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Comment and Reply on "The Choice of Satellite-Borne or Air-Borne Remote Sensing for Geology and Mineral Exploration"

COMMENT

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Dr. Allum's critique of Landsat data as a source of geological information (see J.A.E. Allum, 1984, The Choice of Satellite-Borne or Air-Borne Remote Sensing for Geology and Mineral Exploration: *Geoscience Canada*, v. 11, p. 208-209) may be viewed by many geologists as a wholesale condemnation of the use of Landsat in geology. While his comments may have been directed to digital processing (paragraph 2, p. 208), such emphasis is not clear in most of his text. Our experience with mapping from Landsat images over the past twelve years shows that his comments are not valid generalizations with respect to cerebral processing using the eyes and brain of an experienced mapper. I am dismayed, to say the least, that a magazine for geological scientists and, before that a university, have helped to propagate biased and partly inaccurate points of view.

A detailed refutation of Dr. Allum's comments would require a treatise. In fact, we have demonstrated in practice and in 39 public reports and papers that Landsat MSS images can be enlarged optically, projected to register on base maps at scales up to 1:10 000 and interpreted to provide meaningful information. Our experience is summarized in the following responses to Dr. Allum's major objections to Landsat MSS:

Objection 1. "Landsat MSS data in four bands are not relevant to geology." Many authors have published to the contrary, especially for arid terrains. But even in areas with temperate forest, useful geological information can be obtained if appropriate techniques and scales are used.

Objection 2. "Repetitive coverage is of no use in geology." This is not true for active geological phenomena nor for seasonal enhancements that may assist in interpreting subtle and or small features (e.g. snow cover enhances seismic lines, 3-5 m wide, in boreal forest). Further, two images with different solar elevations for the same scene can provide shadow parallax for a useful stereomodel (see 3).

Objection 3. "Pairs of Landsat images do not produce stereoscopy equal to aerial photographs." This is true; however, it is possible to obtain vertical exaggerations of 4 × to 40 × using shadow parallax in Landsat images. Such stereoscopy can be a useful aid in mapping differential relief for geology and for estimating strike and dip. The technique is not yet quantitative on a systematic basis, although we have calculated heights of pingos to within 2 m of the recorded height.

Objection 4. "Reflected energies are rarely characteristic of rock type." This applies equally to aerial photographs. Local brightness in Landsat data may be diagnostic where geological data are available for calibration. In addition, Landsat may be integrated with geophysics to provide more definitive detail. Since 1974, we have mapped over 200 000 km^2 of Precambrian geology from Landsat and collateral data in areas with both tropical and temperate climates.

Objection 5. "Landsat images do not provide as much detail as aerial photographs." The geological significance of this fact depends upon the mapper's objectives, including scale. For features with an area greater than several hectares, Landsat MSS can provide much useful information especially if integrated with geophysical data at scales of 1:50 000 or smaller. While detailed fracture patterns are not mappable from Landsat (and may not be from air photos), the grosser patterns are. On the other hand, in many areas where soils may diffuse the detail of such structures (e.g. lateritic terrains), Landsat images may present as much geological detail as aerial photographs at a scale of 1:50 000. Of course, there are far fewer Landsat images to be handled per unit area.

Objection 6. "Positioning from Landsat is inadequate for geological mapping." This depends on scale and technique. Separate trees and similar small features are not identifiable, in general, on Landsat images. On the other hand, we have demonstrated that Landsat MSS can be registered to topographic maps at scales as large as 1:10 000. There is adequate detail for geological mapping at scales of 1:50 000 and smaller with accuracies that meet accepted standards. For example, we have experience with over 5000 NTS sheets at a scale of 1:50 000 (about one-third of Canada) which were assessed for change in support of map revision for the Canadian Topographical Survey. We have demonstrated that revisions from Landsat MSS at 1:250 000 scale meet Class A standards for topographic mapping. At scales of 1:50 000, we have shown that the mean error in relative position of linear features (e.g. roads, lakeshores, powerlines, etc.) is 30 m and that 90% of the errors are less than 50 m. Of course, non-linear features with low contrast and or an area smaller than 1 hectare, will not be positioned as accurately and may not be recognized at all.

Objection 7. "Satellite data are more expensive to use than air-borne data." As long as governments continue to sell images (and aerial photographs) as a "public good", the cost of mapping at scales of 1:50 000 and smaller should be less when using Landsat images than when using aerial photographs. The key question, though, is not cost but which set of data will provide the information required to meet the specific geological requirements of the exploration program.

In summary, as we have shown over the past decade, Landsat images and appropriate technology can assist the average geologist in mineral exploration at scales as large as 1:50 000 and in at least eight different ways:

1. overview of terrain;
2. preparation of base maps;
3. mapping of linear features and recognition of faults;
4. interpretive geological mapping by integration with geophysics;
5. stereoscopic viewing with large vertical exaggerations;
6. spectral overlay from Landsat on detail of aerial photographs;
7. spectral anomalies related to ore (rare); and,
8. archival baseline for regional environment.

There is much to learn about the optimal and economic use of data from Landsat and succeeding satellites. Those problems of interest to mineral exploration will not be solved by writing off the data before the data and techniques are assessed in practice.

REPLY

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I am glad that my contribution to "Pyroclasts" has inspired a response from Dr. Gregory. My own talk, on which my contribution was based, was itself inspired by what I regard as the current over-emphasis on data obtained from satellite-borne sensors as compared with that obtained from air-borne sensors in geological mapping and mineral exploration.

With regard to Dr. Gregory's Objection 1, I cannot find the statement he objects to in my contribution. The only place in which I discussed the relevance of the four Landsat bands to geology was in p. 208 paragraph 4. The purpose of this paragraph was to point out that one could avoid wasting money on various computer enhancements by asking oneself whether the raw data obtained under perfect conditions *could* be relevant to one's problem. If it could, then one was justified in working to find the best enhancement technique to make use of it. I think Dr. Gregory must have missed this last sentence.

Of course if the data could not be relevant, then one was wasting both time and money proceeding further.

In the discussion of repetitive coverage (Objection 2), I mentioned (p. 209, paragraph 12(1)) that it was advantageous for some projects to have imagery obtained during more than one season, e.g. in the summer to show vegetation, and in the early winter, when a thin snow-cover emphasized geological structure. These comments have much in common with Dr. Gregory's. However, having images taken during different seasons is not really what we mean by repetitive coverage. By repetitive coverage we normally mean the acquisition of data by the satellite-borne sensors at every satellite overpass. In this sense, repetitive coverage is essential for studying changing surface phenomena, but it is not essential for the study of geology (p. 208, paragraph 5).

I agree with Dr. Gregory's Objections 3, 4 and 5, but I do not understand why he called them objections. His paraphrase of my remarks, "Reflected energies are rarely characteristic of rock type", with which he agrees, is particularly significant with respect to attempts to carry out the lithological interpretation of Landsat data digitally. The interpretation of aerial photographs, however, is based far more on the differential relief of the stereo-model (p. 208, paragraph 6) than on tonal values (reflected energies). Nevertheless I think that there is general agreement that, in the present state of the art, the lithological interpretation of both aerial photographs and satellite imagery is not very reliable.

I am afraid Dr. Gregory has missed the point of the discussion with his Objection 6. His comment apparently refers to my discussion of the relative value of aerial photographs and Landsat images in the field (p. 209, paragraphs 7 and 8). Stereoscopic aerial photographs (but not satellite images) can be used in the field to record *precisely* the sites of geological observations, and mineral showings, or the exact points at which rock specimens, mineral samples, and geochemical samples were collected. Over the past 35 years I have heard of many cases in which it has proved impossible to relocate in the field the reported mineral showings, etc. This loss of important information would not have occurred if the locations of the observations had been recorded permanently on the aerial photographs (p. 209, paragraph 7).

It is recommended that photocopies be made of the aerial photographs to be used in the field. After locating the position of the observation site, etc. on one photograph of the original stereopair, the position can be transferred precisely to the equivalent photocopy. The photocopy is cheaper, and more conveniently stored (filed), than the original aerial photograph.

Dr. Gregory has made a valuable contribution in his Objection 7. In considering the relative costs of data obtained from satellite-borne and air-borne sensors, I should have confined my comments to the immediate costs to the user, rather than to the total cost to the taxpayers. A second point in my contribution that I would like to take the opportunity to correct, is my disparagement of the idea that satellite imagery will be particularly valuable in those countries in which aerial photographs are not obtainable (p. 209, paragraph 6). This is clearly wrong. Landsat imagery can be used as a tool for the production of reconnaissance geological maps. First the imagery can be interpreted in terms of geological units, with these units being delineated on the image. Then field checking can be carried out to determine what rocks are represented by the units. The whole process is analogous to photogeology, although the detail obtained is necessarily inferior. This type of reconnaissance geological mapping is likely to be of particular value in a situation in which it is desired to produce geological maps, in a consistent format, of large areas in limited time (say 2 to 3 years). This situation is particularly likely to arise in less developed countries that have been completely geologically mapped piecemeal, in several different scales and formats.

Discussions of articles or features published in recent issues of the journal may be accepted for publication if they are brief and of a technical or interpretative nature. Replies to such discussions are invited from the original authors and are generally published in the same issues.