Systematic Photo-Geomorphological Analysis of Land Deformation due to Earthquake

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1. Tectonic Movements and Aerial Photographs

Tectonic movements realize anomalies of relief which can be observed stereoscopically on aerial photographs, and photo-geomorphological analyses of relief can indicate the history of tectonic movements, if supplementary field investigations are conducted. Therefore, it is thought that aerial photographs in the hands of expert photogeologists are a tool of great value for structural analysis, and photo-geology is probably closer in theory and method to structural geomorphology than to any other branch of geology. In analyses of tectonism from aerial photographs, structural geologists are engaged largely in a study of topographic anomalies related to bedrock, and the exaggerated vertical scale provides them with an extremely useful tool, which is not available to field geologists on the ground. It is by means of this exaggerated relief and the ability to view a large area at the same time that the geologist is able to distinguish various rock types, establish continuity of certain formations, and detect, with some confidence, structural patterns which may be favorable for the analysis of tectonic movements.

2. Methods and Cirteria of Analysis

Analysis of tectonic movements on aerial photographs can be carried out in both methods A and B mentioned below. Method A is the identification of landform characteristics including drainage patterns, and such photographic characteristics as tonal patterns and lineaments, which are necessary for the analysis of tectonic movements. In method B, landform units covering the whole terrain are identified. The former is the ordinary and traditional photo-geological method and the latter is used particularly for agricultural and engineering geology. Besides, photo-densitometric analysis of aerial photographs clearly delineates nummerically such tectonic phenomena as shatter zones, fracture systems etc. and is being developed as a new technique to identify different geological units.

In a region of pronounced tectonic movements, warping and faulting of erosion surfaces is likely to be clearly evident on aerial photographs. The erosional destruction of such surfaces appears to be slower than faulting movements. Erosion surfaces, therefore, may offer indications of recent diastrophism, and such erosion surfaces can be traced exactly on aerial photographs with the assistances of measuring devices.

An erosion surface existing above a nearly level base may imply that uplift has occurred. The degree of dissection furnishes a rough measure of the time since uplift. Therefore, geomorphologists must pay close attention to elevated and dissected erosion levels. In using old-age surfaces as evidence of diastrophism, however, photogeologists must distinguish of marine planation bedding surfaces resurrected by the removal of their sedimentary cover from surfaces of subaerial erosion such as pediplains.

One of the important points concerning new tectonics is how to determine the age of new tectonics and the degree of activity. For such an aim, Pleistocene deposits should be taken into account during photo-interpretation. Unfortunately, however, unconsolidated soft Pleistocene deposits subjected to tectonics are sometimes easily deformed by erosion and artifical works. Subsequently, newly erupted volcanic deposits should be and have been taken into consideration.

Abrasion benches along the coast raised by former earthquakes, recorded as well as prehistorical or historical, should also be considered. Abrasion benches are easily recognized particularly on infra-red aerial photographs.

Expert photo-interpretation of low relief terrain results in the discovery of topographic anomalies due to local structure. Aerial photographs are usually more sensitive than ground observation to anomalous topography. Photographic techniques of mapping weakly expressed structures are faster and sometimes more accurate than plane table and altimeter methods.

Tectonic features may be emphasized by anomalous behavior of running water and other surface agents. Drainage alignments, alignments of lakes and springs, and disruptions of channel and valley patterns are among the criteria of fault or fault-line traces. Such criteria can be easily recognized on aerial photographs.

However, the relationships between drainage and structure are complex. Runnoff is highly sensitive to lighologic and structural variations in the underlying bedrock, but is also influenced by surface obstacles produced by deposition. Caution is required, therefore, when drainage elements are used for structural interpretation. In addition to the well-known trellis, dendritic, concentric, radial, and annular patterns of drainage, local characteristics such as aligned drainage, ponded drainage, local widening or construction of valleys, have useful implications.

Frequently one can not be any more definite about an anomalous drainage feature than to call it a "drainage anomaly". The usefulness of the drainage network as a key to structure depends chiefly on the interpreter's knowledge can be attained only through long experience and through understanding of regional geology. Interpretation of structure through drainage is not for the novice.

Stereoscopic study enables photgeologists to apprehend the relationships between drainage and structure. This medium reveals both regional patterns and local anomalies. Drainage controls are most obvious in areas of moderate to high relief, where structures are pronounced and bedding most distinct. In such areas, annular and trellis patterns marking domes, folds, and homoclines are usually apparent even through thick cover. Structural features in areas of low relief are less obvious from the air, and structural control of drainage may be confused with patterns developed on surface deposits.

3. Regional Considerations

Generally speaking, photo-interpretation of structure is easiest in regions of moderate to high relief, and in arid or subhumid regions with little surface cover and vegetation. In these regions, rock bodies can be traced, attitudes measured or estimated, and structural conclusions reached rapidly and easily. Where the bedrock is weakly expressed in topography or masked by soil, vegetation, or surficial deposits, photo-interpretation of structure is an important aid to interpretation, but should not be used as the only evidence of structure. Photographic study of topography and structure often suggests relationships which can be quickly confirmed or disproved by field investigations in key places.

In high-relief regions composed of folded or steeply tilted strata, lithologic units reflect the main structural irregularities very clearly; ridge asymmetry is often great enough for identification of the dip and scarp slopes. Closely spaced, parallel hogbacks with recognizable dip slopes indicate steeply dipping homoclinal structures which mark the flanks of uplifts or downwarps, the limbs of fold structures, or tilted stratigraphic sequences. If indentations in a ridge are detected, the "rule of V's" can be employed as a horizon marker for structural mapping. Zigzag ridge pattern indicates a series of plunging folds, and the sharpness of bends in the ridges serves to distinguish synclinal from anticlinal structures. The above mentioned characteristics are easily identified on aerial photographs.

In humid regions of moderate to high relief, the strong topographic expression of some strata permits the interpreter to trace rock units and delineate structures in spite of heavy vegetation. Certain broad inferences about structure can be made from alignments of tress in heavily forested country. It is reported that the forest roof reflects, in a somewhat modified form, the topography of the ground surface. In extreme cases the correspondence is fairly exact. It is usually sufficient, however, to reveal the position of scarps and cuestas, from the distribution of which much physiographic evidence pointing to geological structure can be deduced. In densely vegetated regions, the apexes of high structures may be marked by variations in timber growth or by open spaces.

4. Earthquake Deslocations in Soft and Unconsolidated Deposits

Aerial photo-interpretation is a very useful technique for the survey of earthquake dislocations clearly marked on the land surface. Earthquake dislocations can be grouped into (a) land deformations (b) fire damages following earthquakes (c) damage to constructions such as houses, buildings, bridges, railways, dikes etc. (d) flood disasters due to inundation of lowlying areas including land below sea level and (e) the combinations of two to four times of (a)-(d) mentioned above. Dislocations of all categories can be analysed from aerial photographs.

The Niigata Earthquake, which occurred in June 16th of 1964, was characterized by land deformations, flood disasters due to inundation of the area below sea level, damage to constructions on unconsolidated and soft sediments and fire of oil tanks. Land deformations and damage due to quick sand phenomena were mostly in the area of former river courses composed of unconsolidated and soft sediments, and the area inundated coincided exactly with the area mentioned above. That is earthquake damage was concentrated in the limited area of soft sediments. Consequently, analyses of earthquake damage should

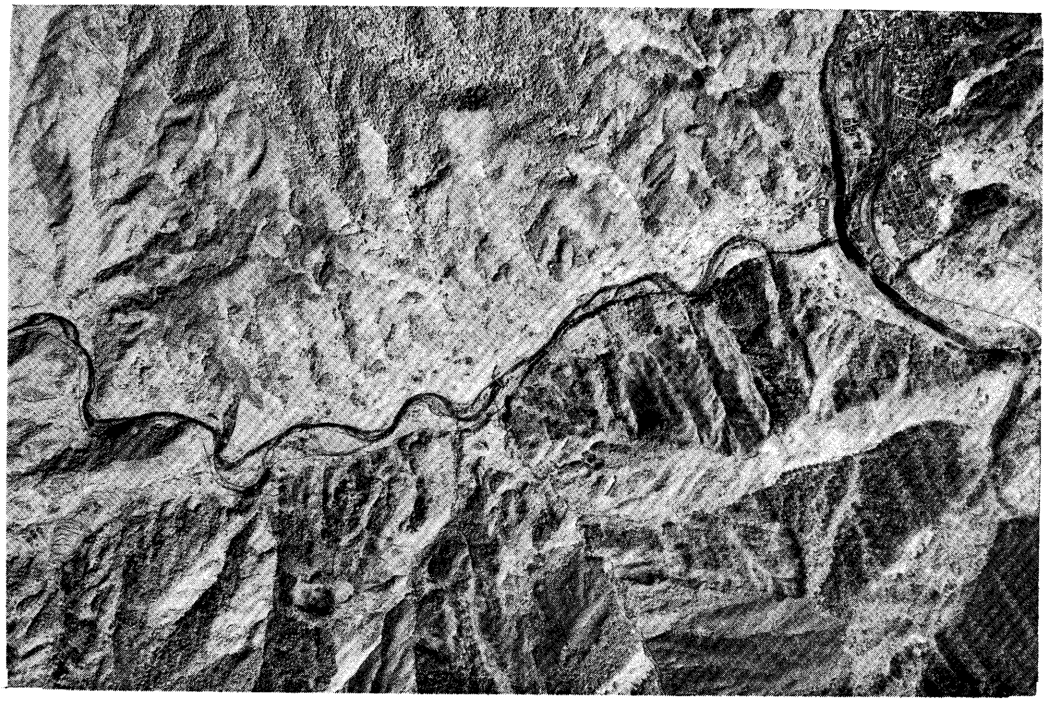

Plate 1 Fault, Kern Col and Kern but near Agematsu on the Kiso River. (Asia Aero Survey Co., Ltd.)

Plate 2 Linearments of Yakushima Island. (Asia Aero Survey Co., Ltd.)

Plate 3 Earthquake disasters due to the Niigata Earthquake in 1964. (Kokusai Aero Survey Co., Ltd.)

be conducted in relation to the distributions of soft sediments, which can be mapped by means of aerial photo-interpretation applying the techniques of engineering soil analysis.

Engineering soil analyses based on the classification of landform and classified landform units, if properly set up, can be interpreted into maps showing the distribution of surface materials. In order to classify landform units, aerial photo-interpretation should be introduced. On aerial photographs, details of landform features can be interpreted and a selected number of landform units set up, which can be inferred into lithological and soil units. For example, former river courses can easily be identified on aerial photographs and materials forming such a landform can be inferred. Sand dunes and beach ridges are composed of sands and easily be recognized on aerial photographs. Relationships between landform, surface lithology and earthquake damage are always high in areas consisting of thick clayey sediments. In the case of the Niigata Earthquake, earthquake damage was concentrated along the former river courses filled up with sandy materials. Tilting and sinking of concrete buildings, bridges, railways, roads etc. due to quick sand phenomena occurred on such sandy materials having a sufficient water content. Quick sand phenomena resulted in the ground water bringing up fine sand from beneath. Quick sand phenomena and damage due to these phenomena was so widespread that the Niigata Earthquake is often referred to as the earthquake characterized by quick sand. However, previous experience of earthquake damage has taught us that the thickness of soft materials closely reflects the damage ratio. This means that Alluvial plains, particularly on drowned valleys filled up by soft and unconsilidated materials, are generally the most sensitive to earthquake damage.

5. Conclusions and Proposals

1) Expert photo-interpretation can even result in the discovery of topographic anomalies due to local and minor structures. Aerial photographs are usually more sensitive to anomalous topography than ground ovservations. Photographic techniques of mapping weakly expressed structures are faster and sometimes more accentrate than using a plane table and altimeter.

Although the possibility of identifying tectonic movements using landform characteristics differs according to regional conditions, photo-geology is still a useful technique for analysis of tectonic movements in such humid and high relief regions as Japan. Photo-geology is not always highly regarded particuarly amongst pure geologists. In order to develope photo-geology in Japan, an exchange of knowledge and techniques on photo-geology should be promoted, not only on photo-geology, but also cooperations with geodesists and geophysicists on the same research projects is proposed to examine photo-geological evidence of younger tectonic and present day movements.

2) Aerial photo-interpretation is a very useful technique for the survey of earthquake dislocations of the regions composed of soft and unconsolidated sediments. Engineering soil analyses based on the classification of landform and classified landform units, if properly set up, can be interpreted into maps showing the distribution of surface materials. On aerial photographs, details of landform features can be interpreted and a selected number of landform units set up, which can be inferred into litholigical and soil units. Relationships between landform, surface lithology and earthquake damage are always high in areas consisting of soft and unconsolidated sedmiments. Attention should be drawn to this fact.