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**Intermountain
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Ogden, UT 84401**

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Evaluating Slope Stability Prior to Road Construction

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RESEARCH SUMMARY

Subsurface bedrock properties play an important role in determining slope stability in the Idaho batholith; however, properties like degree of weathering are difficult to define prior to construction. The usefulness of seismic, resistivity, and vegetation surveys for predicting subsurface strength characteristics of granitic rock was evaluated in the Idaho batholith. Rock strength varies inversely with degree of weathering and fracture density. Rocks that have weathered or altered to the point where they contain sufficient clay to exhibit plastic properties (referred to here as highly weathered rock) are particularly susceptible to mass failure following disturbance. Eleven of twelve zones identified as highly weathered following construction were predicted by one or more surveys along a proposed road centerline. Using the same criteria, 10 other zones would have been predicted to contain highly weathered rock, but did not. Preconstruction geophysical and vegetation surveys may efficiently narrow the number of sites requiring additional surface exploration or drilling for drainage location, or locate sites requiring physical structures for road stabilization.

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SLOPE INSTABILITY RELATED TO ROCK PROPERTIES

The Idaho batholith is a large body composed of multiple intrusions of coarse-grained granitic rock. The batholith outcrops across Idaho more or less continuously for about 250 miles (400 km) in a north-south direction, and 80 miles (130 km) east-west. Most of the land is forested and under Federal management. Eleven National Forests cover more than 80 percent of the batholith lands.

Soils in the Idaho batholith are coarse textured, cohesionless, and highly erodible. Researchers in other areas have found that granitic soils with low aggregate stability have high surface erosion potentials. André and Anderson (1961) compared the erodibility of soils formed from eight different parent materials in northern California and found granitic soils to be most erodible. Wooldridge (1964) compared soils formed from three parent materials in central Washington and also found granitic soils to be most erodible. The lack of aggregate stability directly affects surface erosion rates in unprotected soils. Potential for mass erosion is also high in the Idaho batholith, particularly after disturbance by fire or management activities such as road construction and logging. Shallow, fast-moving failures such as debris slides and debris torrents are common on granitic lands. Deep-seated, slow mass failures are generally absent.

Mass erosion in batholith areas is highly correlated with properties of the parent rock such as structure, fracture density, and degree of weathering. Clayton and others (1975) showed relationships between weathering and landslide activity in the southern Idaho batholith. Highly weathered rock is more prone to mass erosion than unweathered rock. Durgin (1977) described similar relationships between landslide activity and rock weathering on granitic soils in northern California. Megahan and others (1978), in a comprehensive study of 877 landslides in the northern and southern Idaho batholith, found that slide frequency was related to both weathering characteristics and orientation of fractures. In this study there was a tendency for landslides to be more common in highly weathered rock, but the relationship was confounded by slope steepness and an inability to correct for the areal distribution of rock weathering classes considered. For example, 12 percent of the landslides studied in the northern Idaho batholith occurred on the highest weathering class. This highly weathered bedrock is relatively rare; Gray and Megahan (1981) suggest that less than 5 percent of the batholith is comprised of such rock. Had Megahan and others (1978) been able to adjust for the actual distribution of rock types in their population, a stronger relationship between weathering and landslides probably would have emerged. There was no relationship between fracture density and landslide activity in this study; however, fractures oriented parallel to the slope were more commonly associated with landslides.

The hazard potential for mass erosion in the batholith is greatly increased following a disturbance such as logging or road construction. Vegetation removal often results in removal of a critical margin of safety afforded the soil by roots and soil arching between stems (Gray and Megahan, 1981). Changes in slope hydrology associated with interception and redistribution of subsurface flow following road construction also increase the potential for mass erosion (Gray and Megahan 1981). Jensen and Cole (1965) reported that 80 of 89 landslides occurring in the South Fork of the Salmon River in April, 1965 were associated with roads.

Most site properties that show a correlation with mass erosion hazard (for example: slope steepness, position on slope, land type, management history) are easy to recognize by a field reconaissance. Unfortunately, subsurface bedrock properties are not. In a study of rock properties in the early 1970's, Hampton and others (1974) investigated the correlation between seismic velocity and weathering properties of rock. They hoped that seismic surveys conducted on the ground surface could elucidate rock weathering properties at depth. The relationship between seismic wave velocities and weathering classes (as defined by Clayton and Arnold 1972) was obscure. Weathering classes range from 1 (hard, unweathered rock of high mechanical strength) to 7 (very highly weathered or altered, containing considerable clay; plastic when wet). For rocks with similar fracture densities, there was a trend toward decreasing seismic velocity, with an increase in the degree of weathering; however, this relationship was not strong. Clayton and others (1979) found a strong relationship between weathering class and sonic wave velocity transmitted through intact rock cores. From this it seems apparent that structural differences associated with fractures or joints obfuscate the interpretation of degree of weathering from seismic data.

Scientists working on the problem of surface detection of subsurface rock properties felt that a combination of geophysical surveys, for example seismic data coupled with resistivity data, might provide more information about subsurface conditions. The reasoning behind this is as follows: (1) Seismic wave velocity and apparent resistivity of rock are a function of velocity and resistivity of the weathered rock matrix plus the velocity and resistivity of pores (fractures and joints). (2) Within a given weathering class, the resistivity and seismic velocity values of the matrix vary over a relatively small range; however, these parameters vary widely in porous media as pore saturation varies. (3) Resistivity will be affected by partial saturation in a different manner than seismic velocity. Slight decreases from saturation will result in concomitant lowering of seismic velocity; however, resistivity will be relatively unaffected as long as there is continuous wetting of surfaces comprising the pore wall. A complete and theoretical discussion of these ideas, plus a conceptual model designed to fit granitic rock of the Idaho batholith, was provided by Fausset and others (1978).

THE STUDY

In order to explore the idea that seismic and resistivity geophysical surveys together would provide more information about subsurface conditions than either technique alone, a study was proposed in the southwestern Idaho batholith. The Silver Creek watershed (45°25′ N. latitude, 115°45′W. longitude), tributary to the Middle Fork of the Payette River, contains eight smaller drainages in which scientists are studying watershed response to a variety of timber harvesting practices. A high standard forest road to support logging and forest recreation traffic was planned in 1975. This road would run for 2.7 miles (4.4 km) through three of the small research watersheds. From previous road construction in the area, I expected the road would cross some zones of the highly weathered rock that is commonly associated with mass failures in the batholith.

The Intermountain Forest and Range Experiment Station entered into a cooperative agreement with geophysicists from Boise State University to evaluate the subsurface rock properties along the proposed road. The University agreed to conduct the geophysical surveys and make predictions about rock conditions prior to road construction. The Experiment Station agreed to classify the rock properties following construction and evaluate the geophysical surveys and predictions made prior to construction.

METHODS

Data Acquisition

Geophysical surveys were conducted along the proposed centerline of the road in the summer of 1976. Slightly more than 7,900 ft (2 410 m) of the road were examined. Seismic traverses were run using a Bison Model 1570 Signal Enhancement Seismograph[1]. A 120-ft (36.6-m) transect was centered at each 100-ft station point, with geophones placed at each end of the transect. Hammer impact points were spaced at 10-ft (3-m) intervals along the centerline, and run between the two geophones. This design allowed us to obtain reversed profiles of seismic velocity centered at 100-ft spacings along the entire proposed roadway.

The survey crew obtained resistivity profiles along the centerline at the same station centers used for the seismic work. They used a Bison Model 2350 Earth Resistivity System. The Schlumberger electrode configuration was used with a maximum total array length of 120 ft (37 m).

The road was constructed during the summer of 1980. Immediately following construction, the weathering and fracturing characteristics of all exposed bedrock were classified according to the classification system of Clayton and Arnold (1972). Exposed bedrock required the presence of a roadcut. Of the 7,900 feet (2 410 m) examined during the geophysical surveys, 5,300 feet (1 615 m) were eventually exposed by road cuts of sufficient depth to classify the rock.

Data Analysis

Seismic wave velocities were computed for two layers, and the thickness of the first layer was computed by the method of differences (Broughton-Edge and Laby 1931). The velocities of the first layer were consistent with an interpretation that this layer is soil. The first layer depth averages approximately 3 ft (1 m) and overlies a thicker zone of weathered rock with markedly higher velocities. These second layer velocities were the ones of interest and represent velocity of seismic wave travel through the bedrock below the soil.

Resistivity soundings were made using logarithmically distributed Schlumberger AB/2 spacings of 3 to 60 ft (1 to 18 m). Fausset and others (1978) synthesized lateral profiles of resistivity from equidistant soundings at AB/2 spacings of 12, 20, and 30 ft (3.6, 6.1, and 9.1 m). This allowed for greater sensitivity in interpreting lateral changes in rock properties.

The weathering and fracture density data were initially scanned by plotting weathering or fracture density class versus road centerline station numbers. Weathering characteristics are often nonuniform within a particular section of road cut. For example, pegmatite dikes of relatively fresher and less weathered rock frequently cut through highly weathered rock. Similarly, narrow shear zones of very highly altered rock of low strength often cut through less weathered rock. It is difficult to assign a single weathering class to a section of road cut where such cases occur. When plotting weathering versus centerline station number, I described occurrences of mixed weathering classes individually, and assigned a percentage to each weathering class. Granitic rock that classified as weathering class 7 and highly weathered basic dike rock were grouped together in a category termed highly weathered rock (HWR). Weathering class 7 rock exhibits the most advanced stage of chemical weathering recognized in plutonic rocks of the Idaho batholith. It is highly argillized and exhibits plastic properties when wet. The highly weathered rock category is considered most prone to slope instability when other variables such as slope and prior land use are held constant. Fracture density is difficult to evaluate in weathering classes 6 and 7 because joint sets become indistinct. Other features such as intergranular fracturing control the porosity of weathered plutonic rocks, and so fracture density information was omitted from further analysis following the initial scan.

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[1] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others which may be suitable.

Occurrences of HWR were evaluated by graphical analysis in two different ways. The data set consisted of geophysical survey points for which an independent field classification of rock properties could be made following road construction. This data set was plotted with seismic velocity of the second layer on the abscissa versus apparent resistivity (AB/2 = 30 ft) on the ordinate (fig. 1). Those points identified as HWR were then flagged for easy visual identification. Secondly, arithmetic mean weathering class values were computed for each geophysical station having 50 ft (15 m) of classifiable rock on each side of the station center. (Many stations did not meet this criterion because there was no road cut.) These mean values were based upon the linear extent of each class included in this 100-ft (30-m) section. These values were plotted versus apparent resistivity, second layer seismic velocity, and the product of resistivity times seismic velocity. Visual inspection of these three graphs showed such poor correlations that further regression analyses were not attempted. The mean weathering class values were not well distributed; 90 percent of the points fell within the range 5.5 to 6.5.

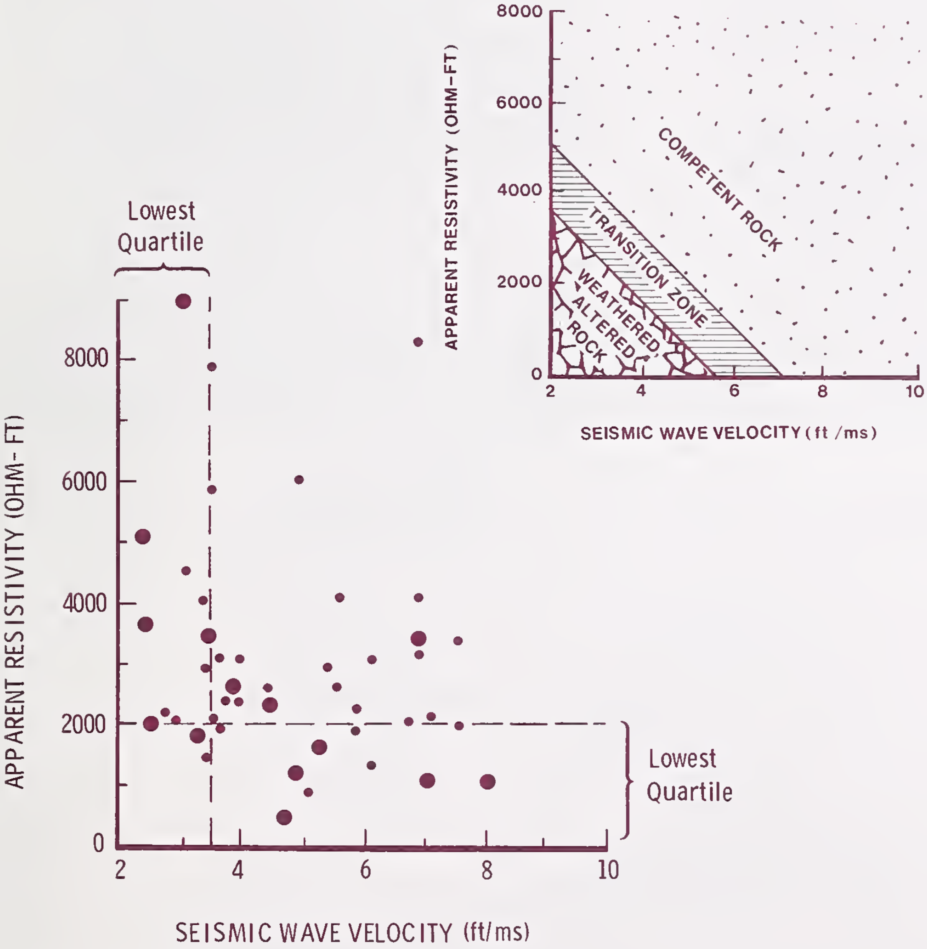

Figure 1. Scattergram of apparent resistivity versus seismic velocity of the second layer. Larger circles were identified in the field as zones of highly weathered rock. Lowest quartiles of resistivity and seismic velocity are identified on the graph. The inset depicts the zones of rock competence interpreted by Fausett and others (1978) on the basis of the seismic and resistivity data.

Results

Table 1 summarizes the location, percent, and type of highly weathered rock encountered during the survey, and indicates the usefulness of each geophysical method for predicting HWR. Of the 5,300 ft (1 615 m) of exposed rock examined, 360 ft (110 m) were classified as highly weathered. This suggests that slightly less than 7 percent of the rock in the study area might fit into the highly weathered category, a high percentage for the Idaho batholith.

Nearly 75 percent of the exposed rock was weathering class 6. Weathering class 6 rock has very low mechanical strength (Clayton and others 1979), but lacks the plastic nature of class 7 rock that results from intense chemical alteration to clay minerals. Weathering class 5 rock, which is more competent than class 6, constitutes 13 percent of the exposed rock. Class 5 rock will spall and readily decompose to grus following exposure due to road cutting. The remaining 5 percent is in weathering classes 2, 3, and 4. None of these weathering classes is extensive. A 20-ft (6-m) section of road between stations 65 and 66 in weathering class 2 required blasting.

In general, the rock along the road could be characterized as a well weathered, coarse-grained quartz monzonite (classes 5 and 6), with periodic occurrences of highly weathered, argillized rock (class 7), and some short zones of harder, more competent rock (class 2, 3, and 4).

The category HWR includes four basic dikes intruded into the granitic rock. Such dikes are not uncommon, generally are highly altered or weathered, and often contain smectite clays (Clayton 1974). Basic dikes make up 46 percent of the total rock included in the HWR category along this road.

The initial results of the two geophysical surveys published by Fausett and others (1978) included a preliminary interpretation of subsurface rock properties. Based on seismic and resistivity data, they grouped the rock into three zones: competent, transition zone, and weathered or altered (fig. 1, inset). Their weathered or altered grouping corresponds to class 7 rock of Clayton and Arnold (1972). Within each zone, the authors further selected data points based upon association with data from adjacent stations. For example, if a very low resistivity reading seemed to be associated with a shallow water table (viz., near a stream crossing), and adjacent data points had correspondingly higher resistivity values, the point with low resistivity would not be predicted to be highly weathered. Using this system, the authors predicted 67 percent of the data points in the weathered and altered zone and 9 percent in the transition zone would prove to be highly weathered rock. They predicted that no points in the competent rock zone would be highly weathered. From the postconstruction survey, the actual percentage of rock classified as highly weathered for each zone is: (1) weathered and altered, 50 percent; (2) transition, 46 percent; (3) competent, 20 percent.

The prediction method of Fausett and others (1978) excluded points of high seismic velocity and very low resistivity, or vice versa from their predicted highly weathered zone. It is apparent from figure 1 that such points may indicate zones of high weathering. Excluding these areas accounted for 4 of the 5 points that made up the 20 percent HWR in their competent zone.

Table 1.—Location, type, and extent of zones containing highly weathered rock. X^{S} indicates the presence of highly weathered rock based on results from one or more preconstruction surveys[1]

Location				Recognized from preconstruction survey		
Station	to	Station	Percent and Type	Seismic	Resistivity	Vegetation
40 + 80		42 + 45	2% W7[2], W6 matrix	x		
59 + 66		60 + 00	100% W7			x
63 + 65		63 + 85	100% W7, basic dike		x	
68 + 20		68 + 80	Clay-rich colluvium	No preconstruction indication		
69 + 50		70 + 25	100% W7, basic dike		x	x
70 + 25		72 + 70	5% W7, W6 matrix		x	
73 + 40		73 + 75	100% W7		x	
77 + 10		77 + 30	100% W7, shear zone	x	x	
77 + 70		78 + 00	100% W7	x	x	
95 + 40		96 + 65	2% W7, W6 matrix	x		
103 + 55		103 + 85	100% W7, basic dike			x
110 + 75		111 + 15	100% W7, basic dike	x		

[1] Lowest quartile of seismic or resistivity values; see text for method used to interpret vegetation survey.

[2] W7, W6: weathering class according to classification system of Clayton and Arnold (1972).

Evaluation

How useful were the geophysical techniques for predicting zones of HWR? Nine of the twelve zones of HWR rock identified in table 1 were flagged by low seismic velocity and/or resistivity values (lowest quartile). One of the three zones missed is an accumulation of clay-rich colluvium in a topographic hollow, similar to the wedge soils that Dietrich and Dunne (1978) describe in the Coast Range of Oregon. The actual condition of the bedrock underlying the colluvium at this site is unknown. This site was classified in the transition zone by Fausset and others (1978).

One of the other sites was also classified in the transition zone, but the third site had a resistivity value in excess of 4,000 ohm-ft and a seismic velocity greater than 5,500 ft/s. From the geophysical data one would expect this to be the location of some of our more competent rock. There is a 40-ft (12-m) exposure of altered basic dike material at this location.

One other survey to predict rock competence prior to road construction was explored. Vegetation along the entire proposed centerline was mapped according to the subsequently published habitat type classification for central Idaho by Steele and others (1981). This system is intended to classify the ecological potential of a site to support a particular vegetation mosaic. Thus, habitat types are good indicators of moisture availability, and possibly soil depth and/or subsurface weathering conditions. Habitat types are named by the overstory present at climax and one or two characteristic understory species. The overstory species along the road are either in the drier Douglas-fir series (*Pseudotsuga menziesii*) or in the more moist grand fir series (*Abies grandis*).

I had not hypothesized any relationships between habitat types and bedrock but expected that the more moist grand fir series might be indicative of greater depths and more intensive weathering. At lower elevations at the bottom of the watershed, the more shaded portions of the road are all in the grand fir series. After climbing to midslope elevations, the predominant habitat types are in the Douglas-fir series; however, interspersed here are five short (less than 200 ft [60 m])sections of grand fir series. These sections of grand fir cannot be explained on the basis of proximity to surface water, or topographic or aspect changes. Three of these five sections are locations of HWR (table 1).

CONCLUSIONS

The following conclusions can be drawn from the results of this study:

1. Using the criteria of low resistivity (<2,000 ohm-ft), low seismic velocity (<3,500 ft/s), and an atypical change in habitat type, 11 of 12 zones of HWR were identified prior to road construction.
2. Using the same criteria, 10 other zones would have been expected to contain HWR but did not. Although this is a high percentage of false-positive findings, it still greatly delimits the number of zones requiring further exploration during or prior to construction and may prove cost effective.
3. Several design features such as underdrain installation were incorporated into the road on the basis of the preconstruction surveys. The number and location of underdrains is normally difficult to predict without preconstruction data, but drainage design was predicted quite accurately on the study road.
4. Prior road construction in the vicinity of the study road suggested that HWR would be expected along the study road. Thus the predictive value was diminished for this job. Preconstruction surveys should prove more valuable in areas where little prior road construction has taken place.
5. A field review of the geophysical survey results is necessary to eliminate areas such as live stream crossings or surface springs that appear to be zones of HWR.
6. This is an evolving methodology. The methods have promise, but more tests are required to improve the predictive capabilities of geophysical and vegetation surveys.

PUBLICATIONS CITED

André, J. E.; Anderson, H. W. Variation in soil erodibility with geology, geographic zone, elevation and vegetation type in northern California wildlands. J. Geophys. Res. 66: 3351–3358; 1961.

Broughton-Edge, A. B.; Laby, T. H. eds. The principles and practice of geophysical prospecting: being the report of the Imperial Geophysical Experimental Survey. London: Cambridge University Press; 1931. 217 p.

Clayton, J. L. Clay mineralogy of soils in the Idaho batholith. Geol. Soc. Am. Bull. 85: 229–232; 1974.

Clayton, J. L.; Arnold J. F. Practical grain size, fracturing density and weathering classification of intrusive rocks of the Idaho batholith. Gen. Tech. Rep. INT–2. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1972. 17 p.

Clayton, J. L.; Megahan, W. F.; Cochrane, A. M.; Nichols, C. R. Rock alteration and slope failure, Middle Fork of the Payette River. Field trip guide, 28th annual meeting, Rocky Mountain Section, Geological Society of America. Boise, ID; 1975. 29 p.

Clayton, J. L.; Megahan, W. F. Hampton, D. Soil and bedrock properties: weathering and alteration products and processes in the Idaho batholith. Res. Pap INT–237. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1979. 35 p.

Durgin, P. B. Landslides and the weathering of granitic rocks. Geol. Soc. Am. Rev. Eng. Geol. 3: 127–131; 1977.

Fausset, N. E.; Applegate, J. K.; Donaldson, P. R.; Eggers, L. D. Geophysical investigation of rock properties near Silver Creek, Boise National Forest, Idaho. In: Proceedings of the 16th annual engineering, geology and soils engineering symposium, Boise, ID; 1978: 201–218.

Gray, D. H.; Megahan, W. F. Forest vegetation removal and slope stability in the Idaho batholith. Res. Pap. INT–271. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1981. 23 p.

Hampton, D.; Megahan, W. F.; Clayton, J. L. Soil and rock properties research in the Idaho batholith. In: Proceedings of the 12th annual engineering geology, and soils engineering symposium; Boise, ID; 1974: 97–111.

Jensen, F.; Cole, G. F. South Fork of the Salmon River storm and flood report. McCall, ID: U.S. Department of Agriculture, Forest Service, Payette National Forest; 1965. 15 p. Unpublished report.

Megahan, W. F.; Day, N. F.; Bliss, T. M. Landslide occurrence in the western and central Northern Rocky Mountain physiographic province in Idaho. In: Youngberg, C. T., ed. Proceedings of the 5th North American forestry soils conference. Fort Collins, CO: Colorado State University; 1978; 116–139.

Steele, R.; Pfister, R. D.; Ryker, R. A.; Kittams, J. A. Forest habitat types of central Idaho. Gen. Tech. Rep. INT–114. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1981. 138 p.

Wooldridge, David D. Effects of parent material and vegetation on properties related to soil erosion in central Washington. Soil Sci. Soc. Am. Proc. 28: 420–432; 1964.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1983-0-676-032/42

Clayton, James L. Evaluating Slope Stability Prior to Road Construction. Res. Pap. INT-307. Ogden, UT; U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1982. 6 p.

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KEYWORDS: road contruction, slope stability, geophysical studies, seismic surveys, resistivity surveys

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

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