simple one as soon as ruled grids of perhaps 0.5 μ accuracy are available. Ruling grids to such accuracy is not a simple undertaking, requiring specially built equipment, and as a result they have not been generally available. It is anticipated that this gap will soon be closed. At present one is usually forced to use grids ruled to lower degrees of accuracy, but furnished with calibrations for each point of intersection. Such calibrations are difficult to obtain to sub-micron accuracy, and taking the errors into account adds appreciably to the labor involved in using the grids.

Conclusion

It is possible, by taking advantage of known error reducing effects, to design 9 inch square coordinate measuring machines to attain the 1 μ accuracy that has so long been no more than the least reading. The effort and cost involved may be appreciable, but small compared with what will be involved in attempting a significant break through the "1 μ barrier." All restrictions become intensified and remote control becomes essential. However, when photographic data of sufficient quality become available, the corresponding instruments will be developed.

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Photo Interpretation in the Highway Materials Program of the U. S. Forest Service

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Introduction

The information interpreted from aerial photography has distinct application in many engineering phases of Forest Service work. This paper, however, is concerned primarily with the role of photo interpretation in the highway materials program in the states of Utah and Nevada and parts of Idaho, Wyoming, Colorado, and California which make up the Intermountain Region.

Several years ago a photogrammetric reconnaissance program was initiated to accelerate the Region's road location program. This program utilizes photogrammetric principles to provide area and route reconnaissance information for forest engineering personnel. An area reconnaissance is a photogrammetric study of several routes that may serve the transportation needs of a general area. A route reconnaissance is more refined in that the routes located by photogrammetric methods adhere to grade and alignment controls specified by field engineers. A complete route reconnaissance consists of route delineated photos, and information sheets that list grades, sideslopes, exposure, vegetative cover, and drainage data referenced to center line stations.

The Photo-Materials Investigation Phase

Recently, it was decided to supplement the reconnaissance program with a photo-materials investigation phase that would anticipate problems such as heavy rock cut sections, unstable soil conditions, ground water fronts, landslide susceptible situations, etc. By anticipating these problems via photo interpretation, it is possible to compensate for them during the preliminary stages of road reconnaissance. This procedure has made it possible to provide the Design Engineer not only geometric road data but also a tentative appraisal of the materials to be encountered during construction.

As this procedure was developed it became apparent that three sciences were involved; Soils, Geology and Engineering. Explaining how these sciences supplement photo interpretation techniques as applied to highway materials problems is the principal objective of this paper.

The Role of Soils

Design Engineers recognize the advantages of constructing roads through A-1-a or A-1-b soils as compared to A-6 or A-7 types.* The A-1 groups are stable subgrade materials, free draining with excellent bearing properties. The A-6, A-7 types are problem soils! They are fine grained, plastic, impermeable soils with high capillary potentials requiring thick aggregate layers to support pavement structures placed over them.

The Role of Geology

In road building, rock, like soil, becomes a construction material. To analyze it effectively the geological sciences are implemented to strengthen photo interpreted conclusions. For example, weathering properties of various rock types are considered in designing stable cut slopes, and drainage structures. Furthermore, it is important for design and estimating purposes to determine the relative cost of excavating limestone, sandstones, shales, etc.

In conglomerate rock types, the degree of cementation affects their stability in a cut slope and will determine their suitability as surfacing materials. Once a rock type has been identified, general conclusions may be drawn that predict relative hardness, associated soil types, and the topographic expression that the rock unit may produce.

The Role of Engineering

Once the type of information available from these sources is known the role of engineering becomes one of assembling the data into a comprehensive materials report.

* These are American Association of State Highway Officials Classifications for highway materials.

Geologic principles and descriptions are used to evaluate the construction nature of rock types. Weathering and erosion principles are implemented to predict soil types that develop from parent rock materials. For instance, granitic rocks may be massive or fractured, but they usually produce sandy, nonplastic soils. Conglomerates depending on their degree of cementation characteristically break down into coarse gravelly soils. Shales generally produce silt or silt loam soils. In addition, it is possible to imply Los Angeles abrasion values to certain rock types. These values, commonly referred to as L.A. rattler values are determined in a test that measures the hardness of rock samples. A value of 25 per cent means that a sample will lose 25 per cent of its content in the abrasion test. In short, the higher the value the softer the rock. For example, the values for quartzites may range from 15 to 25 per cent. Granites vary from 25 to 60 per cent depending on degree of weathering. Shales are variable but generally range from 30 to 50 per cent. These broad interpretations are further refined by applying detailed field descriptions available from various sources.

Up to this point, the need for pursuing a photo-materials investigation program has been developed and its accomplishment has been outlined in general terms. The remainder of this paper will be devoted to the *details* of how this program is carried out.

The Photo Interpretation Phase

The stereogram (Figure 1) will now be discussed.

In the upper right hand corner of the stereogram the land is free of rock outcrops, evenly wooded, and relatively flat.

In the central portion, the topographic expression changes abruptly. There is a pronounced ridge barren of vegetation; below the ridge are small sharp ridges forming valleys that drain to the left. Associated with this pattern are alternating strips of vegetative cover suggesting varying soil conditions and moisture contents.

In the lower portion there is a distinct ridge line below which a lineated pattern of vegetative growth is evident.

The foregoing descriptions are based on the obvious topographic features and contrasting vegetative patterns observed. These

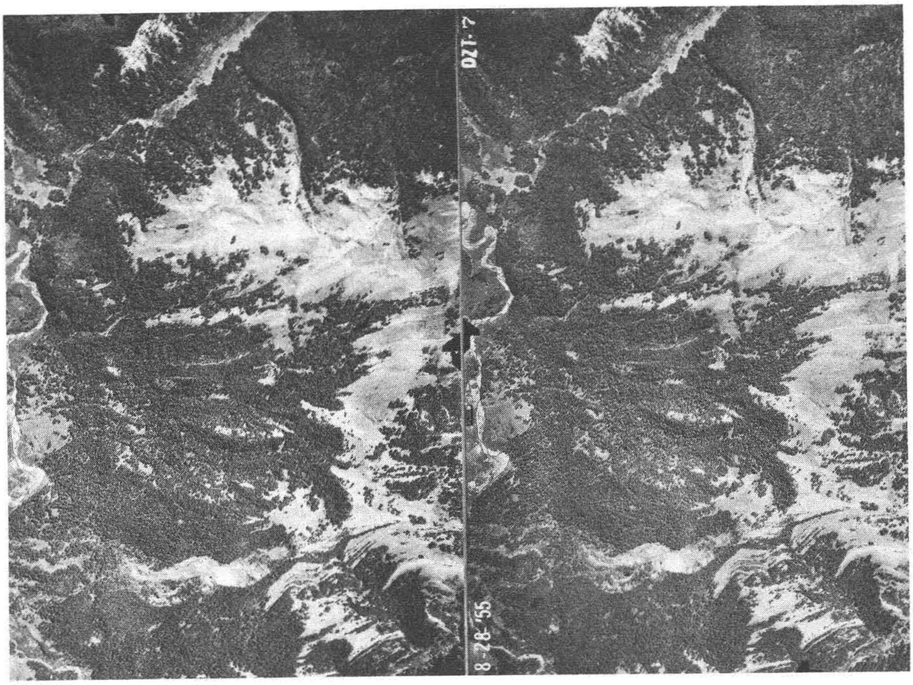

FIG. 1. A stereogram.

observations alone do not provide engineers with information upon which to base road location decisions.

In order to develop decisive information it is necessary to assemble geologic and other source information for the area to be studied. For example, the geologic map (Figure 2) covering the area previously viewed in the stereogram indicates the presence of three geologic formations. (A geologic formation is a rock unit whose physical characteristics are distinctive to the point that it can be field identified and mapped to scale.) The formations occurring in this area are:

1. The Wasatch formation. It occurs at the upper edge and is described as a flat-lying pink sedimentary deposit that for the purpose of this paper is considered a soft shale.
2. The Twin Creek formation. This formation is essentially a massive, erosion resistant limestone interbedded with less competent, erosive shales.
3. The Stump-Preuss formation. This is predominantly a sandstone consisting of two units. The Stump sandstone is greenish gray, limey with green shale partings. The Preuss, underlying the Stump sandstone, is a deep red to gray silty sandstone formation.

In addition, soils maps, mineral reports, oil and gas maps are also utilized. This formation has been prepared by soil scientists and Geologists who have field sampled, tested, described and mapped the same features which are being interpreted.

The vegetative indexes of the area are also considered. For example, in comparing a barren hillside to a wooded hillside, it is obvious that the latter has better developed and deeper soil profiles, that water retention is greater, that less rock is exposed and consequently that depth of weathering is greater. In addition certain vegetative species occur in specific environments. Alder, Willows, Cottonwood and Aspen species require a continual free water supply to thrive. Other species thrive in fine-grained soils. Still others require free draining, sandy soils or specific climate-elevational environments to thrive. From these indexes the interpreter may draw certain conclusions with regard to soil types, profile depths, rock content and their degree of weathering and the presence of water. Admittedly these are inferred conditions. Nevertheless, they are helpful to reconnaissance level planning for the location of roads.

PHOTO INTERPRETED ENGINEERING ASPECTS

Consider now the stereogram (Figure 3) covering the same area as Figure 1. These

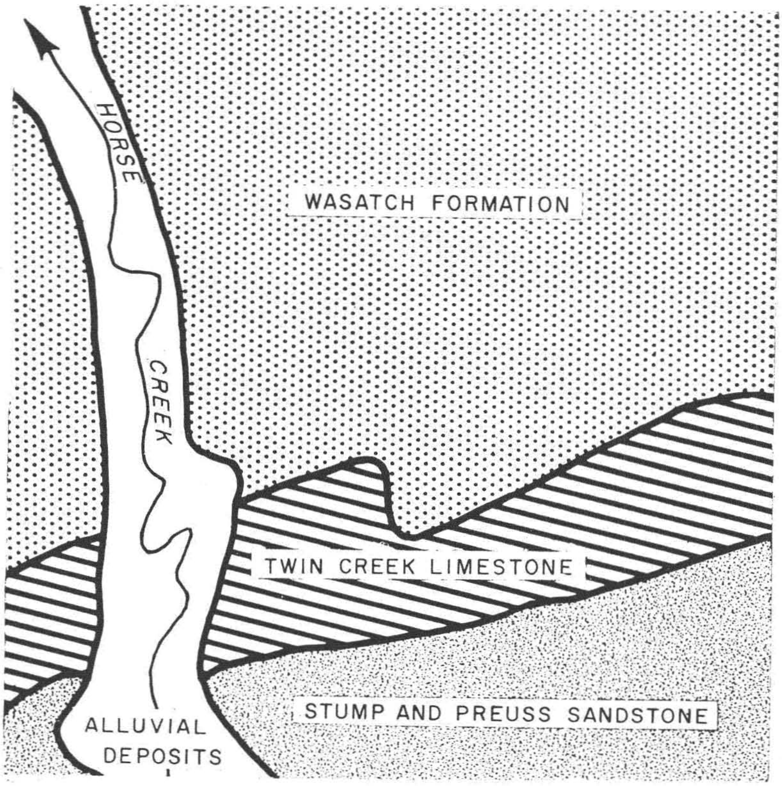

FIG. 2. Geologic map.

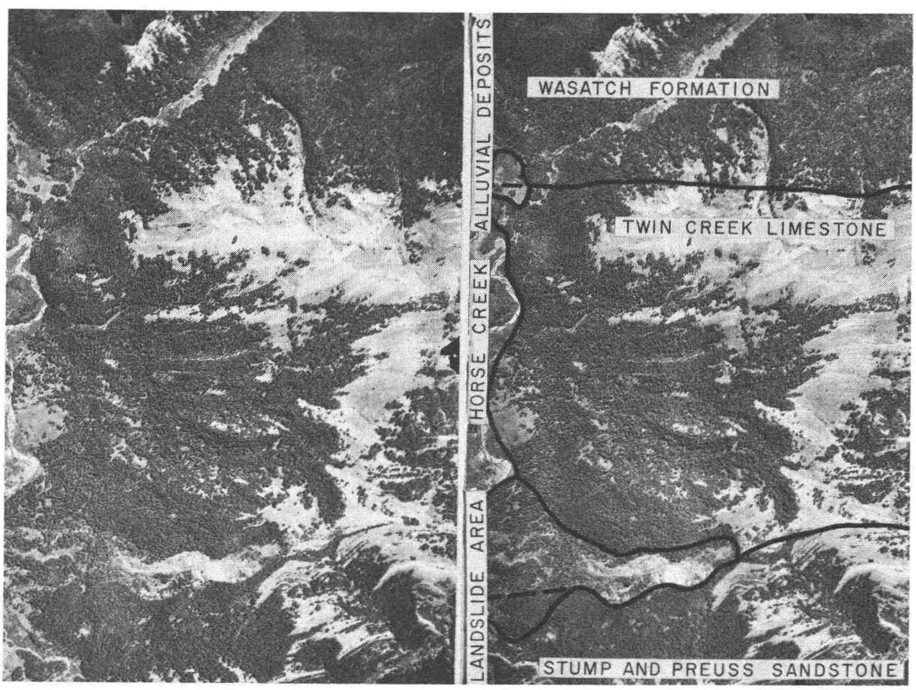

FIG. 3. A stereogram.

figures are identical except that Figure 3 has been annotated by using geologic and other factors previously developed. Geologic contacts have been identified and delineated. Problem areas, made apparent by referring to the source material, are also identified and described.

The lowland topography in the upper right-hand part of the stereogram is attributed directly to the flat-lying, relatively soft Wasatch formation. The rock is soft and may be considered as common, easily excavated material. The soil types associated with this formation are fine grained, with moderately plastic properties that will produce unstable road bed conditions. This information is useful to the Design Engineer in developing preliminary solutions to road surfacing requirements, evaluating erosion hazards, and designing adequate drainage structures within this formation.

In the central portion of the stereogram the abrupt difference in topographic expression is evident. This is attributed to the massive, erosion resistant Twin Creek formation that is in contact with the flat-lying Wasatch formation.

The peculiar left-to-right lineated pattern caused by alternating ridges and valleys is apparent. The geologic information describing the Twin Creek formation as limestone alternating with shale, explains this pattern. The valleys are obviously the shale sections that had been eroded away. The ridges are, of course, formed by the resistant limestone outcrops. These alternating ridges and valleys represent both extremes of road construction problems to the Design Engineer. The valleys, being drainage ways in shale-derived soil types, produce wet, probably plastic, construction materials. In these areas surface and subsurface drainage, as well as stability and surfacing considerations are a must. On the other hand, the limestone ridges pose a different problem to the designer. He must allow for the additional expense of drilling and blasting excavation as well as providing surfacing material to cushion the roadway.

At the lower edge of this same formation, the next contrasting land form observed is a white scar trending from right to left resulting from a major landslide. It occurs at the contact between the Twin Creek and the Stump-Preuss formations. The material along this contact has slumped, and moved to the left a distance of $\frac{1}{2}$ to $\frac{3}{4}$ of a mile. Observed in three dimension there is no question that this is a landslide. Yet during the field reconnaissance of the area, the field engineer had walked over the debris flow, studied the area from a ridge overlooking the landslide area, and still did not recognize it as a landslide. Constructing a road through this area without design consideration for its slide potential could be disastrous. This illustrates the distinct advantage of photo interpretation where comparisons and evaluations are made on a wide scale.

Another important observation is that the debris flow at the toe of this landslide has dammed the surface drainage from the area above. This debris flow is recent and surface drainages have not yet been developed. Lack of visible channels lead to the conclusion that the water drains from the area in a subsurface flow. This advance information permits anticipation of ground water problems by the location engineer. He can expect saturated ground water conditions near the debris flow and must make a field evaluation to determine acceptable road locations.

Continuing to the lower portion of the stereogram the geologic contact between the Twin Creek and the Stump-Preuss formations is noted. This contact is identified by the "pine ridges" that are characteristic of the Stump-Preuss formation in this area. This characteristic is caused by coniferous vegetation that parallels the interbedding of the sandstone with shales.

Generally the Stump-Preuss sandstone will be easily excavated, producing granular roadway materials that will be stable and relatively free of drainage problems. Because of its granular nature certain areas of this formation can be considered by the Design Engineer as a source of surfacing material for other problem areas.

One of the dominant land forms easily recognized is the flood plain created by Horse Creek which flows towards the upper edge of the stereogram. Typical flood plain deposits can be expected along the course of this stream. This area is a definite source of aggregate for road construction and surfacing materials.

Summary

It is recognized that photo interpretations involve generalities which are often insuffi-

(*continued on page 976*)

mosaics compiled of the entire area involved and that the latitude and longitude lines on the mosaic, regardless of the probable error in position, would establish the concession boundary. The allowable maximum error was about 400′. The latitude and longitude lines on the mosaic could be identified on the ground in relation to drainage, trees, bushes, rock out-crops, camel trails, etc. For many areas and many purposes, such a method would not meet requirements. In this case, considering time and cost, the error was considered acceptable.

I have outlined a problem rapidly becoming serious and reviewed methods and accuracies possible by a combination of aerial photogrammetric and ground survey methods. I do not believe there is any possibility of solving future cadastral problems except by this combination of methods and procedures.

In closing I would like to emphasize the necessity of making resources inventories in connection with land subdivision. Intelligent subdivision and lasting agricultural production is not possible without proper consideration of such land capability factors as soil type and moisture conditions. Cadastral surveys are necessary to provide a systematic base for establishing property boundaries and these data must be delineated on maps as a record for use as a base for fair taxation. To avoid the hazards and devastating results of a land boom, now is the time to start serious planning and development of basic information. In the long run, the dividends of a resources inventory, proper land subdivision and cadastral data will exceed by far the glamour of steel mills, chemical plants or similar enterprises in areas without skilled manpower, raw materials and markets for products.

Forest Highway Materials (continued from page 970)

cient for the final location of certain roads. However, a more efficient and conclusive on-the-ground materials survey can be conducted if a photo-materials investigation is performed first. This investigation denotes problem areas that should be looked at more carefully on the ground and isolates problem conditions as they relate to a geologic formation or some other type unit. In addition, aggregate material sources are more readily located through this method than through random on-the-gound searching.

In conclusion it is stressed that photo interpretation of materials problems does not replace on-the-ground materials surveys. However, it is a vital reconnaissance tool and a means of planning more efficient materials surveys in support of the highway program of the Intermountain Region, U. S. Forest Service.