PAGOSA AREA GEOLOGY

Geology is the study of the Earth's rocks, minerals, structure and processes. The first real geological science was organized in the middle 1800's in England, Scotland, and Europe as an attempt to understand how mineral deposits formed and why the modern landscape looked the way it did. The first geologists faced some difficult questions. Why did some rocks cut cleanly across other rocks? Have volcanos, earthquakes, and erosion always worked at the same rate, or have they changed with time? How long does it take to build a mountain and to wear it away? Why do we find remains of plants and animals that have turned to stone, and are encased in rock? Why do we find sea-floor creatures fossilized at the tops on mountains and in the deepest deserts where water never flows? How old is the Earth?

Many of geology's questions are still unanswered, but geologists have begun to understand the broad outline of the Earth's structure and how it has produced the rocks and minerals we see today. In the Pagosa Springs area, we can see a small part of that complex and beautiful machine that is our world. This field trip will cover only a short piece of geologic time, from the Dakota Sandstone to the sediments being laid down today - a trip of about 100 million years. As long as this seems, it is only about 2 percent of the earth's estimated 4.6 billion-year age. Yet it spans the death of the dinosaurs, the rise of the mammals, the birth of the Rocky Mountains, and the age of Mankind.

This paper is designed as a self-guiding road trip. The road log below lists **mileages between points of interest** and **total trip mileage**. It begins at the Vista Clubhouse, at the Pagosa Lakes office at 230 Port Avenue and follows US Highway 160 through Pagosa Springs to the Overlook below Wolf Creek Pass. Driving directions are written in **BOLD LETTERS**. It helps to read ahead before you arrive at a stop or point of interest. Highway 160 is a busy road, so be careful and considerate.

The accompanying map shows the local features and the major geological formations along the trip route. The map symbols, such as **Kmv**, refer to the geological formations described in the road trip log. A large-scale geological map of this part of Southwest Colorado is available from the United States Geological Survey in Denver or on the internet. A detailed outline through time of **PAGOSA AREA GEOLOGIC HISTORY** is included, with references, in the table following the road log.

MILEAGE **PAGOSA AREA GEOLOGY ROAD TRIP LOG**

Between Points	Total Distance	Points of Interest and Driving Instructions
0	0 Map symbol **Kdb**	Start at the Vista Clubhouse parking lot at 230 Port Avenue, off of Vista Boulevard. Leave the parking lot and drive to US Highway 160; **TURN LEFT (EAST) ON US 160.** The road is on the Dakota Sandstone and Burro Canyon Sandstone, locally mapped as one formation (map symbol: **Kdb**), which forms the floor of the wide valley west of Pagosa Springs. The orange-brown color of the stone and the soil that forms from it is the result of oxidation (rust) of the iron contained in the sandstone. Freshly broken stone is gray or white. The Dakota supplies most of the building and decorative stone used in the Pagosa area. The Dakota was laid down as sand and silt in a shoreline environment. A Cretaceous Period sea was gradually overrunning the land between 100 and 80 million years ago, drowning the Dakota river deltas and swamps and beaches. As the land was submerged, the sediment being deposited changed from sand and silt to ocean-bottom mud. It is this difference in sediment type which allows geologists to read changes in the ancient environment from the rocks formed in them. The transition from sandstone to shale marks the end of the land and beginning of the sea in this area, and provides a standard way to divide the rock formations. The Dakota weathers in roughly rectangular fragments because of joints (fractures) in the rock. These joints are the result of mountain-building forces which fractured the brittle sandstone. Erosion has stripped away the softer overlying shales and left a wide, flat valley of pine forests and well-drained soil.
2.4	2.4 **Kml**	The highway is now entering a landscape of Mancos Shale, the rock layer that lies above and is therefore younger than the Dakota Sandstone. The Mancos Shale is locally mapped as the lower (**Kml**) and upper (**Kmu**) shales. It weathers into soft rounded hills and dry, steep slopes, with poor soil development. It is made up of fine clay which makes wet-weather driving such an adventure. The dark gray color is from abundant carbon, the remains of plants and animals which died and settled to the ocean floor. The Mancos Shale was laid down in thin layers of fine mud as the Cretaceous Inland Sea widened and covered the old shoreline of the Dakota-Burro Canyon. The sea was about 300 feet deep and generally very quiet. Mud accumulated at the rate of 1 inch every thousand years, except for rare events when storms or floods on land flushed sand into the sea basin. The Mancos Shale is about 2,000 feet in maximum thickness, representing possibly 20 million years of slow deposition. In its dark layers can be found ammonites (coiled shells up to 3 feet across), fish scales and teeth, oyster and clam shells, and other fossils of vanished marine life. Most are very fragile and will not preserve once exposed -- the shale is too soft.

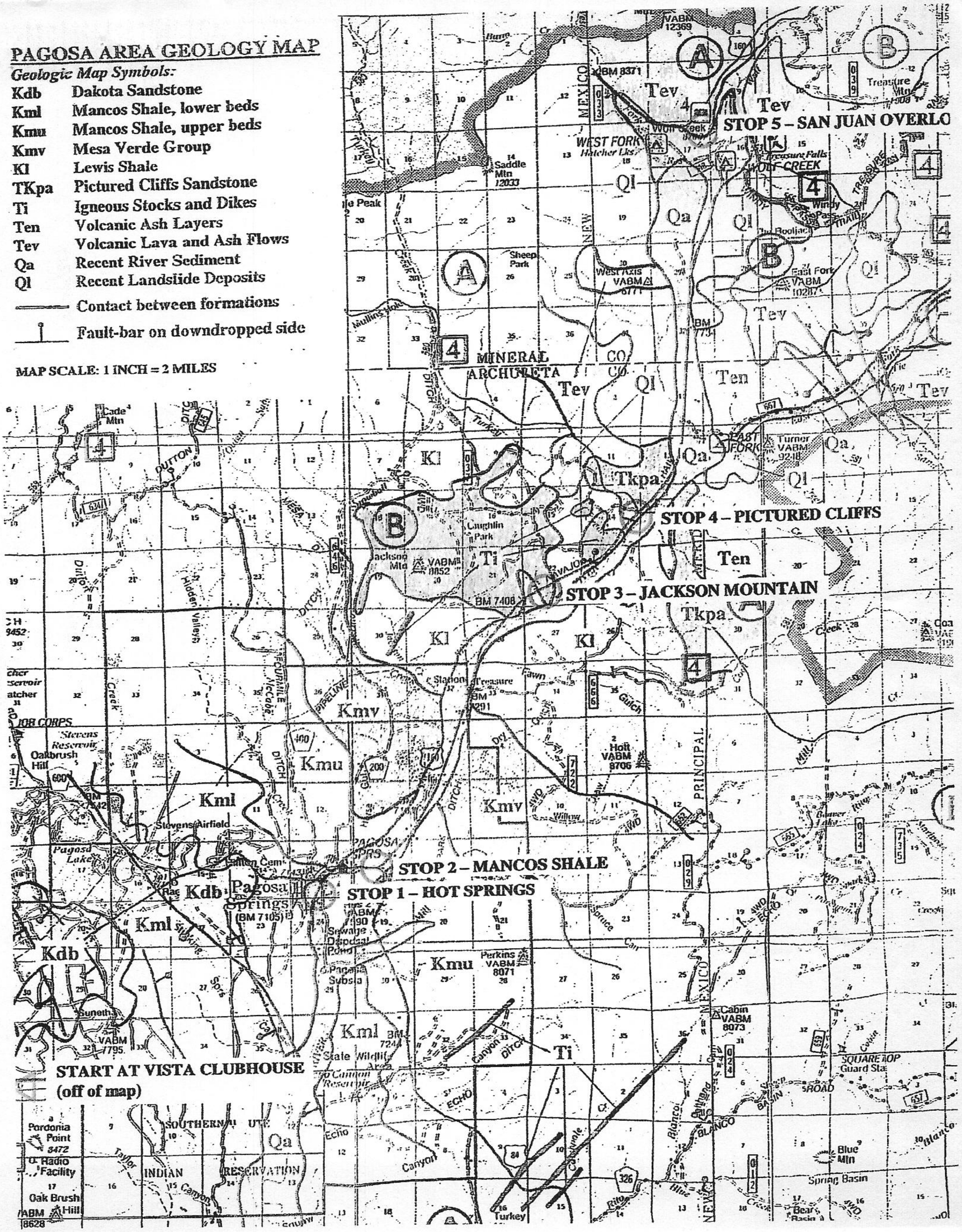
0.3	2.7 **Map symbol** **Kdb**	As the highway climbs Put Hill (named for a man named Puttman), it crosses a fault -- a fracture in the Earth on which there has been some motion between the two land masses. The land to the west (Pagosa Lakes) dropped relative to the east (Pagosa Springs area). The top of Put Hill is Dakota Sandstone east of the fault, which should be below the Mancos Shale rather than above it -- this is what demonstrates the movement of the fault. The older rock is above the younger rock, reversing their proper relationship.
0.7	3.4 **Kml**	Continuing to the east, the highway drops into the Mancos Shale again. The hard Dakota Sandstone at the top of the hill has preserved this structure, called a fault scarp -- the change in elevation across a fault. The Put Hill scarp probably formed many thousands of years ago -- it is not recent, and little movement seems to have occurred since it formed. Ahead is the San Juan River valley and the spectacular San Juan Mountains beyond. The town of Pagosa Springs is built on Mancos Shale, eroded and carved by the river. The San Juan is a small river these days, but during the last glacial period (which ended some 18,000 years ago), it was a torrent of melt water and did some serious eroding. Most of the landforms we see today were the product of those years. Very little has happened in the geologically short time of the last 15,000 years.
2.6	6.0	**STOP 1 - AT THE DOWNTOWN TRAFFIC LIGHT, TURN RIGHT AND CROSS THE BRIDGE.** Park at the rear of the Spring Inn at the Pagosa Hot Springs sign. This is the main pool of the Great Pagosa Hot Springs, with water at nearly 180 degrees. The spring is fed by surface water that sinks into the ground along fissures, is heated by the hot rock below, and rises through the throat of the main pool. This plumbing system is quite complex and includes numerous other smaller springs and seeps, and may extend many miles across the land and many hundreds of feet in depth. The high mineral content of the water comes from the rocks below (Dakota Sandstone and Mancos Shale). The central pool lies atop a broad, low mound made of tufa or travertine (a type of limestone) deposited over thousands of years as mineralized water spilled from the pool and cooled, leaving a thin layer of minerals behind. Although the spring is located within rocks that are 70 to 80 million years old, it is one of the youngest geologic features here. Hot springs do not generally last very long in the geological record -- their heat sources die, their plumbing systems clog, their water sources dry up. The Pagosa Hot Springs may have started its life as a geyser, and it is now in its old age. It will probably fade away in the next fifty thousand years or so. Eventually, erosion, dissolution by rainwater and snowmelt, and the San Juan River will wear away the layers of travertine, and the springs will vanish forever. In geological terms, nothing is eternal. **RETURN TO HIGHWAY 160 AND TURN RIGHT (EAST) AT THE TRAFFIC LIGHT.**

1.0	7.0 **Map symbol** **Kmu**	<u>**STOP 2 - TURN RIGHT**</u> into the parking lot of the Junction Restaurant and drive to the back of the lot. This is an exposure of the upper Mancos Shale. It was deposited in the shallow Cretaceous age sea that covered this area some 90 million years ago. Many fossils, including clams, indicate that the sea was relatively shallow (200 to 300 feet deep) at times. The very thin, even layers show that the sea bottom was calm, with few burrowing animals to disturb the fine mud and clay that filtered down from above. The dark color comes from the carbon of millions of dead microscopic animals and plants; the decay of all this organic material robbed the bottom waters of their oxygen, leaving the lower sea water stagnant and dead. After the clay was cemented into rock, it was fractured and broken by later mountain-building to the north, and the fractures were filled by other minerals such as clear or white calcite and gypsum. <u>**RETURN TO HIGHWAY 160 AND TURN RIGHT. AT THE 160 – 84 JUNCTION, STAY ON 160 TOWARD WOLF CREEK PASS.**</u>
2.0	9.0 **Kmv**	We are now leaving the Mancos Shale and climbing into the younger Mesaverde Group, several thin layers of terrestrial rock. Here the sequence is very thin, but further west it thickens and the Mesaverde is subdivided into separate formations, forming the impressive cliffs and tablelands of Mesa Verde National Park. The Mesaverde represents a brief shallowing of the ancient sea; for a time, the Pagosa Springs area lay near the shoreline, with beaches and sand dunes, river channels and deltas, floodplains and swamps. The rocks deposited by these cycles of dry land, shoreline, and shallow sea include thin coal seams, sandstones, shales and mudstones, and tell the story of a short time when the sea retreated; but eventually, the waters returned to flood Pagosa once more. All that can be seen from the highway is a short break in the shale cliffs, marked by low wooded hills.
1.7	10.7 **Kl**	We are now in the Lewis Shale, a thick sea-bed shale virtually identical to the older Mancos Shale. The area was submerged after the brief Mesaverde period, and the dark, fine mud of the sea bottom quietly accumulated again -- up to 2,400 feet thick in some areas. This was about 80 million years ago, and the sea persisted for perhaps another 10 to 20 million years. The Lewis Shale marks the last time that the Pagosa area was under a sea. As the end of the Cretaceous Period loomed, the western United States began to rise, lifted on upwelling magma from deep in the mantle of the Earth. Tectonic forces began to reshape the west, lifting the Colorado Plateau and sinking the Paradox, San Juan, and other great basins, over the next 40 million years. Mountain ranges composed of huge volcanos lay just in the future. The Lewis sea began to drain and fill; the shoreline advanced over the old mud and clay of the seafloor. Beaches and sand dunes and swamps and river systems would replace the quiet waters for the last time (so far!). The Lewis Shale has several thin limestone layers in its lower section; these weather out as rounded, discontinuous orange ledges. These are lime concretions, formed by crystallization of calcite (limestone) at the floor of the ancient ocean. Near the top of the Lewis are found thin sandstone beds, the result of floods and shoreline deposits that washed sand into the shallowing sea. Each of these thin beds probably represents one event, one instant in time.

2.3	13.0 **Map symbol Ti**	**<u>STOP 3 – LOOK FOR A GRAY ROCK CUT ALONG THE LEFT SIDE OF THE HIGHWAY. PARK OFF THE RIGHT SHOULDER OF HIGHWAY 160,</u>** just past the San Juan River Village entrance. This is the Jackson Mountain Laccolith, an intrusion of magma into the Lewis Shale that caps Jackson Mountain. The magma was intruded during the Tertiary Period, probably around 10 million years ago. The highway crosses the edge of the intrusive body, called a laccolith because it resembles a shallow lake of magma enclosed in the older shale. Cross over to the westbound highway shoulder. **<u>WATCH FOR TRAFFIC.</u>** The intrusive rock is a dense gray andesite porphyry, a fine-grained igneous rock with large single crystals scattered throughout. The orange color of the weathered rock comes from the iron contained in its minerals. The porphyry contains crystals of clear quartz coated with a green mineral called chlorite, rectangular crystals of plagioclase feldspar which demonstrate chemical zoning (this is shown by a change in color from the center out to the edge of the crystal), patches of micropegmatite (coarse crystal mesh of quartz, mica, and feldspar), xenoliths (pieces of older rock torn loose and partly melted by the hot magma), and veins of milky quartz and calcite which filled later fractures in the igneous rock and contain copper and iron pyrite (fool's gold). Along the edges of the igneous intrusive, you can see the contact zone, where the hot magma actually baked the Lewis Shale into a hornfels (a natural form of ceramic, like clay pottery fired in a kiln). This rock is much harder than the Lewis Shale which surrounds it. Look for the drill holes and radial fractures that mark where the stone had to be blasted to widen the highway. Andesite is chemically similar to the mineral composition of the lower part of the Earth's crust, and probably results from partial melting of rock in the upper mantle below the crust, rising and mixing with the cooler rocks above. **<u>RETURN TO THE HIGHWAY AND CONTINUE NORTHEAST TOWARD WOLF CREEK PASS.</u>** The next stop is a road cut – look for a steep cliff on the left, with white sandstone and thin, darker layers of coal arching above the cliff. On the right is a wide flat area where you will park.

2.2	15.2 **TKpa**	**STOP 4 – PARK ON RIGHT SIDE OF HIGHWAY** and cross to the other side along the cut slope. **WATCH FOR TRAFFIC.** This is an exposure of the Pictured Cliffs Sandstone and the overlying Fruitland Formation. The Cretaceous sea was drying up for the last time. Tidal flats and beach dunes spread over the sea-floor shales, and were in turn buried by river sands and the thick vegetation of swamps and floodplain forests. The land was again rising, and the sands of the river and shoreline (the Pictured Cliffs Sandstone) were being rapidly buried; many feet of saturated sand and silt might be dumped in a single flood. The weight of this material pressing down on the sand below caused a process called soft-sediment deformation, which produced a sandstone dike -- the heavier, wet sands above sank and forced up the lighter material below into a convoluted dome, deforming the coal seams above as you can see in the road cut. **CONTINUE ON HIGHWAY 160.**
1.1	16.3 **Map symbol** **TKpa**	This part of the road passes through the Kirtland Shale, a thin sandy shale laid down when the Cretaceous inland sea made an attempt to flood its former bed. But mountains were already rising to the north and east, first as broad domes of the older sedimentary rock, then in violent volcanic upheavals. Tremendous amounts of sediment and volcanic rock were swept into the shallow basin, choking the sea and building new land. The Cretaceous sea was gone, and the Cretaceous Period was close to its end. The Pagosa area was still dominated by dinosaurs, though -- their bones occur as fossils throughout the rocks, but their time was almost over.
1.2	17.5 **TKpa**	We are now in the Animas Formation, a thick pile of river deposits made up of sand, gravel, mud, and volcanic rock washed down from the rising mountains. This was 65 million years ago, and one of the most important geological events of the earth's history occurred: the dinosaurs, along with come 70 percent of all life forms, died out. Among the survivors: birds, small reptiles -- and the mammals. This rock layer may contain the boundary between the Mesozoic Era, the Age of the Dinosaurs, and the Cenozoic Era, the Age of the Mammals, but it has not been definitely identified here. This is the youngest sedimentary formation which we will see on this trip. We are now approaching the skirts of the volcanos that built the San Juan Mountains and covered the sedimentary rocks under thousands of feet of ash, lava, and pumice.
2.5	20.0 **Qa**	We are crossing glacial debris which forms the valley floor; it was washed down from the surrounding mountains during the most recent Ice Age which ended some 12000 to 15000 years ago. This material is too young to have been cemented into rock. The West Fork of the San Juan River valley to the left of the highway is a glaciated valley, U-shaped with a flat bottom and steep sides.

4.0	24.0 **Tev**	**<u>STOP 5 - TURN LEFT INTO THE OVERLOOK PARKING LOT.</u>** This is the last stop of the tour, and a view of the last major geologic activity of the area - the San Juan Volcanic Field. The last 30 million years have seen almost continuous eruption and volcanic mountain-building throughout the San Juan Mountains. The Jackson Mountain Laccolith (Stop 3) is one minor part of this process. The rocks surrounding the Overlook are volcanic in origin. The well-cemented agglomerates (formed by erosion and reworking of volcanic debris) are resistant to erosion, forming the spectacular cliffs and spires; the softer conglomerates (formed by ash and debris flows, eruptions, and superheated avalanches) erode quickly and form the slopes below. Some of the volcanic rock was melted, or welded, together by its own intense heat, forming welded tuffs and obsidian beds. Huge stratovolcanos rose, exploded and laid waste to hundreds of square miles, and collapsed into yawning calderas, only to have new volcanos rise from their ruins. Recent studies (1996) show that some of the largest and most powerful eruptions on the planet occurred here. The La Garita Caldera eruption pulverized some 1,200 cubic miles of rock, with a force equal to 10,000 times that of the eruption of Mount St. Helens, creating a crater complex that stretches from Pagosa Springs to near Alamosa, almost 70 miles across. That single eruption must surely have killed every living thing in the entire Four Corners region.
		Only in the last 4 million years has this area been quiet; as the volcanic activity faded, the last magma squeezed into faults to form the local dikes and laccoliths. Erosion softened the jagged volcanic mountains, and life returned to the land. Hot springs and geysers were abundant as water from rain and snow met the cooling underground pockets of magma. Between 1 million and 18,000 years ago, glaciers grew and melted, carving deep valleys and bulldozing vast amounts of shattered rock into the river channels which carried away their floods of meltwater. When the last glaciers retreated, they left behind canyon walls too steep to support themselves; without the half-mile deep masses of ice to hold them up, they collapsed in landslides and mudflows that continue to this day. This brings us to the present. The continuing process of erosion tears down the mountains, dumping the wreckage in the streams as sediment to form future rocks. The Rocky Mountains and the Colorado Plateau are still rising, about 1 inch every century, but erosion is gaining. The soft volcanic rocks around us can't resist the wet climate. Rain and snowmelt bring more rocks down every year. The dramatic cliffs of the San Juan Valley were carved out by glaciers, but weather is now the dominant force shaping our area. In perhaps ten million years, there will be no more San Juan Mountains, only a range of gently rolling hills dotting a broad river valley. Such a span of time is immense to us humans, but in the life span of the earth, it is less than an eyeblink. As you return to Pagosa Springs, imagine the many environments this small part of our world has seen: ocean bottom; sandy beach; swamps and forests dominated by dinosaurs; seared and barren volcanic wasteland; frozen half a mile deep under glacial ice. The rocks tell their stories, and leave us to wonder what is to come.


PAGOSA AREA GEOLOGY MAP
Geologic Map Symbols:
Kdb Dakota Sandstone
Kml Mancos Shale, lower beds
Kmu Mancos Shale, upper beds
Kmv Mesa Verde Group
Kl Lewis Shale
TKpa Pictured Cliffs Sandstone
Ti Igneous Stocks and Dikes
Ten Volcanic Ash Layers
Tev Volcanic Lava and Ash Flows
Qa Recent River Sediment
Ql Recent Landslide Deposits
Contact between formations
Fault-bar on downdropped side
MAP SCALE: 1 INCH = 2 MILES
STOP 5 – SAN JUAN OVERLO
STOP 4 – PICTURED CLIFFS
STOP 3 – JACKSON MOUNTAIN
STOP 2 – MANCOS SHALE
STOP 1 – HOT SPRINGS
START AT VISTA CLUBHOUSE
(off of map)
MINERAL
ARCHULETA
Pagosa Springs
WOLF CREEK
SOUTHERN UTE INDIAN RESERVATION