic, the mud disappears, leaving a tightly

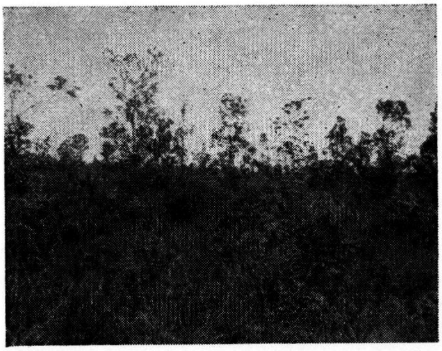

Figure 7. Beginning of Forest Cover over Lava Flow of 1881

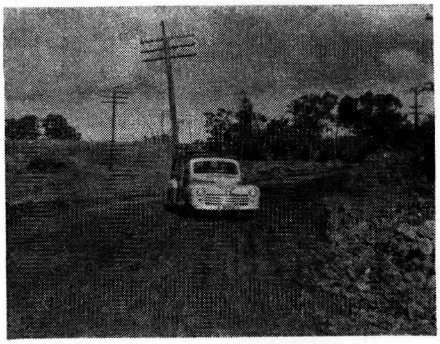

Figure 8. Weathered Aa after Compaction—Note muddy surface.

waterbound surface which no longer turns muddy even during the heaviest rains (See Fig. 9). It is essential in the use of this material that sufficient time be allowed for traffic to "cure" it by working out the mud. Also it is advisable to keep on laying and spreading the material even during rains, since the latter is essential to successful use of this material. If used as a base course and the surfacing is put on too soon, that is, without a sufficient curing period, sponginess with marked rebound will result. Sponginess will also result if the material is laid moist, rolled quickly and covered with pavement.

Laboratory tests confirm the fact that the fines in this type of material turn irreversibly from a plastic to a non-plastic material upon drying. When tested according to A.A.S.H.O method T-91, the fines show an original plasticity index of 14 and over, depending on the extent of the weathering. Upon drying the plasticity index is reduced to 3 or less. In practice drying out the material is not practical because of the frequent rains. At any rate it is only the surface that dries, the interior always remaining moist.

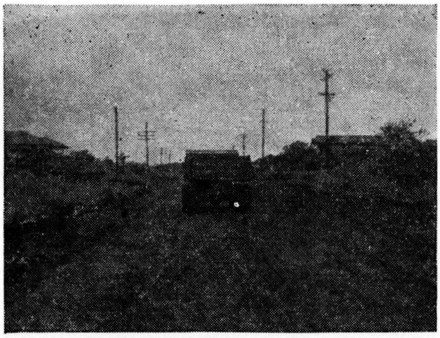

Figure 9. Weathered Aa after "Curing" under Traffic—Compare with Figure 8.

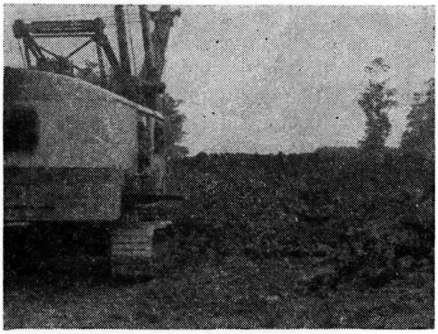

Figure 10. Weathered Aa Pit

This type of material is economical to use. Blasting is generally not required and so it can be loaded directly onto trucks by power shovels and transported to the place of use (See Fig. 10).

AGGLOMERATES

In the andesitic lava flows north of Papaikou, previously mentioned, another type of clinker material is found. In this type of material, lava fragments of various sizes are found to be embedded in a matrix of rock powder. Wentworth (*4*) calls it an agglomerate.

Upon drilling and blasting, the agglomerate breaks up into an aggregate surprisingly well graded from coarse to fine, the grading generally lying within the limits of A.A.S.H.O. Designation M 56-42. Screening out the oversize particles is the only processing necessary. Unlike the previously described weathered aa, the fines in this material, as above mentioned, are actually rock powder. Hence if it is relatively unweathered, it is non-plastic to begin with so that the material does not exhibit any initial muddiness. Hence it is an economical source of base course material. It has also been used to some extent as concrete aggregate, mostly in minor structures such as small retaining walls. It is very often found in mounds resembling cinder cones and is therefore sometimes mistakenly spoken of as cinders. But unlike the latter, the coarse particles are relatively dense and do not show the vesicular structure characteristic of cinders.

Weathered agglomerate exhibits initial muddiness the same as described in the case of weathered aa lava. Sufficient time must be allowed for traffic and rain to "cure" it.

The relatively unweathered agglomerate is of a light blue, or purplish-gray color. The color of the weathered agglomerate varies. Some are reddish, others are yellow. The more highly weathered ones are brown in color and the fines appear to be very much like the ash overburden.

When tested in the Los Angeles abrasion machine, the coarse particles of the unweathered agglomerate show a wear after 500 revolutions of under 40 percent. The weathered agglomerate particles vary in hardness depending upon the extent of weathering. The very highly weathered particles can be easily crushed by hand. The bulk specific gravity is about 2.3 compared to 2.7 to 2.8 for dense aa.

CINDERS

Cinders are usually formed near the source of a flow. The gas-filled molten lava is thrown many feet into the air and breaks up into small particles, which cool and harden quickly before much of the entrapped gas has a chance to escape This results in cinders having a cellular or vesicular structure If the molten lava contains an abundance of gas, pumice is formed. If there is a superabundance of gas, like the froth from a freshly opened bottle of beer or soda pop, the result is thread-lace scoria, or reticulite pellets, perhaps the lightest of rocks, weighing somewhat less than 3 lb. per cu. ft. (*4*)

Cinders have been used extensively on light-traffic secondary roads and on private plantation roads. The cost is low but cinder surfaced roads require considerable maintenance, mostly filling in low spots and blading.

Cinders vary greatly in hardness The less porous approach aa and pahoehoe, with a percentage of wear after 500 revolutions in the Los Angeles abrasion machine of slightly over 30 The usual value is somewhere between 55 70 per cent. Those with a percentage of wear in excess of 70 may prove too weathered or too porous for satisfactory use.

Cinders are usually composed of coarse particles only, so that fines have to be added in some way to achieve stability. Usually because of its friable nature, fines are quickly produced by traffic abrasion and together with moisture suffice to bind the surface quite satisfactorily, at least for light traffic roads.

If used as base on heavy traffic roads, the cinders have to be protected with 2 in or possibly more of good quality pavement such as asphalt concrete One large airfield on the island of Maui, with runways 7000 ft. long to accommodate heavy 4-engine aircraft, was constructed during World War II with a base entirely of cinders, 11 in to 12 in. thick, topped with 2½ in of asphalt concrete.

Cinders that can be compacted to a dry density of approximately 80 lb per cu ft. are satisfactory. As the compacted density drops below 60 lb. per cu ft, the material becomes increasingly unsatisfactory. The latter because of its porosity and lightness are too easily carried away by storm waters

Cinders have been used in low cost bituminous pavement construction on the cross-island Saddle Road between Hilo and Waikii. A mixture of cinders and a non-plastic variety of volcanic ash soil, in the ratio of 65 percent to 35 percent respectively by weight, is combined with fuel oil either on the road (road mix) or at a central location The cinders are too friable to withstand rolling. Hence the mixture is laid loosely on the road and compacted entirely by the passing traffic, which does not include any heavy trucks The traffic compacted surface is surprisingly smooth

TUFF AND ASH

For the purposes of this paper, tuff is defined as lithified (cemented) volcanic ash. Locally it is spoken of by some engineers as "mud-rock." The harder tuffs require blasting. Such blasted tuffs have been used in base courses, usually in a thick layer of about 6 in. with other hard fragments of crushed rock to fill the voids and to provide mechanical interlock Tuffs are not suitable for crushing.

The softer tuffs and the earthy material resulting from their disintegration and weathering are suitable for subgrade use.

Along the rainy east coast of Hawaii north of Hilo, the tuff is highly weathered so that upon rolling it crumbles into a ball of mud in rainy weather During dry weather it can be compacted satisfactorily and much more easily than the overlying volcanic ash. It makes a satisfactory subgrade.

Two general types of volcanic ash are found on the island. The ash found in the drier regions such as Pahala are non-plastic. This property is due to the fact that the particle sizes are practically all in the range of fine sand and silt. It is a difficult material to compact and if any considerable thickness is involved, it has to be wasted.

Along the rainy east coast north of Hilo, a highly plastic volcanic ash occurs. It is stable in cuts but due to its high plasticity, it is impossible to compact in fills in the usual manner. However once put in place and given sufficient time to consolidate, it regains its former stability. Perhaps its most important property from a highway point of view is its capacity for resisting erosion. Because of this property it is a superior material for embankment construction in regions subject to flash floods Thus embankments built of this plastic ash have a better chance of withstanding washouts than embankments built of other materials such as cinders, fragmental aa, or agglomerate, which are more easily compacted. However it must be used in its natural environment Transported to a drier region it dries irreversibly to a sandy material, which washes away easily. This plastic type of volcanic ash has been described in a previous paper (*6*)

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A STUDY OF GLASS BEADS FOR REFLECTORIZING TRAFFIC PAINT

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SYNOPSIS

Glass beads provide the best currently known means of improving the night visibility of painted stripes because of their optical properties which cause the light rays of headlights to be returned to the driver by reflex-reflection, thus providing a paint stripe with positive and striking visibility In addition, the color of the binder is maintained

Because of the differences in the physical and chemical properties of available glass beads, the Missouri State Highway Department undertook a study to obtain technical information upon which an evaluation of the available products could be based, and from which a specification could be designed that would include those products which showed satisfactory performance Eight different glass beads obtained from four manufacturers were studied The beads were graded from the No 20 to the No. 100 sieve Following the standard striping procedure used in Missouri, all beads were applied by gravity on the surface of the freshly applied paint This procedure provides immediate reflectance and the grading of the beads promotes maintenance of reflection since the diminishing sizes become exposed as the binder wears away Standard Missouri Specification yellow traffic paint was used for the binder

Laboratory tests for chemical composition and physical characteristics including gradation, index of refraction, structural stability, solubility in acid, and freezing effects, were made A laboratory method for preparing beaded paints, and several pieces of apparatus developed during the investigation are described Field tests included accelerated (transverse) and unaccelerated (longitudinal) installations Periodic reflectance measurements of the field stripes were made with the Hunter night-visibility meter and, in addition, the stripes were examined under a 20× glass to determine bead damage and loss Visual