Journal of Structural Geology, Vol. 13, No. 9, pp. 1085 to 1089, 1991
Printed in Great Britain

0191-8141/91 $03.00 + 0.00

SHORT NOTE

A diagram for interpreting orientation data for planar features in core

ROBERT I. SIKORSKY

AECL Research, Whiteshell Laboratories, Pinawa, Manitoba, Canada R0E 1L0

(*Received 6 December 1990; accepted in revised form 30 May 1991*)

Abstract—A new type of diagram depicts orientation data for planar structures found in drill core. Strike and dip of fractures intersected by a borehole are plotted independently, side by side, as a function of borehole length. These companion plots show variations in distribution and orientation of fractures. The diagram is used to establish boundaries between fracture domains and to interpret a sequence of fracturing based on the spatial relationship between domains comprising different fracture patterns.

INTRODUCTION

AN important aspect of geoscience research conducted by AECL Research is determination and analysis of orientations of fractures which are intersected by boreholes drilled to depths of up to about 1 km (Whitaker 1987). Good recovery of undisturbed and oriented core is routinely obtained using triple tube drilling techniques and Craelius core orientators (Goodman 1976). Apparent orientations of fractures are then measured relative to a reference line painted along the entire length of the core and recorded in a computer database together with other fracture characteristics including the type of filling material. Following a gyroscopic survey of the borehole to determine its orientation and trajectory, fracture orientations are converted to strike and dip using a modified version of a computer program written by Lau (1983). The data obtained from core is supplemented by observing fractures in the borehole with a borehole television camera and a borehole acoustic televiewer. Using these techniques many hundreds of fracture orientations are obtained for a given borehole, excluding small zones where the core recovery is too poor.

Hemispherical projections, Rose frequency diagrams, and strike and dip histograms are commonly used to display fracture orientation data (Hobbs *et al.* 1976, Priest 1985, Ramsay & Huber 1987). Spatial variation in orientation or in distribution, of planar structures occurring at surface, can be shown by a map decorated with these diagrams. Similarly, orientation and distribution of fractures intersected at depth by boreholes have been displayed using bar diagrams and contoured equal-area nets on a vertical section (McEwen & Hillary 1985). In this instance, bars are extended perpendicularly from the borehole sectional trace so the length of each bar represents the number of fractures intersected per metre. The resulting diagram appears like a histogram and provides a visual impression of the distribution of fractures down the borehole. Fractures from certain segments of the borehole are grouped and plotted on equal area nets arranged along the borehole trace. A single diagram is thus constructed showing both frequency and orientations of groups of fractures intersected by a borehole (e.g. Fig. 1).

This approach requires considerable familiarization with the data so that boundaries between intervals characterized by different fracture patterns can be correctly defined, and thereby the fractures grouped to produce significant equal area plots. There was a need for a method of displaying the spatial distribution of fracture orientations before grouping. The following illustrates the application of a new diagram to present fracture data from borehole WA1 drilled in the Lac du Bonnet batholith in southeastern Manitoba, Canada.

ANALYSIS OF FRACTURE ORIENTATIONS

Borehole WA1, which plunges 66° WNW, was drilled to a length of 1200 m into massive and weakly schlieric to gneissic granite. In correspondence with fractures the granite is altered to a greyish pink colour, otherwise the pristine granite is grey. The only significant variation in lithology occurs below 1070 m where tonalite xenoliths are prominent. The borehole intersected 2200 unevenly distributed fractures, with higher concentrations for a downhole length of 0–365 m and 600–735 m. Two fault zones characterized by closely spaced low dip fractures extend from 307 to 365 m and from 722 to 735 m. The upper fault zone includes a 10 m intersection of severely argillized cataclastite centered at 345 m. Cataclastite in the lower fault zone occurs over 0.5 m at 726 m. Interpolation between fault intersections, in boreholes collared between 30 and 500 m from WA1, shows that the upper zone has an orientation of strike 205/dip 23° NW. Use of slip surfaces to represent overall fault orientation (Kamineni *et al.* 1988) indicates that the lower fault is a shallow dip structure, similar to the upper fault and other faults found in the batholith (Stone & Kamineni 1988a,b, Stone *et al.* 1989).

The distribution and orientation of the intersected

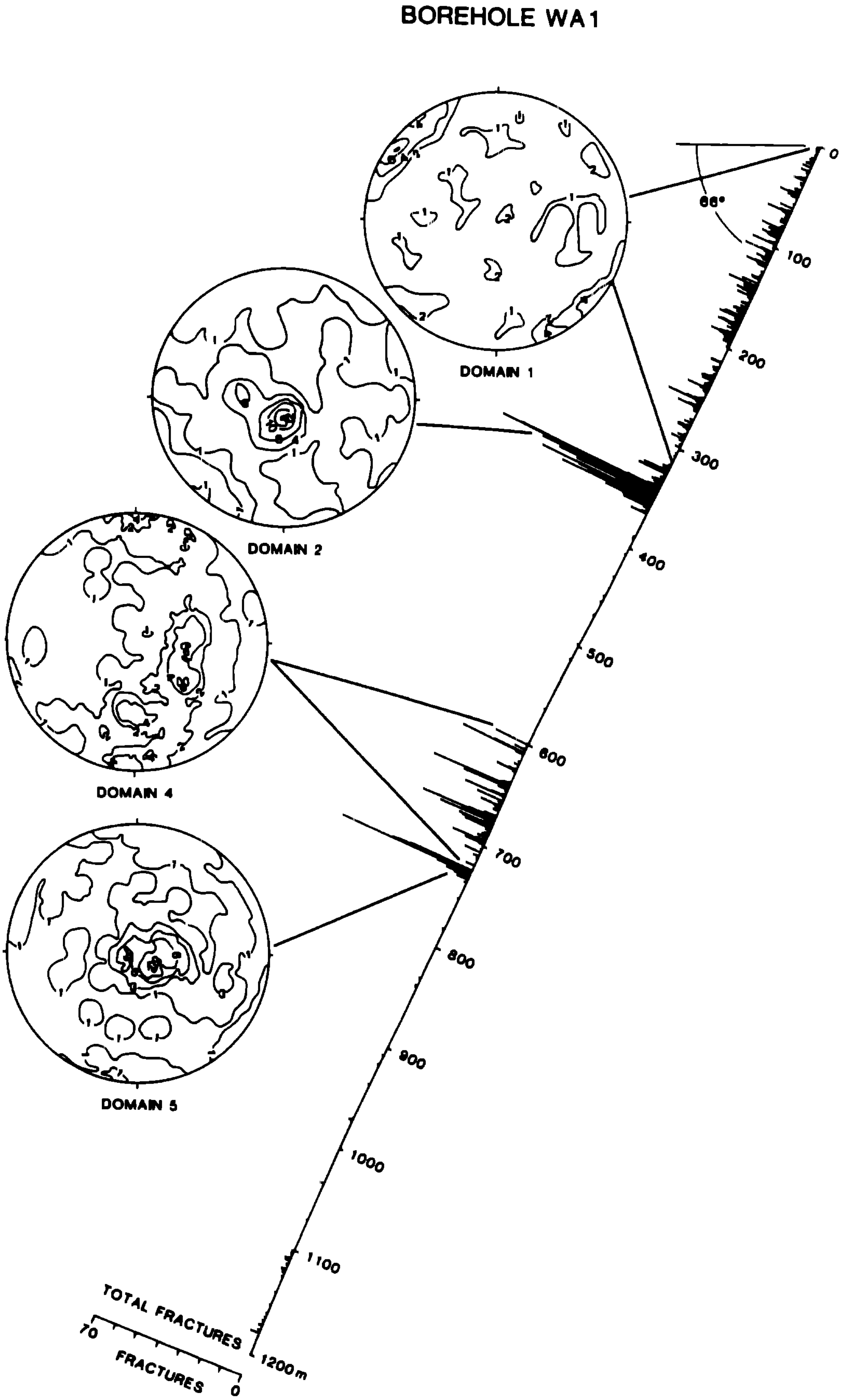

Fig. 1. Plotted along the borehole trace are distribution of fractures (shown as number of occurrences per metre) and contoured lower hemisphere equal area nets of poles to fracture planes for each of four domains. Domain 1, n = 525, contours 2, 4, 6%, maximum 7.0%, per 1% area. Domain 2, n = 196, contours 4, 8, 12, 15, 20%, maximum 20.4%, per 1% area. Domain 4, n = 269, contours 2, 4, 6%, maximum 7.1%, per 1% area. Domain 5, n = 161, contours 3, 6, 9, 12%, maximum 13.6%, per 1% area.

fractures is shown for the entire borehole by the fracture scatter diagram (Fig. 2). This diagram consists of two plots: fracture strike vs borehole length, and dip vs borehole length. Each fracture is thus represented by a point on both plots. The resulting scatter diagram provides a method for rapid visual inspection of the facture data for the entire borehole. It is apparent that fractures are much more abundant in the 0–365 m and 600–735 m intervals than elsewhere.

Certain intervals show clusters of data points, which indicate the preferred orientations of fractures. Intervals characterized by consistent fracture patterns together with common filling materials (Fig. 3) and evidence of faulting, provides a basis for identifying fracture domains, which are useful to the application of other analytic techniques or to geologic interpretation.

Fractures in Domain 1 above the upper fault zone (Fig. 2) are mainly steeply dipping (greater than 70°). For this interval, there is some visible clustering of strike direction at about 30 and 300°. The majority of fractures are unfilled or contain calcite. Domain 2 consists of predominantly shallow dip fractures, in contrast to the subvertical fractures above. In addition to cataclastically deformed fault rocks, this domain is also distinguished by chlorite and hematite fracture filling. Domains 3 and 6 are recognized mainly by scarcity of fractures of any type. Fractures in Domain 4, above the lower fault zone, have more shallow dips with increasing distance from the fault zone and there is a corresponding shift in strike from approximately 270° to approximately 180°. In Fig. 1, on the equal area net, a girdle depicting the shift in orientation is apparent, however the change with dis-

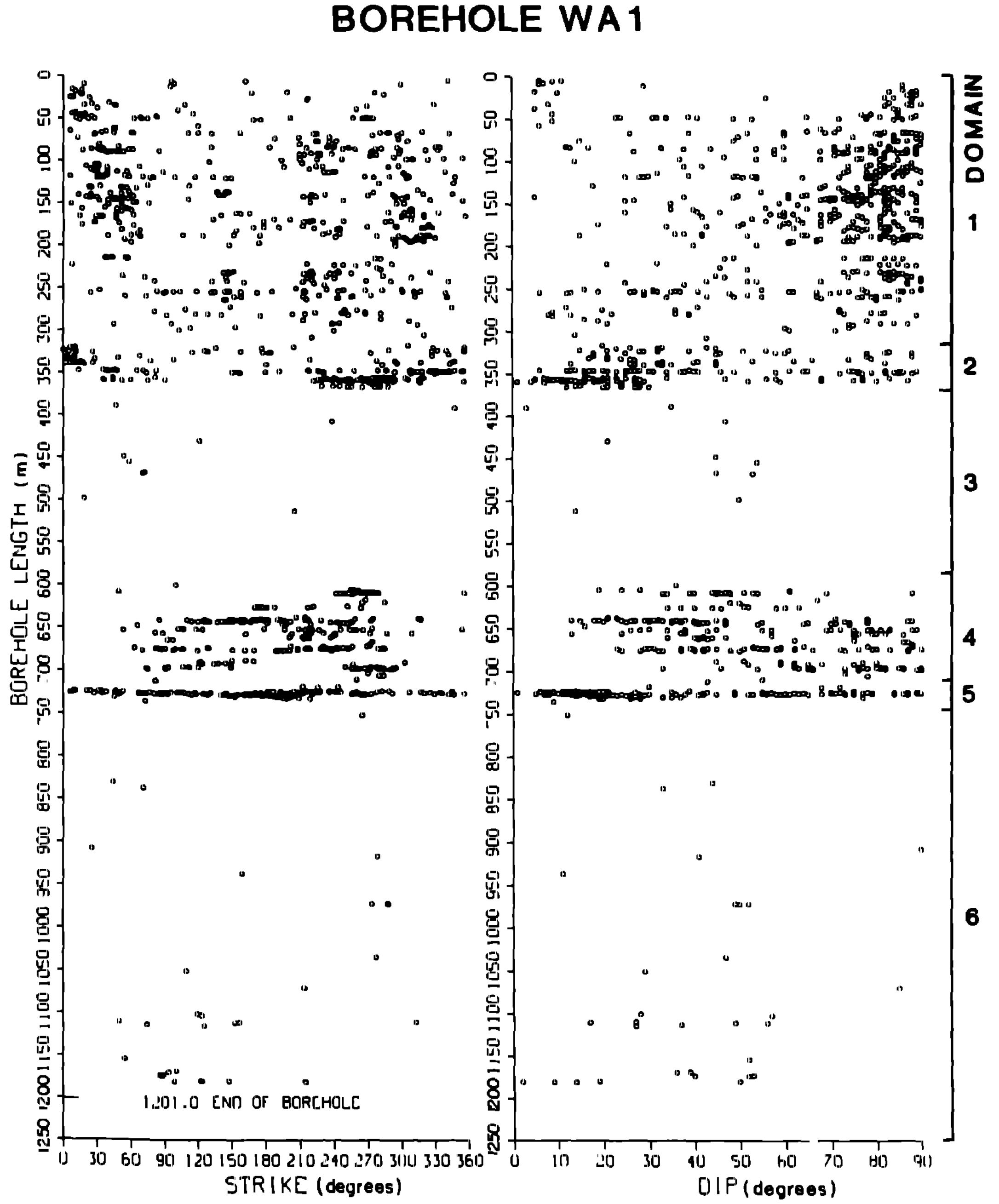
BOREHOLE WA1

Fig. 2. Proposed diagram showing distribution of fractures and variation in orientation with depth. Six structural domains are identified. Dip is to the right of strike direction.

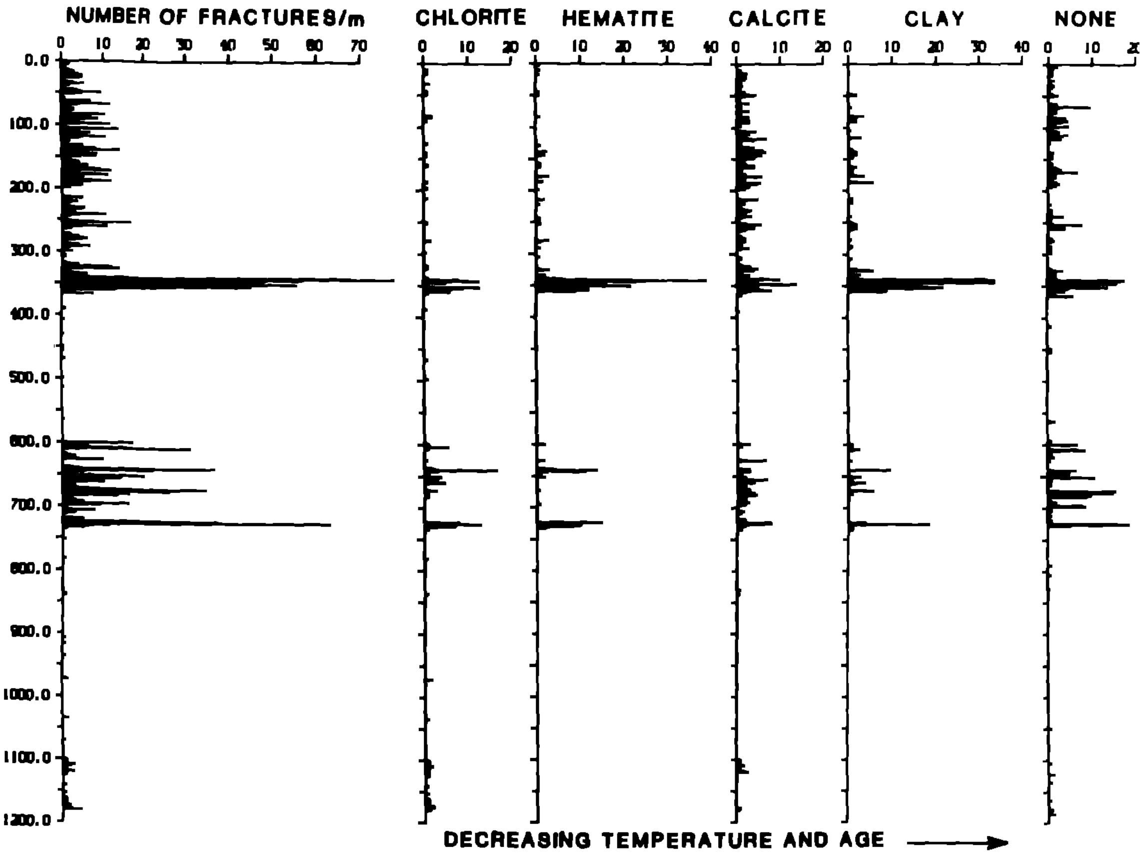

Fig 3 Distribution of fractures and fracture filling minerals along the length of borehole shown as number of occurrences per metre Minerals are arranged in order of decreasing age according to paragenesis after Stone & Kamineni (1982) established by crystallization temperature and cross cutting relationships

tance from the fault is not shown. Some discrete zones in Domain 4 are predominated by chlorite and hematite fracture filling but overall filling proportions are similar to those in Domain 1. Finally, Domain 5 contains very abundant low-dip fractures and also represents a fault zone similar to Domain 2 above

RELATIVE AGE OF DOMAINS

Fractures in Domain 1 are oriented similar to orthogonal NNE and ESE vertical joints found at surface near borehole WA1 The latter set, which is significantly less prominent (McCrank 1985), is relatively underrepresented in the borehole, due to preferential intersection of the NNE which is set oriented at a higher angle to the borehole However, fracture density, orientation and fracture filling mineralogy are shown by the borehole data to be generally consistent throughout the domain. Evidently, the dominantly subvertical fractures extend from surface down to, but not below, the first shallow-dip fault

The steeper fractures in both Domains 1 and 4 extend over true depths of more than 300 and 100 m (Fig. 2) but terminate 9 and 12 m, respectively, above shallow dip fractures in Domains 2 and 5. This implies that the stress conditions that caused fracturing were at variance across the faults The *in situ* stress state has also been shown to change in magnitude and direction across similar faults intersected by a 443 m-deep shaft in another area of the batholith (Martin 1989).

The distribution of fracture fillings (Fig. 3), and hence possibly the age of fractures, change from one domain to the next as well. Fractures in Domains 1 and 4 contain proportionately more calcite filling or are barren, whereas those of Domains 2 and 5 are rich in chlorite and hematite. These data indicate that the low-dip faults in Domains 2 and 5 had formed early and were succeeded, possibly under cooler temperatures, by the steeper fractures in Domains 1 and 4 The faults show evidence of post chlorite-hematite rejuvenation when calcite and clay fillings were deposited

DISCUSSION

There are several applications of the fracture-scatter diagrams to data collected from boreholes. When all fractures are oriented the plot serves as a composite distribution and orientation diagram and can provide a rapid visual impression of a large amount of data The plot can be used for establishing boundaries between fracture domains. If the clustering of data is good, mean orientations may be estimated by inspection For scattered orientations, the plot illustrates the variation. Trends in change of strike and/or dip with depth can be seen. In the preceding case, intervals were determined for six fracture domains, useful to geologic interpretation, and according to which fractures are grouped to produce significant and representative equal area plots. Such a diagram illustrates the spatial variation and association of fracture domains, providing a basis for inferring age relationships when fracturing in one domain appears to have been truncated by fractures in another. The diagram is a supplement to other techniques for analysis of borehole orientation data.

REFERENCES

Goodman, R. E. 1976. *Methods of Geological Engineering in Discontinuous Rocks*. West Publishing Company, St. Paul.

Hobbs, B. E., Means, W. D. & Williams, P. F. 1976. *An Outline of Structural Geology*. John Wiley and Sons, Inc., New York.

Kamineni, D., Thivierge, R. H. & Stone, D. 1988. Development of a cataclastic fault zone in an Archean granitic pluton of the Superior Province: structural, geochemical, and geophysical characteristics. *Am. J. Sci.* **288**, 458–494.

Lau, J. S. O. 1983. The determination of true orientations of fractures in rock cores. *Can. Geotech. J.* **20**, 221–227.

Martin, C. D. 1989. Characterizing in situ stress domains at AECL's Underground Research Laboratory. In: *Proceedings of the 42nd Canadian Geotechnical Conference*, Winnipeg, 61–74.

McCrank, G. F. D. 1985. A geological survey of the Lac du Bonnet batholith, Manitoba. Atomic Energy of Canada Limited Report, AECL 7816.*

McEwen, J. & Hillary, E. 1985. Early fracture evolution within the Eye-Dashwa Lakes Pluton, Atikokan, Ontario, Canada. *J. Struct. Geol.* **7**, 591–603.

Priest, S. D. 1985. *Hemispherical Projection Methods in Rock Mechanics*. George Allen & Unwin, London.

Ramsay, J. G. & Huber, M. I. 1987. *The Techniques of Modern Structural Geology, Volume 2: Folds and Fractures*. Academic Press, New York.

Stone, D. & Kamineni, D. C. 1982. Fractures and fracture infillings of the Eye-Dashwa Lakes pluton, Atikokan, Ontario. *Can. J. Earth Sci.* **19**, 789–803.

Stone, D. & Kamineni, D. C. 1988a. Structural analysis of the thrust fault at a depth of 271 to 275 m in the Underground Research Laboratory shaft. Atomic Energy of Canada Limited Technical Record, TR 461.*

Stone, D. & Kamineni, D. C. 1988b. Recognition of low intermediate dip fracture zones at surface: an example from Permit Area D, Lac du Bonnet batholith. Atomic Energy of Canada Limited Technical Record TR 465.*

Stone, D., Kamineni, D. C., Brown, A. & Everitt, R. 1989. A comparison of fracture styles in two granite bodies of the Superior Province. *Can. J. Earth Sci.* **26**, 387–403.

Whitaker, S. H. 1987. Geoscience for the Canadian Nuclear Fuel Waste Management Program. *Radioac. Waste Manage. Nucl. Fuel Cycle* **8**, 145–196.

---

*Unpublished report available from SDDO, AECL Research, Chalk River, Ontario, Canada K0J 1J0.