PIT SLOPE MANUAL

supplement 2-4

JOINT MAPPING BY TERRESTRIAL PHOTOGRAMMETRY

This supplement has been prepared as part of the

PIT SLOPE PROJECT

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THE PIT SLOPE MANUAL

The Pit Slope Manual consists of ten chapters, published separately. Most chapters have supplements, also published separately. The ten chapters are:

1. Summary
2. Structural Geology
3. Mechanical Properties
4. Groundwater
5. Design
6. Mechanical Support
7. Perimeter Blasting
8. Monitoring
9. Waste Embankments
10. Environmental Planning

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SUMMARY

Photogrammetry, especially aerial photogrammetry, has been accepted by the mining industry as an important tool for surveying of large open pits, for the updating of pit plans, calculation of mined volumes, estimation of mass movements, and the provision of topographical maps.

Terrestrial photogrammetry can be used to obtain geological information on orientation, spacing and length of joints from steep rock slopes with limited access. This supplement, in serving as a guide to principles, accuracy, data collection, analysis and costs, is intended to encourage the use of terrestrial photogrammetry to its full potential. It will assist geologists in assessing the applicability of the technique to their objectives and will familiarize photogrammetric analysts with some aspects of geological discontinuity observation.

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INTRODUCTION

1. There are many combinations of photography with some form of survey control to help the geologist obtain structural information for a pit site. The information can be qualitative, as from photogeology, or quantitative, as provided by various forms of photogrammetry. Aerial photogrammetry can be especially useful for the surveying of large open pits, eg, in updating plans, calculating mined volumes, estimating mass movements, providing base maps and permanent records. Terrestrial photogrammetry can be used to obtain geological information from steep rock slopes with limited access. This method has been used successfully to determine the orientation of joints, their spacing and length.

2. Terrestrial photogrammetry, though successful in many cases, has limitations due to sight restraints in pits, lack of photogrammetric expertise and analytical equipment at mines, and unfamiliarity with geological objectives among operators of photogrammetric equipment.

3. To allow the potential user of terrestrial photogrammetry to assess its suitability for his objectives, and to familiarize the photogrammetric analyst with some aspects of geological discontinuity observation, this supplement provides guidance under the following headings:

- principles of photogrammetry and available equipment,
- errors and limitations,
- design of a photogrammetric system,
- field operation,
- case histories,
- summary of experiences, and
- costs of terrestrial photogrammetry.

PRINCIPLES OF PHOTOGRAMMETRY AND AVAILABLE EQUIPMENT

4. In photogrammetry, quantitative measurements are based on parallax, which occurs if an object is photographed from two different locations. Parallax, which delineates the shift in the position of an object on two overlapping photographs taken from different locations, depends on a simple relationship between the focal length of the lens, the camera-object distance, and the length of the base line, ie, the distance between camera locations. The parallax allows production of a three-dimensional image from two overlapping photographs under a mirror stereoscope.

5. The layout of Fig 1 is used to measure the orientation of joints on pit walls. A base line is set up parallel to a slope and photographs are taken normal to the base line and as nearly horizontal as possible. An overlap of 60% is usual in the photographs. Targets are placed on the slope wall within the field of stereoscopic view so that the photographs can be oriented and discontinuities measured. The photographs are placed in a plotting machine, where a stereoscopic image is produced whence fractures can be located and their orientation measured.

6. The accuracy which can be obtained depends basically on the internal geometry of the camera, ie, focal length of lens and planarity of film, and the external field geometry, ie, base line: distance ratio and target positions.

7. Photogrammetric equipment consists of cameras, survey, and analytical or plotting equipment. The choice of cameras and plotting equipment will depend on the size of the area to be photographed and the number of observations to be processed. An accuracy of 0.01 mm in parallax measurements requires precision instruments.

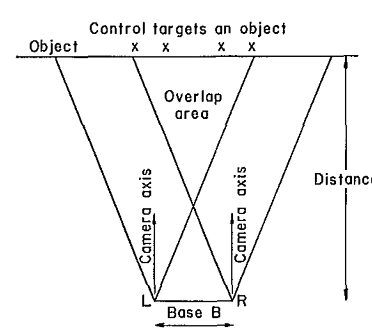


Fig 1 - Field set-up (exterior orientation) to obtain overlapping stereopair (1).

CAMERAS

8. Picture formats vary between 60 x 80 mm and 125 x 175 mm and, because of the long focal lengths, cameras are generally large. An example is shown in Fig 2. Cameras should have a distortion-free lens which, combined with the camera frame and plate or film, should produce a probable error no greater than .008 mm. The resolution of the lens should be greater than 60 lines per mm and the focal length should be 60 mm or greater. A large tilt range is an asset. Combinations of cameras with theodolites are called "phototheodolites". These are useful for topographical work and generally have long focal lengths, eg, 100 mm to 190 mm. A list of typical units is given in Table 1.

Fig 2 - 100 mm focal-length photogrammetric camera (courtesy Carl Zeiss, Jena).

Table 1: Some typical photogrammetric cameras

Manufacturer & instrument name	Description	Focal length	Usable format	Type of film	Available tilts in new degrees, g	Price[1] (1976) $
Galileo-Santoni FGT 1/b	Phototheodolite with camera above telescope	155	90x145	Plate	+100 to -100	(discontinued)
Wild P30	Phototheodolite with camera below telescope	165	95x145	Plate	0,±7,-14,-21	(discontinued)
Zeiss (Jena) Phototheo 19/1318	Terrestrial camera with theodolite-like orientation device	193	120x160	Plate	+9 to -13	6500.
Officine Galileo Veroplast	Terrestrial camera to fit theodolite	150	<130x180	Plate	+100 to -100 per 10 g	5100.
Wild P32	Terrestrial camera to fit theodolite	65	60x80	Plate, c&r[2]	+44 to -44	5500.
Wild P31	Terrestrial camera with three choices of focal length	45 100 200	max 92x118	Plate	0,±7,±14,±25,±30, ±50,+60,+75,+85,+93,+100	15500.
Zeiss (Jena) UMK 10/1318	Terrestrial camera	100	120x166	Plate, c&r[2]	0,±16.5,±33, ±49.5,±66, ±82.5,±100	14500.
Zeiss (Oberkochen) TMK-6	Terrestrial camera	60	80x100	Plate	0,±30,±70,±100	12600.
Zeiss (Oberkochen) TMK-12	Terrestrial camera	120	80x100	Plate	0,±30,±70,±100	12600.
Wild C120	Two stereometric cameras mounted on 120 cm base	64	65x90	Plate	0,±11,±33,±67, ±89,±100	16000.

1) Prices are approximate and vary with accessories

2) Cut and roll film

PHOTOGRAPHY

9. A variety of roll films is available, as well as glass plates. The latter possess greater dimensional stability. Sensitivities are commonly between 16 and 80 ASA.

10. The photographic scale, defined as the ratio of focal length to object distance, should be better than 1:3000 for analyzing geological discontinuities, and usually lies between 1:200 and 1:3000. The scale can vary considerably between the foreground and background of a terrestrial photograph if the object is sloping away from the camera's focal plane. In such a case provision for tilting the camera's focal plane parallel to a slope is a definite asset.

11. The recommended overlap of a series of photographs is 60% but may be smaller in isolated instances, particularly where the base line is lengthened to minimize error. Smaller overlaps result in greater field and analytical effort for a given area.

12. In any field work remote from suitable office facilities, exposed photographs should be developed at the site, so that the quality of photography can be checked before departure.

SURVEY EQUIPMENT

13. For the required high precision, observations must be made with a one-second theodolite. Closure of the survey on the reference station should be within 5 seconds of arc.

14. For topographical work and joint analysis of pit slopes, camera and survey equipment are combined in phototheodolites, eg, the Wild P30 unit of Fig 3. Phototheodolites have an advantage in that, after levelling the instrument and setting the horizontal circle to zero, the optical axis of the theodolite and camera are in the same vertical plane. A similar combination can be obtained by placing a camera attachment, eg, the Wild P32, on a T2 theodolite.

CONTROL TARGETS

15. For easy identification, control targets should be a minimum of 1 ft (30 cm) in diameter for every 400 ft (130 m) of distance. Three targets per overlap are the minimum if the camera station coordinates are known, but six are preferred. If the camera station coordinates are unknown, at least four targets are required. Targets should be placed on the topographic highs and lows of the foreground and background in the area of overlap.

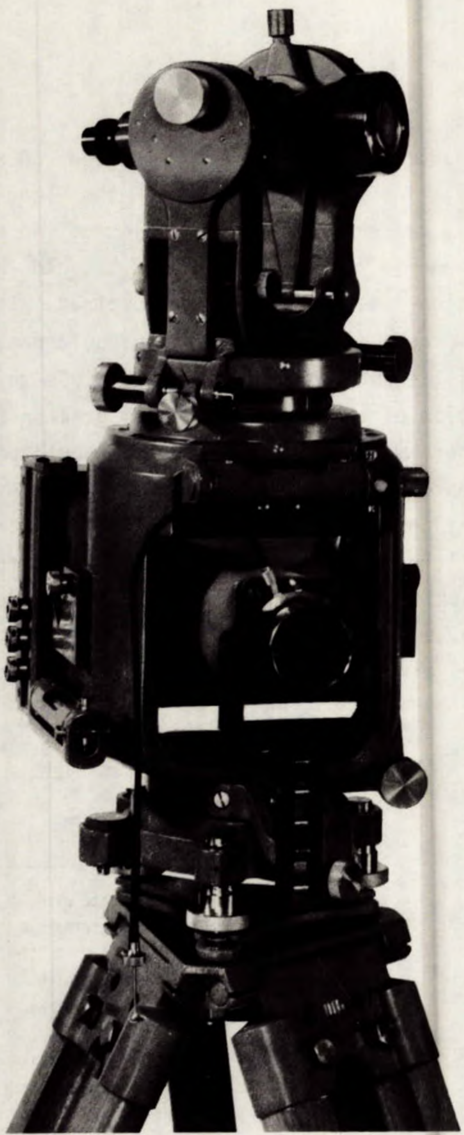


Fig 3 - P30 Phototheodolite with 165 mm focal-length camera (courtesy Wild, Heerbrugg).

16. Targets should be symmetric in shape to help locate the centre, and must be surveyed from two separated base stations. If targets are triangulated, there should be at least two rounds of angular measurements to each target. Elevations should be computed from two stations and the agreement should be within .030 m. Target co-ordinates should agree within .030 m, with a

mean less than .025 m.

ANALYTICAL EQUIPMENT

17. A wide variety of analytical equipment is available to obtain quantitative information from photopairs. This can range from a parallax bar at \$2000 to automated stereoplotters costing up to \$100,000.

18. Measurements are made with the "floating dot" principle, which can best be explained in relation to the parallax bar or stereometer shown in Fig 4(2). In operation, two glass or plastic squares with a target dot on each are mounted on a bar which is graduated like a micrometer so that the horizontal distance between the individual dots can be measured to 0.01 mm. A stereo pair of aerial photographs are placed under a mirror stereoscope and the dots are placed on the same object in each photograph to give conjugate image points. The two target dots, one seen with each eye, are fused stereoscopically into a single dot which appears to float in space within the area of view. The apparent height of the fused dot depends on the horizontal separation of the individual dots. By changing this horizontal separation, the fused dot can be made to appear to float up and down. Sometimes the dot appears to split, in which case adjustment of the stereophotographs is required.

19. To measure the height of a cliff or a hill in a photograph, the fused dot is placed on top of the hill or cliff and the horizontal distance noted. The dot is then placed at the bottom of the hill or cliff and the horizontal distance again noted. The latter horizontal distance is subtracted from the former. This parallax difference (Δp) is then converted to height by a simple calculation (2,3):

$$h = \frac{H}{B} \cdot \Delta p$$

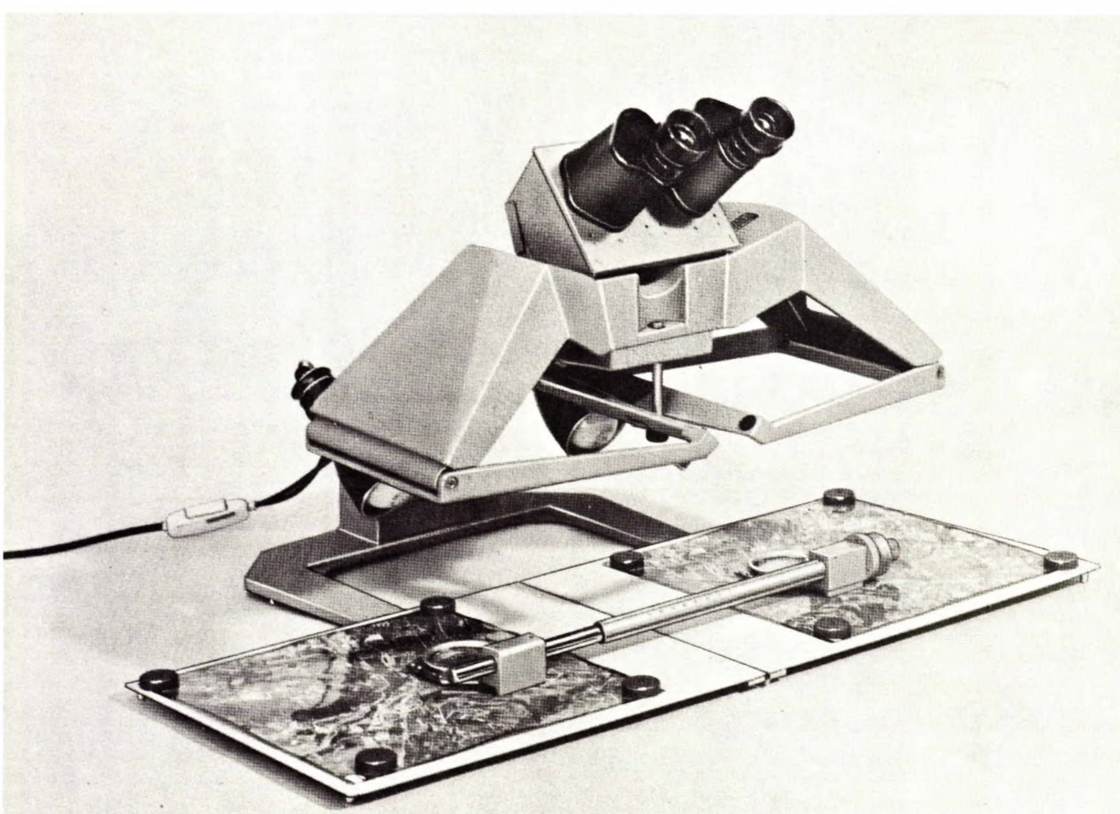


Fig 4 - Mirror stereoscope with parallax bar or stereometer (courtesy Officine Galileo, Firenze).

where h = height of object, H = height of airplane above mean terrain and B = distance between center and conjugated center of each photograph.

20. A mirror stereoscope and a parallax bar are inadequate for carrying out absolute measurements of location and orientation of joints on terrestrial photographs. For this purpose plotting instruments have been developed which are matched to principal distance, ie, focal length of camera lens at infinity, and tilts of the camera. A photogrammetric plotter as shown in Fig 5 reconstructs a stereoscopic model with a geometric projection which has the same interior and exterior orientation as the cameras in the field. Not every plotting instrument, therefore, is capable of analyzing stereophotos from all cameras. Within the stereoscopic model measurements are made with the floating dot principle. The floating dot is controlled in three dimensions within the stereoscopic model by various wheels on the plotter which can be fitted with digitizers for automatic recording.

21. Another unit, the stereocomparator, reconstitutes a three-dimensional model, not by projection but by direct stereoscopic viewing of both pictures. Photographs are measured to 0.001 mm and three-dimensional coordinates are obtained by calculation. The stereocomparator is generally more accurate than a photogrammetric plotter and has an advantage in that focal length and tilts do not have to be matched with the camera.

22. A more recent development is the Stereocord G2 by Zeiss (Oberkochen), a digitized mirror stereoscope which allows working with a desktop calculator and is capable of analyzing 23 cm x 23 cm stereophoto pairs of any focal length.

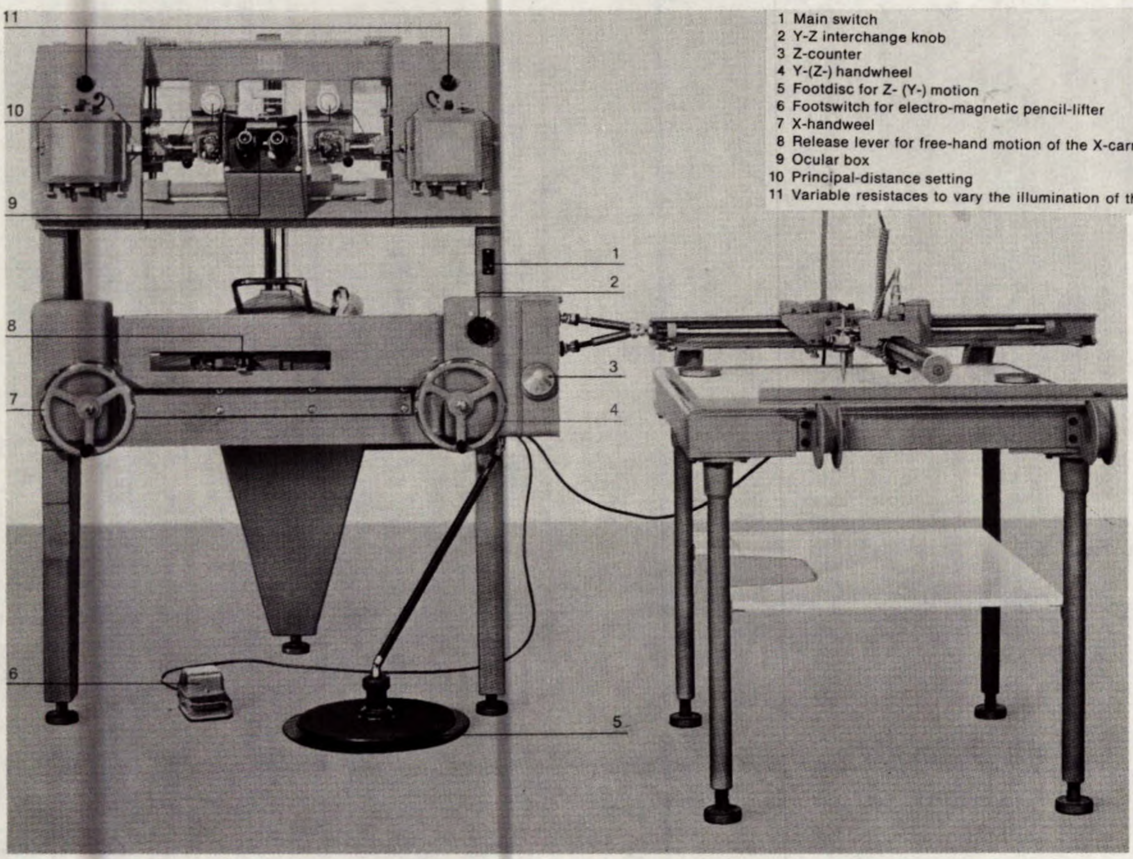


Fig 5 - A 40 autograph for analysis of photographs taken with stereometric cameras with 54 to 100 mm focal-length lenses (courtesy of Wild, Heerbrugg).

Table 2 lists various types of plotting instruments. Further details on equipment and operation can be obtained from the manufacturers.

Table 2: Some typical plotting instruments

Manufacturer and name of instrument	Focal length range mm	Maximum photo format cm	Approx. price (1976) $
Kern PG 3	84 to 310	23 x 23	80,000.* (1974 price)
Officine Galileo Stereosimplex-IIC	85 to 220	23 x 23	29000.
Wild A 8	98 to 215	23 x 23	75000.
Wild A 10	85 to 308	23 x 23	110000.
Wild A 40	54 to 100	9.2 x 12.5	50000.
Zeiss (Jena) Stereometrograph F	85 to 310	23 x 23	70000.
Zeiss (Jena) Technocart	50 to 215	4 x 4 to 23 x 23	45000.
Zeiss (Jena) Topocart B	50 to 215	23 x 23	38500.
Zeiss (Oberkochen) C-8 Steroplanigraph	100 to 610 in steps	23 x 23	**
Zeiss (Oberkochen) D-2 Planimat	84 to 308	23 x 23	95000.
Zeiss (Oberkochen) Terragraph	50 to 65	9 x 12	30,000. (1974 price)
Zeiss (Oberkochen) Stereocord G2 digitized mirror stereoscope		23 x 23	25000.

* With digitizer.
** Price on request.

ERRORS AND LIMITATIONS

23. Within a photogrammetric system, errors can occur in all the system components, such as equipment, field operation, and analysis. Apart from gross mistakes, the most sensitive component of the system is the field layout as it affects the scale of representation. The stereoimage from small scale photographs might be so poor that arbitrary decisions have to be made as to where to place the floating dot. This leads to errors in interpretation which can be so large that the resulting measurements are useless. In Table 3 the components of the photogrammetric system are defined, and their errors are to be described in detail.

EQUIPMENT

24. Errors arising from equipment operation are in general not significant in terrestrial work, since the dimensional stability of the photographic film, glass plates, camera and plotting instrumentation is high. Regular checks and maintenance are nevertheless essential. Calibrations should be carried out with the aid of the manufacturer's instructions. The parallax error (ε_p), which comprises errors from equipment and film materials, is generally accepted as 0.01 mm.

FIELD OPERATION

25. Two main sources of errors in field operations are the limited accuracy of the field layout, and survey errors during the control survey.

26. In a photogrammetric field layout, the most significant element influencing scale and accuracy is the base:distance ratio. Figures 6 and 7 indicate how a decrease in the ratio will increase observation error.

27. The next important variable is the focal length of the camera lens. The focal length of a camera lens is the distance between its rear node and the focal plane, with the lens in focus at infinity. The film or photoplates are positioned in the focal plane. The focal length of photogrammetric cameras generally ranges between 60 and 193 mm. The ratio of focal length to object distance defines the scale in which the object will be represented on a photograph.

28. From the camera focal length and the base: distance ratio the accuracy or parallax can be

Table 3: Sources of error in a photogrammetric system

System components	Variables	Error definition
Equipment		
Film, Camera, Plotting instruments	Dimensional stability photo resolution	Parallax error (ε_p) -
Field Operation		
Layout	Camera focal length (f) field base (B), and distance (D).	Theoretical photogrammetric error (ε_t) $\varepsilon_t = \frac{D^2}{fB} \cdot \varepsilon_p$
	Definition of images	Interpretation factor (i_f) Observation error (ε_o) $\varepsilon_o = \varepsilon_t \cdot i_f$
Control survey	Survey observations, Target spacing	Survey error (ε_s) Control survey error (ε_{cs}) $\varepsilon_{cs} = \frac{\varepsilon_o + \varepsilon_s}{S}$
Analysis		
Character of discontinuities	Joint definition, roughness of joints	Interpretation factor (i_f) Plane fitting error (ε_{pf})
Photogrammetric point distribution	Point plotting procedure	Plane observation error (ε_{po})

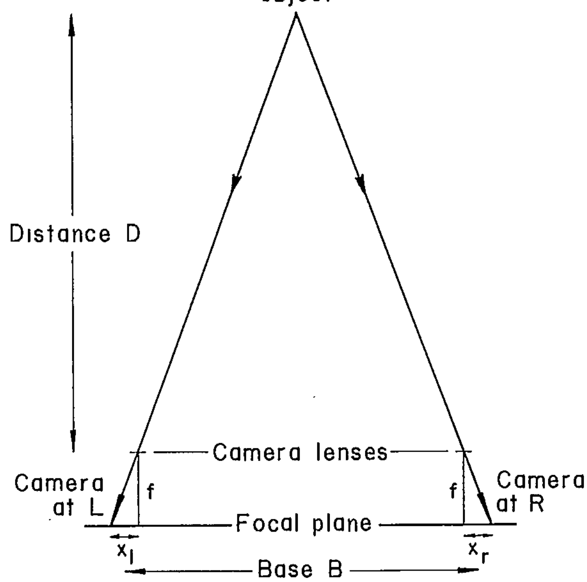


Fig 6 - Elements defining theoretical photogrammetric error (1).

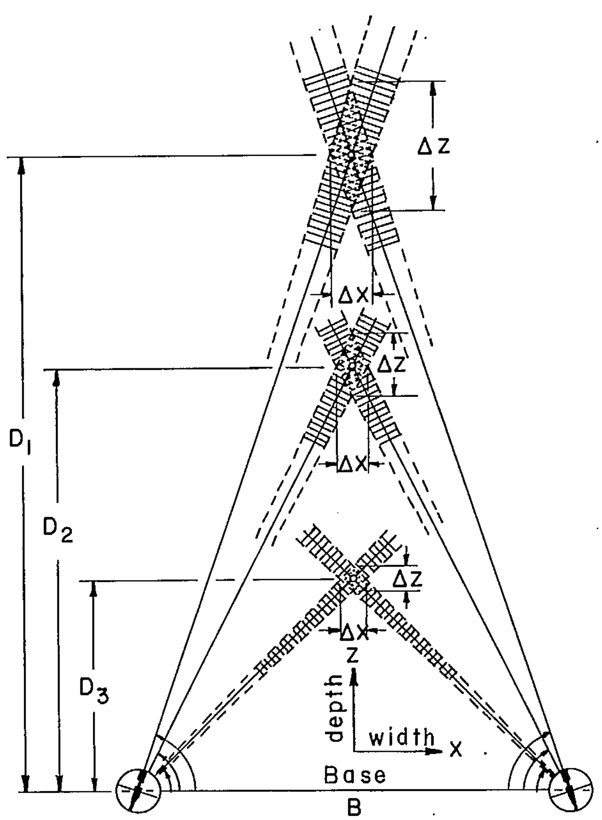


Fig 7 - Variation of Δz and Δx error with a change of base: distance ratio.

calculated. The sketch of Fig 6 shows a typical field geometry, and the equation below defines parallax.

$$\text{parallax } (p) = x_l + x_r$$

$$\frac{x_l + x_r}{f} = \frac{B}{D}$$

$$p = \frac{f.B}{D}$$

29. From this equation the theoretical photogrammetric error is derived as:

$$\varepsilon_t = \pm \frac{D^2}{f.B} \cdot \varepsilon_p$$

with ε_p, the parallax error, being generally 0.01 mm.

30. The above formula allows prediction of the accuracy with which coordinates can be determined in the field by photogrammetry. For example, assume:

$$B = 160 \text{ m}$$
$$D = 510 \text{ m}$$
$$f = 165 \text{ mm} = 0.165 \text{ m}$$
$$\varepsilon_p = 0.01 \text{ mm} = 0.00001 \text{ m}$$

$$\varepsilon_t = \frac{510^2 \ . \ 0.00001}{0.165 \ . \ 160} = 0.099 \text{ m} = 99 \text{ mm } (\sim 4 \text{ in.})$$

This defines the error in the x direction parallel to the base line and the vertical y direction. The z axis is at right angles to x and y and ideally follows the camera's optic axis. The z error is generally somewhat larger.

31. For quick estimation, the theoretical photogrammetric error is defined in the graphs of Fig 8 for different focal lengths and base:distance ratios. For a focal length of 120 mm the errors given in Fig 8 for f = 60 mm should be halved.

32. The errors in Fig 8 are based on a parallax error (ε_p) of 0.01 mm. This value applies only to ideal conditions and with clearly defined objects. In other than ideal conditions, eg, where rock joints are surveyed, difficulties in image identification will increase the error. To take care of this, Ross-Brown et al. (4) found

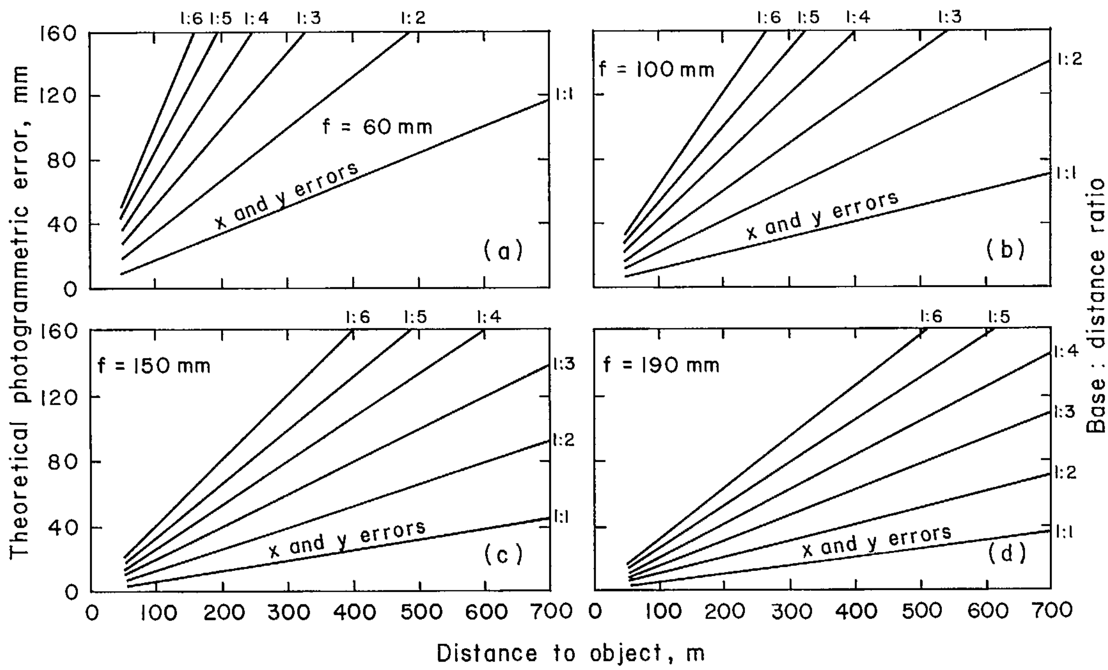


Fig 8 - Theoretical photogrammetric error with a change in base: distance ratio and different focal lengths (4).

it useful to define an interpretation factor (i_f) by which the theoretical photogrammetric error has to be multiplied to obtain the observation error:

$$\varepsilon_o = \varepsilon_t \cdot i_f$$

33. The i_f values are typically between 1 and 3 for premarked targets and between 2 and 6 for points on joints. Where joints are observed close to the edge-on position, the interpretation factor can reach a value of 10 or more. The interpretation factor has been plotted against base:distance ratios in Fig 9, which is based on empirical information from case histories. This figure is meant to provide guidance only on the general magnitude of error. Accurate assessments must be made for individual cases at the analysis stage.

34. In addition to the observation error (ε_o), the error from the control survey must be considered in accurate assessments of joint orientations. The field survey error (ε_s) is represented

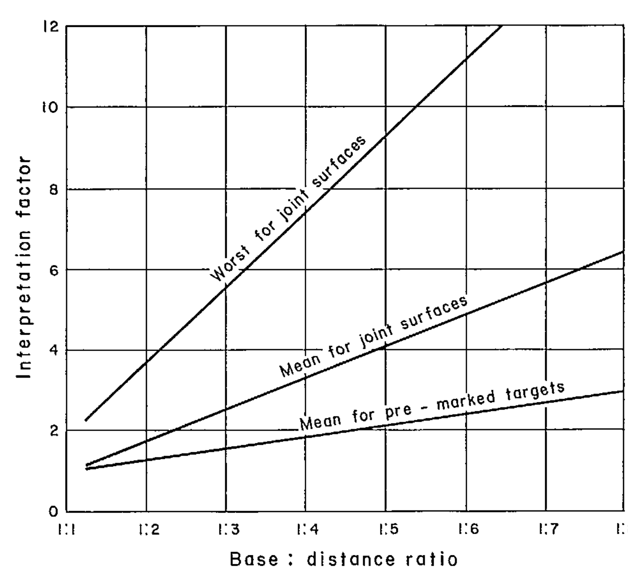


Fig 9 - Estimation of the interpretation factor (i_f) from base: distance ratio and type of object (4).

by the survey standard error (3) and is normally small if the targets are adequately spaced within the overlap area. The observation error (ε_o) and the field survey error (ε_s) together define the control survey error in mm. To obtain the control survey error for analyzing accuracy of a joint orientation, the sum of $\varepsilon_o + \varepsilon_s$ is related to the distance between the two nearest corner control targets(S):

$$\varepsilon_{cs} = \frac{\varepsilon_o + \varepsilon_s}{S}$$

which is shown graphically in Fig 10.

ANALYSIS OF JOINT ORIENTATIONS

35. The character of discontinuities can cause errors which are often beyond the control of the operator, eg, the degree of joint definition in altered and weathered rock. Partial control can be exercised if curved joints can be represented by a plane as in Fig 11(a). Two sources of error can be identified during fitting of a plane to a curved joint. These are the plane fitting error (ε_{pf}) resulting from the natural roughness of joints, and the plane observation error (ε_{po}) resulting from the point plotting procedure Fig 11(b).

36. The plane fitting error is negligible for near-perfect planes in any orientation, and for rough planes normal to the camera axis. The error becomes very significant for rough planes approaching the edge-on position.

37. The plane fitting error (ε_{pf}) depends on the roughness of the joints and their orientation to the camera axis. The natural roughness of a joint is defined as the percentage that the maximum amplitude, a_n, measured normal to the joint, bears to to the strike width, W, of the exposed joint, Fig 11(a):

$$r_n(\%) = \frac{a_n \cdot 100}{W}$$

38. Sets of photogrammetric observations made on joints will show an apparent roughness which is partly due to the natural roughness of joints, and partly to the observation error (ε_o) which applies to each pointing. Although the observation error effect is usually the more dominant, the two effects cannot normally be separated so that apparent roughness is of more concern than natural roughness in estimating fitting errors. The apparent roughness is defined as the percentage ratio of the maximum apparent amplitude, a_a, to the strike width (w) of the pointing distribution

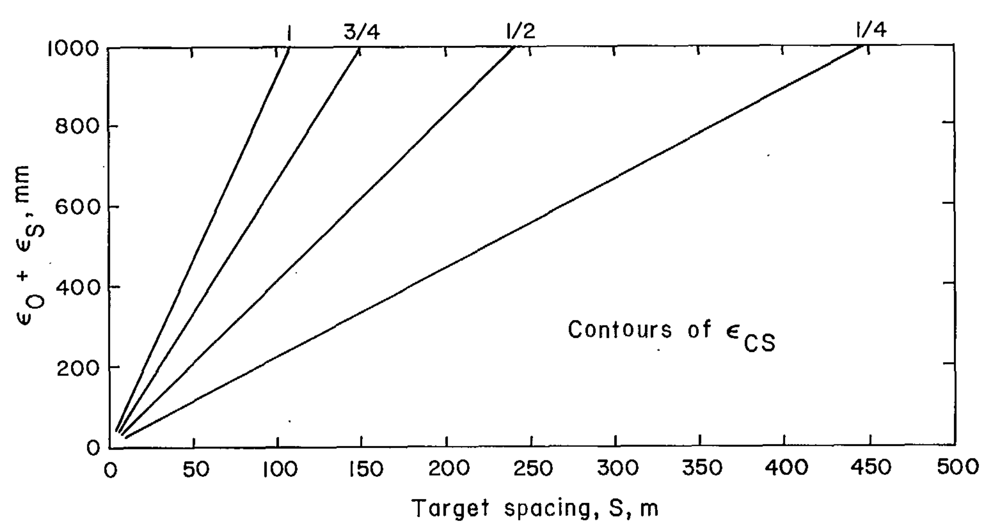
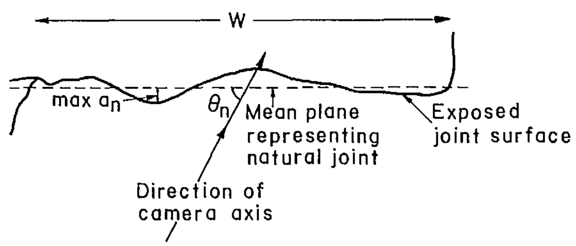
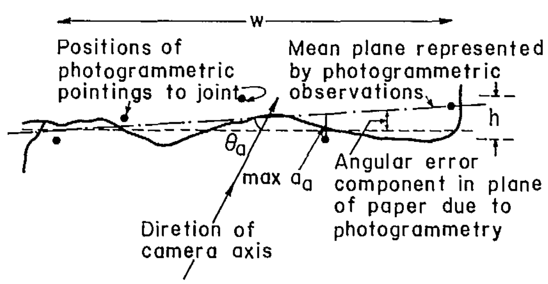


Fig 10 - Control survey error as defined by observation error (ε_o), survey error (ε_s) and target spacing (4).



W = Strike width of exposed joint
a_n = Natural roughness amplitude
θ_n = True joint orientation to camera axis

(a)



w = Strike width of pointing distribution
a_a = Apparent roughness amplitude (from pointing to mean plane)
θ_a = Apparent joint orientation to camera axis

(b)

Fig 11 - Plane fitting errors (ϵ_{pf}) arising from roughness of joints and photogrammetric pointings. (a) natural roughness; (b) apparent roughness from pointings (4).

as shown in Fig 11(b):

$$r_a(\%) = \frac{a_a \cdot 100}{W}$$

39. To predict the maximum apparent roughness for a photogrammetric field situation, it is necessary to measure the exposure length and natural roughness amplitudes for typical joints in the field. From the likely observation error (ϵ_o), the maximum apparent roughness can be estimated as:

$$r_{a_{max}}(\%) = \frac{\sqrt{a^2_n + \epsilon^2_o}}{W} \cdot 100$$

40. As indicated, the plane fitting error will increase as the joint plane approaches the edge-on position relative to the focal plane. Ross-Brown et al (4) carried out simulations to define the magnitude of the plane fitting error in regard to apparent roughness (r_a) and the orientation of a joint to the camera axis (θ). From these computations it was apparent that errors due to plane fitting vary with the distribution of pointings on the joint plane. For a typical distribution pattern of pointings on a joint plane the graph in Fig 12 can be used to estimate the error in the z direction. During the simulations it became clear that the strike width (W) represents the most significant factor in this context.

41. The photogrammetric point distribution gives rise to an additional error which is called the plane observation error (ϵ_{po}) (4). For a particular joint this varies with the shape and the dimension of the pointing distribution on a joint plane. Figure 13 has been drawn on the pessimistic assumption that, in the case of four pointings per plane, two adjacent pointings are separated from the mean plane on one side by the observation standard deviation, and the other two adjacent pointings are separated from the other side by the same amount, causing an angular error in the computed orientation of the plane. The maximum probable angular error for the case of the joint normal to the camera axis can be estimated from the graph if the strike width of the joint is known.

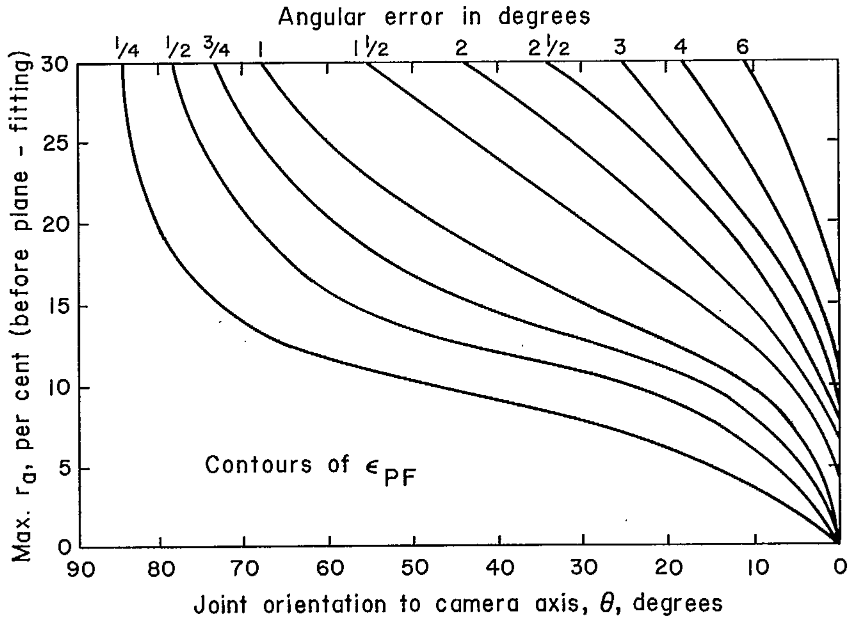


Fig 12 - Plane fitting error (ε_{pf}) expressed by joint orientations to camera axis (θ) and apparent roughness (r_a) (4).

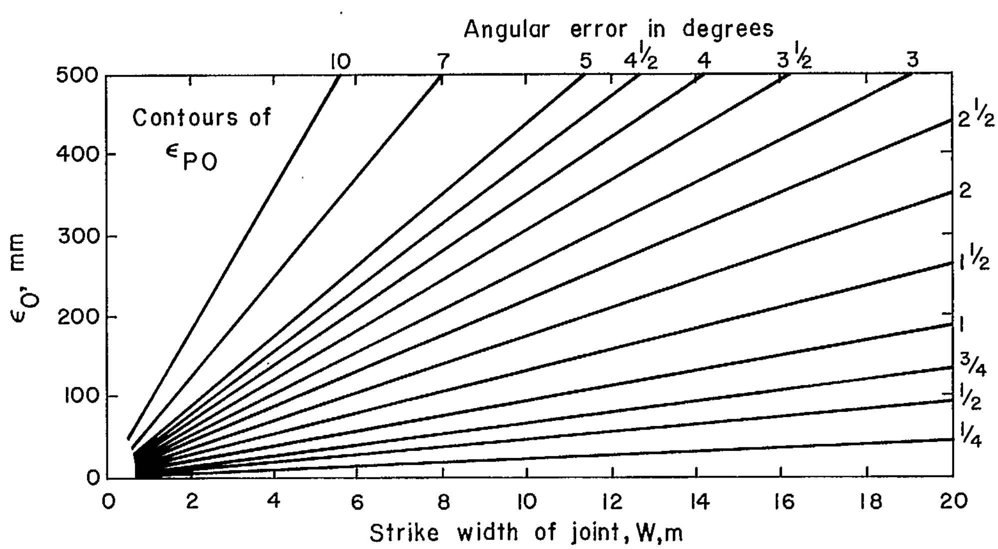


Fig 13 - Estimation of point plotting procedure error (ε_{po}) from observation error (ε_o) and strike width of joint (4).

SUMMARY OF ERRORS

42. In the above description the following errors have been defined:

Basic errors	Symbol	Unit	Derivation
Parallax error	ε_p	mm	Empirical (0.01 mm)
Theoretical photogrammetric error	ε_t	mm	$\frac{D^2 \cdot \varepsilon_p}{f \cdot B}$
Interpretation factor	i_f	--	Empirical
Observation error	ε_o	mm	$\varepsilon_t \cdot i_f$
Survey error	ε_s	mm	Standard survey error

Errors applied to joint orientations			
Control survey error	ε_{cs}	degrees	$\frac{\varepsilon_o + \varepsilon_s}{S}$
Plane observation error	ε_{po}	degrees	$f(\varepsilon_o, W)$
Plane fitting error	ε_{pf}	degrees	$f(\varepsilon_o, r_a, \Theta)$

Since the three errors in joint orientations are more or less independent their root mean square is taken to obtain the standard error for joint orientation as follows:

$$\varepsilon_{sum} = \sqrt{\varepsilon_{cs}^2 + \varepsilon_{po}^2 + \varepsilon_{pf}^2}$$

The error ε_{sum} represents the angle by which a photogrammetrically determined joint orientation or vector can be in error.

DESIGN OF A PHOTOGRAMMETRIC SYSTEM

43. This section deals with the practical aspects of setting up a photogrammetric system at a pit site to obtain suitable terrestrial photographs which can be analyzed either at the mine site or elsewhere.

44. The general steps involved are:

a. definition of objectives,
b. site restraints,
c. control targets and photography,
d. survey of camera stations, base lines and target locations,
e. photogrammetric analysis, and
f. reporting of results.

In the following paragraphs, these are discussed and some case histories presented.

DEFINITION OF OBJECTIVES

45. Joint surveys should be set up within the general geological mapping program so that cross-checks are possible and the objectives clarified before establishing the system. The wall to be photographed must be studied beforehand to obtain an indication of what information is wanted, eg, minimum joint size, whether all possible joint orientations can be analyzed from one stereopair, or whether more pairs are necessary to avoid edge-on positions.

46. In general, the accuracy of the technique increases with the scale of photography. For long distance observations, as across a pit, a camera with a lens having a longer focal-length can be useful. This improvement is offset however by a reduction of the overlap area which limits the permissible base:distance ratio. If photographs can be taken at close range, cameras with short focal length lenses are desirable as they allow larger base:distance ratios.

47. The geologist has to compromise in regard to the desired information which can be obtained under the given restraints of permissible base:distance ratios and lens focal-lengths. Large joints can in general be mapped quite precisely but the accuracy in measurement of smaller joints may not be acceptable, as discussed in the section on errors and limitations.

SITE RESTRAINTS

48. As a general rule, the photographic base line should be parallel to the object, eg, a slope, to avoid changes in scale of the object on

the photopairs. The optical axis of the camera should also be at right angles to the base line.

49. Coverage from the base line depends on the vertical and horizontal field angles of the camera. A diagram representing the horizontal field angle of the camera, as shown in Fig 14, can be placed on a plan in the office or on a plane table in the field to obtain the best compromise in required coverage and length of a base line (Fig 1). Vertical coverage can be evaluated in a similar way.

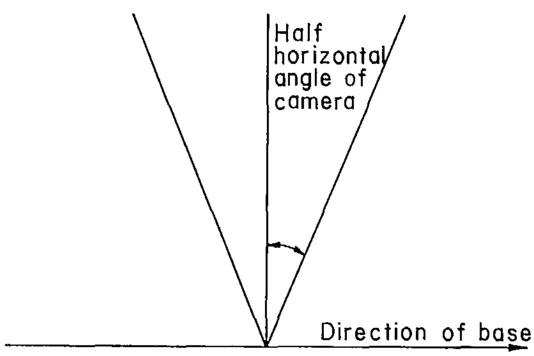


Fig 14 - Field angle diagram for horizontal coverage.

50. When planning vertical coverage, the required camera tilt has to be considered because tilting the optical axis of the camera towards the toe of a slope as in Fig 15 will reduce differences of the base:distance ratio and improve coverage. With a section of the overall slope and a vertical field angle diagram, the optimal tilt can be obtained for a nearly constant base:distance ratio along the slope.

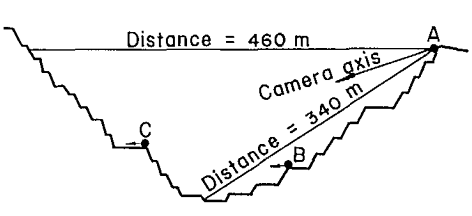


Fig 15 - Effect of camera tilt on base: distance ratio (4).

CONTROL TARGETS AND PHOTOGRAPHY

51. For a distance of 1600 feet (487 m) the targets should be a minimum of 4 ft (1.2 m) across. It is advisable to be generous with target size and to paint them in a symmetric pattern.

52. Before the targets are permanently mounted, tripods should be set up on the ends of the selected base line and the distribution of the control targets determined within the overlap area. Many cameras accommodate a ground glass screen in the focal plane to assess the overlap area. Six targets should be visible in the overlap area in that better control of target positions is possible and the loss of one or two targets does not invalidate the entire survey.

53. Photographs can be taken after the targets are placed in suitable positions. Details about field procedures on photography and film development, are given in para. 57 to 86.

SURVEY OF CAMERA STATIONS, BASE LINES AND TARGET LOCATIONS

54. After the plates are developed, the coordinates of the camera stations within the mine system are determined by triangulation. The base line direction and length provide a convenient check. Following this the position of the control targets can be determined.

PHOTOGRAMMETRIC ANALYSIS

55. With the control survey evaluated and suitable photopairs available, the work can be specified for photogrammetric analysis. Enlargements from the negative film or plates are useful for marking the desired rock type boundaries, and joint or fault positions. The analysis will provide the coordinates of the control targets, coordinates for desired cross sections, and orientations of specified joints or faults.

REPORTING OF RESULTS

56. For future reference the following information should be collected and recorded for each analyzed stereopair:

a. Camera location and orientation, Fig 16:
   - location,
   - weather and date,
   - film material,
   - coordinates of camera stations and orientation of optical axis, and
   - remarks.

b. Angle measurements for control points, Fig 17:
   - location,
   - weather and date,
   - theodolite location, and
   - measured horizontal and vertical angles.

c. Calculated angles for control points, Fig 18:
   - location,
   - weather and date,
   - theodolite location, and
   - calculated horizontal and vertical angles.

d. For each joint subsequently analyzed, the following information should be requested:
   - unique identification number,
   - coordinates,
   - the dip and dip direction of the plane or the normal to the plane, and
   - the standard errors in joint orientation.

e. Optional information which may be generated for each joint includes:
   - distance from camera and angle of joint to camera axis,
   - equation of computed plane,
   - size and area of exposed joint,
   - apparent roughnesses including the mean and the maximum, and
   - classification of standard errors into components.

FIELD OPERATION

EQUIPMENT DESCRIPTION

57. Table 4 lists the equipment necessary for a field survey. For this supplement the field work was carried out in an open pit with a Wild P30 phototheodolite. Units of similar suitability are given in Table 1.

58. The Wild P30 is a T2 theodolite with a removable terrestrial camera, Fig 3. This repetition theodolite has a lower motion which allows the alidade and the camera to rotate in azimuth as a unit, and an upper motion which allows the alidade to rotate in azimuth relative to the camera. The lower motion is not used for turning repeated angles, but for orienting the camera. Repeated angles can be measured by using the upper motion. Both the horizontal and vertical angles can be read directly to one second of arc. This theodolite is capable of observations for second-order triangulation under favourable conditions, and the instrument is precise enough for all the geodetic work, including indirect distance measuring, eg, determination of the base length using a subtense bar. The telescope has a magnification of 28X.

59. The camera is supported in two V-shaped bearings by a pair of trunnions attached to the camera; the axis of the trunnions intersects the optical axis of the camera. When the theodolite has been levelled, the optical axis can be inclined at $+7^g$ (elevation angle, +6° 18'), 0^g (0° 0'), -7^g (depression angle, -6° 18'), -14^g (-12° 36'), or -21^g (-18° 54'). A precisely machined tiltsetting bar located on the front of the camera is used to set the desired inclinations.

60. When the horizontal circle reads 0° 00' 00", the optical axes of the theodolite and the camera are in the same vertical plane. A reading on the horizontal circle gives the angle between the telescope and the camera axes when measuring horizontal angles.

61. The camera has a distortion-free lens focused at infinity, thus making the focal length or principal distance approximately 165 mm. The aperture is fixed at f/12 and exposure times up to 1/500 s can be set. The lens and the pressure plate, which holds the emulsion surface of the film in the focal plane are both solidly mounted on a rigid cone for high stability. The angular field of the camera is determined by the principal distance and the effective size of the

Table 4: Basic equipment for photogrammetric surveys

Preliminary survey
- Tripods, tribrachs
- Optical square
- Abney level
- Plane table and reconnaissance diagram
- Phototheodolite or terrestrial camera with ground glass screen

Photography and control survey
- Tripods, tribrachs
- Phototheodolite
- Interchangeable tripod targets
- Plumb bobs
- Photographic plates or film
- Light meter
- 6 control targets and identification markers
- Subtense bar

Plate development
- Suitable darkroom or light-proof changing bag
- Developing tank and developer
- Stop bath tank and stop bath
- Fixing tank and fixer
- Negative carriers
- Funnel
- Rubber tubing
- Clock
- Thermometer
- Continuous supply of clean water
- Photo-flo solution

photographic plates which are 100 x 150 mm. The horizontal coverage of the Wild P30 camera is about 45° (2 x 22.5°) and the vertical coverage about 30° (2 x 15°).

PRELIMINARY SURVEY

62. A preliminary field survey should be carried out before any photographs are taken in order to locate a suitable base line and the photo-stations, as discussed in the section on errors and limitations.

63. The base line should be parallel to the pit wall and can be paced off roughly in this preliminary survey. The base line length depends on the distance to the object being photographed and should not be greater than 1/4 of the shortest distance and not less than 1/10 of the longest distance. This latter ratio can be reduced to 1/20 if necessary, but in that case good control points must be located in the most distant areas. If the photographs are not taken perpendicular to the base, 1/15 should be the absolute minimum. For mapping and plotting, base:distance ratios of 1:20 can be tolerated, but for monitoring pit slope movement, the ratios should be as close as possible to 1:4 to obtain the required accuracy.

64. The camera stations should be as high as possible and at approximately the same altitude. A plane table and reconnaissance diagram, or the phototheodolite by itself, can be used to locate the final stations which will give the required overlap. A ground glass plate can be inserted in the camera to see the actual coverage of the camera with the shutter held in the open position.

65. The control targets in the overlap area must be clearly visible. Large white crosses or symmetrical white backgrounds painted around the control targets are recommended. Large identification numbers or letters close to the target are helpful. Six control targets should be evenly distributed over the area and visible in each photopair.

66. Normally the photographs are taken with the optical axis of the camera set perpendicular to the base line and in the horizontal plane. In some cases the pit geometry may limit the choice of station positions. Convergent photographs can be taken by tilting the axis of the camera vertically and by altering the horizontal angle between the camera axis and the base line. This convergent procedure requires special analytical procedures for processing the photopairs.

LOADING PHOTOGRAPHIC PLATES

67. The glass photographic plates must be

loaded into their holders in complete darkness. The cover slide of the plateholder is removed to reveal a spring-loaded bar which holds the plate in place. The holder can be oriented to position the bar on the left side of the holder. If the bar is held back with the left thumb, the plate can be inserted so that the two notches on its edge are located in the upper left corner of the holder. This ensures that the plate is loaded with its emulsion side up. The cover slide is replaced and the plateholder is then ready for use.

FIELD PHOTOGRAPHY

68. For the field photography, a tripod is first set up on each photogrammetric station. Tribrachs are placed on each tripod and levelled. The phototheodolite is placed on one station while an interchangeable target is placed on the other. Both are locked in place with the tribrach clamp, and the instrument levelled.

69. The appropriate horizontal angular displacement between the base line and the optical axis of the camera is then set. With the instrument at station L in Fig 1, the telescope is put in the direct position, ie, with the mechanical sights on top of the telescope; the lower motion is clamped and the horizontal circle is set to read 90° 00' 00", or whatever other angular displacement is required, using the upper motion clamp and tangent screw. The lower motion is then loosened and the opposite end of the base line, station R, is sighted. This operation sets the camera axis perpendicular to the base line or at the required angle. A field record is given in Fig 16.

70. When the camera is located at station R, a horizontal angular displacement of 90° 00 ' 00" is again required, and the same procedure as outlined above is followed, except the horizontal circle is set at 270° 00' 00" which is 360° 00' 00" - 90° 00' 00".

71. The plateholder is inserted into the back of the camera and the camera door is securely closed. With the pressure knob in the full pressure position the cover slide is pulled out. The desired vertical camera tilt and the plate reference number can then be set.

72. The exposure time is determined with a light meter, the shutter speed is set, and the shutter cocked. If a standard yellow filter is used, the exposure time is increased by a factor of four.

73. The level of the instrument and the orientation of the camera are checked. If the bubbles indicate disturbed orientation, this is corrected.

74. The shutter is gently opened with the cable release. After the plate is exposed, the cover slide is pushed back into the plateholder as the pressure knob is slowly released. The plateholder is removed and stored in its case. Two photographs at different exposures are recommended at each station as a precaution against breakage or photographic error. All photographs should be taken as quickly as possible to avoid large differences in the shadow patterns shown on the left and right negatives.

75. The horizontal and vertical angles are recorded with the telescope in the direct position while still sighting the target on the opposite base station. The telescope is reversed and the opposite base station is again sighted. The horizontal and vertical angles are recorded a second time. Before making any vertical angle readings, the bubble of the collimation level must be brought to centre by turning the fine-adjustment screw of the level until the two ends of the bubble appear to coincide. The same procedure is repeated at the other base station.

CONTROL SURVEY

76. After the photography has been completed, the camera can be removed from the phototheodolite and the horizontal and vertical target angles measured from each end of the base line. The survey may be an independent operation, not necessarily using the same stations. Field notes from a typical control survey are given in Fig 17.

77. Horizontal and vertical angles are double-sighted to the control targets and to at least three other stations whose coordinates are known. From these observations and the angles entered into Fig 16, the camera and control target coordinates may be calculated as shown in Fig 18.

78. The base line can be measured by setting

PHOTOGRAMMETRY SURVEY — CAMERA LOCATION AND ORIENTATION DATA SHEET 1

Mine *KIDD CREEK OPEN PIT* Date *July 24/1975* Temperature *20° C*

Location *TIMMINS, ONTARIO* Weather *OVERCAST - RAINY*

Purpose *STRUCTURAL GEOLOGY SURVEY*

Photographic Plates *AGFA GEVAERT - AVIPHOT PAN 30 (80 ASA)*

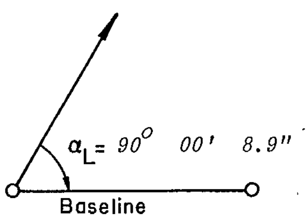
Camera Type *P30 PHOTO-THEODOLITE No. 311 FOCAL LENGTH 163.78mm, f/12*

CAMERA LOCATION :

Camera Left : Located at Station *EAST (#10 bench)*

Plate Holder No. *17* / *18* Plate Reference No. *013* / *014* Exposure *1/4* / *1/7*

Vertical Tilt *0° 00' 00"* Horizontal Angular Displacement *90° 00' 8.9"*

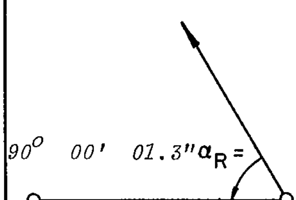


SIGHTING		HORIZONTAL °	'	"	VERTICAL °	'	"
WEST	F.L.	*90*	*00*	*10.0*	*90*	*01*	*53.2*
	F.R.	*270*	*00*	*07.8*	*269*	*58*	*07.2*

Camera Right: Located at Station *WEST (#10 bench)*

Plate Holder No. *19* / *20* Plate Reference No. *015* / *016* Exposure *1/15* / *1/8*

Vertical Tilt *0° 00' 00"* Horizontal Angular Displacement *90° 00' 01.3"*



SIGHTING		HORIZONTAL °	'	"	VERTICAL °	'	"
EAST	F.L.	*270*	*00*	*00.0*	*90*	*09*	*48.5*
	F.R.	*89*	*59*	*57.5*	*269*	*50*	*05.0*

BASELINE (LENGTH = *521.24 ft*)

Station	X - Co - ordinate	Y - Co - ordinate	Z - Co - ordinate
WEST	*Northing = 214991.52 ft*	*Easting = 215035.00 ft*	*Elev. = 496.94 ft*
EAST	*Northing = 215106.46 ft*	*Easting = 215543.41 ft*	*Elev. = 496.25 ft*
Remarks:	*Camera axis to top of stn. tripod*	*target to top of stn. tripod*	*height of stn. tripod*
at STN WEST	*0.48 ft*	*0.31 ft*	*4.375 ft*
at STN EAST	*0.48 ft*	*0.31 ft*	*4.20 ft*

Fig 16 - Records of camera orientation and location.

PHOTOGRAMMETRY SURVEY — ANGLE MEASUREMENTS FOR CONTROL POINTS DATA SHEET 2

Mine *KIDD CREEK OPEN PIT* Date *July 24/75* Temperature *20^{o} C*

Location *TIMMINS, ONTARIO* Weather *OVERCAST - RAINY*

Purpose *STRUCTURAL GEOLOGY SURVEY*

THEODOLITE LOCATED AT LEFT STATION *STN EAST (#10 bench)*

SIGHTING		APPROXIMATE LOCATION		HORIZONTAL			VERTICAL		
		HORIZONTAL	VERTICAL	°	'	"	°	'	"
STN WEST	F.L.			00	00	10.0	90	0.1	30.0
	F.R.			180	00	06.5	269	58	33.0
A	F.L.			271	18	48.8	78	37	42.8
	F.R.			91	18	51.7	281	22	17.0
3.2	F.L.			273	09	22.5	78	56	42.9
	F.R.			93	09	29.5	281	03	22.0
B	F.L.			279	13	17.6	79	51	01.8
	F.R.			99	13	19.8	280	08	56.0
1.5a	F.L.			270	19	40.8	86	02	54.1
	F.R.			90	19	46.6	273	57	10.1
2.5a	F.L.			276	04	38.8	86	28	19.3
	F.R.			96	04	31.0	273	31	37.0
4.5	F.L.			285	18	58.5	87	13	28.2
	F.R.			105	19	01.0	272	46	37.0
5.5	F.L.			287	09	33.5	87	19	58.8
	F.R.			107	09	38.7	272	39	59.0
6.5	F.L.			289	06	53.5	87	23	42.1
	F.R.			109	06	50.2	272	36	18.1

THEODOLITE LOCATED AT RIGHT STATION *STN WEST (#10 bench)*

SIGHTING		APPROXIMATE LOCATION		HORIZONTAL			VERTICAL		
		HORIZONTAL	VERTICAL	°	'	"	°	'	"
STN EAST	F.L.			00	00	10.0	90	09	51.0
	F.R.			180	00	06.4	269	50	04.5
A	F.L.			73	02	36.5	79	07	42.8
	F.R.			253	02	41.2	280	52	20.8
3.2	F.L.			75	12	31.0	79	18	22.0
	F.R.			255	12	37.4	280	41	31.5
B	F.L.			82	29	14.3	79	49	40.9
	F.R			262	29	19.0	280	10	24.0
1.5a	F.L.			66	50	58.0	86	23	25.8
	F.R.			246	51	3.3	273	36	28.8
2.5a	F.L.			74	39	42.0	86	36	12.8
	F.R.			254	39	47.6	273	23	45.8
4.5	F.L.			86	54	19.3	87	06	34.6
	F.R.			266	54	15.2	272	53	29.8
5.5	F.L.			89	33	17.0	87	14	00.7
	F.R.			269	33	23.0	272	45	53.5
6.5	F.L.			92	29	13.7	87	16	00.0
	F.R.			272	29	9.4	272	43	52.6

Fig 17 - Angle measurements for control points.

PHOTOGRAMMETRY SURVEY — CALCULATED ANGLES FOR CONTROL POINTS DATA SHEET 3

Mine KIDD CREEK OPEN PIT Date July 24/75 Temperature 20^{o} C

Location TIMMINS, ONTARIO Weather OVERCAST — RAINY

Purpose STRUCTURAL GEOLOGY SURVEY

THEODOLITE LOCATED AT LEFT STATION STN EAST (#10 bench)
(Angles measured counter - clockwise from baseline)

SIGHTING	HORIZONTAL			VERTICAL		
	°	'	"	°	'	"
A	88	41	18.0	+ 11	22	17.1
3.2	86	50	42.3	+ 11	03	19.6
B	80	46	49.6	+ 10	08	57.1
1.5a	89	40	24.6	+ 03	57	08.0
2.5a	83	55	33.4	+ 03	31	38.9
4.5	74	41	08.5	+ 02	46	34.4
5.5	72	5.0	32.2	+20	40	00.1
6.5	70	53	16.4	+ 02	36	18.0

THEODOLITE LOCATED AT RIGHT STATION STN WEST (#10 bench)
(Angles measured counter - clockwise from baseline)

SIGHTING	HORIZONTAL			VERTICAL		
	°	'	"	°	'	"
A	73	02	30.7	+ 10	52	19.0
3.2	75	12	26.0	+ 10	41	34.8
B	82	29	08.5	+ 10	10	21.6
1.5a	66	50	52.5	+ 03	36	31.5
2.5a	74	39	36.6	+ 03	23	46.5
4.5	86	54	09.1	+02	53	27.6
5.5	89	33	11.8	+ 02	45	56.4
6.5	92	29	03.4	+ 02	43	56.3

Fig 18 - Calculated angles for control points.

the subtense bar on one station and observing it from the other. The distance is calculated from the mean of 10 measurements of the subtended angle. As a check, the procedure is carried out from both ends of the base line.

DEVELOPMENT OF PHOTOGRAPHIC PLATES

79. The equipment required to develop the plates is listed in Table 4 and shown in Fig 19. Until the plates have been developed and fixed, they must be protected from any light at all times. Special tanks and negative carriers are available for field work, and allow several plates to be processed at a time. The conventional tray development process can also be used.

80. Three tanks are required in the development process; one each for developer, stop bath, and fixer. The solutions are prepared with clean tap water and should have an operating temperature of about 20°C.

81. In a darkroom or light-proof changing bag the plates can be removed from the holders and placed in the negative carriers. They are then

Fig 19 - Equipment used to develop glass photographic plates.

immersed in the developing solution and the lid placed on the tank. The tank is sharply tapped against a hard surface several times to dislodge any air bubbles attached to the plates .

82. The solution is agitated continuously by tilting the tank from side to side in an arc of about 180 degrees. The instructions for the photographic plates should be checked to determine the best type of developer to use and the best development time. Good quality negatives have been produced using Kodak DK-50 developer at 1:1 dilution. The plates were developed for 10 minutes in a tank with continuous agitation.

83. When the plates are developed, the lid is removed from the tank and the carrier is transferred to the stop bath, where the plates are rinsed for five to ten seconds. Christie V79 Short Stop performed adequately in the case cited.

84. Following the stop bath, the plates are placed in the fixing tank where they are fixed for the required time. Christie V88 Vacofix Rapid Fixer, which requires the addition of an emulsion hardener, has been used successfully to fix negatives. The plates are left in the fixer for five minutes with intermittent agitation. A hypo check can be used to test the fixer if its quality is in doubt.

85. The plates can be washed in daylight through a rubber tube connected to the lower nipple of one of the tanks. The pressure of water pouring through the tank from bottom to top ensures a thorough washing. Thirty minutes in running water is adequate.

86. The plates may be rinsed in a detergent solution, eg, Kodak Photo-Flo 200 which aids uniform drying and produces plates free of water marks. They are then dried in a dust-free atmosphere, after which enlarged prints can be prepared and used to specify the work to be done.

CASE HISTORIES

87. Various case histories are reported here, to present a balanced view of the difficulties and advantages of joint-mapping by stereophotogrammetry.

HELEN MINE, NORTHERN ONTARIO

88. D.M. Ross-Brown et al have analyzed stereophotographs of the mined-out Helen pit in Northern Ontario (4). The inaccessible hanging wall is exposed over 1000 ft (300 m). Control was provided by two weighted tapes suspended over the edge of the pit with targets attached near the top and the bottom. Because of site restrictions, camera elevations differed by 22 ft (6.6 m) over the 119 ft (35.7 m) base line and it was necessary to tilt each camera differently. Also, the camera axes were swung 5° from the direction normal to the base. Photographs were taken with a Wild P30 instrument and analyzed with a Wild A5 plotting instrument.

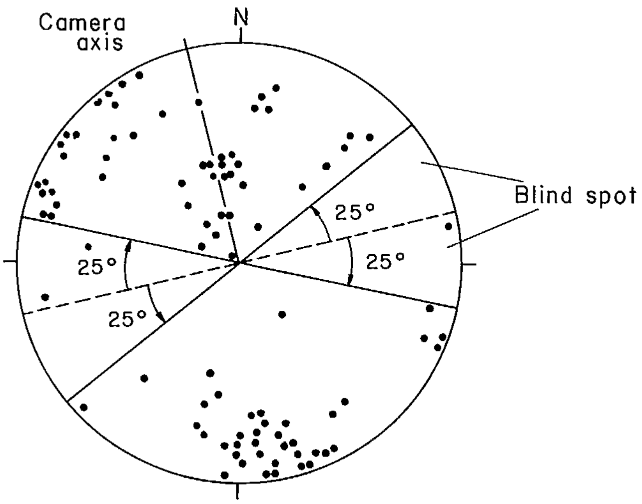
89. Results were obtained as presented in Fig 20(a) and (b). Errors were calculated as shown earlier. Of 100 observed joints, 7 were rejected due to operating mistakes, orientation errors exceeding 10°, and the joint striking within 5° of edge-on to the camera axis.

90. Independent of this activity, joint and fault orientations had been mapped throughout the the mine site by the Canada Centre for Mineral and Energy Technology in 1968-1970. The observed patterns are displayed in Fig 21(a) and (b). Although the joints and faults displayed in Fig 20(a) and 21(a) are not obtained from identical locations, the sets are penetrative on the mine scale and a comparison is possible as in Table 5.

91. Joint sets I, II and III agree well in both mapping procedures, whereas set IV is underrepresented in the photogrammetric results. When the camera orientation is related to pole distribution of the joints, a blind spot appears to exist for planes nearer than 25° to the camera axis. A second photopair taken with a different base line orientation could have corrected this.

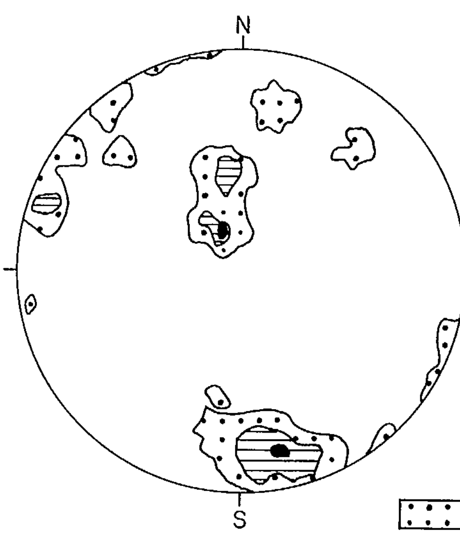
BRENDA AND ENDAKO MINES, B.C.

92. Walls of the Brenda and Endako pits, which had already been mapped by detailed line mapping, were photographed in the 1973 field season to compare photogrammetric data with direct data



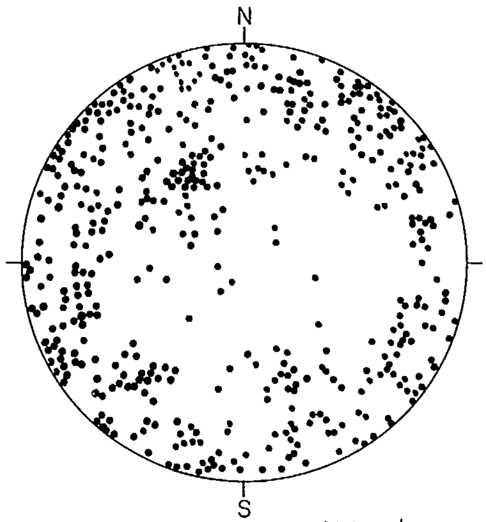
93 poles (4)
in lower hemisphere
of equal area net

(a)



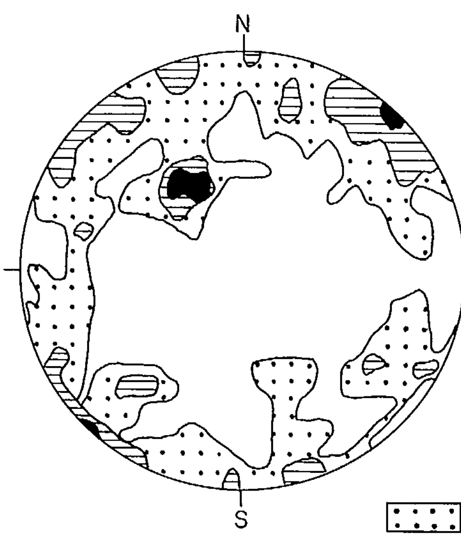
(b)

Fig 20 - Joint orientations from photogrammetric mapping (Helen Mine).



486 poles
in lower hemisphere
of equal area net

(a)



(b)

Fig 21 - 486 Joint observations at G. W. MacLeod Mine (Helen pit and environs).

Table 5: Comparison of fabric patterns at Helen Mine

After data by D.M. Ross-Brown (4) from photogrammetry (93 observations), and data by G. Herget from field measurements (486 observations)

Cluster designation	I		II		III		IV	
observer	(RB)	(GH)	(RB)	(GH)	(RB)	(GH)	(RB)	(GH)
Number of observations	11	35	23	9	15	27	- -	51
Dip direction (degrees)	120	125	347	345	163	150	- -	42
Dip (degrees)	84	90	78	90	27	38	- -	90

already obtained. For comparison, two cameras and three compilation systems were used.

93. Early in July, 1973, a portion of the east wall of the Brenda pit, N7600 to N8400, was photographed from a base line set at the 5000 level and about 490 ft (150 m) from the wall. Photographs were taken with a Wild P32 camera mounted on a Wild T2 theodolite. Later in the same month a portion of the same wall, N7800 to N8400, was again photographed with the Wild P32 and the Zeiss Terrestrial camera 19/1318 to compare the highly versatile and rapid Wild P32 and the longer focal length Zeiss 19/1318.

94. In August, 1973, a portion of the Endako pit was photographed with the Wild P32. Part of the south wall, E28800 to E29700, was photographed from a base line set on the 2970 level about 490 ft (150 m) from the face. The same face was photographed from the 3230 level bench on the north side about 1310 ft (400 m) away. Part of the north wall was photographed from the south 3130 level bench.

95. Compilations were made by McElhanney Corp., Lockwood Corp., and B.C. Institute of Technology, all of Vancouver, B.C. The plotting equipment used was a Zeiss Topocart B, a Wild A8, and a Wild B8. The McElhanney Corporation has a Zeiss Topocart B for photographs of focal length 50 mm to 215 mm in either the vertical or the horizontal plane. It is a versatile machine ideally suited to this type of mapping, but it should be digitized for scaling joints. Twenty-seven planes were scaled in the Endako pit and 30 in the Brenda pit. The strikes and dips were plotted on the map at 10 ft (3 m) contours to provide identification and a graphical check by direct scaling. The machine coordinates from the plotter were later computed to mine coordinates.

96. The Lockwood Corporation used a Wild A8, f=195 mm Zeiss photographs and a contour map at 1:120. A digital computer was used to convert scaled coordinates to mine coordinates.

97. For the Endako pit, a typical "plotter day" was set up and 196 planes were scaled from enlarged P32 diapositives. The Lockwood A8 plotter is digitized, and coordinates are computer punched on cards.

98. At the B.C. Institute of Technology, 9 planes in the Brenda pit were scaled using a non-digitized Wild AB and the Zeiss - 195 mm photographs. Twelve common points were selected and a Wild B8 was used to scale parallax differences on Wild P32 diapositives to compare accuracies.

99. All three compilers had scaled common planes which provided an excellent check. This revealed the accuracy of photogrammetry to be within ± 3°.

100. To convert from machine coordinates - whether digitized or not - to mine coordinates, generally requires a digital computer which prints out the mine coordinates of the points, and provides punched cards or tape storage. The field

work was carried out with an accuracy of 0.025 m in X, Y and Z coordinates for any point. This is easily achieved by a 0° 00' 01" theodolite in triangulation, or by using an electronic distance measuring device.

101. Joint orientations on the east wall of the Brenda mine and on the south wall of the East pit of the Endako mine are shown in Figs 22 and 23.

102. The principal feature of the photogrammetrically determined fabrics is the strongly developed preferred orientation of the fabric poles about the direction of the camera axis as indicated on the diagram. Both groups of photographs were taken from a base line nearly parallel to the pit wall, with the camera axis perpendicular to the base line.

103. Some of the preferred orientations determined by detailed line mapping do not appear in the photogrammetric data and this suggests that measured photogrammetric fabrics are dominated by directional bias. More than one base line should be used to remove obvious bias.

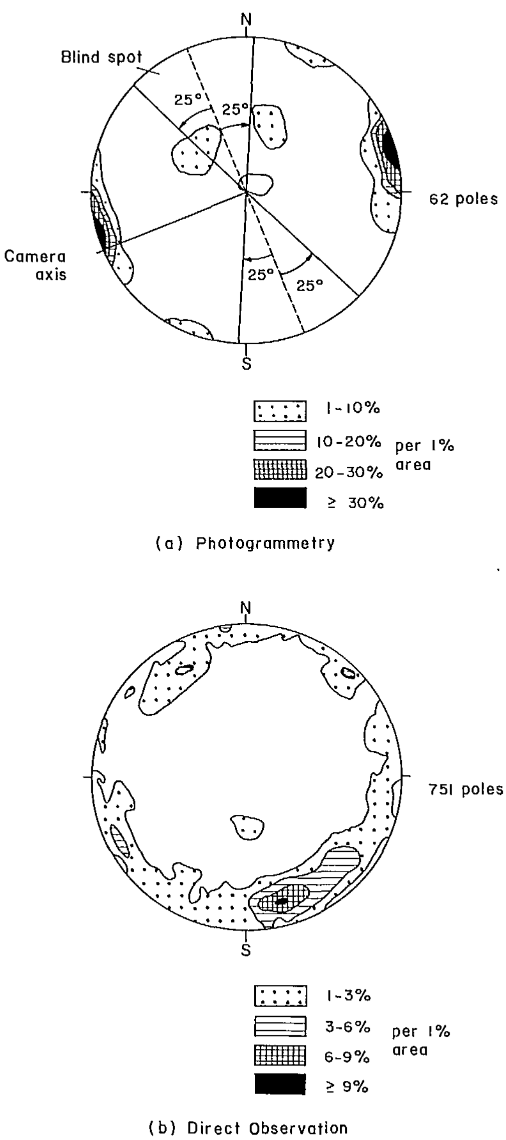


Fig 22 - Joint fabric of east wall of Brenda Mine pit.

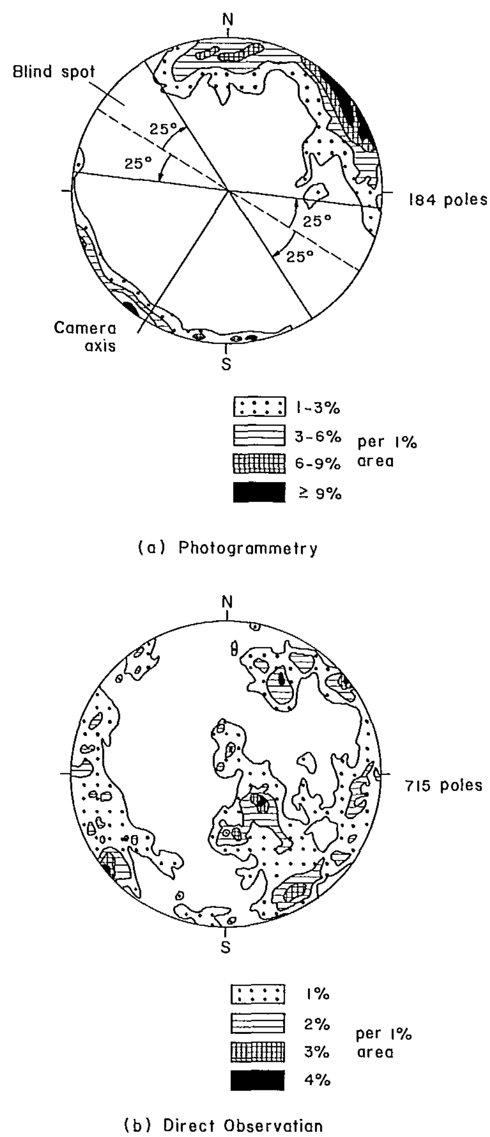


Fig 23 - Joint fabric of south wall of Endako east pit.

COMPARISON OF TWO PHOTOTHEODOLITES

104. The Wild P32 is designed for close range mapping and is mounted on a Wild T2 theodolite. Roll film or glass plates may be used. Because the format is small (6.5 x 9 cm), a large number of plate cassettes can be carried and this avoids loading and unloading in the field. The average time of setting up, levelling, pointing and shutter release is 5 minutes. Technical data are given in Table 1.

105. The Zeiss Terrestrial Camera 19/1318 was developed many years ago. The reason for the long focal length is to obtain the maximum photo scale for long distances, such as in long, narrow mountain valleys. It uses 13 x 18 cm glass plates in wooden cassettes which must be reloaded in the field if there are more than 12 pictures. Technical data are given in Table 1.

106. It has been argued by lens manufacturers that lenses of high resolution and minimum distortion, but of short focal length, should be equal or superior to lenses of low resolution and greater distortion, but of longer focal length. The long focal length provides a better photoscale which, in turn, facilitates scaling in the plotter. The small aperture associated with lenses of a long focal length increases light diffraction and reduces the resolving power of the lens. The disadvantage of the short focal length is the small photo scale and this results in an error of greater magnitude.

107. Twelve random points were selected in the comparison. With the 195 mm focal length Zeiss, the average distance was 590 ft (180 m) which yielded a photo scale of 1/900. The Wild P32, with a focal length of 64 mm, was used at 426 ft (130 m) for a photo scale of 1/2000. Both cameras were on different base lines but had common targets in their fields of view. In scaling the targets, the P32 yielded a slightly higher error than the Zeiss and A8 plotter combination.

108. The versatile and relatively inexpensive P32 is attractive for many uses, but for scaling joints its limiting distance from the face is 650 ft (200 m), unless the joints are very large. For mapping contours at 1:240 its limiting distance is 1640 ft (500 m). Although the Wild P30 is still widely used, its manufacture has been discontinued.

FIELD EXPERIENCES

109. Field scheduling can be relatively easily arranged within two weeks; and base lines can be set, targets coordinated and pictures taken without incident.

PHOTOGRAMMETRIC ANALYSIS

110. The major problems experienced in the selected test cases have two aspects: timing, and comprehension. Photogrammetric mapping companies often have a backlog of 3 to 6 months' work. Any interference with a job being plotted may cause a week's delay in its resumption. All plotter operators understand aerial mapping, a few understand terrestrial photogrammetry; but only a very few know the significance of strike, dip and joint. The problem of communicating geological significance to the chief, to the operator, and to successive shifts often causes frustration. Therefore, a photogrammetric project should be set up by a professional familiar with geological objectives who can also communicate effectively with photogrammetric analysts.

COST OF TERRESTRIAL PHOTOGRAMMETRY

111. Costs, which depend largely on requirements of a project, include costs of camera and survey equipment, field crews, and the analysis of stereo photopairs.

112. Equipment costs for terrestrial cameras are listed in Table 1. In an open pit with good access, a crew can set targets, photograph and survey six target positions for 1 to 3 overlaps a day. In 1974, the field costs of photographing and surveying about 1600 ft (500 m) of slope were about $300 for a crew of two.

113. Professional services should be hired for analyzing photopairs. A minimum of 5 points should be obtained from each joint. Four hundred and fifty points or 90 joints could be digitized in a plotter in one day for about $200 at 1974 prices. The punched cards or tape can then be processed through a computer for X Y Z coordinates including dip direction and dip. The total cost is likely to be less than $3.00 per joint. Lower unit costs can be achieved for greater volumes of data handled.

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SYMBOLS

f - Principal distance of camera (focal-length at infinity)

B - Base length

D - Distance between camera location and photographed object

θ - Angle of joint plane to camera optical axis

p - Parallax

ε_p - Parallax error

i_f - Interpretation factor

ε_o - Observation error

ε_t - Theoretical photogrammetric error

ε_s - Survey error

ε_{cs} - Control survey error

ε_{po} - Plane observation error

ε_{pf} - Plane fitting error

r_n - Natural roughness amplitude

r_a - Apparent roughness amplitude

S - Spacing between the two closest corner targets