GEOLOGIC GUIDE TO THE TRAILS AT PHILMONT SCOUT RANCH

by

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GENERAL OUTLINE OF THE GEOLOGY AT PHILMONT RANCH

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Note: This outline is written for the information of those who intend to supervise geologic activities of Scouts at the Ranch. It is not for the use of individual Scouts.

The Ranch occupies about 200 square miles in northwestern New Mexico, located along the eastern slopes of the Cimarron Range, which is the name of the easternmost of the several north-south trending ridges that southward continue the Front Range of Colorado. The scenery is varied. The eastern portion belongs to the flat and relatively featureless plains known as the Great Plains that stretch from Mexico north beyond Alberta, accompanying the Rocky Mountains on the east. The central part of the Ranch property includes several steep, forested ridges that rise appreciably above the level of the Great Plains. Their western endings merge with the high, completely forested mountains that make up the western part of the Ranch.

A view from Tooth-of-Time Ridge will show that the vicinity of Cimarron and the Philmont Ranch headquarters is a relatively low area, surrounded on the north by the Raton Basin plateau, a great mass of Cretaceous and early Tertiary shales and sandstones; and surrounded on the south by several other, higher plateaus, of which Ortega Mesa is one of the largest. Urraca Mesa, seen from Headquarters, is a smaller one. These southern plateaus are all capped by a flat basalt flow which overlies thesofter Cretaceous shales. The resistant sandstones of the Raton Basin plateau are, I believe, generally lacking on the south.

The low easterly portion of Philmont Ranch lacks the mesa-forming, resistant layers, and is, instead, underlain by the soft Cretaceous Pierre shales. They are well exposed in many low hill slopes. Asseverywhere in the Rocky Mountain foothills, these strata slope at low angles east or northeast.

Where the Pierre shales approach the axis of the Cimarron Range, they have been penetrated by many dikes of quartz-monzonite porphyry, and the presence of this very resistant rock has greatly influenced the scenery of the middle portion of the Ranch area. Some of the dikes trend north-south, dip vertically, or at high angles to the east. They have given rise to several steep ridges. The longest is the one that extends from north of Sawmill Canyon southward to the west end of Tooth-of-Time Ridge. It is easily seen by the large gray cliffs it forms along its entire course.

Tooth-of-Time Ridge is underlain, along its axis, by a porphyry dike that strikes east-west, is about $\frac{1}{2}$ mile thick, and extends along the entire east-west length of the ridge. On the south flank, the Pierre shales dip at about 40° south. Whether they show up at the north base, I do not know. Whether the Tooth-of-Time dike connects with some of the meridionally trending dikes, is also uncertain at present.

Neglecting the dikes, we should expect that from below the eastward-dipping Cretaceous shales older and older strata should emerge as we proceed into the mountains. This they do. However, in this part of the Front Range, there appears only a relatively thin sequence of red shaly sandstones and conglomerates (mostly, it seems, of late Carboniferous age), before the crystalline rocks of the core of the range are reached. And the combined effect of the porphyry dikes and the generally soft nature of these redbeds is to conceal these old sedimentary rocks. They are, however, fairly well exposed along the trail up Cimarroncito. Creek, and are seen for a few hundred feet along Rayado Creek. As the

Cretaceous beds, the older sedimentary rocks dip eastward, but more steeply, 30-45°.

The crystalline, pre-Carboniferous rocks that underlie the core of the Cimarron Range, consist of an oldest system of northeast-trending amphibolites, or hornblende schists, well layered, generally fine-grained rocks, dipping with intermediate or steep angles southeast. They are intruded by thousands of lenticular, conformable masses of a pink or reddish granite, commonly so coarse-grained that the name, pegmatite, is appropriate. Where large numbers of these have entered the amphibolite, the rocks display mixed characters, and the amphibolite is more feldspathic than elsewhere. Cross-cutting dikes of granite are, however, rare and, it seems, restricted to short, thin dikes and stringers. The most continuous exposures of the pre-Carboniferous (very probably Precambrian rocks) are along the trail from Abreu Base Camp to and beyond Rayado Camp (also called Fish Camp).

The attitudes of the crystalline and later rocks are consistently at variance, and there must be a profound angular unconformity between both rock groups. However, exposures in the forested mountain territory are relatively scarce, and at the moment there is no known exposure of the unconformity near any trail. According to Smith and Ray (Geol. Soc. Amer. Bull., vol. 54, 1943), who have done the only somewhat detailed geological work in this part of the range, the core of the Cimarron Range, including Bonito, Black, Bear, Clear Creek, and Tolby Mountain, is a solid mass of crystalline rocks. However, it is possible that some of the highest and least accessible areas will reveal later sedimentary and volcanic rocks resting on the crystalline basement.

Very generally, the history of the Cimarron Range is as follows: Probably in Precambrian time, and certainly long before the Carboniferous period, a series of basaltic lava flows and ash or tuff deposits were piled up in a very thick series of layers. They were subsequently tilted, but apparently not folded, were brought to levels of the crust several miles below the then surface, and it was here that the system of layers was mineralogically altered to amphibolites, and penetrated by very large volumes of granitic rocks. The more gaseous fractions of these crystallized as coarse quartz-feldspar-mica aggregates, the so-called pegmatites. Ordinary sedimentary rocks, such as sandstones, limestones, or shales, must have been nearly absent in this series of rocks. At least, their metamorphosed equivalents are conspicuously lacking.

In Carboniferous and Permian time, this complex of metamorphosed rocks has been a land mass, probably mountainous, and on both the west and east sides large masses of coarse sandy debris accumulated. At least on the west, there was a sea, and several thousand feet of sandstones and sandy shales, with abundant marine fossils, are exposed on U.S. Highway 64, between Taos and Eagle Nest. Interbedded with these marine strata are others that appear to be swamp deposits for they contain many well preserved fossil plants, and some coal beds.

In Cretacous time, a sea advanced, and in the thick series of Pierre shales are preserved many marine bivalves, cephalopods, as well as marine dinosaurs. Then the sea gradually withdrew, and fresh-water sands succeeded the shales. They form the high plateau rim rocks north of the Philmont Randh, and are the economically important sandstones of late Cretaceous and Eocene age of the Raton coal Basin.

Some time after the deposition of the Eocene (early Tertiary) sediments, the region changed from one of deposition to one of up-lift and erosion. Exactly when this part of the Rocky Mountains has experienced its greatest uplift, and whether this uplift occurred once or in several stages, is not quite certain at present. There is reason to believe that perhaps in Miocene time the quartz-monzonite porphyry dikes were intruded. They do cut the Cretaceous sedimentary rocks, so they are later than these. Perhaps the dikes were intruded at about the time of of greatest uplift of the range. It is probable that some of the dikes have served as feeders of lava flows. A large flat-lying flow of aphanitic (dense) stony rhyolite crops out south of Touch-me-not Mountain, north of Cimarron Canyon, just outside the ranch area. But whether it is connected with the great sill, or dike, that forms the Palisades of the Cimarron, has not yet been investigated.

Some time after the extrusion of these siliceous lavas, the canyon-cutting of the Cimarron Range began. It has developed in several stages. At an early stage, possible Pliocene, the eastern slopes seem to have been fairly smooth, connecting the high crest of the range with the flat foothills of the Rocky Mountains. Evidence of this stage is found in the widespread boulder-strewn smooth slope remnants preserved both north and south of Tooth-of-Time Ridge. The present valleys have cut their profiles into, and below, these older slopes. A good example is on the low mesa, about 1 mile west-northwest of Headquarters.

The extensive basalt lava flows that cap Urraca, Ortega, and other mesas in the southern ranch area, were probably extruded after the large, smooth slopes had been established. The basalt rests on Cretaceous shales, and judging from cursory observations I am inclined to assume there is a slight unconformity at the base of the flows. Whether the lava also rests on gravels that had been accumulated on the high-level slopes, I do not know. Some of the basalt mesas lie horizontal, others dip gently eastward, perhaps reflecting the general regional slope of the Pliocene period. Rayado and other creeks appear to have cut their present canyons several hundred feet below the levels of these basalt flows. There are no basalt flows that occupy canyons or valleys of the present time.

There is no evidence that this part of the Cimarron Range has been glaciated during the Pleistocene period. There are no moraines, cirques, or roches moutonees.

INTRODUCTION

Geology at Philmont Trails

A rare opportunity is waiting for you. You have heard that Geology is the science that deals with the features of the Earth. Perhaps you have already read your Geology Merit Badge book, and you think that Geology is an interesting Science. While at Philmont Scout Ranch, you can prove to yourself that it is!

You arrived at the Ranch, and looked around as every good geologist should. On one side - which one? - , you notice flat, featureless plains, and if you came from the East, you have been travelling across some 1,000 miles of them, and will remember them. You are fortunate that you did not have to cross these thousand miles in a slow covered wagon for you would have been held up by the care for horses and the constant search for drinking water. But as you look west, you see that the plains are over. You are face to face with one of the most enormous systems of mountains we have on the globe, the Rocky Mountains. One hundred years ago, men recognized that mountain ranges and their origin are one of the large, fundamental problems of the Earth. After a century of study, we are still far from a solution of this problem; but we have learned something. We now know that nearly all geological problems, and certainly that of mountains, must be approached with patience, and by close observation. You had better remember those two words. If you do, you may be the one who advances our knowledge and understanding of geology far beyond what we now know.

Now let us look at some of the details. The Philmont Scout Ranch covers about 200 square miles. This is a minute fraction of the area of the Rocky Mountains, but you are fortunate that within these 200 square miles some very important and interesting features can be seen. Learn to observe them, and go about your work patiently, and when your time is up, you may have the great satisfaction that what you have seen, begins to make sense; that you have begun to understand something about the nature of the rocks around you; and that you have acquired a feeling of what a geologist has to do in the field.

Mountains and valleys, plains and canyons do not happen. They are caused, like thunderstorms or traffic accidents. It is for you to discover some of these causes. Do not worry if you don't discover all of them. Geology deals with big things, and we human beings are so small in comparison that we are lucky if we succeed in comprehending how some of the "biggest wheels" in the geological laboratory work. To do even this well, you have to keep your eyes open, your mind alert, and notebook and sharp pencil ready to record what you see, and what you think.

As you start your work, you learn that you can study very different things. You may want to study the large valley that leads from Headquarters straight into the mountains (Cimarroncito valley). Or you may wish to study the kinds of rock that underlie the slopes of this and neighboring valleys. You will find much of interest there. Eventually, you will want to extend your investigation farther into the mountains, to see whether mountains and plains are underlain by the same types of rocks or, if they differ, what the relations are between the various rock formations. The plan of your geological work, while at Philmont, is very elastic. It allows you to spend somewhat more time on those items that, in you opinion, are particularly interesting. If you are wise, however, you will not want to leave this area without having seen something of as many rocks, minerals, fossils, and outcrops as are characteristic of this beautiful mountain land.

A good place to start your geology work, is the south-slope of the hill, about 1 mile west of Headquarters. Leave the road where you begin to see rock outcrops, i. e. masses of rock in place, not just loose boulders or pebbles. Walk over these rocks slowly, and look carefully. What is the color of the rocks? What is the nature of the surfaces of the ledges? All solid, massive rock? Or does the rock tend to break up into thousands of little chips? Is each chip a firm piece of rock, or is it easy to break them down into still smaller chips? When you have made some observations of this kind, sit down, take a little time, and write your observations into your notebook. Write clearly, do not use telegraph style, or abbreviations. Three days later, you have forgotten the meaning of these scribbled letters, and unless you have a photographic memory you cannot trust your recollection of details. If you rely on your memory only you may as well start another science. Your geology will be unreliable, and the next man who walks over your outcrops, will find your statements incorrect.

Make it a rule never to leave a group of rock ledges before you have written down all you saw. There are nearly 3 million square miles in the United States. There are little more than 20,000 geologists and fewer than 2,000 work in the field. To improve our knowledge of this vast terrain, every geologist must learn to make reliable and fairly complete observations at the places he saw.

If there is time, walk on westward over this hill slope. You will have noticed by now that the most abundant rock shown many nearly horizontal lines on the surface. Study them. They are important. Are they mere lines, as if a painter has drawn a number of streaks on the surface of the rock? Or would you say this whole mass of rock, as far as you can examine it, is made up of layers?

This one is an easy question. You saw in every little gully and rill on that hill slope that the streaks continue into, and around it. Therefore, every cubic yard of that rock must be composed of layers. You will find in your Geology Merit Badge book much information on the origin of layers in rock. Read this in the evening, not now, because your time on the hill is too precious.

Continue your study of the hill. Perhaps this rock contains fossils. They are remnants of animals or plants. In the beginning, you will make all kinds of mistakes, picking up odd-shaped bits of rock in the belief they are fossils. Generations of geologists before you have made the same mistake, so don't be discouraged if some one with more experience says to you: "No, that one is just a form of weathering, or a peculiar crack in the rock." Some day, you'll come through with a really good one, and then you'll know the difference. Perhaps you'll find no fossils at all on this entire hillside. Then, after you spent many hours there looking for some, you'll know that there are either none, or that they are pretty hard to find. This may be just as important a discovery as a bag full of fancy forms. Remember you are trying to learn the nature of rocks; you are not a collector of curios. Whether you return with a collecting bag full of mineral specimens or fossils is unimportant, but that you leave this hillside with some clearly written notes on what you have seen there is exceedingly important.

Let's go still farther west on that hill. Where it slopes down towards the Animal Hospital, there is something unusual. There are a few little greenish knobs, about half way down the slope. Study them carefully. Are the knobs arranged haphazardly on the hill, or does there seem to be some system in their location? Examine the rock itself. Is it identical, similar to, or dissimilar from the rock you studied before? If it differs, observe carefully in which respect it differs, and write down your observations after you seem to have seen nearly all the surfaces.

If you have a knife with you, see whether you can pry loose some of the shiny dark specks on the rock surface. Lay a few of them at the tip of your finger, or a sheet of paper, and notice them carefully. What is their shape, their color, their size? If you happen to have a magnifying glass, observe the grains through it. Should you agree that all or most of these grains are flat, like tiny sheets, that they are of a brownish or a greenish color, that they measure about 1 millimeter across, and that they seem to be uniformly distributed through the rock, you have found about all you can with the limited equipment at hand, and have done all that any one can do to describe these grains. To go beyond it, and identify the substance accurately, would require a petrographic microscope that is operated with polarized light and nicol prisms, as well as a set of specially prepared oils. With all this, and tables prepared by mineralogists, checked and rechecked over many years, an experienced mineralogist could tell you that you have grains of the mineral biotite before you. This is the name (given in honor of a French mineralogist, Biot) of a kind of mica. No doubt, you have heard of this mineral before, and perhaps you have seen large sheets of a nearly colorless, flexible mica, that could be peeled into thinner and thinner sheets. You may also have heard that such mica sheets are commercially important because they provide good electrical insulation. Sheets, about 1 square foot in size, are used in generators of modern battleships. Obviously, our grains are much too small for such a use. You are now up against a familiar geological problem: You have found a large amount of a commercially important mineral, but in your outcrop the mineral occurs in such small grains that it could not be mined at a profit. Remember, we have competition in this world, and mica deposits much better than yours have been discovered in many other parts of the world.

Don't let this discourage you. You are out on this hill to learn, not to start a mica quarry. You have to learn a thousand and one more things before you are ready to start a commercial enterprise. So let us study the ledges some more. By now, you have probably noticed that the ledges of the mica-rich rock extend dominantly in one direction. Which is it? Be sure you write that into your notebook. Next, try to figure out the shape of the rock body to which these mica-rich ledges belong. You realize, of course, that some of the rock may have been removed by rainwash and wind before you arrived there, so that you should try to reconstruct the shape of this rock mass. Would you say, the dark micaceous rock has the approximate shape of a ball, a plate, a cube, a system of roots, a row of lenses, a matchbox? Whatever your conclusion, write it down, and write alongside your reasons for calling it the one and not the others.

Now, note another very curious feature. Where the surrounding dark grayish-brown rock that makes up most of this hillside approaches the micaceous rock, it changes within a few feet into a nearly black, splintery, very hard and tough rock, so different from the ordinary one that you would not know that loose specimens of both came from one and the same formation. Yet they do, as you can check in many places. Be sure you write down all these observations as <u>you</u> make them. Don't take anything in this folder for granted. Trust neither your memory nor anyone else's words. They may be all wrong. You alone can make those observations that you can rely on.

If you and I made about the same observations, we may agree that the micaceous rock has had some peculiar effect on the surrounding grayish-brown rock. If you look carefully, you will recognize that the layers of the surrounding rock that chips so easily, remain visible in the darker, hard rock. The layers go right up to the boundary with the micaceous rock, and arc then cut off.

If you saw this, and perhaps noticed also how the layers of the surrounding rocks have been tilted and deformed at one of the easternmost exposures of the dark micaceous rock, you have made some very important observations, provided you wrote them all down in your notebook in clear, readable form. If you want to do something extra, sit down in front of one of the most interesting ledges, and sketch with your pencil what you see before you. Nobody expects you to be an artist, but if you want to be a geologist, you must learn to draw, perhaps crudely, what your eyes have seen. It is astonishing how much most of us overlook if we never sketch rock outcrops in nature. When you finish your sketch, mark in the upper left- and right-hand corners the appropriate geographic directions. If you look straight to the south, you have east on your left and west on your right. If you face northeast, you have northwest on your left, and southeast on your right, and so forth.

If you are still around this ledge, have written down all your observations, and perhaps made your first geological sketch, you deserve a little reward, because to complete all this will have taken you well over an hour, and your feet may ache. You now want to know what these rocks mean, how they got there, and what you can learn from them. Two hundred years ago, nobody would have told you anything about such hillsides, and you might have left them utterly perplexed about the curious nature of rocks. Nowadays, you have at your disposal the accumulated experience of many generations of geologists, made easily accessible in textbooks and special reports. A few geologists have walked over the hill you stand on, and the surrounding terrain. Thanks to their studies, you can learn that the main rock on this hill is a shale, was formed during the so-called Cretaceous period of the earth's history and, as you should verify, the layers of this shale do not lie exactly horizontally, but slope (or, as we in geology, dip) gently downward to the northeast. The dark, micaceous rock is a volcanic rock, in fact a very rare type as volcanic rocks go. It has the scientific name, minette, and in addition to the dark mica, biotite, it contains a large amount of potash feldspar, and traces of several other rarer minerals. If you observed, as you have been asked, what the shape of this rock is, you will agree that it could be called a tabular rock body, perhaps 6 feet wide, and exposed for about ___ feet in a ______ direction. You had better fill out these two blank spaces before you leave the hill. Estimating distances is something all Scouts and Geologists must be able to do. Also, look up your Geology Merit Badge book to find a special name by which geologists refer to tabular volcanic (or igneous, in reference to the Latin word for fire, ignis) rocks that penetrate the rock layers of the earth's crust.

You now have quite a collection of questions you will want to read up on at home. (1) What is a shale? (2) How is it formed? (3) Is the Cretaceous period relatively late or early when we consider the age of the Earth? (4) Roughly, how many years is the Cretaceous period believed to have lasted? (6) Can you tell something about the age of the minette? you must think twice before you are ready with an answer here.

On one thing, your booklet does not supply the information. It does not tell you why the Cretaceous shale, as it approaches the minette, turns into a dark, splintery rock. Well, an 83-page booklet can not provide all the information you need in a particular area. Experience has shown that many non-igneous rocks have been altered in some way where they have come in contact with volcanic rocks. In this particular example, the effect happens to be very similar to what we do artificially when we make bricks. For brick-making, you start out with clay (and as you will find in your booklet, clay and shale have the same composition; the main difference is that shale has been compressed to some extent), you shape the soft clay, and push the soft bricks in rows into a brick-oven, where you heat them to temperatures of over 1,000° Fahrenheit. The clay substance, exposed to this heat for many hours,will then develop crystals, and most of them are hard. Therefore, the fired brick is a pretty hard rock. The Cretaceous shale has been baked into something like a natural brick in contact with the minette. This particular rock, composed of dark minerals, so small you can not identify them with the naked eye, and commonly of a brownish, or dark gray color, has been called, hornfels (meaning "horn-like rock" in German). The term is used internationally for this type of rock and a rock so altered by igneous heat is called "contact-metamorphosed". You can say: "The hornfels is a contact-metamorphosed Cretaceous shale", or "The splintered rock is a Cretaceous hornfels".

You will have more questions as you leave this hill. You wonder, of course, whether this mass of minette belonged to a former volcano. If there was one, it has disapperaed before our time. Perhaps there was no volcano. You can not get the answer at this hill. But keep the question alive in your mind. Somewhere else, at some other opportunity, an answer may present itself. You probably also are wondering why the hillside is strewn with so many large boulders of rocks unlike the Cretaceous shale. Again, the answer is not at hand. You can see, therefore, why you should be patient in geology. If every hill gave us the answer to all our questions, geology would, indeed, be an easy science. But don't despair. We will come across more boulders elsewhere.

TRIP TO CIMARRONCITO CAMP, AND WESTWARD TOWARDS LAMBERT AND CYPHER'S MINES

Trip to Cimarroncito Camp, and Westward towards Lambert and Cypher's Mines

On your exploration at the hill, 1 mile west of Headquarters you became acquainted with the brownish-gray Cretaceous shale that flakes easily into little soft chips. Today, you will proceed farther into the mountains to the west. You will drive along the same road and, as you pass the ledges, they should look familiar to you, and you should have no difficulty recognizing the minette outcrops near the west end of the hill.

Westward, for about 5 miles, the road follows the broad, flat-bottomed valley of Cimarroncito Creek and does not pass many conspicuous rock outcrops. While driving through this area, continue to make observations. Remember, you are spending only a few days or weeks in this camp. You have very much to observe and record if you want to leave with a reasonably complete idea of the geology. From the car, you can see smooth, grassy slopes, of the same grayish colors as the hill with the minette ledges, to the north and south of the road. Sometimes they are fairly close, sometimes over a mile away. All of these featureless slopes, if youhad the time to walk over them, would prove to be underlain by the same flaky brown or grayish shales. As you won't have the time to map every square mile of the Ranch during your stay, you may as well be told that the shales underlie most of the foothills leading to the forested slopes farther west. Shales of the Cretaceous period are, in fact, one of the most widespread types of rock anywhere between Mexico and Alberta. This particular shale formation was first described in South Dakota, about 90 years ago. In reference to a locality there, it is called the Pierre shale. You will find this name printed on your Ranch map (in pocket of your brown Program Hand Book). The name stands for a large area underlain by the Pierre shale. Twenty years from now, we shall probably have a much better map in which the exact limits of this formation have been drawn. But when it comes to geological exploration, New Mexico is still pioneer country, and our knowledge of the distribution of the various formations is not very accurate. Some of your future observations, if they are reliable, will help us extend our knowledge.

From these remarks, it should be clear to you as you look across the valley to the south, that the steep crags that make up Tooth-of-Time Ridge, are probably of a different rock, - one that seems to resist weathering processes much better than the soft Pierre shale. A geologist, travelling in new terrain, should always keep his eyes open for such differences in relief forms. Here the contrast is extreme, In other areas, the difference is more subtle, yet recognizable. Many a productive oil and gas field has been discovered by geologists who kept their eyes open to the meaning of these slight contrasts in terrain and relief features.

Where the road passes close to Webster Lake, you see shale exposures near the road, and on your right (north), forward, you can see the large flat-topped hill, called Deer Lake Mesa. Mesa is the Spanish word for table. You can see why the word is appropriate. Nearly all mesas owe their flat top to a particular kind of rock. In the Rocky Mountain region, there are scores of mesas, small ones and large ones. The largest ones you can call plateaus. Perhaps you have heard, or read, something on how plateaus are formed. It has something to do with a flat, resistant plate of rock, and erosion. Keep this in mind. Some time later you will have a chance of studying this matter in more detail.

As you proceed, the surface rises, and the road becomes rough; finally, you pass a large, tall gray cliff to the north. In front of it is a beautiful reservoir with drinking water for the town of Cimarron. At this cliff, you have left behind the gently rolling hills and plains of the Rocky Mountain foothills, and you are now in very different terrain, mountainous, forested, more complicated, but more interesting. Soon you leave the car at the Cimarroncito Base Camp. Gather up your notebook, hammer, magnifying lens, see to it that your pencil is sharp, and that you have a knife to sharpen it from time to time.

We follow the trail that leads westward from Cimarroncito Base Camp along Middle Fork of Cimarroncito Creek.

Directly as you start out, you will notice yellowish-gray gravel on the trail. Don't stop now, but remember it. Thirty feet beyong the barbed wire gate, on your right (north), there is an outcrop of rock. Stop, and examine it, and be sure you write down what you see. You should know this rock as an old friend now. If you examined the rocks at the hill, 1 mile west of Headquarters, you should know very soon that this outcrop, even though it is small, is the same Cretaceous Pierre shale.

This is a very important discovery, and it should puzzle you. So far, you have learned to associate the dark Pierre shales with flat, open country. Now you have passed across high, steep cliffs, and yet here you find the same soft shale. This does not make sense. Obviously, the steep cliffs must be composed of a different rock, resistant to weathering. The soft shale can not give rise to vertical crags. As you had to stay in the car until you arrived at the Cimarroncito Base Camp, you could not examine the rock in the large cliff north of the reservoir. Fortunately, you can make up for this. Walk on 100 feet, and just as you come to the creek, you find on your north side a ledge. Take out your hammer, and go to work on this rock. It is worth it. The ledge is not large, and the blocks are hard to get off, but you must get hold of a reasonably large piece, and then obtain a <u>fresh surface</u>. If you get one, you will at once see why this is important. The ordinary weathered surfaces of most rocks look quite different from the fresh rock inside. To recognize a rock, and to spot its constituents, you must examine fresh surfaces. By the creek, you will find many loose, clean blocks. They seem to be the same as the rock in you ledge. But as you are concerned with the rock of this one ledge, you had better forget these nice, clean blocks for the time being, and concertrate on that dark, inconveniently located ledge.

If you have great diffuculty getting your specimen here, walk some 100 feet beyond the ford. There is another ledge on the south side of the trail. Specimens from either ledge are good for your purpose.

If you look at a fresh, clean, dry surface of this rock, you will at once recognize dozens of white or yellowish grains, squarish in shape. They make up more than one-half of this rock. Turn the surface in the sunlight, and you will recognize that the light-colored grains reflect the light from smooth internal planes. If you have a hand lens, and examine them with care, you will spot some grains that reflect from two sets of such smooth planes. Where they intersect, they show straight minute edges. If you were a chemist, you could analyze these grains. You would find they all are composed of silica (SiO_2), alumina (Al_2O_3), lime (CaO), soda (Na_2O), and potash (K_2O). Substances that have an identifiable chemical composition, a characteristic structure and build up rocks, are called minerals. This particular mineral, with this chemical composition, and the two systems ofplanes that are smooth (and other characteristics which you learn in a course in mineralogy), is called feldspar. It is a very important and widespread mineral. The property of a mineral to split along sets of smooth internal planes, is called cleavage, and we say that feldspar has 2 good cleavage systems. Actually, feldspar has a third cleavage, but the planes of that set do not split easily, so you are not likely to spot them.

What else do you see on fresh surfaces of you new rock? There are dark grains, smaller than the feldspars, nearly black, usually a dark green. See that you find a few good ones. If you do, you will notice that some have the shape of short sticks, or needles, whereas others are like flat plates. If you are lucky, you'll see that some of them have a shape like a hexagon. With your knife, try to pry some of these dark grains off the rock. You will find that the slender dark needles do not come off easily, but some of the flat, shiny grains do. If they are large enough, try your magnifying glass on them. You will then recognize a mineral familiar from the trip to the minette ledges. The flexible sheets are biotite mica, the same as in the minette. The other dark mineral, in slender prisms and needles, lacks the perfect cleavage of the biotite. As you can not tell much more about it without a microscope, you may as well know that this mineral is called hornblende, or amphibole. This is, in fact, the name of a large group of minerals. They have a wide distribution in the earth's crust. Your kind of hornblende is dark on account of iron oxide, which is combined in the mineral with silica, alumina, lime, magnesia, and some manganese oxide. Amphibole entirely free from iron oxide is colorless. You find it in certain marbles. But most amphiboles are greenish, even black.

There is still another mineral in your rock. It, too, forms large grains. If they broke out whole, they look like gray or pinkish pebbles. If you broke them through, they are colorless inside, like glass. This mineral is quartz, probably the most abundant mineral in the crust of the earth. You can easily identify quartz; it lacks cleavage, and it will scratch your steel knife. Few other minerals are so hard. Quartz is like glass in that it has no color of its own. But if a minute amount of a mineral pigment is present in quartz crystals, it will at once color the quartz, -yellow, red, black, brown, nearly every color has been found. Remember, therefore, that the color of quartz is not diagnostic, nor its accidental shape; but is hardness, glass-like greasy luster, and lack of cleavage are good criteria in determining the mineral.

Why the quartz grains in this rock should look like pebbles is unknown. It is an uncommon feature as is the opaque, whitish shell of the grains. You will find that the amount of quartz in this rock varies from one ledge to another. The last portion of the rock you must note, is the very fine-grained groundmass, of dark gray color. I have not seen it under the microscope, and do not know what minerals it may contain. Perhaps in another year, the rock will have been examined microscopically.

Even so, you can see that this rock is totally different from the Pierre shale. It consists of a great many crystal grains (the words, crystal, and mineral, could be used interchangeably; some persons prefer the first word if the grain is terminated by straight faces. Don't worry about other connotations of these 2 words). They are, however, of sufficient size for you to recognize them. And between them is a groundmass, or matrix, of microscopically small grains.

The two ledges of this rock do not allow you to estimate the shape of the rock. But you see that it builds up tall cliffs around you. It extends generally across the valley of Middle Fork Cimarroncito Creek, and you do not see any layering. Two hundred years ago, a very famous leader in geology would have pronounced this rock an ocean deposit, like sand or mud. He did not know that crystals of feldspar, amphibole, and biotite require temperatures of about 1,000° Fahrenheit to form; and it has been established that many volcanic rocks which congeal before our eyes from molten lava, carry such crystal grains in suspension. The frozen rock displays thousands of nicely formed crystals in a fine-grained groundmass. Our rock, in short, is another volcanic, or igneous rock. Quite different in appearance from the minette. Again, there is no volcano overhead, and again you can not tell where at the surface of the earth this lava erupted. The rock is completely cold now, and you wonder how long ago this lava flowed through the rocks. Nature rarely answers many questions in one place. There are more rock outcrops to come, so keep an eye on those problems for which you lack an answer. However, as you do not yet know how to examine a rock microscopically and determine the scientific names of igneous rocks, you may know that this rock is in composition somewhat similar to granite. It is called a "quartz-monzonite porphyry". The word, porphyry, means that the rock is composed of large, well formed crystal grains embedded in a much finer-grained groundmass. The word, monzonite, refers to Monzoni, a village in the Italian Alps, where such a rock was first described by geologists. If you go on with Geology in later years, come to a good library, and can boast of a smattering of German, you may enjoy the first chapter in Waldemar Christian Broegger's "Die Eruptivgesteine des Dristianiagebietes, Vol. 2: Die Eruptionsfolge der triadischen Eruptivgesteine bei Predazzo in Südtirol", Videnskabs-Selskabets Skrifter, I. Mathematisk-maturv. Klasse, No. 7, 1895. It is a classic, like Darwin's "Origin of Species", or G. K. Gilbert's "Geology of the Henry Mountains, Utah". In this chapter, the Norwegian geologist,Broegger, looks through the guest book of the Hotel "The Golden Ship", at Predazzo, near Monzoni, and recalls the achievements of the scores of famous geologists who registered there while making geological observations on the huge cliff walls near Monzoni. They were concerned with problems that are still among the most fundamental in physical geology. But you need not waste time with this now; instead, you had better continue your observations.

One thing you have not been able to discover at the last outcrops: the shape of the igneous rock. If you had ample time, you might climb up on the cliffs to the north and south of the ravine, and perhaps you could see the general shape of the monzonite porphyry. But the pines grow so thickly that you can not see enough from the bottom of the ravine. Be patient again, and remember that you want to find out what the shape of the igneous rock is when the opportunity comes.

The cliff of monzonite porphyry soon withdraws from the trail, and you see no rocks for about 1,000 feet. This gives you a chance to look at some of the boulders that lie by the trail. They are loose, and of various kinds. Break a few with a hammer, to obtain fresh surfaces, and compare them with rocks you already know. Make a note in your notebook what kinds of rock you think you recognize. If you see others, examine them also, write down what you can see, and again be patient. If the boulders lie around in the bottom of this ravine, quite probably there will be ledges of them where you can examine them at your leisure. And should you be unable to follow this particular valley far enough to come to them, there is a chance of finding them in some other trail.

As you pass through the next few hundred feet, you may observe the bottom of the small creek. It is covered in most places with boulders. Why should this be so? You will see so many while you are at Philmont, and they are discussed in your Merit Badge booklet that you do not need any special information on this.

About 1,000 feet after you passed the last monzonite outcrop, you have low ledges on the south side of the trail. By now you are an old hand at examining rocks. So take off your pack, get out the hammer, break a few characteristic blocks through, and examine them. Then, as usual, write down whatever you observe. Now you should be so experienced that you do not need any further explanation. The minerals in this rock you have seen before. Perhaps the grains are of different size or color from those in another rock; but that is common.

Next try to decide whether this rock is composed of layers, like the Pierre shale, or structureless, like the porphyry. It does not make very much difference what you may decide in this particular outcrop. As always, the main thing is that you try to observe the rock as carefully as you can, and record what you see.

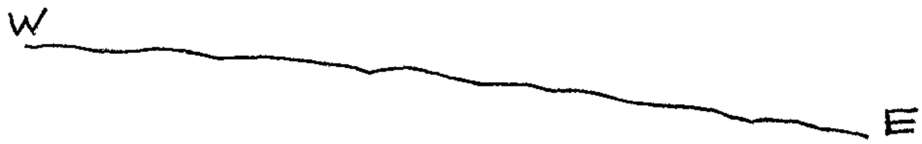
About 60 feet farther up the trail, you pass more ledges. Repeat your observations, and write down what you find. Climb up on the large ledge directly north of the creek, and examine it. Don't hurry. Spend plenty of time on the rocks. When you come down from that ledge, you should have settled the matter of layered vs. structureless, unlayered, rock. You should have seen the coarse, and fine-grained beds, and you should have a pretty good idea of what kind of rocks make up most of that cliff. If in doubt, consult the chart on page 32 of your Merit Badge Booklet.

Did you also observe and record in your book whether the layers lie horizontal or, if they are tilted, in which general geographic direction they are dipping, and at about what degree of inclination? Be sure you write down a few words. Later, you will need that information.

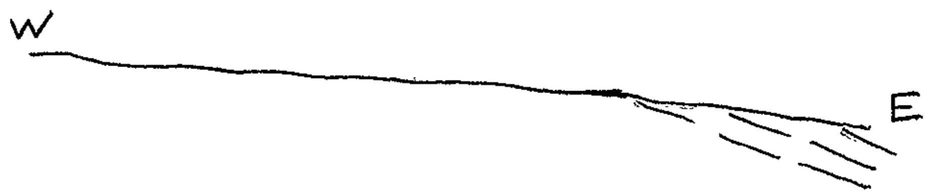
West of this ledge, the North Fork of Cimarroncito Creek joins our Middle Fork, and a trail follows the North Fork to an abandoned mine. We stay on the main trail, because from now on we shall have much to observe and record. Directly west of the mouth of North Fork starts a hillside on the north bank of Middle Fork. Examine the many outcrops of rock on it, and record the usual things, colors of the rocks, types of layers, attitude of the layers, composition as far as you can observe it.

If time permits, climb up a short distance on this slope, and look around. By now, you have seen a strip of country, nearly 6 miles in an east-westerly direction! You are already among fairly high mountains, and you have been patient enough to make careful observations from one outcrop to another. Gradually, some rewards for that patience will come in. You want to know, as every geologist does, why the mountains are there; why they are so high; and by what kind of a mechanism such huge masses of rock are built up into a chain of mountains. Take out a clean sheet of paper, or a page in your notebook. Draw a thin pencil line sloping gently from the left down to the right, and write a W just above the left end, and an E at the right one.

Thus:



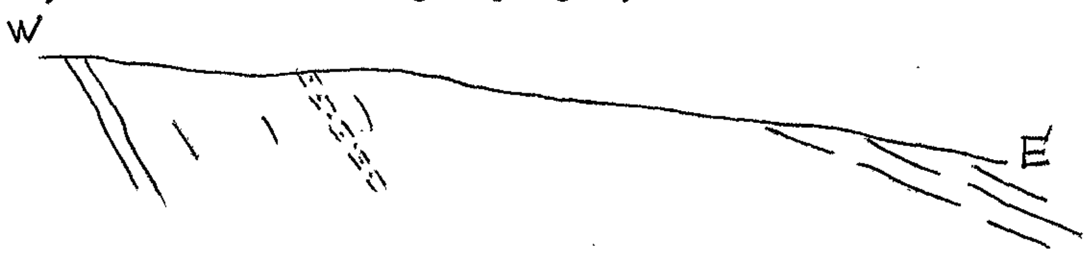
This line may represent roughly the earth's surface, as it slopes from where you stand eastward to the hillside with the minette and Pierre shales. Look up in your notes in which direction the shales dip at the minette hill, and at about how many degrees. Now draw a few lines below the "skyline", on the eastern portion of your diagram, to represent the dipping Pierre shales, thus:



They dip northeast, at about 5-8°, so the lines should be inclined to the right in your diagram. The exact angle of the dip is not important at this moment, but keep it gentle. In the middle of the diagram, you can not draw anything because that is the 5-mile stretch where you drove through, and did not stop to examine any outcrops. But you remember that from the distance you saw Pierre shale ledges there, and, as you started out on this trail, you passed that outcrop of Pierre shale, 100 feet west of Cimarroncito Base Camp. Look up in your notes at about how many degrees the shale beds in that outcrop dip, and in what general direction. Don't tell me you forgot to observe and record that! For that serious omission, you should be required to walk right back to that ledge, and complete your notes.
But fortunately, you are as yet a beginner, and it takes time before you remember everything in a new occupation. So, just this one time, the missing facts and figures will be supplied: The dark brownish-gray shale, 100 feet west from the Camp, dips at about 36 degrees downward to the

northeast. Better stop there when you return from this trip, and make sure that this is correct.

About 1/3 inch from the left in our diagram, we draw lines sloping down to the right at about 35 degrees. For the time being, let us omit the porphyry in our traverse, and now, at the left (western) end of our diagram, we draw the variegated shales and sandstones that are before us, also with their average dip angles, thus:



Now you can see something very interesting: The layers of Pierre shale and sandstone dip steeper to the northeast as you follow them from east to west. In your Merit Badge book, you have read that nearly all layered rocks are deposited originally in horizontal or nearly horizontal beds. Our strata are inclined. That means, they must have been tipped up in such a way that the western ends of the beds were raised, or the eastern ones lowered. It should be clear, also, that the strata in front of you underlie the ones farther east. So, if you want to obtain a specimen of the yellow, green, or gray sandstone beds before you (shown with dots in diagram) at the minette hill, 6 miles east, you'd have to drill, and some hundreds or thousands of feet below the surface you are likely to run into them, thus:

You can visualize what has happened in the earth's crust, if you stretch out your right hand, palm flat, finger tips pointing to the left. Now raise your left fist slowly from underneath your right fingers.

The fingers are forced to bend, and your palm will be tipped up steeper and steeper the farther you raise your left fist. If that picture resembles what has happened to the rocks here, you can make a few guesses: As you continue west, and pass more layered rocks, in what general directions would you expect the layers to dip? Generally speaking, do you expect the layers farther west to dip more gently, or steeper?

Our guesses and experiment are, of course, not quite adequate. For one thing, we have left out the porphyry . But at the moment, it looks as if the high mountains west of you have been pushed up from underneath, somewhat like your fist under your flat palm. Now let's continue on our trail.

Nearly continous, low outcrops along the trail for the next 300 geet display a variety of purplish sandstone, shale, and siltstone beds, with a few very fine-grained calcareous lenses. Be sure you stop at the ledge just where the trail crosses over to the south side of the creek. What you see here is most interesting and important for this entire trip. You see layer upon layer dipping in the familiar northeasterly direction. But at the last 7 feet or so, an entirely different rock appears; however, as you break fresh surfaces from this ledge, you will recognize it at once as the rock you saw ¼ mile babk: "quartz-monzonite porphyry". There is no doubt about it. The same whitish feldspar crystals, biotite, and hornblende needles, again some of the peculiar pebblelike quartzes, and a dark gray groundmass.

Now be sure you examine the surface there the two different rocks meet. It is spoken of as the contact. If you make your observations with care, as you should, you'll notice that both the porphyry and the shaly layers change as they approach each other. The changes in the shale should at once recall which other outcrop? What did you note there? Did you find about the same thing here? If you do, how would you interpret the change in the shaly rocks? If you look up your notes from that other trip, all the details will come back, and you have the satisfaction that at two entirely separate places you can check the same important change in a rock. Very probably, then, the cause was also the same in both places. So far, you had to take my word for it that the monzonite porphyry was an igneous rock that was once very hot. Now you have before you confirming evidence. The shale had to be heated nearly a thousand degrees before it turned into the gray, dense hornfels. So this does make some sense, even though all the rocks are now cold. If you continue geological studies, you will find, over and over, that your job is to reconstruct processes, movements, causes and effects, and sequences of events. It is this reconstruction that permits you to bring the earth's crust truly to life, and you can depict stage after stage in the evolution of a mountain range, a former volcano, or even a continent.

As you examine the contact surface between the quartz-monzonite porphyry and the baked shale, you notice two things: the surface runs parallel to the beds of shale, and within some 5 inches from the contact, the feldspar phenocrysts become smaller and smaller, and the dark gray goundmass increases in volume correspondingly. This is a fairly common behavior of igneous rocks. It is explained by saying that the molten lava that came first in contact with the cold rock, lacked the large feldspar crystals, or that only small ones could be squeezed into an originally thin crack in the shale, and froze onto its wall.

After crossing the creek, you can walk for about 250 feet across monzonite. Then, on the south side of the trail, comes another important outcrop which you should examine just as carefully as the last one. You will see that it is about the "mirror image" of the last ledge. In the first, the shale lay on top of the monzonite, now the monzonite lies on top of the shale. The shale is again contact-metamorphosed (or "hornfelsed") at the contact, and if you will examine, as you were asked, the entire ledge, you will find, as a special, local contact mineral, scarlet-red jasper. This is quartz, stained red by iron oxides. Don't demolish the entire cliff on its account. Next year, too, some Scouts will want to collect a little bit of it.

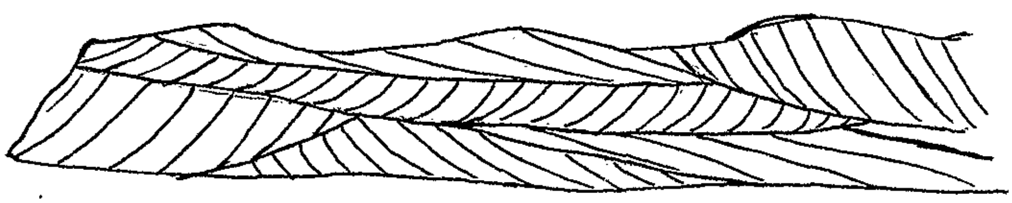
Before you leave the ledge, take out your paper and pencil, and try to extend your cross-section diagram to the westward. So far, it shows the Cretaceous Pierre shales at the minette hill dipping gently eastward; the 5-mile gap in observations; the steeper dips where the sandstone ledges are, near the mouth of North Fork Cimarroncito Creek; and the imaginary drill hole at the minette hill. Now draw the sky-line farther to the west. If you have no room, start a new diagram of which the right (eastern) part coincides with the left (western) part of your first diagram. Draw all the purplish, gray, and yellow sandstones and shales that dip northeastward between the mouth of North Fork and the ledge where the shale rests on the monzonite. Now, if you can estimate dip angles fairly well, you will find that in both outcrops the contact between the shale and the monzonite has almost exactly the same dip angle, to wit, 37-40°, down to the northeast. As you see it at the jasper ledge, the contact is parallel to the shale or hornfels beds. In your section, therefore, you can draw two lines having the same dip as that of the shales, and the rock between them will be monzonite porphyry, not shale. It should be clear to you that the porphyry has the shape of a layer, or plate, dipping at the same angle and in the same direction, as the surrounding shales and sandstones. There is a name for an igneous mass that has the shape of a plate parallel to the bedding planes of layered rocks. You'll find it in your Merit Badge book. Estimate the thickness of this plate of quartz-monzonite porphyry, and add that figure on your diagram. Be sure not to confuse the distance between the two contacts, as you walk it on level ground, with the distance of an imaginary line at right angles to the upper and lower contact planes.

By now, you should realize that in your section a great many masses of quartz-monzonite porphyry are involved. First, you saw the large cliff north of the reservoir, just east of the base camp. This cliff, you may as well know, was porphyry. Then you passed that mass, about 100 feet after starting on the trail. But the contacts with the layered shales were concealed. Now you have passed a large sheet-like mass, that dips northeast, as if it were a layer of a sedimentary rock. By now, also, you will realize that the many tall, gray cliffs that surround the creek on the north and south sides, are apparently all composed of porphyry. If we could remove all the porphyry, leaving only the soft shales, the entire scenery around us would in all probability be much more subdued, resembling the rolling foothills farther east. You can see now that if one of two adjoining regions is composed of a resistant rock, the other of a less resistant rock, it stands to reason that the first region will have a higher surface, in general, than the other. This is an important principle in geology. You will find it discussed in your Merit Badge book. As all principles, this has exceptions.

Perhaps this paragraph causes you some confusion! A while back, you drew a cross-section, showing the Cretaceous shales dipping steeper on the west; and with your hands you made a simple experiment showing that it looked as though the high mountains to the west of you had been pushed up. That seemed perhaps a plausible explanation of how mountains were made. Now comes quite another principle into this story, the resistance of different rocks. If you have resistant rocks on the west, and soft rocks on the east, then too, you might expect high mountains on the west side.

All this need not confuse you. Rather, it should make you aware that Geology is a complicated science. Like a machine that consists of many parts, each of which has a certain effect on the workings of the whole mechanism. You must study all parts before you can say that you understand the entire machine. We know that all kinds of factors have entered into the formation of the Rocky Mountains. You will meet many more as we go along. The creek and trail make a curve, west of the jasper ledge. The shale is again interrupted by monzonite porphyry of which you pass some tattered ledges on your right. They have more quartz than the monzonite outcrops east. About 150 feet farther northwest, gray, sandstone crops out. It dips again northeast, but the contact with the quartz-monzonite porphyry is concealed. The igneous rock could be another sheet, or it might have any other shape. You can not tell. The sandstone is again interrupted by porphyry, some 100 feet west. It is apparently a small mass only, because soon you see again tan, or pale brown shale, and then come several ledges of a purple sandy shale, dipping at about 35° northeast. On some bedding planes, you can see little sparkling blebs. They are white mica, or muscovite. It differs from the brown or green biotite in that it lacks the iron oxide, and therefore has no color.

You will note in these outcrops that not all the layers are parallel to each other. Some groups of beds are beveled by others, thus:



This is called "cross-bedding". You can find it where sand has been blown about by the wind, and heaped up in dunes. You also find it where swiftly flowing water carries much sand, silt, or gravel, and has to force its way around obstacles. It will then push the sediment in many small channels which may cross each other as time goes on, and the sand deposited yesterday in one channel, may today be worn away by another channel. Nearly all cross-bedded sediment was deposited in shallow flood plains by river water, or blown together by wind. So we learn here something about the mode of origin of this rock.

At the base of these cross-bedded layers, you find others that are composed of fairly well-rounded pebbles, some nearly $\frac{1}{2}$ inch across. In your Merit Badge book, you will find a reference to such rocks. If the cross-bedded sandstone was formed in either flood plains or through accumulation of sand in dunes, you can reach a conclusion as to which of these alternatives is the more probable one for this particular group of beds.

For some 150 feet the trail passes purple shale in small outcrops on the right side. Just after you pass a curve in the trail, the shale is suddenly interrupted for some 12 feet by a different rock. You are now so experienced in recognizing the Philmont rocks that it takes you just one minute, after breaking a fresh block of this rock, to recognize it as another mass of quartz monzonite porphyry. And you need no reminder that you must not walk on before you have tried to determine the shape of this relatively small mass of porphyry. This is made somewhat easy because fromthe trail you can see the porphyry extending upward along the hillside. If you have a compass, you can determine the direction in which it runs. If not, use the position of the sun to estimate the general geographic direction. Would you say the rock has the shape of a plate? If so, is it horizontal, vertical, or inclined? If it is inclined, a geologist must determine in which of the two possible directions the plate dips. To do that, you must of course look for the contact plane. Put your eyes and mind to it, and you will find the answer. By now you will also know whether this mass should be called a dike, or a sill.

You are now familiar with most of the rocks you will encounter on this trail. As you continue, you pass several more masses of quartz-monzonite porphyry, and should make an effort to determine the most probable shape of each mass. If you were paid to map the geology of this ravine, you would have to climb up the walls every time you pass a porphyry mass, to determine and measure its exact orientation. Not all the contacts are exposed, and it's quite a job to determine the shape of the concealed contacts. But for the sake of accurate and reliable mapping this must be done.

Between the monzonite porphyries, you pass again many out-crops of reddish, purple, or buff sandstone. Associated with them are layers of conglomerate. A good one is on the northwest side of the trail, about 100 feet above the "Stone Face" marker. Measure, or estimate, the diameters of the largest pebbles in this rock. Take a good look at the rocks of these pebbles. Do they look familiar to you? Whether they do or not, a conglomerate will always interest you if you study Geology. We go into picture galleries and museums, or may open books with pictures showing what clothes people wore, hundreds or even thousands of years ago. On the Greek temple friezes, we can see scenes showing people talking or arguing; we can see what gadgets they used for weighing merchandise, what pencils for writing on papyri, what buckles they wore on their sandals. Now a conglomerate is something just as precious. It is something like a photograph of a busy railroad station, many millions of years ago. Our trains are, of course, the streaming water particles in a former creek, and the passengers are the thousands of rock pebbles that have all been urged on, pushed about, and finally dropped by the water train. Where did they come from, how far did they travel before they were deposited? If you are waiting for a friend at a rail road station, you can give an exact answer only for your friend, because you know where he comes from, and how far he traveled. For the other passengers, unless they wear a turban or a kilt, you would not know that. It is very much the same when you study the pebbles in a conglomerate. If you know that there is a ledge at such-and-such a place of this or that rock which lies before you as a pebble or boulder, then you can assume that some time ago the stream that collected all these pebbles, picked up some of them at the vicinity' of the place you know. But if you have never seen a fock, you can not tell where that ancient stream acquired this material.

Right now, you are not yet familiar with all the rock formations of the Philmont Ranch. But in another week or so, you will be. Just now, if you are energetic, examine some of these pebbles carefully, and write down at least a few brief notes on the color, grain size, and other striking characteristics of some of the pebbles. Should you later find outcrops of rocks that resemble the ones you see before you in pebbles, you can still get an answer to your question.

This little search among the pebbles will make you realize that much of a geologist's activity is similar to that of a detective who constantly is on the lookout for clues and hints that may lead to the apprehension of the felon. Our geological felons are many: Right now, we want to know where that former stream got its pebbles. Before, we wanted to find out where that molten lava was going that made the many porphyry dikes, or that minette lava that passed through the hill 1 mile west of headquarters. Is it hiding a volcano from us? If there was one, did it have a grand plan up its sleeve, perhaps, to push the Cimarron Range up into the cold of the higher atmosphere? Like a good detective, you don't jump at conclusions, but wait till all the clues converge toward a story that can be checked. In any case, you already have quite a few reliable and interesting clues, after less than 2 days in the field. This is rapid progress. There are regions where a geologist may spend days, weeks, or even months without getting anywhere. In the humid tropics, for example, hills and valleys may be covered by deep soil, so continuous that you can never see a fresh outcrop of rock. A few years ago, a geological party, working along the coastal plain of northern Alaska, saw exactly one rock outcrop during an entire field season!

If you continue on this trail, you pass another mass of porphyry some 300 feet west. Notice the larger amount of gray fine-grained groundmass in it, and the small amount of quartz. You will probably find several specimens in which the dark hornblende crystals are a bright green. The green mineral is called epidote. (Translated from Greek, the word means, "given in addition to", and goes back to an incident, about 150 years ago, when the famous French mineralogist and prelate, Hauy, experienced great difficulty in determining the particular crystal system of this mineral. All specimens had one crystal surface that destroyed the mineral's suspected symmetry. The problem was finally solved, but the ammoying plane was remembered when the mineral was named. The crystals you see, are so small, however, that you are not likely to recognize crystal surfaces.) Epidote has about the same chemical composition of horn-blende, and under certain physical conditions, the molecules of hornblende will change over into those of epidote.

From now on, much more monzonite porphyry is in evidence. Soon, a large cliff of this rock forms the north wall of the canyon, and the coarse debris sand from its ledges strews the slope to such an extent that you can not see any other rocks that may be buried underneath. Nevertheless, if all the debris (Also called talus in geology) could be removed, you would probably find the same reddish and purple sandstones and conglomerates that you saw farther east.

In your diagram, you may now add another section, extending as far west as you went; if your observations on the contacts of the various porphyry masses are correct, you can add these as lines having the appropriate directions of dip. Some, as you recall,dip to the northeast, like the sedimentary rocks. Others dip across the layers. So it looks as though the porphyry has broken across these beds in some places, and squeezed in between the layers in other places. Volcanic rocks in many parts of the world do that. If you continue to the Lambert or Cypher's Mine, you see practically nothing but porphyry varieties, some of which have much more quartz, and the feldspar crystals do not show the cleavage well, but look chalky. We will discuss the rocks at the mines on another page.

TRAIL FROM ABREU BASE CAMP WEST ALONG RAYADO CREEK

To reach Abreu Camp, you drive west from Carson Maxwell Ranch. Again, you start in the eastern foothill belt, and are deep in the mountains, where you reach Abreu Camp. As you drive west, you find the skyline flat on the north and south, though not everywhere horizontal. From an earlier trip, you know what these flat-topped mountains are called in this part of the United States. But you don't know what kind of rock crops out at the top. Whatever it is, it must be very extensive. Keep your eyes also forward to the left (southwest). There, individual mountains practically disappear in one large plateau. Incidentally, the northern edge of this large plateau coincides with the southern boundary of Philmont Ranch. Below the plateau cap rock, north and south of lower Rayado Creek valley, you have smooth, relatively featureless slopes. You can suspect the familiar rock: Just fill out the space.

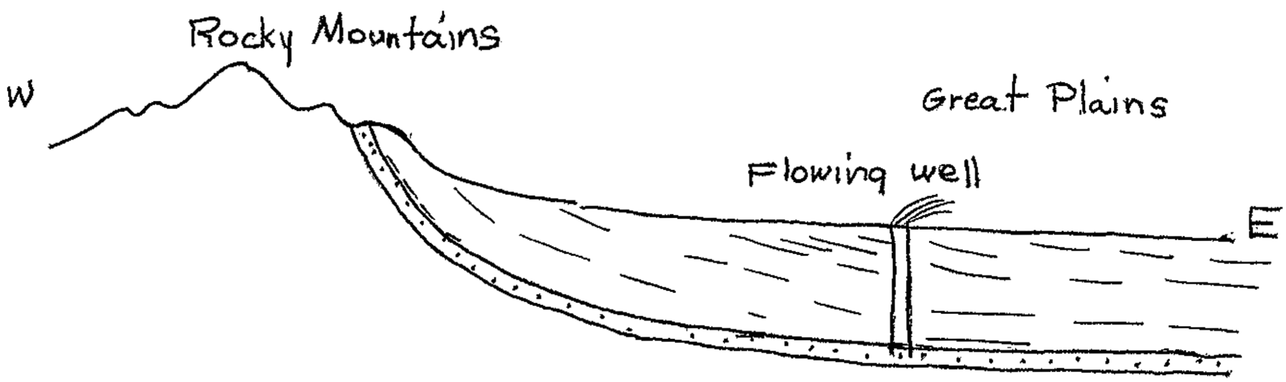
Before you leave, look around Abreu Camp. On the north, across the gorge of Rayado Creek, is a magnificent cross-section of a part of the same formation that accompanied you since you drove over from Carson Maxwell Ranch: Directly south of the Camp, the pines are fairly thick, but you can pick up large boulders on the slope. Take a good look at them. Break off, as usual, a fresh surface, and examine it. To make sure you examine the right rock, look for those that have many vesicles and cavities, are of rather dark gray, sometimes purplish color, and are pretty hard at the blow of the hammer. Fresh surfaces show, apart from the many little holes, a uniformly fine-grained rock that does not tell you very much of its composition and texture, except that it is not layered. Every now and then, however, a surface in sunlight will show a few small, weakly reflecting grains. As you can not determine the rock on the basis of so few criteria, you may be told that this rock is basalt. Next to branite, limestone and sandstone, it is about the most abundant rock in the earth's crust. This particular basalt is fine-grained, and you need a microscope to identify the individual minerals. If you had one, you could recognize the minerals feldspar and pyroxene (translated from Greek, pyroxene means "friend of fire", in reference to its growth from molten lava). Rarely do they form phenocrysts, about 1/8 inch long.

Keep in mind, then, that the large mesa, southwest of you, and always on the south bank of Rayado Creek, is a large flat plate of basalt, a true lava flow, in every respect similar to the ones we can see erupt in the Hawaiian Islands, Iceland, or other basaltic regions of the earth. Once you recognize the typical appearance of this basalt mesa, you will see that the north slope of Rayado Canyon, too, is in places crowned by basalt cliffs, but they are less continuous than the southern ones and, as you can see from several points of vantage, the basalt on the north side of the canyon overlies the gray Pierre shale.

For over a mile, the trail leads through slope debris, and the pine forest does not allow you to get a clear picture of the geology of the underlying rocks. However, reconnaissance work has shown that the Pierre shale in all probability underlies the canyon. Finally, you pass a large cliff of a hard rock. With little effort, you can make out the layers in this rock, and examination of fresh surfaces will convice you that this is not the Pierre shale any more.

If you recall your observations along the trail leading westward from Cimarroncito Base Camp, you will see that you encounter the same sequence of rocks as you go from east to west: first a large mass of shale, dipping northeast, away from the mountains (on this trail, you have been unable to study the attitude of the shale layers, but here, too, they dip to the east and northeast); then, layers of a hard, gray or yellowish, fine-grained homogeneous rock, dipping more steeply eastward. If you had time, you could climb up on this steep ledge on the north bank, and if you follow it across several other canyons, you would come out at the ledge by the Cimarroncito trail, about 1,100 feet west of the Base Camp. The outline of that trail did not tell you very much about that rock. But I shall assume that you have examined the rock carefully, both at the Cimarroncito trail and this one, and you may now be told that this is a very famous and important formation of the entire Rocky Mountain region, the Dakota sandstone. Through the Dakotas, Montana, Wyoming, Colorado, Utah, New Mexico, and Arizona, the Cretaceous shales rest nearly everywhere on this sandstone formation. As you can see in the cliff before you, the beds dip east at about 30-40 degrees. You can see exactly the same on the east slope of the Laramie Range in Wyoming, along the entire Front Range of Colorado, and in the foothills of the Black Hills in South Dakota.

In most sections, the Dakota sandstone is a porous rock. Therefore, it acts like a wonderful receptacle for rain water that flows off the east slopes of the Rocky Mountains. The rainwater flows into the pore spaces of the sandstone, which conducts it along its bedding planes deeper and deeper into the earth's crust. If you stand in western Nebraska, where water is scarce, and drill through the Cretaceous rocks, you hit the Dakota sandstone, and since the surface of the Great Plains is much lower than the surface at the foothills of the Rocky Mountains, the water in the Dakota sandstone will rush to the surface, cold and filtered by nature, and provides what is known as flowing wells:



You will understand now that the sequence of layered rocks, and their structure, as you observe and record it in the various canyons on Philmont Ranch, are parts of a large and persistent geological plan that dominates the entire eastern slopes of the Rocky Mountains; and as a by-product of it, the Great Plains, fnom North Dakota to western Texas, are provided with fairly adequate amounts of excellent ground water. The amount would be even larger had the early settlers and communities shut the valves of their flowing wells when they did not need water. Instead, hundreds of them were permitted, year after year, to flow their full amount of water, the early settlers assmming there was an inexhaustible supply of it. Since the first decade of this century, the amount of water decreased, and pumps were installed. When even pumps did not supply enough water, it became clear that a water shortage was imminent. Since that time, conservation measures have been applied, and now the amount of groundwater in the Great Plains is generally adequate, but strict regulations of maximum discharge per well and county are in effect.

Whereas the eastward-dipping Cretaceous strata are a characteristic geologic feature of the eastern slopes of the Rocky Mountains, the many monzonite porphyry dikes and sills which you see in this area, are not. Clusters of volcanic rocks, east of the crest of the Front Range, are found in this northernmost part of New Mexico and the adjoining portion of Colorado, as well as in Montana. The Spanish Peaks, which you ean see, about 70 miles north of the Philmont mountains, are two great eenters of these igneous rocks. But in most of Colorado and Wyoming, you can drive or walk all the way up to the crest of the Front Range without seeing volcanic rocks.

For some 2,000 feet west of the cliff of Dakota sandstone, there are no outcrops by the trail. Then you pass another ledge of sandstone. Notice that it too is composed of layers that dip eastward at about the same angles as the Dakota sandstone. It should be clear to you that the 2,000 or so feet between these two prominent cliffs are underlain by other rocks which here happen to be covered by talus and vegetation. If you were to map the canyon, you would have to leave the trail, and search both slopes for possible outcrops of these rocks. Perhaps there are scattered exposures, perhaps not. It might be necessary to spend several days in such a search, yet you might find nothing. If you are in danger of getting discouraged by such an experience, you had better recall an incident in the life of Thomas A. Edison. On the morning train from Menlo Park to New York, he used to sit together with other passengers whom he knew. One morning, one of them said to him: "Mr. Edison, I have noticed you look a little unhappy nowadays." "Well", said Mr. Edison, "For the past 5 weeks I have tried 325 different metal filaments hoping to find one that would be incandescent in an electric bulb. Not one of them is." His friend expressed his sympathy with Edison, and the colossal waste of time. "What do you mean, waste of time?" shot back Edison, "It was no waste at all. Now I know that these 325 alloys won't work."

If you are wondering what the concealed area may contain, it may pay you to look up your notes from the Cimarroncito trail. There below the Dakota sandstone, i. e., west of it, you passed quite a series of gray, greenish, and purplish shale and sandstone beds. You can see now why it pay to have complete notes on rock outcrops from every trip. As a matter of fact, these rocks are present in the Rayado Canyon, too, but here happen to be covered up by the talus debris. The cliff of sandstone at which you now are is, of course, an older rock than the Dakota sandstone. If you don't believe this, draw again a cross-section, as you did at the Cimarroncito trail, draw your skyline, mark W and E in the usual way, and draw the Dakota sandstone, dipping east at about 30 degrees. Then leave a space of about 2,000 feet free, and draw the second sandstone, dipping at about 45 degrees east. This bed, obviously, underlies the Dakota, and it is therefore older.

As you continue west, up Rayado Creek, outcrops continue to be few, but after about ½ mile, you will notice small chips and boulders of a reddish and purplish rock. Keep an eye on them. Soon you pass an outcrop of this rock on the south bank of the creek. It is somewhat disintegrated but still good enough to make out its composition. Note and record whether the rock is layered, about how steeply the layers dip and in which direction. Prominent in this rock are pink grains with cleavage, about 2-5 millimeters across. Take a few of them into your hand. If you have a hand lens, observe them. Does the mineral have one cleavage system, or more? Right you are, two cleavage systems, intersecting at about right angles. Other tests you can not well make, so you may as well know that the mineral is feldspar. In addition, you will probably guess correctly what the many glass-like colorless grains are. In short, you have a layered rock composed for the most part of quartz and feldspar grains. Such a rock is called arkose, or feldspathic sandstone.

It should be clear to you that this rock must have been derived from some other rock that was particularly rich in these two minerals. In addition, it has many larger pebbles. They, too, are reddish, seem to be composed of quartz and feldspar. Others are dark, and themselves layered. If you kept your eyes open to all the various rocks at and near the trail, you will now recall that you have passed many boulders in the stream bed that fit this description. It seems, therefore, as if the source rocks for the arkose crop out somewhere west of you. Watch from now on the boulders in the creek, and you can not fail to spot the pink or red ones, as well as the dark greenish-gray layered ones. They are altogether different from rocks you have so far seen in any outcrops. If you kept accurate notes on boulders seen about $\frac{1}{4}$ mile west of Cimarroncito Base Camp, you will find descriptions that fit your boulders here closely. Apparently, then, a whole formation of rocks is somewhere in the more westerly terrain, but you have not yet seen outcrops of it. In geological work, it is important to notice all kinds of loose blocks and rock specimens. With experience, you learn to save much time through such incidental observations. No geologist has so much time that he could hope to visit every ledge of rock in each region. He saves time by visiting the largest and most rewarding outcrops, and by arranging his field trips so that he passes the maximum number of rock formations in the least time. To become acquainted with all the formations on the Ranch, you know now you must extend your trips farther west.

At the moment, then, you are walking across a formation of arkoses, purple sandstones, and shales. Had you more time to go off the trail you would find numerous outcrops of these rocks, all dipping east. It is this series of rocks, older than the Cretaceous system, that you studied on your trip west from Cimarroncito Base Camp.

A short distance west, you pass on the north side of the creek a large talus slope of purplish basalt boulders. The rock crops out at the rim of the canyon, and remains in evidence for several miles.

About at the west end of this talus mass, you can see forward to the right (north canyon wall), several large conical red promontories. As you approach them, between the pines, you see crags of grayish color. If they are not too far above the trail it may pay you to climb up to one of them.

It is a fair guess that if you had never in your life seen an automobile, and the first one were shown you after every single bit of its steel, brass, upholstery, rubber, and glass had been smashed to bits, and the whole shapeless lump cemented with Duco, you are not likely to recognize it as an automobile, to say nothing of the brand! The ledges you now approach, are exactly this, except that ordinary rocks have been used. For nearly two miles, every single ledge, despite its resistance to weathering, turns out to be an extraordinarily crushed and recemented rock, so utterly distorted and fractured that you can not tell much about it.

Every block or specimen you touch with the hammer, crumbles into tiny bits and slivers, and you quickly realize that this rock has been as completely smashed as a bottle you hurled against a wall.

If you have never seen such a rock, it is worth while to examine it carefully, and ponder the situation for a few minutes. To crush with a sledge hammer a boulder, about 1 cubic foot in volume, takes a strong man about 10 minutes. A tough rock would take much longer. Here, you can walk along completely crushed rocks for nearly 10,000 feet, and if you have the time you can climb up about 400 feet, and the crushing would not diminish. If a tunnel were driven into the northern canyon wall, it would encounter the same mashed rock for probably more than a mile. And my guess is that the same contition continued downward for well over 10 miles. One cubic mile has 5,280 x 5,280 x 5,280 cubic feet of rock. Our strong man would really wear himself out on such a mass.

When you realize the immense volume of completely crushed rock, you will understand that a very powerful force must have acted on it. It has. You can find the story in the huge pyramids that tower high above you. If you wish to examine them, you had better take 2 hours for the trip. If you have the time, you will enjoy the geology just as much as you will be annoyed by the inconvenience of passing over large, insecure masses of talus debris.

In case you don't have the time to climb up there, I give you a brief description. About 400 feet above the valley, the ledges of breccia (an Italian name that denotes sharply fractured and recemented rocks) end, and about 50 feet above begin totally different rocks. They are all volcanic, but of the most diverse kinds. From the distance you can make out that they are in crude layers, dipping at about 30 degrees to the northwest, into the mountain. The layers and lenses are from 3 to 10 feet or more thick. Some consist of solid, dark gray basalt, others are ashes, i. e. millions of small volcanic fragments loosely cemented together, but with abundant pore spaces and cavities between. Other zones consist of large basaltic fragments, 1 to 5 feet across, some layered, others compact, some red, others gray or black, The whole assemblage forms a huge pile, like a massive plug, about a mile across. If you worked your way up to these impressive cliffs, you could look across the canyon, and see before you, to the south, the large Ocate Mesa. All of it is capped by one immense lava sheet, about 100 feet thick. Where did it come from? You don't see a large volcano. Well, you stand directly under one.

A volcano, as you can see illustrated on page 21 of your Merit Badge book, has a feeding channel that leads into great depths of the earth's crust whence all the molten lava and ash came. Volcanoes of which you have seen pictures, like Mauna Loa in the Hawaiian Islands, Lassen Peak in California, or Vesuvius near Naples, Italy, are active ones. They raise the earth's surface by the expelled material. However, like all living things, a volcano and its eruptions die some time. Some volcanoes have "lived", i. e. erupted for only a few years. Others are a few centuries old, some probably several thousands of years. After the last lava and ashes were blown out, an extinct volcano is a mountain no better or worse than any other mountain, and as such is subject to the removal of its rocks by the never-ceasing forces of the atmosphere: rain, wind, frost action, and the sliding of loose rocks on steep surfaces. If enough time has elapsed to remove all, or most, of the volcano proper, the feeding channel will finally be the only part of the edifice that survives. And it will, of course, survive for a very long time because it leads to very great depths of the channel. You can not tell how high the former volcanic pile above may have been just as you can not see the feeding channel of Vesuvius or Lassen Peak. Only the one or the other part of a volcanic center can at one time be exposed to man. Our volcanic plug, then, has about the shape of a vertical tube, or perhaps a steep-walled funnel, with a diameter of perhaps a mile. Once the whole Philmont Ranch has been surveyed geologically, we will know the dimensions much more accurately. Perhaps you will be able to contribute to our knowledge of it. As the crushing of the wall rocks is confined to the vicinity of the volcanic plug, we may assume that the first eruption was such a violent burst that it shattered all rocks within a radius of about half a mile.

The lava that is part of this plug, is identical with the basalt south of this canyon, and it is almost certain that this plug is at least one, perhaps the most important, feeding channel by which the basalt was extruded that flowed out as a huge sheet to the southward, burying under itself valleys and hills of that day. It will take many thousands of years before this lava sheet, too, will have been removed by erosion.

When you do geological field work, you are well advised to take time out, every now and then, (a steep hill you are climbing is a good place to do this!), sit down, and try to put together all your observations and their meaning. At this stage, you can see that Geology is an historical science in the sense that we must fit all observations into a sequence of events, or a succession of processes. Whether you wish to understand the meaning of scenery, the formation of a cave, or hope to discover an oil field or a mining claim, the correct understanding of the gradual evolution of every part of the earth's crust is the fundamental objective. In this respect, Geology differs from all other physical sciences. Without this guiding principle, all your discoveries are like curiosities of Nature, without rhyme or reason, meaning or consequence.

One conclusion you can draw: If this plug on the north bank of Rayado Creek fed the lava flows that spread southward, the present canyon must have formed after the volcanic eruptions had ceased. We now have several important items that allow us to reconstruct the geological history of this region. (1) The basalt, as you saw at the start of this trip, just north of Abreu Base Camp, lies above the Cretaceous Pierre shale. That means it was erupted later than the Cretaceous time. (2) The volcanic eruptions that produced the great basalt mesa to the south, and smaller ones east and north of you, must have ceased so long ago that in the subsequent time the erosion could remove the volcanic pile above the basalt plug, and Rayado Creek could erode its deep notch across the basaltic rocks, into the underlying Cretaceous strata. (3) Before the Cretaceous time, streams deposited the reddish shale and arkosic debris you saw before you came to the basalt plug. (4) We know that there are rocks even older than these red arkoses. Very probably, they are at the surface some distance west of the plug, because we have found them as boulders in Rayado Creek.

As you climb down from the steep basalt talus slopes, and pass again at the base of the gnarled gray ledges, you naturally wonder what these rocks originally were. This has been a stiff and exerting climb. And as you have no microscope at your disposal yet, you need again a little reward. The breccia is the first outcrop of the last, oldest formation in the Ranch, of which you have seen the red and dark greenish-gray, crystalline boulders in the creek, and pebbles in the red arkose. Nowhere else will you encounter these rocks in such a deplorably mashed and crushed conditions. This can happen, and if you are a novice, you should collect specimens from such rocks, take them with you, carefully labeled and wrapped in paper, and keep them for future reference. A microscopic examination would still disclose the mineral composition and nature of these rocks. In fact, if you continue on the trail toward Rayado Base Camp (also called Fish Camp), you will pass these rocks for many miles where they lend themselves much better for close study.

TRAIL FROM WEBSTER PASS TO RAYADO BASE CAMP, AND ON WEST

Trail from Webster Pass to Rayado Base Camp, and on west.

The road to Webster Pass leads through many miles of pine forest, which accompanies you from the low elevations at which you start, to near some of the highest elevations in the Ranch area, almost 10,000 feet. As you observe from the car, the mountains are deeply dissected, ravines and canyon walls are well over a thousand feet high, and steep. Between the trees, you rarely see large rock outcrops, but loose boulders are much in evidence. This is a common condition in the southern Rocky Mountains, which makes geological work difficult. To make a reliable map showing the distribution of the various formations, a geologist needs many evenly distributed outcrops. They need not be huge, but they should be large and fresh enough to permit him to identify the rocks, and secure specimens for subsequent study.

If you must map the rock formations in terrain that has only boulders, you can not determine the boundaries and limits of the formations with great accuracy because each boulder may have moved downhill an unknown distance from its original resting place. Should you, therefore, locate a boulder of quartz monzonite porphyry on a hill slope at a known elevation of, say, 7,320 feet, all you can say is that this rock occurs, very probably, at an elevation x feet higher than 7,320 feet; but how much higher you can not tell. If you are in a region of many dike rocks, and you find a loose block of such a rock at the intersection of 2 trails, at a trail-stream intersection, or any other easily identifiable point on a slope, it would not be correct to show an outcrop of that rock at that point on the map.

You will appreciate, therefore, that the mapping of geological formations at the higher elevations in the area - apart from the greater distance and terrain problems - is much more difficult and slower than in the relatively open low-elevation country. Even with the best effort, the final map is bound to be less reliable than the one for the flat Cretaceous shale areas. Nevertheless, progress is possible, and on this trip you will see what rocks underlie most of the higher mountain slopes.

Along the half-mile or so where you walk up to Webster Pass from the east, you do not pass a single rock outcrop, nor do you see many boulders. But don't fail to observe the material under your feet. Directly as you started out from Cimarroncito Base Camp, you noted a small area of gravel near the trail. On this trip, you will constantly be walking over small bits of rock, mineral fragments, and small, rough stones. At the moment, you do not know where this loose debris comes from, but you make your usual observations; (1) The common colors of the fragments.

(Fill out). - (2) If you think you can identify any particular minerals because you feel sure you have seen them before, and can recognize specific properties or features, write them down.

(3) Common size, shape, and dimensions of the fragments.

After a short distance, you realize that there are about 2 or 3 different kinds of material. Presumably, you will be inclined to distinguish fragments of individual minerals from small rock fragments, each composed of more than one mineral species. If you compare this with what you found when you walked over the slopes of the minette hill, you will agree that the rock in these fragments is definitely coarser-grained than the minette shale, and not as homogeneous as the brownish-gray shale. With a little discrimination, you can recognize the two principal types of material, one dark and shiny, the other granular, of pink, whitish, yellow color, and - we may as well agree on this one point - associated with quartz.

From Webster Pass, you have a fine view to the south and west. Through the trees, you can see the flat skyline of Ocaté Mesa to the southward, whereas cliffs of pink and reddish hues are on your side of the canyon. At the pass, a few feet south of the trail, is your first outcrop. If you have plenty of time, walk over and look it up. If you are in a hurry, go on. You will see better exposures farther down. Further, <u>for your information</u>: The best and most interesting outcrops are directly north and west of Rayado Base Camp. It will take you about half an hour to reach the camp from Webster Pass. So try to economize your time so that you have enough left for the study of the cliffs by the Camp.

The following information will assist you in studying the rocks of the Rayado Canyon area. (1) There are ledges of "red" rocks, and "dark" rocks. Both rocks may appear in one and the same outcrop. (2) All rocks are sufficiently coarse-grained that you can, and should, observe and identify at least the more common minerals after a little practice. (3) The dark rocks are practically everywhere layered; the reddish rocks may, or may not, show layering.

The first outcrop of bedrock at the trail is a short distance from the pass. Stop briefly here, and examine it. Is the rock layered? If you can recognize layers, record, as usual, the direction in which the layers dip, and about at what angle. Use compass or the sun for general orientation. If you found layers, do they dip in the same direction as the Pierre shale, the Dakota sandstone, and the purple and reddish sandstones you saw west of Cimarroncito Base Camp, or not? This is a very important matter, as you shall see in due time.

Perhaps this small outcrop is not suitable for examining and answering all these questions. But even if in a hurry, make it a point to stop for just a moment here and there, to assure yourself that nothing important in a series of small, inconspicuous outcrops is missed. If you were new in this region, and nobody told you that at the Camp there are better exposures (nobody told me!), you would certainly stop at some length and obtain all the data you could from even very small showings of rock.

As you now proceed along this trail westward down to Rayado Canyon, you will note that the small outcrops of rock, just like the rock debris east of Webster Pass, exhibit two different kinds of rock: the one dark, usually well layered, commonly with greenish hues, and in some places full of strongly reflecting scales of a mineral already known to you and tested at some other trip. Fill out the name.
Not in every single ledge can you see it, but enough of it is there to leave little doubt about its identity.

The rock, however, is not mica schist as perhaps you are guessing. If biotite mica were the only dark mineral, you might call it that, but associated with it is another dark mineral which you learn but gradually to recognize: hornblende. The same mineral you found previously in which rock: In the ledges here, you have difficulty recognizing it because it is intimately mixed with mica. However, hornblende under almost all conditions develops slender little prisms, and if you have a dark, unweathered, fresh surface of this rock, and you hold it in the sunlight, you will be able to observe hundreds of these minute needles, all pointing in about the same direction, - as if you had drawn hundreds of parallel short chalk marks on a blackboard. Because hornblende makes up a larger volume in this rock than mica, the rock is called hornblende schist, or amphibole (remember from an earlier page that hornblende and amphibole are two names from the same mineral group. Hornblende means in German: "horny substance with cleavage", and amphibole, in Greek, means "the deceiver", because some varieties of this mineral deceive you easily). Before you can observe more about the nature of this rock, you should inspect a few outcrops of the reddish rock. These, in the sunlight, show abundant pink or flesh-colored crystals, some with excellent cleavage planes, and so large that you can conveniently pick out individual crystal fragments and turn them around in your hand. If your eyesight is at all good, you will easily identify two systems of cleavage planes, intersecting at very nearly right angles; perhaps, if you have enough time for your examination, you will recognize a few grains that show the third, imperfect cleavage system. By now you should have no further doubts that you have again feldspar crystals before you. Where, and in which rock, did you see this mineral for the first time?

Closely associated with these feldspar lenses is quartz, in individual small grains, glassy and, as usual, without cleavage; or in larger, whitish masses and veins. Upon close examination, you will note a few other minerals in the reddish rocks. White or pale yellow to greenish mica (muscovite), also a coal-black mineral at a very few places, of prismatic shape, and commonly a number of these prisms are joined together, like a pencil of rays. However, if you fail to find this mineral on this trip, you need not be disappointed. Somewhere in the western mountains, along a trail or a creek bed, you are likely to pass a block. This black mineral, like quartz, has no cleavage, and if you can pry a crystal loose from the surrounding rock, it will show you its lateral faces, six in number, just like a pencil. This is tourmaline. In some Rocky Mountain localities, tourmaline crystals over a foot long have been found. On Philmont Ranch property, so far, only small crystals have been found. But keep your eyes open. You may be the one to find a larger one.

As you follow down the trail to the Camp, you will note that both the dark and the reddish outcrops remain small, say, 2-10 feet across. Try to figure out their general shape, just as you did with the quartz monzonite porphyry dikes. And do not neglect to ascertain, from time to time, the direction in which layers of these rocks dip, and at what angle.

After many turns and loops, the trail brings you to Rayado Base Camp, at the junction of Rayado and Agua Fria creeks. After refreshing yourself, and inspecting the luxurious layout of this beautiful camp, we may resume our study of the local rocks. Go to the prominent ledges, directly northwest of the Camp, back of the stables, or on the north bank of Agua Fria canyon.

If you stand about 300 feet upstream from the stables, where the beaver dams are ponding the water of Agua Fria Creek, and look northeast, you can make out three different rocks. At the lower right (east), just north of the stables, you have prominent reddish ledges over a trail which leads to get past the creek. At the lower left, you have a large ledge of the dark rocks you saw in many outcrops when you walked from Webster Pass down to Rayado Base Camp. And the upper half of the embankment is occupied by a large group of dark gray cliffs. We may begin to examine the lower left, dark ledge. If you missed the layering in the smaller outcrops by the trail, you will certainly agree that this large ledge is well layered. Take your time in determining the direction and angle of dip of the layers. If you have it, look up what you recorded for the outcrops along the trail. If you observed correctly, all your directions should be in good agreement. The layers dip at about 40 to 55 degrees to the southeast. If you come to another conclusion, try to discuss it with somebody whose eyes are geologically trained.

All right, if you now stand before this ledge, and realize that for at least a mile or so to the northeast and east all the dark layers of the amphibolite dip to the southeast, you will realize that this is completely at variance with the northeasterly dip of the Cretaceous Pierre shales, the Dakota sandstone, and also the purplish, green, and gray shales and sandstones that underlie the Dakota sandstone. All these strata dip uniformly to the northeast and east. Now supposing you make another little experiment with your hands: Hold your right hand so that the index finger points diagonally forward to the left, horizontally, and let the palm slope away forward to the right. If you are facing north, your right hand represents the Cretaceous layers that dip at about 35 degrees northeast. Now hold your left hand so that your index finger is again horizontal, pointing diagonally forward to the right. Turn your palm until the back is sloping towards you at about 45 degrees, and let the two palms touch each other. Your left hand now represents the dip of the hornblende schist masses before you. You have a primitive model of two sets of strata, each many thousands of feet thick, but inclined in totally different directions. When groups of rocks are in such a relationship, you say that they are unconformable to each other, or that they are separated from each other by an unconformity.

Whether you will be able to see this unconformity anywhere in this area, I do not know. It has not been described by any geologist as yet, although from other places in northern New Mexico such contacts have been reported. Once again, you can see how much remains to be done before all the geologically important facts of this part of the Rocky Mountains will be known and carefully studied. At any rate, try to comprehend that in the Cimarron Range obviously two great blocks of entirely different rocks are involved, the one, occupying the eastern slopes, consisting of a great series of sedimentary rocks, shales, sandstones, arkoses, conglomerates, and so forth. It rests, or leans, on the high part of the range, and this, as you now can see before you, consists of quite different rocks, different in mineralogical composition, origin, and structure.

So far, little has been said about the red, purple, and greenish-gray sandstones and shales that underlie the Dakota sandstone. The age of the Cretaceous rocks you will in due time be able to check by means of characteristic species of fossil animal and plant remains for which this system is justly famous. But the exposures of the older purplish strata are poor within the area of the Ranch, and no fossils have as yet been found. Fortunately, in surrounding districts enough information has been gathered to permit the conclusion that these rocks were formed during the Jurassic, Triassic, Permian, and possibly the Pennsylvanian periods. In your Merit Badge book, on page 2, you will find out about how long ago this was. You will understand that we are dealing here with older periods in the earth's history than the Cretaceous. Now the really important thing is that occasionally the streams of these older periods already rolled pebbles of the same rocks that form the present Cimarron range. This should give you pause to reflect on an important matter: In magazines and books of general information, you find statements that so-and-so many million years ago, in a certain part of North America, there was a large volcano, a glacier, a mountain range, or an arm of the ocean. Very rarely do the writers add how that is proved. But geologists must, of course, constantly look at the evidence when they try to reconstruct events in the history of an area. For this particular region, you can say that the rocks which form large cliffs in front of you, and which apparently crop out over a very large portion of these high mountains, must also have stood at the earth's surface during these older periods, so that streams draining these slopes, picked up pebbles, just as they do now, and finally deposited them along with the debris of red feldspar, quartz, and much mica. Perhaps this will impress you, perhaps it won't. At any rate, you should realize that we can make some very positive and reliable statements about certain things. When you keep in mind that geological time is measured in millions of years, not just centuries or millenniums, like human history, you will at least admit that we are concerned here with times as remote compared with human history as is the space of the galaxy in comparison with the space of our solar system.

Some of us need a special stimulus to become enthusiastic about such things. If you need one, consider this: Supposing you are not in these mountains to piece together a certain geological story, but you have been hired by a mining company to explore this area economically, let us say for metallic ore deposits, such as tungsten, cerium, molybdenum, niobium, tin, or copper. You would then examine the reddish conglomerates, and if you find among the pebbles some that contain these metallic minerals, you would at once draw an important conclusion as to which rocks may contain deposits of these metals? When you keep in mind that it may take a day or more to map one single square mile of this mountainous terrain, you can figure out how much more effectively your exploration will proceed if you know in advance that only one group of rocks, <u>but not any other</u>, is likely to contain the deposits you wish to locate. Alertness in making geologic deductions, and an awareness that nearly every discovery in "pure Science" has its direct commercial applications will convince you that it pays to work out carefully these larger relationships between individual formations.

As a matter of fact, the present Cimarron and Sangre de Cristo Ranges seem to have been at least as large and as high as they are now. If you drive on U. S. Highway No. 64 from Eagle Nest to Taos, you pass for over 12 miles some of the same strata on the west slope of the range. Here they are not as coarse as some of the conglomerates in Philmont, but there are thousands of feet of them, and if you stop often enough, you can collect many well preserved fossils in these sandstones and shales. The range therefore must have been a highland that provided the streams of that time with all the debris to build up large piles of sediment around it. Every mountain range at the present time acts in the same way as a source area for stream debris.

The picture of a high mountain range that stood here back as long ago as the Pennsylvanian period, is only a momentary glimpse into the geologic past of this part of New Mexico. It would be wrong to assume that the Cimarron Range has been a mountain range ever since the Pennsylvanian period. Some time after the Pennsylvanian streams flowed off this range, the land probably sank, and quite a different scenery followed. But we are getting ahead of our story. Let us return to the ledges in front of us.

Before us are still the ledges of amphibolite and the red rocks. It is time now to find out something about their origin and nature. Geologists long before your time have tried to obtain fossils from amphibolites. They are so well layered they suggest sedimentary rocks. The layers appear quite undisturbed, and fossil shells might therefore be preserved. All these attempts have failed. It is the same with mica schist, and in some of the dark ledges in Agua Fria Canyon there is so little hornblende that the rock could be called a mica schist. If a geologist finds a fossil in mica schist, he writes forthwith an article announcing this remarkable fact. He publishes a photograph of it, and his friends are likely to drop in on him to see the remarkable find. Yet mica schist and amphibolites underlie many thousands of square miles in every continent.

It has taken geologists a long time before they figured out just why these rocks lack fossils. If we can observe the conditions that produce, say, a cubic yard of dune sand, or a ton of mud or gravel, we can pretty well understand how these rocks have formed on a larger scale in nature. However, no mica schist or hornblende schist has yet formed under the eyes of human beings, and no experiment has yet successfully produced these rocks. There are reasons for this. Nearly all the rocks you see are composed of minerals in which silica, or the oxide of the element silicon (SiO_2), is the most important single constituent. This oxide, when pure, appears as quartz, and you have seen it in many places. But as silica combines with other elements to form more complex silicates, it imparts to them the unpleasant property of requiring very high temperatures to form crystals. Furthermore, most of these crystals grow extremely slowly, and some have, so far, refused to form any crystals under laboratory conditions.

You need not go into all this detail, but two things are worth remembering: (1) Nearly all the minerals in the rock before you require temperatures above the boiling point of water to form: (2) Rocks, like mica schist and hornblende schist, do not form where volcanic lava has acted on ordinary surface rocks, although a rock like the Cretaceous hornfels, west of Cimarroncito Camp, has some minerals in common with hornblende schist and mica schist.

Many schists and amphibolites have been chemically analyzed, and it is known that a mica schist has the same chemical composition (and also the same layered structure) as mud and shale. There is very good evidence to show that if a shale will be brought into relatively deep levels of the earth's crust, say, 4 or 5 miles below the surface, it will be under sufficient heat and compression to start growing mica flakes; and if the shale had a certain amount of lime, it will develop both mica and amphibole crystals. Our hornblende schist and mica schist have almost certainly gone through such a process, and rocks of this kind are spoken of as "metamorphosed rocks". Metamorphosed, in Greek, means "of changed shape", and refers to the changed crystal fabric. The formerly powdery, fine-grained mud or shale is now composed of large enough flakes of mica so you can recognize individual crystals.

You will understand, then, that the frail shells of bivalves or other fossils are not likely to preserve their shape if the entire substance of the rock has been so thoroughly changed. This is thought to be the main reason why fossils in metamorphosed rocks are excessively rare. Yet a few have been found in various parts of the world, and they prove that many metamorphosed rocks are of the same, or of younger age than ordinary unmetamorphosed sedimentary rocks. Some time ago, it was thought that all metamorphosed rocks are very old. This has been disproved in recent years. A good many metamorphosed rocks are old, but others are not so old. The matter must be examined in each region, and judged on its own evidence.

So much for the dark schist in front of you. As you walk on, up Agua Fria Canyon, you will pass many more ledges of it, all dipping at intermediate angles to the southeast, and you will realize that this is a huge system of steeply tilted metamorphosed sedimentary rocks.

How old are they? To this question a geologist can not always give a direct answer, just as you can not if you meet an unknown man on the street. But you can use some common sense. The man certainly is not a baby any more because he walks on his own legs: and he walks along quite briskly so he is probably not yet over seventy. We apply the same reasoning when we try to figure out the age of a new rock. We may not know its exact age, but may know that it is younger or older than some other rocks whose age we do know. Do a little thinking, then, and write down your best guess.

Now we come to the red rock, in front on your right. We have been staring at this cliff for so long a time, we should be off to examine it. But it may be as well to stay at the observation point for another minute, because the story of the red rock is not so simple. The rock itself, as you have found out by now, is a rather coarse-grained aggregate of pink and yellowish feldspar crystals, with much less quartz in irregular grains or larger masses, plus still less mica, either musco-vite or the dark biotite. Rocks having this mineral composition, may be called granite although, when the grains are as coarse as they are in our ledge, most geologists call them pegmatite. Don't worry about that name. It is derived from a Greek gadget used on the stage, but we need not go into all this.

Now as you examine the ledges, you will find that the red rock, whether coarse- or fine-grained, appears as many lenses in and between the amphibolite. You can also see true dikes of the pink rock, for instance, in the cliffs on your left. They break across the layers of the hornblende schist. Remembering your experience with the quartz monzonite porphyry, you will consider them volcanic rocks, and about 150 years ago, it was assumed that if all volcanoes of the earth had been visited, and their eruptions and lava studied, some would be discovered that erupted granite lava. But there are none that do, and we now know that there probably never were any that did. Instead, many volcanoes have been found that produce a lava that resembles granite in composition, but nowhere are such volcanic eruptions actually connected with masses of granite. The two rocks carefully avoid each other. An enormous amount of work has been expended during the last 100 years to solve this riddle of the granite. It is, however, so complex that to this day the complete answer is not known.

For the rocks in Philmont Ranch, you can and should make the following observations: (1) Their mineral composition is nearly everywhere the same, and quite simple; (2) The majority of the granite outcrops are massive rocks. If they are layered, the layers conform to the layers of nearby schist and amphibolite; (3) Occasionally, stringers and dike-like offshoots extend from a granite or pegmatite lens across the dark rocks, and in some dark rocks you find thin films, nests, and quite irregularly shaped bodies of the pink rock. They may be coarse-grained, medium-grained, compact, or faintly layered; (4) In some outcrops, you can not draw sharp boundaries between the red and dark rock. Instead, the white or pinkish feldspar grains are scattered through the dark rock in all proportions and without sharp boundaries. When you stand in front of a true dike of granite that cuts across the layers of schist, you can hardly fail to assume that the granite was something like a liquid that was forced into a fissure of the dark rock, and pried the walls apart, an inch here, maybe more there. This interpretation is still favored by many geologists, and outcrops like these justify the belief that at least some granite is a liquid, deep in the crust of the earth, that will rush into any available spaces of the surrounding rocks. However, as you read before, liquid granite has never been observed to flow out at the surface of the earth. As it seems to break <u>into</u> other rocks, but fails to extrude at the earth's surface, such material, when solidified, is called an "intrusive" rock, whereas volcanic lava that does break through the crust, is called an "extrusive" rock.

These somewhat lengthy comments have been given here because the study of metamorphosed and intrusive rocks is much more difficult than that of ordinary sedimentary and volcanic rocks. As you walk from one ledge to another, and pass the endless succession of irregular masses of granite, pegmatite, or mixed rocks, on the canyon slopes you will remember the contrast between the simple layers of the Pierre shale, the purplish sandstone, or the gray Dakota sandstone, and these metamorphosed rocks, complex in origin and variable in composition and texture. In this part of New Mexico, however, the amphibolites, schists, and granite varieties are the most ancient rocks. They underlie the cores of the

Sangre de Cristo, Cimarron, and Truchas ranges, and continue as a huge complex in the Front Range of Colorado. Many striking mineral localities and many deposits of economically important metal minerals have been found in these rocks, though not within the area of Philmont Ranch.

If you have examined the many ledges of the dark, schistose amphibolite, and the numberous lenses and stringers of red granite, and if you have some strength left, you can examine the third ledge you saw from your observation point at the beaver dams. Remember: the top of the cliff north of them looks quite different from the metamorphosed rocks underneath. A brief visit to that ledge is well worth while.

You climb to the top of the red granite-pegmatite, and the red color of the loose blocks ceases. Many gray ones lie around, some firm, others full of holes and pore spaces. If you have previously walked along the trail from Abreu Base Camp to Rayado Canyon, and studied the great volcanic plug on the north side, you will feel like a veteran from the World War who condescends to take a shot gun and shoot a squirrel. At any rate, your geologically trained eyes will spot at once the texture and firm composition of this gray rock as typical of the basalt that underlies Ocaté Mesa, south across the Agua Fria Canyon. Right you are. This is basalt. Now walk to the base of the cliff. Is it all firm basalt? Almost, but not quite. If you walk slowly around the base of the cliff, you will find a few small showings of basalt-tuff. A tuff is volcanic ash, cemented together.

Some forms a firm, strong rock, some is so full of gas cavities that it is little more than loose bits of rock. The tuff lenses at the base of the lava cliff slope at about 30 degrees northwest. (You had better verify this. Never believe anything without first checking up on it.) To that extent, they do the same as the ash and tuff layers at the south base of the large plug, west of Abreu Base Camp. But obviously, the rest of the cliff is a much more modest affair. If you have time, walk on north, always along the eastern base of the basalt cliff. The going is a bit slow, but after some 300 feet you come to the end of the ledge. While you are up there, take a good look across Rayado Creek to the northeast. There are some interesting-looking outcrops, at exactly the same elevation as the base of your basalt cliff. Do not hesitate to go up there if there is time.

You can retrace your steps, following the basalt ledges back to the north bank of Agua Fria Canyon, and as you do, you will realize that this mass of basalt is quite small, perhaps 400 feet or so from west to east. If you were at the large plug, you will recall the interesting speculation we made there in regard to the age of the basalt, and how old or how recent Rayado Creek might be. You can see that this place here involves the same problem. Across the canyon, you have the immense mass of mesa basalt. Here you stand at about the same level as the base of that mesa, but in between is that deep ravine. How do you explain it?

The tuff at the base of our basalt cliff may mean that the first eruption started as an explosion of ash, and then a large basalt flow followed and buried it. But it is probably not necessary to assume that this basalt cliff is another plug or feeding channel of the basalt extrusions. Certainly the red granite and dark amphibolite ledges underneath show nothing comparable to the extreme crushing you saw at the base of the large basalt plug.

As you inspect the basalt ledge that faces the stream, you notice vertical columns. Basalt all over the world shows this. The columns tend to point at right angles to a surface that cooled the basalt when it erupted. Therefore, vertical columns form above a flat cooling surface; horizontal columns demand a vertical cooling surface. Try to figure out what kind of a shape (and there is a name for it!) a mass of basalt must have to show horizontal columns. - A familiar analogue of columnar basalt is cracked mud in a dried-up puddle. Here, too, the mud columns are at right angles to the cooling surface. Both features have in common that the substance has shrunken. The mud loses its water; the cooling basalt lava loses a large volume of associated gas and steam.

As you walk back from Rayado Base Camp to Webster Pass, you will notice by the trail quite a few blocks of basaltic lava. If you have extra time, climb up, some 400 feet after leaving the camp. You will find more cliffs of volcanic rocks there, and may find it interesting to determine the shape of these masses. - Ponder another point: If the basalt cliff on the north bank of Agua Fria Canyon is not a remnant of a feeding channel, how did the basalt get there?

TRAIL FROM RAYADO (FISH) CAMP TO ABREU BASE CAMP

This section of the trail gives a typical picture of the principal types of crystalline rocks that underlie the core of the Cimarron Range. The trail, accompanying the creek, follows a southeasterly direction, whereas all the layered rocks strike northeast-southwest (or nearly so). Thus the trail is a true cross-section, across the strike of the bedrock formations. As elsewhere in the crystalline rocks of the Cimarron Range, two principal rock types make their appearance: (1) Dark greenish-gray amphibolites (or hornblende schists), and (2) pink or light gray granite (in places layered, or foliated), blending commonly into the coarse-grained varieties known as pegmatite. These two rocks constitute, for the most part, a great system of parallel layers and lenses. There are practically no complications, and both structure and mineral composition of the rocks are easily learned.

The first ledge, about 1,000 feet southeast of Rayado Camp, on the southwest side of the trail, shows well layered, typical amphibolite, with layers dipping at about 25 degrees south. Some layers are darker and coarser than others. This is due to more amphibole (or hornblende; both terms denote the same dark greenish to black, prismatic mineral) and less of the light-colored minerals quartz, and white mica (muscovite). Two pink to maroon pegmatite lenses, 1-2 feet thick, are parallel to the amphibolite layers. This is almost the only ledge in which the amphibolite is slightly folded.

About 300 feet southeast, in the trail, the amphibolite layers dip at about 45 degrees southeast, and are accompanied on the northwest by a large pegmatite mass, partly in the creek bed. Prominent joints dip at about 60 degrees northeast. Here and in subsequent outcrops, it might be well to point out the great importance of fractures in rocks for the circulation of ground water and other solutions in the earth's surface.

The rocks in this ledge continue across the creek in a large cliff. "Last Mile Bridge". On the left (NE) side of the creek is a large ledge of pink pegmatite, accompanying amphibolite, some layers of which are rotten and brown, due to oxidation of the iron compounds in the hornblende and black mica (biotite). The pegmatite is conveniently located for a study of its principal minerals, and their identification. Nearly all the pegmatites in this area have two varieties of feldspar: the pink potash feldspar, or orthoclase, and the white soda-lime feldspar, or plagioclase. Occasionally, the pink feldspar in pegmatites shows wavy, white or grayish, thin zones. This variety is known by a special name, perthite. The thin wavy zones are very thin plates and films of plagioclase within the more voluminous orthoclase. It is generally thought that when these crystals originally formed, they were homogeneous. But upon cooling, the two different types of molecules separated into these thin films. It can also happen that white feldspar is the potash-bearing variety, but where pink feldspar is present, the white one is nearly always plagioclase. Cross gate in wire fence. Above it, on the north side of the canyon, are large pegmatite cliffs. They are steeply dipping lenticular masses that reach nearly all the way up the slope.

150 feet southeast, the trail crosses over to the southwest side of the creek. Soon afterwards, the north bank exposes large plates of dark gray amphibolite, dipping at 60-70 degrees southeast. This is a very characteristic view of the structure of the amphibolite formation in this entire canyon area. Each layer, 1 or more feet thick, can be followed along its course for over 100 feet. Note that these layers are merely tilted not folded. If folds were present, one would almost certainly see the places (apices) where the layers bend around the axis. There are apparently no such places anywhere around.

After an interval of about 1,000 feet where the trail runs over talus debris, it skirts a steep ledge of pegmatite on the south bank of the creek. Here the rock is layered in places. The layers dip at about 30 degrees to the southwest. At the southeast end of this ledge, the trail crosses over to the north bank. The pegmatite continues here, and shows many large feldspar crystals. The reflecting cleavage surfaces reach the size of a man's palm. At the ford, there is a light gray quartzose lens in the pegmatite. Just possibly this is a small mass of a former sandstone, metamorphosed to quartzite, and so thoroughly soaked by the pegmatite that some feldspar got into it. The rock might be called a quartzose gneiss. This rock continues for some 120 feet downstream on the north bank. The rock shows well developed layers, and they dip in the usual direction, to the southeast, at about 75 degrees. The resistant rock makes a prominent reef in Rayado Creek. Note also the sharp fractures. Nearly all brittle rocks have them.

Farther southeast, the quartzose gneiss is interlayered with dark, thin amphibolite layers, and this rock increases in volume farther southeast. At one place, where the trail skirts the steep northern front of a prominent ledge, many loose slabs of amphibolite show nicely the individual hornblende crystals, as black thin needles, about 1/8-inch long. They show best in light-colored, muscovite-rich blocks, and here and there, the hornblende needles are concentrated in little radiating clusters, set in the white, glistening micaceous base.

The trail crosses and recrosses the creek at short intervals now.

Near the east end of this large group of steep ledges is a beaver dam (incomplete as yet), and the creek makes a sharp right-angle curve, turning from east to south. At the knee of the stream, fine-grained pink gneiss dips at about 30 degrees south.

Again, the trail crosses the stream at short intervals because so many steep cliffs are crowded together now that there is not much room for the trail. Many of these ledges display typical, coarsely crystalline pegmatites, and it is impossible to overlook the many large cleavage fragments of feldspar. It will be noted that all larger cleavage surfaces are composed of individual, small surfaces that have nearly, but not quite, the same orientation. Such "mosaics" are the normal thing in rocks that have gone through deformation and uplift. The originally large and uniform crystals have been strained, not quite enough to rupture each crystal, but enough to dislocate nearly every individual internally. The microscope shows that these small dislocations go to much smaller dimensions.

Farther east, amphibolite reappears, striking northeast, but dipping to the southeast as well as to the northwest, and near the eastern end of the tract, the rock becomes massive and somewhat coarser-grained, with many small pink crystals, probably orthoclase.

At this point, it may be well to explain to the Scouts what an amphibolite is. Chemically, these rocks agree closely with the composition of basalt lava, but also with that of calcareous shales. In other words, where rocks have been metamorphosed (and all amphibolites are metamorphosed rocks), two rocks of entirely different origin can give rise to the same metamorphosed rock.. It is always desirable in geology to ascertain the origin of rocks. This ledge of massive amphibolite helps. A calcareous shale is a sedimentary, i.e. layered rock. Although the process of metamorphism replaces the original minerals of the sediment with another mineral association, it rarely can do away entirely with the layered structure of a sedimentary rock. A massive amphibolite, therefore, is suggestive evidence that the rock was not a sedimentary rock to begin with, but a basaltic one. Although some basalt lava is also layered, this is the exception, and not the rule. On the highway (U. S. Highway 64), west of the Palisades of the Cimarron, there are many fine outcrops showing amphibolites grading into fine-grained basalt that has only slightly been metamorphosed. Therefore, there are 2 lines of evidence for the basaltic origin of these particular amphibolites. Well layered amphibolites can also be of basaltic origin, in the sense that they may represent metamorphosed basalt ash, or tuff, which is commonly layered.

At the east end of the massive amphibolite, many pink granite lenses penetrate the rock, which here becomes again better foliated, or layered. The trail now crosses over to the south side of the stream, and climbs over a large mass of pegmatite, with pink and white feldspar, and a more generous admixture of white mica (muscovite) than is common here. Biotite and quartz are also present.

At the east end of this pegmatite promontory is an obsolete shelter on the right side of the creek. About 80 feet southeast of the shelter, on the right bank of Rayado Creek, the southern contact of the pegmatite mass is exposed. The surface dips at about 55 degrees north and the pegmatite rests on fine-grained feldspathic gneiss that has the regional southeasterly dip. Its layers are cut off by the contact. Directly opposite the shelter, on the northeast side of the creek, is a white quartz vein of irregular shape in the pegmatite ledge.

The trail crosses on a wooden log bridge over to the north bank of the creek, and pegmatite with much muscovite continues there. Pink fine-grained gneiss is exposed east of the pegmatite. Some 100 feet east, on the north bank of the creek, and directly by the trail, can be seen the floor contact of an irregularly shaped pegmatite, which rests on the fine-grained gneiss.

300 feet east, the trail crosses to the south side at a steep rocky gorge. Pegmatite is again the most prominent country rock, and about 200 feet east, on the north bank, is a steep tan-colored pyramid of pegmatite and fine-grained gneiss, nearly 200 feet high. Only loose blocks are on the south side where the trail goes; but about 150 feet farther east, pink fine-grained quartzose gneiss is passed in the trail.

About 40 feet downstream, the trail crosses over to the north bank. Yellow, rotten gneiss, with amphibolite zones, strikes northeast-southwest here, dipping at about 75 degrees southeast. The amphibolite from here on east looks crushed, and chunks of it appear in twisted position in the pegmatite.

This is the last outcrop in which the crystalline rocks exhibit their normal features. On the north bank, east of here, appears the west end of the huge talus pile that strews the southern slopes of the great volcanic plug, which culminates in the two spectacular pyramids of brick-red color. Several outcrops of the crystalline rocks are passed just north of the trail, and despite the immense cliff surfaces it will be very difficult for anyone to recognize the familiar amphibolite, fine-grained gneiss, or pegmatite. All rocks have been crushed by the force of the volcanic eruptions that blew the lava and ash through the crust of the earth, and every single ledge is shattered by thousands of cracks, even though the rocks hold together fairly well. In a few of these brecciated cliffs, however, coarse-grained, massive hornblende rocks are still identifiable, but their relationship to the surrounding granitic rocks is effectively obscured by the crushing and the staining of all crack surfaces with iron oxides, silica, or other coatings of fine-grained cementing material.

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