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Introduction

If one were casually to survey the recent literature on geological remote sensing, one might conclude that the activity began in 1972, when the first satellite dedicated to the Earth's resources (ERTS I now known as Landsat I) was put in orbit. This conclusion would be wrong because, photogeology, which is still the most used method of geological remote sensing, can be traced back to World War I.

In the present paper the view has been taken that photogeology began with the first scientific papers discussing the geological interpretation of aerial photographs. The term "photogeology" was defined in this way by Rea (1941). The relevant sentence is: "For this little known branch of geology the writer suggests the term 'photogeology', which is defined as the geological interpretation of aerial photographs". Fischer *et al.* (1975 p. 34) traces the term back to "The Committee on Photographs of the Geological Society of America" formed in 1890. He states that, "From that committee came the reference to a new activity called 'photogeology' "

While preparing a thesis on photogeology (Allum, 1960), it was found that, starting with references in the then current journals, it was possible to work back through the literature to 1920. Ignoring brief and casual comments, a total of 188 references preceding 1960 were found that were of sufficient significance to justify inclusion in a selected bibliography; no less than 86 of these references preceded 1946. This literature survey was excluded when much of the thesis was published (Allum, 1960-61).

The present paper was compiled from the above thesis, in the hope that it will be of interest to modern practitioners of geological remote sensing. References and comments have been confined to those papers that appeared to break new ground.

There are some important limitations in the following discussion. All the papers referred to were either published in English or were already available in English as translations. There is no doubt that good work was being published in foreign-language journals during some of the period under discussion. A comment that a particular paper is the first on a particular subject means only that it was the earliest reference found in the literature studied. A second limitation is that the references concern essentially classical photogeology. There are no references to the development of photography, cameras, airplanes etc.

For a much more comprehensive but less detailed history of photogeology, Mekel (1974) or Fischer *et al.* (1975) should be consulted.

Fathers of Photogeology

An early reference to the use of aerial photographs for geological interpretation is a paper by Thomas (1920a) describing an investigation into the possibility of using aerial photographs for the production of maps in Egypt during World War I. Thomas claimed that it was there that the strip system of aerial photography was developed, as distinct from the old system of photographing a number of adjacent points in no regular order, known as pin-pointing. He stated that form lines were added to all later maps, and that these were based on the stereoscopic examination of adjacent photographs.

Thomas was apparently much ahead of his time in the evaluation of the stereoscopic view, because it was to be some 14 years before it was generally accepted that a photogeological investigation should consist of a stereoscopic examination of aerial photographs.

Another very early reference is that to a lecture delivered by Thomas to the Geological Society of London on November 5, 1919 (Thomas, 1920b). In the course of this lecture Thomas noted that some aerial photographs showed the general geological structure of a district, and gave evidence of faulting at different periods. He also noted that aerial photographs could be used: in teaching geology, in illustrating some branches of physical geology; as a means of research in connection with river development; and as a means of research in those areas where the surface of the ground was very complicated and the main features were obscured by a mass of less important detail.

At this very early stage of development, Thomas had an astonishingly clear understanding of the potentialities of aerial photography for the purposes of geological study He has a strong claim to be regarded as an originator of photogeology.

Brooks (1920), can also lay claim to being an originator of photogeology. In referring to work done during World War I he wrote: "In drawing the boundaries on a scale larger than the original, some use was made of aero-photographs. The base of the heavy cliff-forming Bajocian Limestone could for example be rather accurately delineated from the photographs. The same results could probably have been obtained without the photographs, if a better contoured base map had been available. Another feature that favoured the drawing of this contact for part of the Moselle Valley was the fact that the vineyards of this area, which were outlined on the base map, are all on the Bajocian Limestone." Brooks' observations must have been approximately contemporaneous with those of Thomas.

Stereoscopy

Perhaps the earliest comprehensive paper on photogeology was that by Matthes (1928). Matthes fully realized the value of the stereoscopic interpretation of aerial photographs. He was apparently the first writer to state that the relief exaggeration in a stereoscopic model as compared with reality, was an advantage rather than a disadvantage in photogeological interpretation.

Another important comprehensive paper was that by Gill (1932). This paper brought the controversy concerning the necessity of using a stereoscope (see Figs. 1 and 2) in the photogeological examination of aerial photographs to a climax. Gill specifically stated that' ". . . interpretation of geology from air photographs is very largely a question of the systematic and careful examination of stereoscopic pairs of photographs." In the discussion of this paper (Wade, 1932), referring to the use of stereoscopic pairs of photographs said: ". . . this, though helpful, is not at all necessary for the determination of geological structure especially where height and time (of the photographs) have been well chosen."

This opinion of Wade's,that a stereoscopic examination of aerial photographs was not always necessary for photogeological interpretation, was quite widely held for a number of years (see Clute, 1926). In fact Taylor (1939) stated that the stereoscope was hardly used for interpretation up to 1934.

Loel (1938), wrote that you can see as much from the aeroplane as you can on the photograph. Loel also stressed, like many of his predecessors (see Clute, 1926; Wade, 1932; Woolnough, 1933a and b), the importance of time of photography, in order that the shadows cast should emphasize the topographic relief. These two statements make it appear probable that Loel was

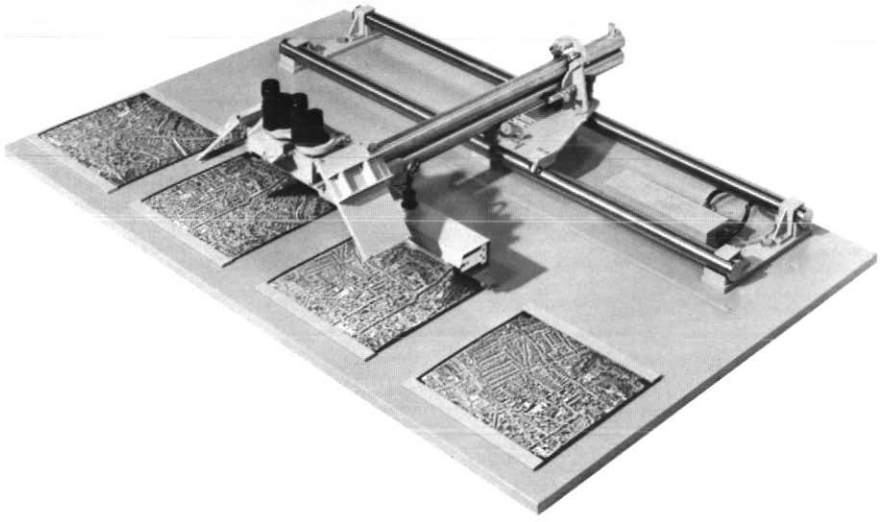

Figure 1
Mirror stereoscope with parallel guidance mechanism. (Courtesy of C.F. Casella and Co. Ltd.)

Figure 2
Pocket stereoscope with cut-away leg. (Courtesy of C.F. Casella and Co. Ltd.)

referring to the use of single photographs, and also that he did not study photographs stereoscopically as a matter of routine. Stereopairs of aerial photographs usually produce exaggerated relief (Matthes, 1928), and because of this, it is not true that an observer with normal stereoscopic vision can see as much from the aeroplane as he can on the corresponding stereopair of photographs.

Desjardins *et al.* (1939) apparently assumed that all aerial photographs would be studied stereoscopically. They stated that breaks in slope and vertical intervals between breaks in slope were the two most valuable criteria in mapping aerial geology. A stereoscope would be essential to make use of these criteria. This paper appears to mark the end of the controversy concerning whether or not aerial photographs should always be studied stereoscopically.

Expanding Scope of Photogeology

An early reference to the photogeological interpretation of igneous and metamorphic rocks was by Bruce (1922). In this paper Bruce described how to discriminate between granite and granitic gneiss photogeologically. In the same year, MacLaurin (1922) wrote an article drawing attention to the value of aerial photographs as an aid to prospecting. The great achievement of 1922, however, was the publication, by the American Geographical Society, of a book by Lee (1922) entitled: "The Face of the Earth as seen from the Air". This book, which can be read with pleasure by photogeologists today, contains many beautiful aerial photographs of land forms. The use of stereoscope is recommended, and the possibility of contouring from stereopairs of photographs is noted.

After the excellent publications of 1922, a veil of secrecy seemed to fall over photogeological work until 1925, when Sampson published what was probably the first paper on photogeological techniques. Eight years later, according to Rigby (1933), the habit of secrecy was still handicapping the development of photogeology.

Among the earliest papers categorically linking photogeology with oil exploration was that by Clute (1926). In this paper, great emphasis is placed on the use of mosaics, but the possibility of full stereoscopic photogeological interpretation is almost disregarded.

In 1936, Farrington wrote one of the rare, major papers, on the photogeological interpretation of igneous and metamorphic rocks. Farrington included sixteen photographic plates. He showed that contacts, faults, dykes, and folds were recorded on the photographs. He insisted that some field work should precede interpretation. Later writers, however, were of the opinion that

photogeological interpretation should precede the field work (see particularly Stringer, 1953).

The close relationship that exists between the vegetational cover and the underlying geology was noted by Bourne (1928). He wrote that despite the marked influence of native cultivation on the natural vegetation and soil, a distinct correlation between vegetational types and the geology of localities was repeatedly observable. He also noted that if a perspective view is obtainable from the air, or from aerial photographs, it becomes easy to identify basement schists.

These important observations led to the widening of the scope of photogeology to include areas covered by vegetation, which had hitherto been regarded as unsuitable for interpretation. This process continued until eventually even thickly forested or marsh country came to be regarded as suitable subjects for photogeological investigations (Fitch, *et al.*, 1949; de Blieux, 1949).

The value of aerial photographs in the study of large scale structures in the Canadian Shield was demonstrated by Wilson (1948). He succeeded in showing that the interpretation of aerial photographs can provide useful structural information rapidly over great areas, and that the information so obtained can be interpreted in the light of physical theory.

New Knowledge from Photogeology

Woolnough's papers (1933a and b), which undoubtedly gave a great impetus to photogeology, described enthusiastically the results achieved in a reconnaissance flight around Australia. His most important observation, however, was that much geological structure, which is quite invisible on the ground, can be seen on aerial photographs.

Hemming (1934) also noted that much geological information, which cannot be seen on the ground, was recorded on aerial photographs. Referring to the Wanderer Mine, he wrote: "This mine has been very highly geologized on the ground and worked over for a good many years, and yet the photographs show up much information not previously known to geologists."

Some years later Eliel (1937) gave his views on how it is that geology, which cannot be seen in the field, can sometimes be interpreted on photographs. He wrote that: "It is a never-ending source of amazement to people who have not used aerial maps (photo-mosaics, J.A.E.A.) extensively that small-scale pictures can reveal information that cannot be detected from an examination of the ground itself. On careful reflection, the reason becomes apparent. The geologist on the ground sees only what is immediately near him. One isolated bit of evidence often has little significance. However, if that is an outcropping of a vein, which has another little outcrop a half mile away, and another a mile beyond that, this alignment and continuity enables the geologist using the aerial map to correlate his information. This same thing is particularly true of faults and contacts, which frequently show up strikingly in the photograph over long stretches of country. These are often difficult to find on the ground, because of the gradual melting of one formation into the other in such a way that definite evidence is not clearly available."

Criteria for Interpretation

Apparently the first paper discussing the criteria for photogeological interpretation was that by van Nouhuys (1937). van Nouhuys did not attempt the monumental task of describing the different photographitic characteristics of each rock type in all the different climatic, structural, and erosional environments. He wrote instead: "Geological interpretation of air photographs is thus partly art and partly science, and can, therefore, at this early stage, be adequately explained only by means of samples."

An interesting attempt to classify the criteria for photogeological interpretation of Basement areas was made by Fortier (1947). He classified the criteria under the headings topographic lines, finer lineaments, tabular features, colours, relief, and systems of orientation.

Techniques for Interpretation

The techniques for the interpretation of aerial photographs were discussed by Desjardins (1950). He indicated how photogeology, in certain respects, was becoming an exact science. This observation, however, applied mainly to the study of sediments, where it was possible to measure dip slopes and to contour particular horizons, using stereopairs of aerial photographs. This increasing emphasis upon direct measurement on aerial photographs must have been taking place for some time when Desjardins wrote, yet it was not apparent in the literature.

Textbooks

By 1942, the interpretation of aerial photographs had apparently become of sufficient importance to justify the production of text books. Two were produced in quick succession (Eardley, 1942; and Smith, 1943) both books represented a valuable synthesis of existing knowledge.

In 1951 a six volume key containing many stereopairs of aerial photographs of different rock types was produced (Liang, Ta. *et al.*, 1951).

Colour Aerial Photographs

An early paper describing practical work with colour aerial photographs was that by Laylander (1952). In evaluating true colour photography for photogeological interpretation, Kent (1957) found that the colours or rocks in early stages of alteration were useful criteria for recognizing them, but that highly altered rocks had the same colour within several different lithological units. It was also found by Petrusevich *et al.* (1955), and Fischer (1958) that some rocks could be discriminated on colour but not on black and white photography.

Later Days

My systematic study of photogeological literature stopped in 1959, before the great flood of remote sensing literature began in the nineteen sixties and seventies, which dealt with such subjects as: infrared, true colour, and multispectral photography; radar, thermal, and satellite imagery; and methods of digital image processing and enhancement. Photogeology became absorbed into the larger subject of remote sensing.

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