UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Water Resources Division

GEOLOGY OF SAN ANTONIO CANYON, CALIFORNIA,

IN RELATION TO GROUND-WATER STORAGE

BY

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At least two periods of relative stability in the history of the erosion of San Antonio Canyon are indicated by the bench-like features produced by the laterally cutting stream and by the remnants of older alluvium left by the stream when it was cutting at these higher levels. In addition, a much older and probably mature surface is suggested by certain features of the higher ridges and the near-summits of Ontario and San Antonio Mountains.

Near the mouth of the canyon, and best preserved on the west side, terraces underlain by 10 to 30 feet of alluvium are continuous with terraces along the mountain front which are mapped by Eckis[1] as older alluvium. The terraces are at least 75 feet above the present channel of San Antonio Creek and were probably elevated to their present position by the most recent uplift of the San Gabriel Mountains. Terraces at about the same elevation above the stream channels are to be found in the Cucamonga drainage. The alluvium buried beneath the Hog Back landslide may be of the same age as that of this lower terrace and small patches on the slope south of Bear Flat suggest that it may once have been much more widely distributed.

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[1] Eckis, Rollin C., Geologic map of upper Santa Ana Valley, in California Div. Water Resources Bull. 45.

About 800 or 900 feet above the present canyon floor, shoulders on the ridges in the lower part of the canyon and flat-topped hills from Spring Hill north to Sugar Loaf Peak give evidence of a surface developed at an earlier date and to a more advanced stage than that represented by the lower terrace. The hills which lie entirely to the east of the present canyon were once, and parts of them are still, capped by a deposit of older alluvium which is usually tightly cemented with calcium carbonate and iron oxide. If later landslide masses had not partly covered these hills their summits would be much flatter and more nearly accordant. The older alluvium underlying the later landslide material aids in the reconstruction of the erosion surface. At the head of Stoddard Canyon, and also on the divide between Stoddard and Cucamonga Canyons, large areas of this surface still covered with the older alluvium are preserved.

The older alluvium mapped on the San Antonio - Lytle Creek divide consists of a few well-rounded boulders mixed with much angular residual material.. The fact that these rounded boulders occur along the course of the anomalous drainage channel referred to below suggests that both may be relics of an old erosion surface. The gentle slopes on the north side of Ontario Mountain between elevations of 7,250 and 7,750 feet and the broad ridges on San Antonio Mountain at about the same elevation are bther dim but suggestive lines of evidence also point to a very early and probably mature erosion surface.

The erosion history of the canyon thus involves at least three stages, and perhaps others whose record has been destroyed by the later cycles. The drainage patterns of the earlier cycles were modified by erosion during later cycles and the evidence of some of these drainage changes is still preserved.

Some of the drainage near the San Antonio - Lytle Creek divide is certainly anomalous and appears to have been inherited from an earlier erosion cycle. (See fig. 3.) For a distance of nearly a mile a channel runs parallel with the ridge and at right angles to the present drainage. It runs southeastward past two of the main tributaries before turning abruptly southwestward to follow a much smaller tributary. Its location on a divide at an elevation of about 7,750 feet suggests that this stream may follow a course inherited from the near-summit erosion surface. A reservoir to hold water, piped more than a mile around rugged terrain, was built in this draw by the early hydraulic miners.

Remnants of the Spring Hill terrace, 800 to 900 feet above the canyon floor, all lie east of the present canyon. The older alluvium which underlies these remnants is thickest on the east side of the hills, indicating that during the development of the terrace surface the stream followed a course from Sugar Loaf Peak to Spring Hill, which was from an eighth of a mile to nearly a mile east of the present course of San Antonio Creek.

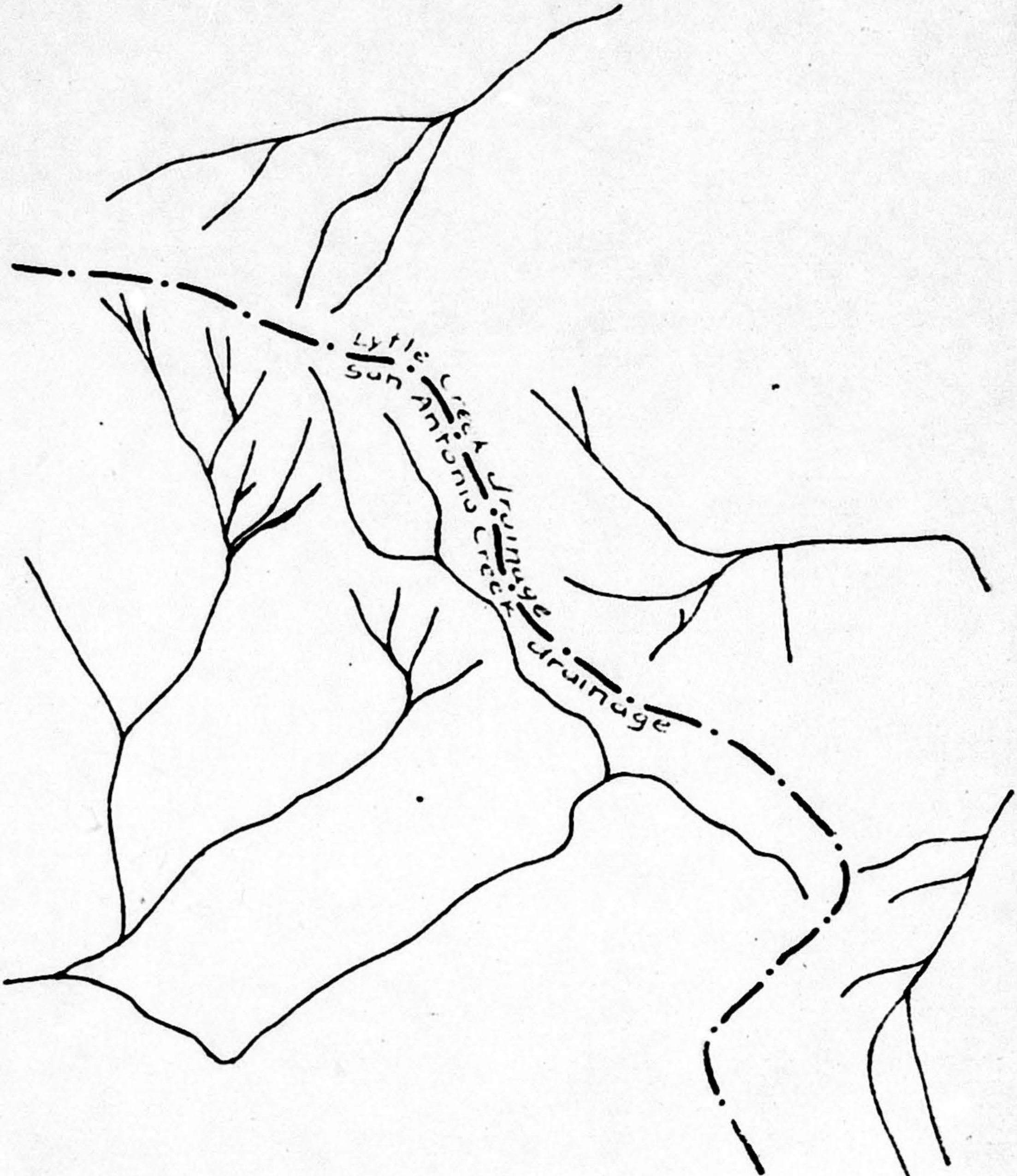

Fig. 3 The drainage pattern on San Antonio-Lytle Creek divide showing a portion inherited from a previous erosion cycle. Sketched from airplane photographs.

West of Spring Hill and south of the Hog Back a southeastward-flowing tributary lacks only 50 feet vertically and 200 feet horizontally of entering the main stream, then turns southwestward parallel to the main stream for about half a mile before breaking through the small ridge that separates them. The present southeastward course was developed during the uplift of the Spring Hill erosion surface and may have been determined by faulting.

Only a low divide separates Cow Canyon, a tributary of the San Gabriel River, from the upper portion of San Antonio Canyon. Headward from this divide San Antonio Canyon has a southwesterly course whereas downstream from the divide the course is southerly. This alignment of upper San Antonio Canyon with Cow Canyon is most striking when viewed in a northeast-southwest direction from the divide. The alignment is well shown on the topographic map and one is led to suspect that the upper part of San Antonio Creek once flowed across Bear Flat and through the saddle west of Bear Canyon into Cow Canyon. Later, following its present course southeast of Bear Flat, it may have crossed the low divide at the site of the Prison Detention Camp and so out through Cow Canyon into the San Gabriel. The San Antonio with its steeper gradient would thus have captured the headwaters of a portion of the San Gabriel River. Small patches of the older alluvium were observed in the Bear

Flats area but the material is too angular and too poorly assorted to offer good evidence that the main stream once flowed through these gaps. It is certain that no drainage has gone over the low Cow Canyon divide since the large landslide mass filled this portion of the canyon, for the large, permeable masses of rock debris and the small undrained depressions have not been filled or modified in any way by stream flow over them.

Geology

Bedrock formations

Type f rocks involved.- For the purposes of this study the rocks may be conveniently divided into bedrock and mantle rock. The bedrock is made up exclusively of crystalline rocks - metamorphic rocks and later intrusives. The mantle consists of older alluvium, landslide, mudflow, and avalanche material, talus, and stream deposits.

For the purposes of field mapping it has been found convenient to sub-divide the crystalline complex into (1) recognizable metamorphosed sediments, again roughly subdivided into a quartzite series and a marble-slate-gneiss series; (2) Pelona schist; (3) greenstones, green gneisses, etc., of undetermined origin; (4) diorite; and (5) granite. No attempt was made to map the many small dikes.

Metamorphosed sediments.- The rocks easily recognized as of sedimentary origin include marble, phyllitic slates, gneisses, schists, and quartzites. The marble generally contains muscovite, in addition to recrystallized calcite and in some places it is thin-bedded and associated with the schists and gnesses. Beds of relatively pure marble 15 to 25 feet thick occur on the southwest slopes of Ontario Mountain.

Quartzites are the most abundant metamorphic-rocks and apparently were derived from thick sandstone beds. Gneisses and other rocks are also interbedded with the quartzites. These old sedimentary rocks are intruded, engulfed, and near some contacts partly assimilated by both the diorite and, more commonly, the granite. It appears that the metamorphic rocks lay along, or formed a zone of weakness in, the diorite-metamorphic mass and the granite invaded this zone more profusely than other parts of the diorite body. These rocks are most extensively exposed on the west slope of Ontario Mountain, where Cascade Creek, Kirkoff Creek, and other tributaries have cut gorges more or less parallel to the strike of the beds. Small exposures of these crystalline metamorphic rocks and associated granite occur at the margin of Spring Hill, where they underlie older alluvium and landslide materials. On the west side of the canyon a belt of these rocks can be traced from Evey Canyon northward above the alluvial terraces to a point north of the Camel's Back. It is quite possible that these rocks may join those at Spring Hill beneath the alluvium of the canyon. A third belt of gneisses, which include some marble and consists in part, and perhaps entirely, of metamorphosed sediments, occurs on the south slope of the mountain front at the mouth of San Antonio Canyon.

Regularly bedded geneisses, which form most of the summit of Sunset Peak, ridge, may be metamorphosed sediments of lava flows, but no marbles or quartzites were found associated with the gneisses.

Pelona schist.- The Pelona Schist of the San Antonio region is continuous with that shown on H. Stanton Hill's[1] map of the Lytle Creek-Lone Pine Canyon area. It makes up the portion of San Antonio Mountain from the Gold Ridge gulch to the fault in the main canyon. It is a regularly bedded series of schists and fine-grained gneisses, the great majority of the beds being distinctly schistose. A massive green chlorite schist is the most abundant rock type in this area but gray sericite schists and green chlorite-sericite schists are also common. A division into the three types recognized by Hill was not attempted but could probably be made. The schists are invaded by the diorite of San Antonio Peak and they are cut by dikes and sills of granite and light-colored porphyry, and finally by basic dikes. Quartz veins and pegmatite dikes also occur. No marbles or quartzites were found in the Pelona schist and they are nowhere in normal contact with the metamorphic sediments in the San Antonio area.

Light-colored gneisses, greenstones, and other rocks of undetermined origin.- Above the "falls" in San Antonio Canyon the intrusive diorite and the Pelona schist are separated by green fine-grained rocks which in many places, but not everywhere, show gneissic banding. In some places it appears that these rocks have resulted from an intimate lit-par-lit injection of the dioritic magma into the schists, and most of the rocks mapped as undifferentiated gneisses

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[1] Hill, H. Stanton, Petrography of the Pelona schist of Southern California, Master's thesis, Pomona College, Calif., 1937.

in this area may be of this origin. The gneisses of Sunset Peak ridge are certainly intimately associated with and intruded by the underlying dioritic body, but their regularly bedded character indicates that a part of them at least were derived from sediments or bedded flow rocks. Where the igneous rocks have been most intensively sheared their original character is difficult to determine and some of the undifferentiated gneisses undoubtedly were sediments or flow rocks.

Diorite.- The diorite is the most widespread of the rocks in San Antonio Canyon. It makes up much of the western part of San Antonio Mountain, the base of Sunset Peak ridge, the base of Ontario Mountain, and both high ridges west and south of Stoddard Canyon. It is usually coarse and fairly even-grained. The ferromagnesian minerals are usually distinctly green and the light and dark minerals are present in about equal quantities. The rock is commonly foliated and minutely sheared, the shear planes and foliation being nearly always parallel or approximately so. Joints and other fracture planes may cut the rock at any angle to the foliation, however.

Granite.- The granite is a fine-grained light-colored rock cutting the diorite and metamorphic rocks. The largest mass forms Telegraph Mountain, and smaller dikes, sills, and irregular masses occur throughout the area. Light-colored porphyry dikes probably were derived from the same magma. North of the saddle at Dry Lake the granitic intrusive is distinctly pegmatitic and large sills and dikes of quartz-feldspar-muscovite pegmatite occur. Except for basic (basalt ?) dikes the granite is the youngest of the bedrocks. It is evident that the diorite was already foliated and the sediments tightly folded and metamorphosed before the granite was intruded. Although not commonly foliated, the granite is highly fractured and sheared in many places, and it appears that the plane of intrusion of the granite served later as a plane of movement. There is a striking contrast between the highly weathered character of the diorite and the relative fresh appearance of the granite. This may be in part the result of the greater abundance of ferromagnesian minerals in the diorite but is chiefly due to the greater fracturing of that rock.

Structure of the bedrock formations.- The rocks that can be definitely recognized as of sedimentary origin have been complexly folded, faulted, and invaded by igneous rocks. Their occurrence is essentially that of highly metamorphosed roof pendants, everywhere underlain by the intrusions. In Evey Canyon and on Ontario Mountain above Spring Hill, isoclinal folds are to be seen in exposures of the marble and phyllitic slate series. Where more intimately invaded by the granitic magma the resulting gneisses are crenulated and contorted. The diorite intrusive shows a distinct foliation, apparently developed as a flow structure during intrusion. Shear features and joint planes are usually present in two or more cross-cutting systems. In many places the most pronounced shear fractures are parallel to the foliation or bedding planes.

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In a general way the rock attitudes, as indicated by the dip and strike symbols on the map, are parallel to the mountain ridges. Northwesterly, westerly, and northly dips are common but southerly and easterly dips are rare. The gneisses of Sunset Peak ridge have a general north-south strike and a westerly dip. The foliation of the diorite in the mountain south of Stoddard Canyon strikes northeast and dips to the northwest. On Ontario Mountain both the foliation in the diorite and the bedding planes in the metamorphic rocks strike northeast and dip to the northwest. On the east side of San Antonio Canyon the prevailing strike is northeast, with dips to the northwest. West of San Antonio Canyon the prevailing strike is northerly and the dip is westerly. The angle of dip is commonly greater than 45 degrees.

Near faults the attitudes are likely to be more variable than at some distance from them, and near the major faults the strike has a tendency to be nearly parallel to that of the fault. The rock fracturing that accompanied faulting during the several periods of uplift of the San Garbriel Mountains has left the rocks everywhere broken by numerous joints and shear planes. Offset dikes and re-oriented planes of foliation indicate that many of the shear planes are faults along which varying amounts of displacement has occurred. More intensely brecciated and pulverized zones, sharp contacts between different rock types, and physiographic evidence of weakened zones mark the faults along which the major movements have probably occurred. Single continuous fault planes along which major movements have occurred are lacking. All the evidence from slickensides, fault drag, and the highly shattered condition of the rocks indicates that the deformation occurred under compressive stresses and all the fault planes indicate reverse (thrust) faults. Commonly the fault planes are steep, but low-angle thrusts also occur. Within the broad zone which marks the trace of each of the major faults two sets of fault planes, with dips in opposite directions, frequently occur. The strike of both sets of fault planes usually is roughly parallel to the main fault zone and the dip angles are most commonly around 45° to 50°. The angle of dip of many of these fault planes was measured in the field, and it was found that the traces of the fault zones across the rugged topography always indicated that the fault zones had higher angles of dip than the individual fault planes within them. Thus the topographic expression of the major fault which runs through upper San Antonio Canyon and Bear Flats indicates a vertical or near-vertical dip of the fault zone. Individual fault planes within this zone dip to the north and south with angles of 40° to 55°. Also in the vertical fault zone which cuts Telegraph Peak are relatively low angle faults dipping in opposite directions. The major fault zones appear to have angles of dip from 75° to vertical.

No data were obtained in the San Antonio area from which the amount of displacement along the fault zones could be determined, and it is not known whether movement along these faults within the mountain mass accounted for a considerable portion of their elevation above the surrounding lowlands or whether most of the differential movement occurred along frontal faults at the edges of the mass.

Most of the major fault zones have a northeast-southwest trend and a second and apparently weaker group trend nearly north-south. No off-setting of one group by the other is apparent and their age relationship was not determined. The fault along the course of upper San Antonio Creek separates the Pelona schist from the undiferentiated gneisses, etc., at the head of the canyon. Bear Flats and a prominent saddle in the ridge west of Bear Canyon mark the course of one branch of this fault as it crosses the divide into Cow Canyon. Another nearly parallel zone swings around the south side of San Antonio Peak and enters Cattle Canyon.

The north boundary of the belt of sediments which occurs in San Antonio Canyon upstream from Evey Canyon is probably marked by a fault. What may be a continuation of this fault carries through Spring Hill and between Sugar Loaf and Ontario Mountains, and thence up Icehouse Canyon.

The mouth of Stoddard Creek lies along a fault zone which continues across the divide into the Cucamonga drainage basin. This fault has a more nearly easterly trend than those farther north, and the fault in the quartzite south of Evey Canyon trends east-west, parallel to the front of the range. The upper course of Stoddard Canyon and probably the lower course of San Antonio Canyon are determined by north-south faults.

Mantle rocks

In view of the extremely steep slopes which prevail in San Antonio Canyon and its tributaries it is always surprising to find how clogged with mantle debris are the floors and side slopes of the gulches. Perhaps the two most important factors in producing this mantle are the highly shattered condition of the bedrock materials and the favorable situation for frost action, especially at the higher elevations.

When the areas of mantle rock are mapped the width of the canyon and that of its larger tributaries are seen to be much greater than appears from a glance at the topographic map or from a brief journey between the steep canyon walls in some places. Broad areas like Cedar Flats and Sheep Flats are duplicated many times by similar smaller areas over the entire drainage.

Stream-wash materials.- The occasional torrential floods which pour down some of the main arteries of the drainage system leave boulders, gravel, and coarse sand in the canyon bottom as they carry the finer materials beyond the mountain front. Toward the heads of the tributaries these materials grade into the talus, avalanche, and creep materials from which some of the fine material is removed by the subsurface water and the wind, but which for the most part is so fresh that little fine material has yet been produced by the agents of weathering.

In the main canyon this strip of stream-washed material has a total length of about 10 miles and a width varying from zero at the Hog Back to 1,500 feet or more above Camp Baldy and averaging about 700 or 800 feet. Below the Hog Back, almost to the mouth of the canyon, the thickness of the stream wash above bedrock is not great, and exposures of the bedrock occur in the canyon bottom at several localities, such as just below Spring Hill and near the Camels Back. Profiles of the tunnels of the San Antonio Water Company at the mouth of the canyon show a thickness of alluvium of about 90 feet. Above the Hog Back the thickness of the alluvial materials above the bedrock of the canyon bottom is not known, but several lines of evidence suggest that it may be rather great.

As pointed out in the discussion of landslide materials, there is good evidence that landslides have filled the canyon several times, creating dams behind which stream-wash materials must have accumulated to considerable depths. A shaft sunk in 1893 north of the Chapman lake is reported to have gone down 100 feet without reaching bedrock. Assuming that the stream was on bedrock before the Hog Back landslide came down and that the gradient had a uniform acceleration upstream, the fill behind the Hog Back is about 450 feet thick. Using the same method of calculation, it appears that the fill behind the Snowcrest landslide mass is about 200 feet thick. As no allowance is made for accumulations behind the older landslides in the Hog Back area, and as the stream probably was not flowing on bedrock, these figures should be considered as estimates of minimum thickness.

Talus.- Talus deposits, many of them active enough in their creep down the slope to prevent the establishment of any type of vegetative cover, others on which some trees and a few shrubs have grown, are found abundantly on all the steeper slopes of the area. Only the larger, active talus slopes are shown on the geologic map. Actually over 50 percent of the entire drainage area is covered by these loose, angular rock debris developed on oversteepened slopes below the shattered rock ledges.

There is a wide variation in the size of the constituent particles of the talus material. Some of the lower portions of the rock slides, for example those along the north side of Icehouse Canyon, consist of boulders from 2 to 8 feet in diameter. At the other extreme are the higher slopes, for example, those in the Pelona schist near the Lytle Creek divide at the head of San Antonio Canyon, which have a talus made up of shaly chips seldom more than an inch or two in diameter. There is every gradation of size between these two extremes.

The three principal factors responsible for the formation of the talus are oversteepened slopes, highly fractured rocks, and frost action. Thus the higher slopes of San Antonio Mountain and Ontario Mountain are the sites of the chief talus accumulations, because the slopes are in general steeper in these areas and frost action is an important agent of rock disintegration for a large part of the year. The rocks are all highly fractured but the extremely shattered rocks along the principal fault zones are most likely to form talus slopes. Movement down the slope segregates the coarser materials above the finer materials. This coarse, permeable material at the surface is very absorptive and the finer materials below are relatively retentive.

Landslides and mudflows.- The steep slopes, together with the highly fractured and faulted character of the bedrock, have given rise to numerous landslides and mudflows in San Antonio Canyon and its tributaries. The principal area of landslides is in the main canyon between the Hog Back and Snowcrest, although small slides occur throughout the drainage area. The present surface is covered with these deposits to the extent of a total area of about 2 square miles, and many older slides no doubt have been partly or entirely covered by other types of alluvial deposits.

In character these deposits vary from surface fault land-slip[1] areas in which large blocks have broken along pre-existing faults and have slipped down the slope a few hundred feet, leaving large portions of the block more or less intact, to actual mudflows in which enough fine-grained rock materials and water were mixed with the boulders to permit movement down the canyon as a viscous mass.

In size the slides range from patches too small to map, some so recently fallen from cliffs that the scars made by their removal are still fresh, to the large mass that formerly filled the canyon from the mountain east of Camp Baldy to the Prison Detention Camp, on the Cow Canyon divide. Many of these masses are, no doubt, made up of the accumulated debris from many slides that have occurred at different times. Recurrent slides are suggested by the stratification of certain slide masses, the various layers being made up of rock material from

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[1] Sharpe, C. F. S., On landslides and related phenomena, New York, 1938.

different sources. A great part of the mass around Chapman's dry lake, for example, is composed of dark sedimentary gneiss and some boulders of quartzite and marble, covered and overlapped to the south by a small slide along the top of the ridge consisting almost exclusively of granitic boulders.

A large slide or surface fault land-slip has resulted in the formation of the undrained depression south of Sunset Peak, known as Dry Lake. A fault or shear zone, extending from the Cow Canyon divide south-westerly to the large saddle in which the Dry Lake occurs, has permitted great blocks of the mountain side to slip probably a hundred feet or more down the slope toward San Antonio Canyon. Evidences of the land-slip nature of this area are offered by the undrained depression occupied by the dry lake, the bench-like area crossed by the Forest Service trail northeast of Sunset Peak, the generally hummocky and irregular topography, the abrupt change in orientation of the planes of foliation of the bedrock below the fault, and the generally broken and twisted character of bedrock where exposed. The large blocks of the bedrock appear, however, to have remained essentially intact. From a hydrologic point of view the material is highly fractured bedrock, but it is nevertheless bedrock and the area has not been mapped as landslide material.

Sheep Flats, a bench-like shoulder about 1,000 feet wide by 1,500 feet long on the north slope of Ontario Mountain, is another landslide similar to the one just mentioned. The basal bedrock exposures appear to be essentially intact, but the upper portion of the area has suffered considerable movement. The surface is hummocky, with undrained depressions, and large blocks of rock are mixed heterogeneously with finer materials. Only the upper surface of this area has been mapped as landslide material.

Just south of San Antonio Peak a large cirque-like scar, the slopes of which are now covered with talus, marks the origin of another landslide. A mass of the debris still remains at the base of the scar and extends as a terrace-like tongue down the east side of the gulch. At the base of the "cirque" the stream has intrenched itself in bedrock about 25 feet below the landslide material. At the lower end of the landslide tongue the stream is about 250 feet below the landslide debris. Thus the stream has cut a gorge, essentially in bedrock, from 25 to 250 feet deep since the landslide occured and the gradient of the gulch into which the landslide was dumped was more gentle than that of the present stream.

The Hog Back is a comparatively small landslide mass derived from the west wall of the canyon, as indicated by the scar above it and by the fact the fact that its blocks are of diorite like the mountain to the west rather than the metamorphosed sediments which occur to the east. Its upper surface is hummocky, with small sinkhole-like areas and its mass is made up exclusively of angular fragmented blocks. The slide covered an area of older alluvium in the bottom of the canyon, as can be clearly seen in the highway cut.

From Chapman's dry lake south to Kirkoff Canyon, and from the mouth of Sugar Loaf Canyon to the Prison Detention Camp on the Cow Canyon divide, the surface material is chiefly landslide debris. Erosion since the landslide has formed the present stream channel and has exposed bodies of bedrock material which were covered by the landslide. It seems probable that the debris on the west side of the canyon was once continuous with that on the east side, and that the canyon was therefore filled and the stream for a time was dammed behind this slide. The debris on the west side of the canyon, like that on the east side, is composed of sedimentary gneiss, marble, and quartzite. These materials could have been derived only from the mountains on the east side of the canyon, for the mountain above the (northwest of) prison camp is a granite intrusive and Sunset Peak Mountain is composed of gneiss and foliated diorite.

Another large landslide mass occupies most of the San Antonio Canyon between Icehouse Canyon and "Glacier" Flats. Exposed sections of this mass indicate that it filled the canyon to a depth of 200 to 300 feet. The percentage of fine material in this mass is much greater than in most of the other landslide masses, and it seems probable that a part

ILLUSTRATIONS

at least came down San Antonio Canyon as a great mudflow. However, there is a definite scar on the mountain slope east of this slide and a part of the present mass or perhaps an earlier slide was evidently derived from it.

Older Alluvium.- Remnants of alluvial materials deposited during at least two periods of relative stability in the development of the mountains are found underlying terraces and bench-like areas along the margins of San Antonio Canyon and its tributaries. For the most part the pebbles and boulders in these deposits are angular to subrounded, and the deposits are poorly assorted and rudely stratified. They probably represent the deposits of short torrential streams mixed with talus and slope-wash materials and thus indicate conditions of accumulation not greatly different from those under which similar deposits are accumulating in the stream bottoms at the present time.

From the mouth of the canyon to Spring Hill a series of terraces, best preserved on the west side of the canyon, are underlain by alluvial materials which are weathered to a yellowish-brown color. Although not cemented, they are so well compacted and so firmly held together by the clay components that they stand well and do not slough even in vertical cuts. The clay material seems to be derived at least in part by weathering, for lighter-colored (less weathered) areas contain little or no clay. Many of the boulders show weathering by exfoliation. The terraces stand about 75 to 100 feet above the present stream channel and the alluvium has a maximum thickness of more than 100 feet.

Capping Spring Hill where it is not covered by landslide material, and cropping out beneath the landslide materials as far north as Kirkoff Canyon, is another series of alluvial deposits apparently much older than the terrace materials at the outh of the canyon. Some of the lower beds of these deposits contain well-rounded boulders but much of the material, especially the upper part, is very angular and coarse. Blocks up to 4 or 5 feet in diameter occur in it above the old prison camp north of Spring Hill. This alluvium is deep brown or, in some places, black in color. In most exposures it is well cemented with iron oxide and calcium carbonate, and more rarely with a mixture of iron and manganese oxides. Prospect drifts have been run into it in several places. Only one or two small patches occur south of Spring Hill but shoulders of bedrock at elevations comparable to that of Spring Hill may represent the same surface downstream, from which the alluvium has been removed.

Residual mantle.- An appreciable amount of residual soil has been developed only on the lower, more gentle slopes with their cover of chaparral, and on the broad summit divides. On the lower slopes the voids in the angular rock mantle have been more or less filled by the products of rock decay mixed with organic matter from the plant cover. The resulting mantle has, with the exception of the older alluvium, the lowest permeability of the surface rock materials, and numerous small channels left by surface runoff during the 1938 flood on these low fronted slopes are in marked contrast to the almost total absence of such channel scars in the upper drainage area. This residual soil is not impervious, however, and as far as the lower rainfall intensities are concerned its absorption is high.

Residual soils also occur on the more gentle of the higher slopes, which commonly occur at elevations between 7,200 and 8,000 feet. These slopes are presumably inherited from an earlier erosion cycle. Heavy stands of conifers on many of these slopes have added their needles and other organic fragments to this mantle and its absorptive properties are probably still rather high. On ridges where trees are widely spaced a surface cover of angular talus material is underlain by a layer in which there is considerable soil. The finer materials apparently have been removed from the surface layer by wind action. No evidence was seen of channeling in this residual material on the summit divides, perhaps because othe heaviest storm precipitation here occurs as snow. During April and May the residual mantle quickly and completely absorbs the snow melt.

Hydrologic properties of the rock materials

From the point of view of this study the rock materials are chiefly of interest as to the amount of rainfall they will absorb without allowing any considerable portion to escape from the canyon as flood runoff; and as to the extent to which they will retain this water, delivering it up slowly during later months and later years. It is obvious that in order to be both highly absorptive and highly retentive, as the rocks of the San Antonio drainage area have proved to be, there must be a suitable combination of rock materials, for a rock permeable enough to be highly absorptive would also be expected to release the water rapidly, and one retentive enough to store up the water for months and years would be expected to have a relatively low permeability and hence a low absorptive capacity. When the hydrologic characteristics of each of the rock types discussed in the preceding section are considered in connection with their distribution in the canyon, the reason for the highly absorptive and yet highly retentive character of the rock materials becomes apparent.

The crystalline bedrocks

As a group and as contrasted to the mantle rocks, all the bedrock types have a low permeability and tend to be poorly absorptive and highly retentive. They are more permeable than similar rocks in most other areas, however, because of their extremely fractured condition. Although there are a few outcrops of bare rock in the area, these rocks everywhere underlie the mantle rocks. Even though the sepcific yield (percentage of voids available for water storage) is comparatively small, the total volume of these rocks is so large that the total storage capacity is also rather large.

The metamorphic rocks, because of original bedding planes, are probably somewhat more permeable than the igneous rocks. The quartzites are brittle and haave been extensively shattered by the earth stresses to which all of the rocks of the region have been subjected. The permeability of the marbles may have been augmented by the development of solution cavities, although none were found during the present study. The gneisses are similar in hydrologic character to the igneous rocks and the schists, being relatively plastic during deformation, are in general less fractured and less permeable than other crystalline rocks. Numerous dikes of brittle rock, and the relatively massive beds that occur in places in the schist, offset to some extent the naturally impermeable characteristics of the schist. All the springs issuing from the Pelona schist that were seen are located in shattered dikes and sills which cut the formation.

The undifferentiated gneisses and the diorite, having been subjected to periods of deformation before the intrusion of the granite, are in general more permeable than the granite. However, the planes along which the granite was intruded frequently served as planes of movement during later deformation and the granite, though not foliated, is highly brecciated in many places.

More important than the type of rock in determining the permeability of the bedrock materials is the degree of fragmentation and brecciation to which they have been subjected. No areas were seen where these rocks had escaped some fracturing and crushing but certain areas were much more intensely fractured than others. It was chiefly for the purpose of locating these areas of intense brecciation with their relatively high permeability, that an attempt to work out the major structural features of the bedrock was made. In general, ground-water movement will be down the dip of the bedding planes and planes of foliation. For example, water penetrating the bedrock along the Sunset Peak ridge will move westward towards the Cow Canyon and San Dimas drainages, for the well-developed foliation of the bedrock has a prevailing westerly dip. As a rule the rock is more permeable along the fault planes than along the planes of foliation, and ground-water movement is frequently concentrated along the faults. Evidence of this is found in the numerous springs which issue from the fault zones in the areas of bedrock outcrops. The faults shown on the map are in general bounded by, or represented by, broad belts or zones of relatively intensely crushed rock. A general movement of ground water along these zones is to be expected, and is confirmed by the water found in tunnels cutting the faults, such as the Gold Ridge drift, south of San Antonio Peak, the tunnels in Bear Canyon and Below Bear Flats, etc.

The mantle rocks

The mantle of more or less unconsolidated rock material which covers a large percentage of the drainage basin is, in general, rather permeable because of the small proportion of fine sand, silt, and clay. Angularity and relatively poor assortment render these rocks less permeable than corresponding stream-worn materials, but the large fragments making up many of the deposits are separated by large interstices which allow large quantities of water to enter and move freely through the material.

The talus is the most absorptive and least retentive of the mantle rocks. Even the finer talus on the high slopes shows no evidence of having been channeled by surface runoff from the intense rains which caused the 1938 flood, nor by runoff during 1941, which is one of the wettest years on record. Rain water or melt water from snow sinks immediately into these coarse, angular, and highly permeable materials to travel rapidly through them, and it either issues again at the surface at lower levels where the bedrock crops out or lies near the surface, or finds its way into other types of mantle rock through which it percolates more slowly and so contributes to the runoff over an extended period of time. It is fortunate for the water-storage capacity of the region that the bases of the talus slopes are commonly covered by stream-wash and landslide materials which serve as a relatively impermeable dam to check the flow of water through the more permeable talus.

Even where the talus is not interbedded with other types of mantle rocks the runoff is slowed somewhat by flow through the talus materials, but most of the discharge occurs in a matter of hours or days after the precipitation. These materials thus play an important role in producing the "B" type of runoff. They also serve as important intake areas for the waters which find their way into the other types of mantle materials and into the bedrock and eventually contribute to the "C" type of runoff.

The stream-wash materials are second to the talus in permeability. They permit water from rainfall, from snow melt, and from stream flow to enter readily into their interstices. Percolation through these materials, although less rapid than through the talus, is nevertheless rapid enough that most of their storage capacity could be drained in a few months if it were not for the dams of landslide and mudflow debris. Upstream from the Hog Back there are no long stretches of stream-wash materials which are not intimately interbedded with these less permeable materials. The high permeability of these materials is well illustrated by the underground flow of the stream from Icehouse Canyon. About a quarter of a mile above Icehouse Canyon Resort a stream, which had a flow in excess of 10 second-feet in May 1942, disappeared into the stream gravels and boulders, and the surface channel remained completely dry to a point below the bridge in San Antonio Canyon, a distance of more than a mile.

The interstices of the stream-wash materials above the landslide masses constitute an important underground reservoir which contributes heavily to the base flow or "C"-type of runoff and also probably plays an important role in converting flood or "A"-type runoff into "B"-type runoff.

The landslide and mudflow deposits have a low to moderate absorptive capacity and are moderately to highly retentive. There is a wide range in the permeability of these materials. Small recent slides just south of Sugar Loaf mountain are composed exclusively of fresh angular rock fragments not greatly different from the talus with which they are associated. On the other hand, in some exposures of the mudflow or landslide mass between Icehouse Canyon and Glacier Flats the coarse boulders are set in a matrix of clay and other fine materials. As compared to the talus and stream-wash materials, these deposits serve as effective dams. The relatively low permeability of these materials is indicated by the fact that springs issuing from them are commonly located from 50 to 100 feet or more up the slopes from the bottoms of the stream channels.

The older alluvium is a relatively impermeable material, owing to the presence of clayey weathered products and cementing materials. Areas capped or underlain at shallow depths by these deposits have low absorptive capacities and may produce considerable runoff of the A and B types. The total area of these deposits is rather small, however, and they have a very dense cover of chaparral which serves to prevent A-type runoff for low to moderate rainfall intensities.

Certain lines of evidence indicate that the total storage capacity of the mantle rocks of the San Antonio Canyon drainage area is large. In the first place, more than 80 percent of the entire surface area is covered by some type of alluvium or rindual mantle, and as percolation through even the most permeable type of alluvium is much slower than surface flow, the entire rock mantle serves to some extent as a retention or storage basin. More important from the point of view of long-period storage, however, is the alternation of permeable stream-wash and talus deposits with less permeable landslide deposits, creating ground-water basins of various sizes. Some of the larger of these are worthy of specific mention.

Behind the large landslide mass which originally filled the canyon from Kirkoff Canyon to the Prison Detention Camp, stream gravel and boulders must have accumulated for some time before the present breach was cut through the mass. The broadest part of the canyon floor above the Chapman dry lake was thus formed and the stream-wash materials extend well up into Icehouse Canyon. Near the landslide the gravels are known to be at least 100 feet thick and may be several hundred feet thick.

Behind this same landslide to the east are the talus and stream-wash materials from Sugar Loaf, Kirkoff, and other canyons draining Ontario Mountain. Although not as large as the basin in the main canyon, the importance of this eastern basin is indicated by the large perennial springs, the water of which moves from the basin through the landslide mass, notably Chapman Springs, Camp Baldy Springs, and Kirkoff Springs.

Glacier Flats are the top of the broadest part of another alluvial basin formed behind a landslide mass which extends from Snowcrest to the mouth of Icehouse Canyon. Large springs, representing the overflow of the basin, issue from the landslide mass about 100 feet above the channel of San Antonio Creek.

Cedar Canyon Flats, on the north side of Icehouse Canyon, at the base of Telegraph Mountain, also lie behind a landslide mass; and perennial springs draining into Icehouse Canyon give evidence of the ground-water storage in this basin. Sheep Flats, the "Cirque" below San Antonio Peak, and other small landslides also form smaller basins throughout the area.

During the period of formation of the present canyons, the deposition of stream-wash and talus materials has been interrupted periodically by landslides and mudflows. This vertical alternation of permeable and less permeable materials, in addition to their alternation in horizontal distribution, adds to the total storage capacity of the mantle materials and greatly extends the period of ground-water retention.

Comparison of the absorptive and storage functions of the bedrock and mantle rock

With the hydrologic characteristics of the various types of materials in mind, and using the longitudinal section of the canyon and the geologic map to gain an idea of the vertical and horizontal distribution of the materials, a general picture of the ground-water storage in the drainage basin can be obtained.

Geology of San Antonio Canyon in relation to ground-water storage

Introduction

This report was prepared as a part of an investigation of the hydrology of the San Bernardino Mountains and the eastern part of the San Gabriel Mountains. The investigation is being made in cooperation between the Geological Survey, United States Department of the Interior, and San Bernardino County.

As shown, by studies of the Geological Survey, the flood runoff from San Antonio Canyon constitutes only about 9 percent of the total flow and has occurred during only 43 days of the last 20 years. In view of the fact that the average slope of the ground surface in the 16.9 square miles of drainage basin is 49 percent, this extremely low flood flow is most striking. Chiefly on the basis of studies in the eastern United States, where average slopes are much more gentle, Army Engineers and others find that for rainfall intensities of over 1 inch per day the storm runoff constitutes 50 percent or even more of the precipitation. For the San Antonio Basin the figure is 10 percent or less. Furthermore, not only is most of the heavy storm precipitation checked temporarily and floods largely prevented, but large amounts of water are stored in underground basins to keep up the base flow of the stream through several successive years of drought.

The fractured bedrock functions chiefly as a long-period storage basin. The porosity and permeability of these rocks are very low as compared to those of the unconsolidated mantle, and their waters are returned to the surface or into the alluvium as small perennial springs and seeps whose flow continues even during years of very low precipitation. They also absorb water very slowly, only a small amount entering by direct penetration from rainfall. Where covered by stored water in the mantle rocks, however, the fractures gradually become filled. Much of the upper portion of this great bedrock basin receives water only during periods of heavy precipitation or periods of penetration from melting snow, when the mantle cover on the higher slopes is saturated and is rapidly discharging water in the "B" bype of runoff. Part of the snow melt finds its way down to the bedrock and into the more permanent bedrock storage basin. The bedrock basin is never completely filled or completely drained. It contributes only "C"-type runoff and is most important during the periods of lowest stream flow. The proportion of the base flow contributed by the bedrock, whether 15 or 50 percent, is not known, but a comparison of the size and number of springs from the mantle rock and from the bedrock suggest that it is nearer the former than the latter figure.

Summary

Detailed studies of precipitation, temperature, and stream-flow records made by the Geological Survey show that, in spite of steep gradients, the San Antonio drainage basin has no flood runoff except during heavy storms which follow periods of large antecedent storage, nd that the usuable underground storage amounts to about 24,400 acre-feet. The water stored in this underground reservoir is largely free from evaporation and transpiration losses and finds its way slowly back into the stream as a base flow which has never fallen below 3 second-feet during the past 40 years.

The geologic studies indicate that unusually extensive accumulations of talus and stream-wash materials are chiefly responsible for the high absorptive capacity of the rock materials, and that these materials, accumulated behind semi-permeable landslide and mudflow dams, constitute the larger ground-water storage basins. The highly fractured character of the bedrock materials has made them more permeable than crystalline rocks generally are, and ground-water storage in these fracture zones constitutes an important, although probably minor, source of the base flow or "C"-type runoff.

The purpose of the geologic studies has been to determine the factors of rock structure and distribution that have contributed to this favorable situation; to determine, if possible, where and how the waters which yeild the "B" and "C" types of runoff are stored; and to determine the possibilities of evaluating, from these studies, runoff characteristics of the other areas where precipitation and stream-flow records are less adequate.

The geologic field work was done during 6 weeks of April and May 1942, and consisted in mapping on contact prints of aerial photographs, at a scale of approximately 1: 20,000, the geologic formations constituting the bedrock and mantle materials. These data have been transferred to the topographic sheets of the U. S. Geological Survey, photographically enlarged about nine times, to a scale of 3 inches to the mile. The legend indicates the relative absorptive characteristics of the various types of materials. Nearly all the important springs of the area are also shown on this map (fig. 1).

All accessible tunnels and shafts in the basin were examined. Records of water-level measurements in four wells, situated near the Chapman spring, made by the San Antonio Water Company in 1911, were obtained through the courtesy of A. C. Reynolds. One of these wells was located and re-dug in 1942 and water-level measurements are being made periodically in this well and the Chapman well.

Vegetative cover

A thick cover of vegetation prevents the formation of gullies and tends to minimize flood runoff, especially during storms of low to moderate intensity and duration. The vegetation covering the slopes in the San Antonio basin undoubtedly acts in this capacity, but the unique properties of high absorption with high retention probably are chiefly functions of rock structure and distribution, as other areas with similar vegetative covers have widely different runoff characteristics.

The higher and steeper slopes of the area are covered by a sparse growth of pine, balsam, and fir. The lower and more gentle slopes are covered with a dense chaparral of buckthorn, manzanita, and other brushy shrubs. Along the permanent stream courses alders, willows, and other water-loving trees and thrubs (phreatophytes) form dense growths.

The trees at higher altitudes aid in checking the rate of movement of the talus and other mantle materials down the slopes but they probably do not greatly change the absorptive characteristics of these materials. A thick chaparral covers most of the areas underlain by the older alluvium and certain areas where rock decay has produced considerable clay into the residual mantle. These materials are the least absorptive of the mantle rocks and the dense plant growth which covers them helps to offset the tendency of these areas to produce rapid runoff during storms.

Physiography

The extremely high gradients of San Antonio Creek and its tributaries have already been mentioned. The average slope of the ground surface in the 16.9 square miles above the Hog Back is 49 percent and is exceeded in this area only by the Cucamonga drainage to the east, with an average slope of 54 percent.

Changes in the gradient of San Antonio Creek are striking and significant. (See fig. 2.) In the first 3 miles of the canyon from its mouth to Spring Hill the gradient is about 4 percent (200 feet per mile); in the next mile, to the top of the Hog Back it is about 16 percent (850 feet per mile); the next stretch, from the top of the Hog Back to the mouth of Icehouse Canyon, has a gradient of about 8 percent (440 feet per mile); in the mile from here to Snowcrest there is a rise in elevation of 900 feet (17 percent grade); for about a mile across Glacier Flats the gradient is a little under 8 percent (400 feet per mile); and above this flat the slope becomes increasingly steeper to the summit. These changes in gradient are the result of large landslide masses which have been only partially removed by subsequent stream erosion. Along the steep down-canyon slopes of these masses the streams are vigorously cutting, whereas behind their upstream slopes partial filling by stream-wash materials has created the "flats".

A glance at the topographic map will show that the drainage does not have a simple dendritic pattern inherited from consequent courses upon uniform rock material, and field study indicates even more clearly than the map that the drainage has adjusted itself to the rock structure. Cascade Creek, the Gold Ridge fork of San Antonio Creek, and other tributaries follow the strike of the beds or the foliation. Most of the streams, however, follow the zones of intense fracture and breccia-tion along the principal faults. The upper course of San Antonio Creek trends southwesterly, as do Cattle Canyon, Coldwater Canyon, and other streams in the San Gabriel drainage to the west. This portion of its course is cut along a major fault which extends southwestward through Bear Flat into Cow Canyon. The sharp offset in San Antonio Canyon at Spring Hill appears to be chiefly the result of the intersection of north-south and east-west faults. Stoddard Canyon follows a fracture zone southward until it encounters the more intensely fractured north-east-southwest fault zone which controls its course to its junction with the San Antonio. It is the smaller tributaries, however, which are most strikingly adjusted to the structure. Where exposures are good each gulch can be seen to follow a fracture zone more pronounced than those cutting the intervening ridges and where two sets of fractures cross, as they do in many places, the tributary may follow one set for some distance and then abruptly change to follow the other.

Landslides have modified the normal drainage and general topography of the area. The surfaces of these bodies are hummocky and irregular and small undrained depressions are common. Because landslides of various sizes have occurred throughout the area, small undrained depressions are preserved on most of the ridges, those formed in the canyon bottoms having been largely filled and destroyed by subsequent stream erosion. Chapman Lake, Dry Lake south of Sunset Peak, and the depression east of Timber Mountain are the largest of these "dry lakes", as they are called locally, but several others large enough to be shown on the map are outlined by dashed lines. Oversteepened slopes are formed where the landslides have broken from the ridges. The slopes resulting from the more ancient landslides are more or less covered by talus, but those of recent slides are still quite bare. The prominent landslide scar just south of San Antonio Peak, when viewed from a distance, resembles a glacial cirque.

Of special interest in the present study is the fact that few of the tributary gulches have surface drainage channels, the bottoms of the gulches being so filled with talus and other permeable debris that the drainage is entirely subetrranean. Even during the 1938 flood most of these tributaries appear to have contributed water only by subsurface flow. The streams are typically intermittent, flowing beneath a cover of mantle rock throughout most of their courses and appearing as surface flows only where the bedrock is exposed.