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# Addressing the Longitude Reference Problem in Antarctica: A Method for Regional Comparison of Structural Data Using Modular Arithmetic

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**Abstract** - At high southern latitude in Antarctica, the convergence of meridians of longitude toward the South Pole causes unique problems for geometrical comparison of structural geological and geophysical datasets. Vector data (strike, trend) are ordinarily measured with respect to the geographic North direction provided by lines of longitude. However upon the Antarctic continent, the longitude reference directions differ between sites due to the rapid decrease in horizontal distance represented by a longitude degree near South Pole. The angular difference in reference direction is of consequence for regional tectonic interpretations that compare faults, dike arrays, and tectonic or ice lineaments gathered at disparate sites.

Here we present a simple modular arithmetic conversion, of a type commonly used in number theory, as a means of normalizing geological orientation data to a common reference direction. In spreadsheet format, the function is $S_C \equiv \mathrm{MOD}\ [(S_M + \Delta L), 360]$, where $S_C$ = converted strike; $S_M$ = measured strike; $\Delta L$ = angle in degrees longitude between reference site and study site; and 360 = the divisor. If implemented by the international geological community, this approach may form the basis for a protocol that will allow direct comparison of structural/geophysical data between geographically separated study regions in Antarctica.

## INTRODUCTION

Comparison of regional structural and geophysical datasets is hindered, in Antarctica, by the convergence of meridians of longitude at high latitude, due to the progressive decrease in distance between longitude lines with approach to the South Pole. Measured parallel to lines of latitude, the distance in km represented by one longitude degree is 111.1 km at the equator, 78.6 km at 45°S, 28.8 km at 75°S, and 0 km at 90°S. Measured orientations of geological structures and geophysical lineaments (strike; trend) are ordinarily reported with respect to geographic North (after correction for magnetic declination), but the true North reference direction varies with longitude position due to proximity to South Pole (Fig. 1). This is of consequence for regional tectonic interpretations that compare geometrical and kinematic information from faults, dike arrays, geophysical lineaments or ice surface lineaments gathered at diverse sites around the perimeter of the Antarctic continent and in rock exposures in the southern Transantarctic Mountains nearest to South Pole.

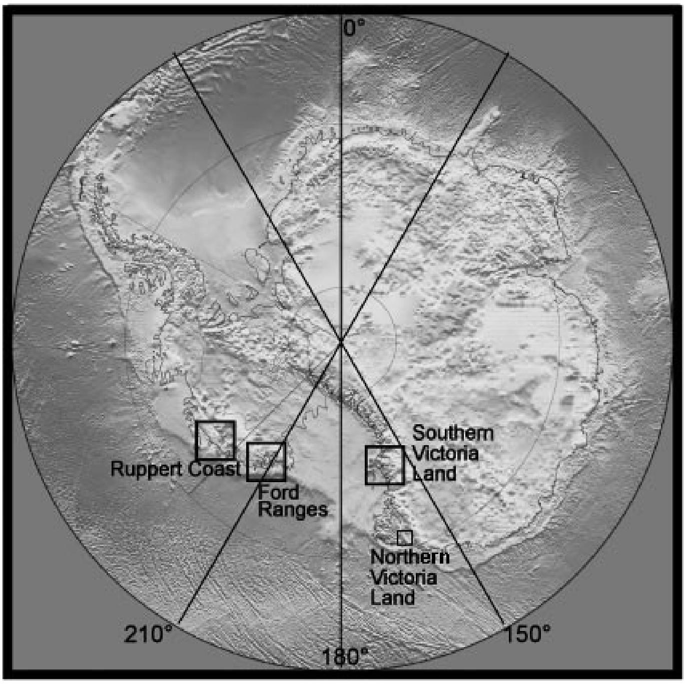


*Fig. 1* - BEDMAP image of the Antarctic continent in polar projection (Lythe et al. 2000), illustrating the convergence of meridians at high latitude nearing South Pole. Boxes frame the four localities used for comparison of structural data from the Lanterman Range, northern Victoria Land; the McMurdo Coast, southern Victoria Land; the Ford Ranges of Marie Byrd Land [MBL]; and Ruppert Coast, central MBL. The angular difference in orientation of reference North is 55° between the Transantarctic Mountains bordering the western Ross Sea and the Ford Ranges in MBL on the eastern Ross Sea margin. Outcrops in MBL for which structural data are available are distributed over a range of ~25° longitude.

For example, comparison of structural data collected at 76°S in mountain ranges on opposite margins of the Ross Sea (Fig. 1) should involve normalization of data to a common reference orientation, because the reference North direction differs by up to 55° between the two sites. At 76°S, this difference of 55° in longitude position is accomplished over the horizontal distance of 1425 km that separates the Transantarctic Mountains (TAM), bordering the western Ross Sea at 160°E, from the Ford Ranges of Marie Byrd Land (MBL) along the eastern Ross Sea at 215°E (145°W). Even within the MBL terrane (Dalziel & Elliot, 1982; Storey et al. 1988), outcrops are distributed across 48° of longitude from 202°E to 250°E (158°W to 110°W), over a distance of 1255 km. The most extreme variation in longitude reference direction in Antarctica occurs in the southern Transantarctic Mountains, proximal to South Pole.

In contrast at mid-latitudes in North America (*e.g.* 40°N), an east-west distance of 1425 km represents only 16° of longitude. Consequently in the low and middle latitudes, the issue of longitudinal convergence is ignored in regional comparisons (*e.g.* Marshak et al. 2000). However, it’s questionable whether it would be constructive to implement a normalization procedure for tectonic analysis of fault arrays when the angular difference in reference North direction between sites is small, since the natural variation in fault strike orientations within an array would ordinarily exceed the small angular correction. Should the need arise in the circum-Arctic regions, however, the modular arithmetic method presented here could be used to normalize data to a uniform reference direction.

A simple modular arithmetic conversion provides a means of normalizing geological orientation data to a common reference direction, for geometrical comparison of structural/geophysical data from geographically separated study regions in Antarctica. In this paper, we first discuss the Antarctic Navigation Grid (Air Force & Navy, 1973) as an example of an application of modular arithmetic conversion that has long been in use for air navigation in Antarctica. However, for geological applications it will ordinarily not be favorable to change both data sets to "Grid North" as has been previously proposed (Siddoway, 1998), because the conversion puts all of the vector data into an unfamiliar reference frame where directional meaning is lost. In this paper, we formulate a general modular arithmetic expression that can be used to convert geometrical data to a selected reference direction (*e.g.* the reference north direction of 163°E for researchers in the central and northern TAM). We then present three examples using datasets from Victoria Land and MBL.

The conversion method presented here is an approximation, in that it does not use spherical geometry and trigonometry to account for curvature of the Earth. However, neither is Earth curvature ordinarily calculated as part of regional tectonic analysis elsewhere. We suggest that the geometrical approximation provided by the modular arithmetic conversion is useful for tectonic analysis, and point out that the simplicity of the conversion makes it accessible for broad geological applications.

The normalization to correct for longitudinal convergence is of primary concern when comparing vector data collected over a large range of longitude, for example, near the South Pole (Goodge & others, 1991; Fitzgerald, 1992; Paulsen & others, 2004) or across the wide East-West distance separating outcrops along the coast of the Southern Ocean (*e.g.* Kleinschmidt & Brommer, 1997). Corrections are of small concern for comparison of data from sites along strike within the segment of the Transantarctic Mountains (TAM) that is approximately parallel to 160°E longitude, or along the Lambert graben/Prince Charles Mountains, subparallel to 70°E longitude.

The aim of this paper is to introduce and illustrate a method for comparison of geometrical data from study sites at different longitude positions in Antarctica. The method addresses the problem of convergence of meridians of longitude - which provide the reference North directio- to the South Pole (Fig. 1). This problem has not so far been addressed in Antarctica. Ordinarily in the published literature, structural data are not presented in polar projection but in standard equal area stereographic plots referenced to local North (*e.g.* in the recent literature: Wilson, 1995; Capponi et al., 1999; Rossetti et al., 2002, 2003; Siddoway et al., 2004b, 2005).

Consequently, the modular arithmetic conversion method opens up new opportunities for researchers to test for geometrical compatibility of structural trends in regions that have been tectonically active during the same geological time periods; to identify prevalent trends of geological structures (including geophysical lineaments, *e.g.* Finn & others, 1999; and ice surface lineaments, *e.g.* Cianfarra & Salvini, 2005) across vast regions such as the West Antarctic rift system; and to perform direct comparisons of structural features suspected of being co-linear and formed in the same stress state or tectonic environment.

## APPLICATIONS

### ANTARCTIC NAVIGATIONAL GRID

For air navigation in Antarctica, the convergence problem is solved through use of a rectilinear grid constructed parallel and orthogonal to the Prime Meridian, referred to as the

Antarctic Navigational Grid (ANG) (Air Force & Navy, 1973). Converting compass bearings from geographic to grid coordinates amounts to a modular arithmetic conversion. Modular arithmetic is commonly used in number theory as a means of partitioning integers into sets whose elements have the same remainder upon division by a set integer (Burton, 2001), in this case 360 for the number of degrees of longitude. The example of the ANG conversion provided the inspiration to devise a more flexible, reliable means to compare geometrical data that have a geological significance.

The conversion of longitude bearing to ANG direction can be expressed as a modular function, composed in spreadsheet format (*e.g.* Microsoft Excel), in this way:

**ANG bearing =MOD [(longitude position + bearing with respect to true north), 360]** [1]

This function serves to convert a measured **strike** to "ANG strike," or the angle with respect to the Prime Meridian (longitude 000°). To be consistent with spreadsheet format for the MOD function, we substitute the "=" sign for the "≡" symbol used in number theory to indicate congruence.

## CONVERSION OF GEOLOGICAL DATA TO THE LOCAL REFERENCE DIRECTION OF A KNOWN SITE

The ANG modular conversion changes the vector data from *both* regions of interest to the grid north direction used for navigation in Antarctica, as will be illustrated below. However, a problem with using Grid North from the ANG system as a geological reference (*e.g.* Siddoway, 1998) is that the ANG direction is not ordinarily used by geologists and therefore has no inherent or intuitive directional meaning. Therefore users likely will prefer to use the modular function to normalize structural data to the local north reference direction for the study area in which they personally work and have acquired data.

To rotate a comparison dataset into a specified reference frame, the *general expression* is:

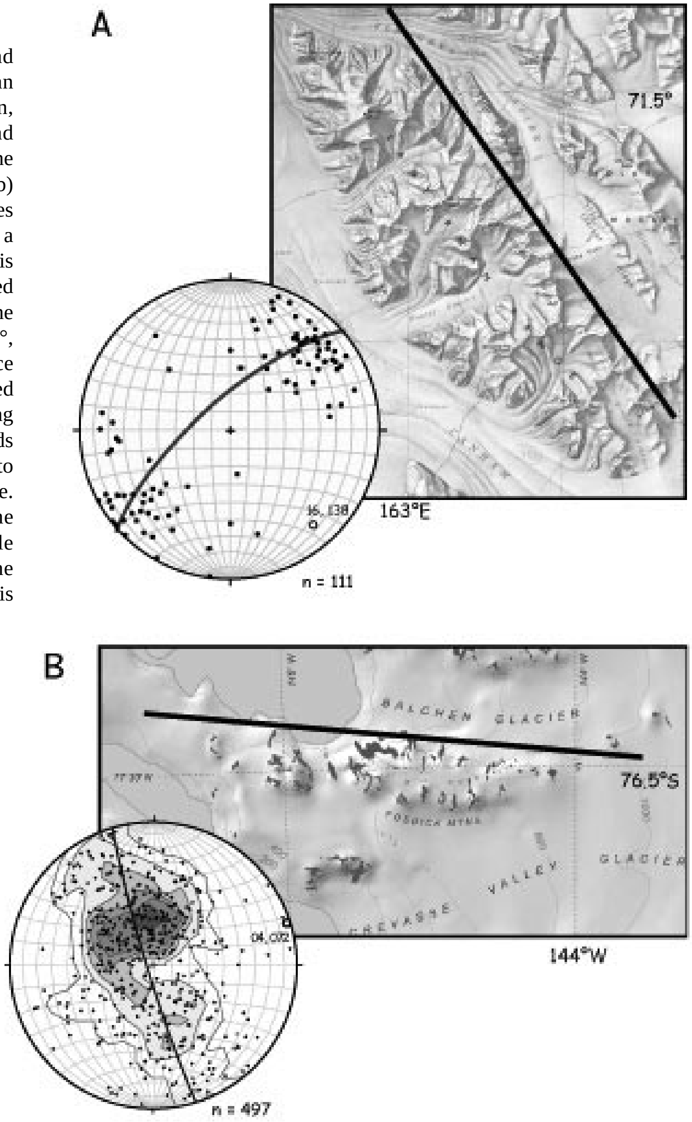
$$\mathbf{S_C = MOD\ [(S_M + \Delta L), 360]} \qquad [2]$$

where $\mathbf{S_C}$ = converted strike; $\mathbf{S_M}$ = measured strike; $\mathbf{\Delta L}$ = angle in degrees longitude between the reference site and the study site; and **360** = the divisor. In the function given here, $\mathbf{S_M}$ is substituted for the "bearing" term. $\Delta L$ must be determined site by site, measuring from the reference longitude to the longitude of the study site, noting that angles measured in the counterclockwise direction have a negative (-) sign. The expression does not account for the small effects of curvature of the Earth or for distance from South Pole, which are not trivial to calculate but are very small when the comparison regions fall within a narrow range of latitude.

## AN EXAMPLE FROM NORTHERN VICTORIA LAND

A first example of the modular arithmetic method compares the trends of two high grade gneiss complexes on opposite sides of the Ross Sea; namely, the Lanterman Range at 163°E in NVL (Capponi et al. 1999; Talarico et al. 1998) and the Fosdick Mountains at 215°E in MBL (Siddoway et al., 2004b). Both ranges have fault-controlled geometry and a length:width ratio of approximately 4:1 (Fig. 2). The sites bear comparison because the NVL and MBL tectonic provinces originated along Gondwana's active margin in Paleozoic time (Bradshaw et al. 1983; Adams 1986; Borg & DePaolo 1991), represented by marginal sediments of the Robertson Bay

*Fig. 2* - Topographic maps and stereographic plots that provide an orientation to the lat/lon position, macroscopic geometry and predominant foliation geometry of the a) Lanterman Range, NVL and b) Fosdick Mountains, MBL. Both ranges consist of high grade gneiss and have a high length:width ratio (~ 4:1) that is potentially fault-controlled. Measured with respect to reference North, the Lanterman Range trends 145 – 325°, measured with respect to reference North at 163°E longitude. Folded foliation defines a broad arch plunging 16, 138°. The Fosdicks range trends 095 - 275°, measured with respect to reference North at 215°E longitude. Folded foliation defines a dome plunging 04, 072°. A simple geometrical comparison of the geometrical elements of the ranges is provided in the text.



Group, NVL, and Swanson Formation, MBL (Ireland et al. 1998; Adams 1986). Whereas peak high pressure metamorphism affected the Lanterman Range during the Paleozoic Ross Orogeny (Ricci et al. 1997; Palmeri et al. 2003), the Fosdick Mountains experienced high temperature metamorphism arising during Cretaceous rifting (Siddoway et al. 2004a, b). Although the tectonic context and timing of metamorphism and exhumation entirely differ for the two sites (*e.g.* Capponi et al. 1999 and DiVincenzo et al. 1997; Siddoway et al. 2004b), it is hypothesized that Cretaceous and younger transcurrent faults have a fundamental control on the present-day range geometry for both high grade gneiss domains (Rossetti et al. 2002 & Capponi et al. 1999, and references therein; Siddoway et al. 2005).

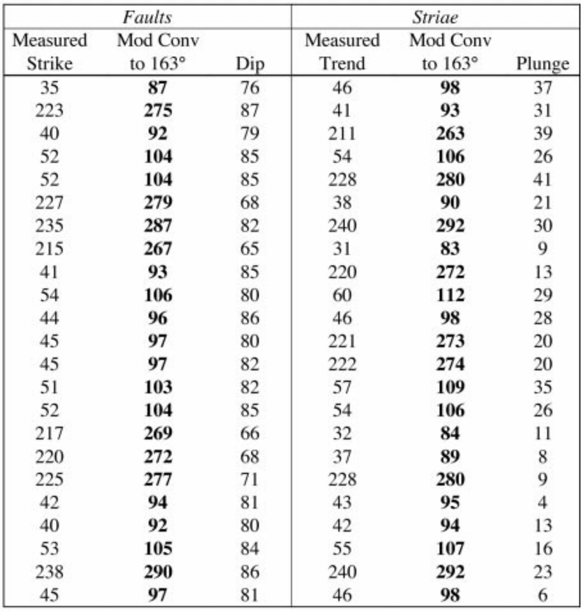
Measured with respect to reference North at 163°E longitude, the Lanterman Range trends 145 - 325, ° azimuth bearing. Measured with respect to reference North at 215°E longitude, the

Fosdicks range trends 095 - 275°, azimuth bearing. Comparing the trends measured on-site with reference to the local North direction, the apparent angular difference in range trend is 50°. Poles to foliation (Fig. 2) in the Lanterman range fall upon a π-girdle with π-axis oriented 16, 138° (Talarico et al. 1998), whereas poles to foliation in the Fosdick Mountains describe a π-axis oriented 04, 072° (Siddoway et al. 2004b).

Equation [2], above, can be used to determine whether the mountain ranges have parallel trends and internal fabrics. For this comparison, DL = 52°. To convert the Fosdick Mountains' trend of 275° to the reference North direction at 163°E longitude, therefore, the expression becomes: $S_C$ = MOD [(52+275), 360] = 327°. The conversion reveals that the long dimensions of both the Lanterman and Fosdick ranges are virtually parallel. However, the conversion of the Fosdick Mountains' π-axis trend to Lanterman Range coordinates produces a converted trend of 124°; showing that there is a difference in trend of 14° between the two π-axes for folded foliation. The fold fabrics internal to the ranges are not geometrically parallel.

A possible interpretation of these results is that the different geometries of foliations and folds (Fig. 2, stereoplots) developed during dynamic metamorphism that took place during different events and are therefore unrelated; whereas the morphology and trend of the ranges are controlled by transcurrent faults that initiated in the Cretaceous during breakup of the Australia-Antarctica-New Zealand sector of Gondwanaland (*e.g.* Rossetti et al. 2002 and references therein). The possibility of tectonic correlations between NVL and MBL for Cretaceous-Tertiary time is a potential topic of future research.

*Tab. 1* - Planar and linear data for MBL faults. For data from this region, the expression that converts strike and trend values (columns 2 and 5) is $S_C$ = MOD((52+ $S_M$), 360), where *measured trend* is inserted for $S_M$ when linear data are being converted. Dip values require no correction. The number "52" is ΔL, the angle in degrees longitude between study site and reference site, measured in the positive direction (counterclockwise). The terms $S_C$ and ΔL are explained in the text.

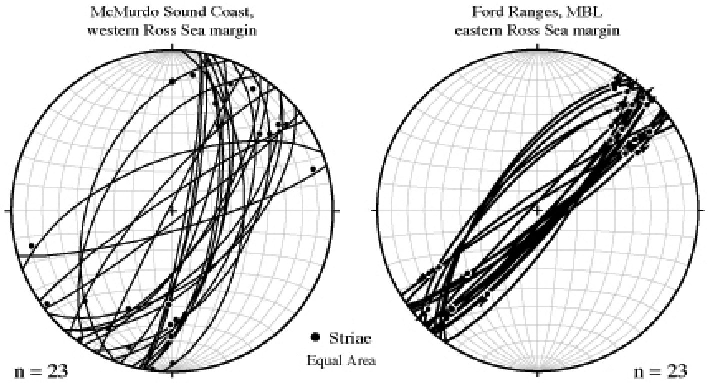


| *Faults* | | | *Striae* | | |
|---|---|---|---|---|---|
| Measured Strike | Mod Conv to 163° | Dip | Measured Trend | Mod Conv to 163° | Plunge |
| 35 | **87** | 76 | 46 | **98** | 37 |
| 223 | **275** | 87 | 41 | **93** | 31 |
| 40 | **92** | 79 | 211 | **263** | 39 |
| 52 | **104** | 85 | 54 | **106** | 26 |
| 52 | **104** | 85 | 228 | **280** | 41 |
| 227 | **279** | 68 | 38 | **90** | 21 |
| 235 | **287** | 82 | 240 | **292** | 30 |
| 215 | **267** | 65 | 31 | **83** | 9 |
| 41 | **93** | 85 | 220 | **272** | 13 |
| 54 | **106** | 80 | 60 | **112** | 29 |
| 44 | **96** | 86 | 46 | **98** | 28 |
| 45 | **97** | 80 | 221 | **273** | 20 |
| 45 | **97** | 82 | 222 | **274** | 20 |
| 51 | **103** | 82 | 57 | **109** | 35 |
| 52 | **104** | 85 | 54 | **106** | 26 |
| 217 | **269** | 66 | 32 | **84** | 11 |
| 220 | **272** | 68 | 37 | **89** | 8 |
| 225 | **277** | 71 | 228 | **280** | 9 |
| 42 | **94** | 81 | 43 | **95** | 4 |
| 40 | **92** | 80 | 42 | **94** | 13 |
| 53 | **105** | 84 | 55 | **107** | 16 |
| 238 | **290** | 86 | 240 | **292** | 23 |
| 45 | **97** | 81 | 46 | **98** | 6 |

The example here shows that if one is not concerned about the distinction between compass measurements which differ by 180° (that is, two bearings that point in opposite directions, *e.g.* 145-325 above), the modular conversion could be expressed equally well as $S_C$ = MOD [($S_M$ + ΔL), 180]. However, the sense of direction does matter for right-hand-rule strike and linear data; consequently we formulate the general expression in terms of MOD 360.

## AN APPLICATION FROM SOUTHERN VICTORIA LAND

A second example explores the apparent geometrical compatibility of post-Jurassic strike-slip faults in MBL (Siddoway, 2004; Luyendyk et al., 2003: *Figure 7*) and south Victoria Land (Wilson, 1995: *Figure 5*). Outcrops in both locations host arrays of NE-striking, moderately steeply dipping brittle faults. Shear sense



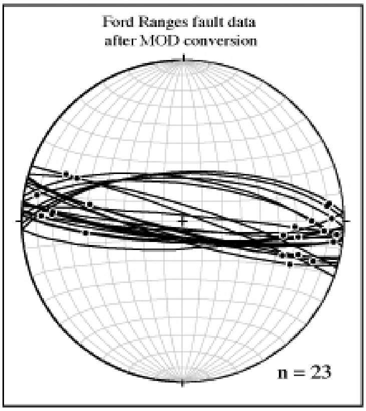


*Fig. 3* - Comparison of post-Jurassic dextral strike-slip fault data of **a)** SVL (Wilson, 1995) and **b)** MBL (Siddoway, 2004; Luyendyk et al. 2003). c) Fault data from MBL normalized to the SVL reference direction of 163°E. For discussion, see text. In this case, MBL data are converted to the Transantarctic Mountains North reference direction, in order for the data to have geographic relevance for the larger number of Antarctic researchers who work in the TAM than MBL.

indicators associated with shallowly plunging striae indicate dextral- to dextral-oblique sense of shear. The measured fault data are as summarized in figure 3a-b and in table 1. If the difference in reference North direction for the two sites is disregarded, it appears that the NE-striking fault sets and fault striae are generally parallel, even while SVL faults have somewhat more variation in strike and less steep dips. Based on fault strike and kinematics, one might entertain the hypothesis that the dextral-slip faults of Cretaceous age or younger are somehow genetically related.

As a test for parallelism of the MBL and SVL fault arrays, we employ equation [2] to convert brittle fault data from the Ford Ranges at 215°E in Marie Byrd Land to the coordinates of the McMurdo Sound coast at 163°E in south Victoria Land (SVL). A choice was made to convert the brittle fault data from the Ford Ranges, collected by the authors, to the coordinates of a “comparison region” in the vicinity of Ross Island in recognition that a larger number of Antarctic geologists work in and may be acquainted with the brittle structures of the TAM/western margin of Ross Sea. After conversion the MBL data (Fig. 3c) can be compared directly to the SVL data (Fig. 3a).

Structural data are summarized in table 1, with measured strike values in column 1 and $\mathbf{S_C}$, converted strike, in column 2; followed by measured dip values in column 3. The stereographic plot in figure 3c shows that, when considered with respect to the same reference North direction as the SVL data, that MBL and SVL fault arrays arenot parallel. Had they been measured in NVL, the steep strike-slip faults of the Ford Ranges would have a WNW-ESE geometry, distinctly different from that of the SVL faults. Consequently, a geometrical and genetic relationship between the fault arrays is unlikely.

## Conversion of mafic dike orientations, Marie Byrd Land

Two further examples of the modular conversion are illustrated here, using geometrical data for dikes that make up the mafic dike swarm of MBL (Sheraton et al., 1987). The data to be converted are strikes of the planar margins for Cretaceous dolerite dikes of 1 to 30 meter width (Siddoway et al., 2005; Storey et al., 1999). Dike margin strikes were measured with respect to local geographic North at outcrops situated **a)** along Ruppert Coast in central MBL, between 218°E - 226°E (Storey et al., 1999) and **b)** in the Ford Ranges of western MBL at 212° to 216°E (Siddoway et al., 2005). The majority of dikes in both locations dip > 60°. The MBL dikes have been interpreted to record breakup of the Gondwana active margin, potentially influenced by a mantle plume, with the ENE-WSW to NW-SE striking dikes in the Ruppert Coast sector

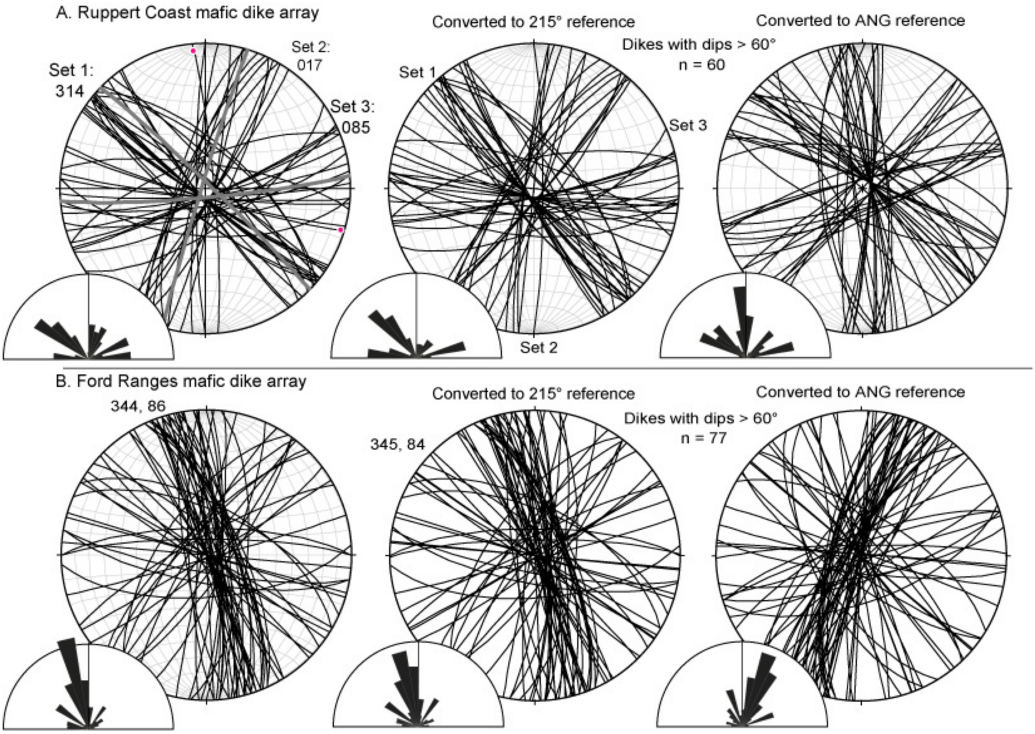


*Fig. 4* - Stereographic diagrams summarizing the structural orientations of mafic dikes in western MBL versus central MBL. Strike/dip of dike margins for dikes with dips >60° are plotted. Diagrams in Figure 4a *(upper row)* are from the Ford Ranges (Siddoway et al. 2005) and diagrams in figure 4b *(lower row)* are from Ruppert Coast (Storey et al. 1998). Left column presents structural attitudes as measured. Middle column shows data after modular arithmetic conversion to the reference North direction at 215°E, the meridian of longitude that passes centrally through the Ford Ranges. Right column presents both mafic dike datasets converted to the ANG reference azimuth of 000°. The equivalent values of strike for each case are given in table 2. Stereoplots are equal area lower hemisphere projections. The half-rose diagrams are equal area, circle at 20%.

forming a conjugate array indicative of stretching orthogonal to the rifted MBL margin (Storey et al., 1999).

A qualitative comparison of the dike geometries, as measured (Fig. 4, left column), suggests that none of the subsets of dikes are strictly parallel, but some subsets' orientation is nearly parallel. However, because the MBL data were collected over a range of 14° longitude, it would be inaccurate to lump the field data together and directly compare the dike margin orientations; to determine the regional maximum principle finite strain axis from the dike opening direction, for example (*e.g.* Tsunakawa, 1983; Best, 1988). After conversion, the dike orientations can be directly compared to assess whether the dikes emplaced over a broad area form part of consistent regional geometrical array and to examine the spatial configuration of the arrays. Dikes with dips <60°, the predicted dip value for a conjugate tensile set, are excluded from this analysis.

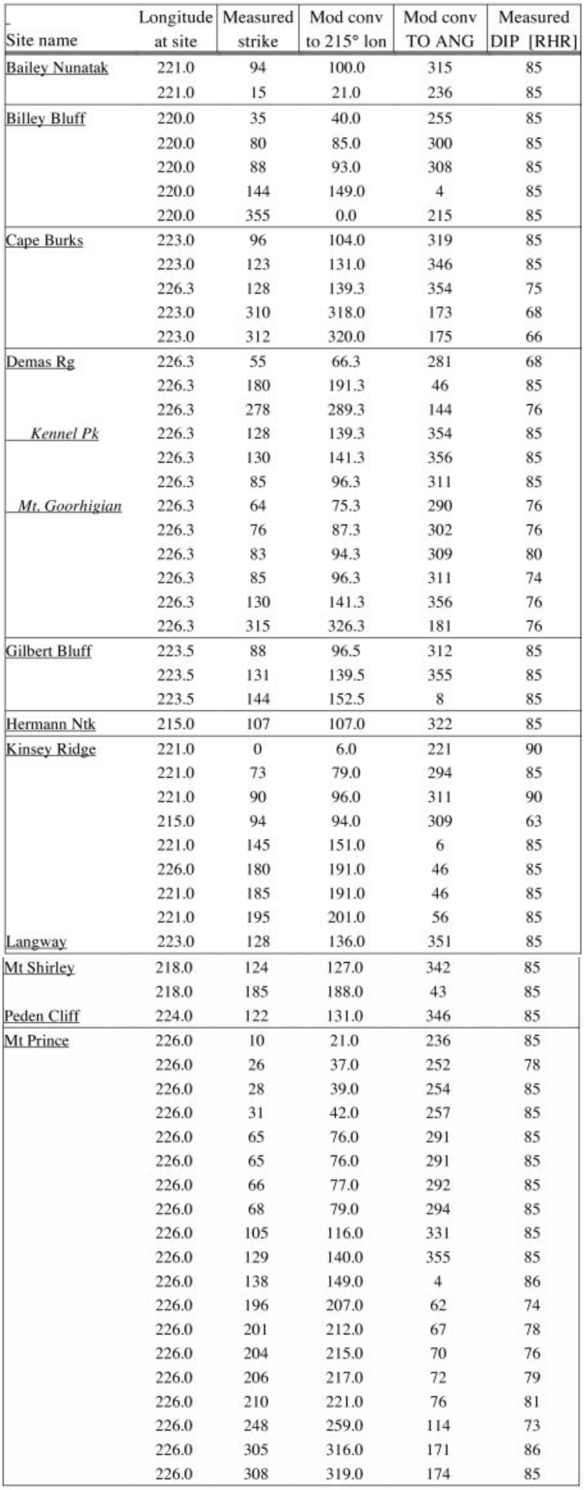
The first example normalizes all MBL mafic dike data (Fig. 4, left column) to the North reference at 215°E, (Fig. 4, middle column), selected because 215°E is situated centrally upon the Ford Ranges, a region of abundant outcrop and numerous dikes. The second example converts both mafic dike datasets to the ANG reference azimuth of 000° (Fig. 4, right column). The first exercise amounts to one further example of the conversion of geological data to the local reference direction of a known site, as above. However, the task is more involved because dike outcrops are found over such a range of longitude. Consequently, a single formulation of equation [2] cannot be used and site-by-site corrections are performed (Tab. 2) for both examples in this section. For this reason, the comparison is not made with simple rotation of the entire rose diagram.

The prevalent strike orientations of mafic dike margins in the Ruppert Coast study are NW-SE, NNE-SSW and ENE-WSW (Fig. 4a, left & middle columns). The mean strike values for the three subsets are 314, 017, and 085 (Fig. 4a, left). Based on field relationships and geometry, Storey et al. (1999) have interpreted the NW and ~E-W dikes as a conjugate array that records NNE stretching at the time of emplacement. From stereonet analysis, the interfacial angle between the 314 and 085 mean planes is 50°. After carrying out the conversion to the 215°E reference direction (Tab. 2), the measured strikes are for the first time normalized to a single reference direction and can be compared directly (Fig. 4, middle column). When converted, the mean strikes of the three subsets become 315, 023, and 099. A tighter definition of dike subgroups in Figure 4b vs. 4a is obtained because the strikes were measured with respect to true North at sites distributed over the 8° range of longitude between 218°E and 226°E. After the data are normalized, the interfacial angle between the NW and ~E-W mean planes is 38°.

In the Ford Ranges, the most prevalent dike orientation is NNW-SSE, with a scattering of subvertical dikes in other orientations (Fig. 4b). The mean strike and dip of the NNW-SSE dikes is 344, 84 NE (Fig. 4b, left). After the data are all converted to the 215°E reference direction, the mean orientation is 345, 84 NE (Fig. 4b, middle). The change in mean strike for Ford Ranges data is very small because the Ford Ranges study sites lie between 214°E to 216°E and most data require a correction of only 1° or less (Table 2).

The same patterns and angular relationships discussed in the preceding paragraphs are evident in the conversion of the MBL dike data to the ANG reference direction (Fig. 4, right column). However, changing both data sets to ANG puts all of the vector data into an unfamiliar reference frame where directional meaning is lost. Therefore we provide a summary of the ANG conversion in figure 4, but we center the following discussion of geometrical analysis upon the data conversion to the 215° longitude reference in western MBL.

Comparison of the Ford Ranges and Ruppert Coast data (Fig. 4) shows that the mean strike



| Site name | Longitude at site | Measured strike | Mod conv to 215° lon | Mod conv TO ANG | Measured DIP [RHR] |
|---|---|---|---|---|---|
| Bailey Nunatak | 221.0 | 94 | 100.0 | 315 | 85 |
| | 221.0 | 15 | 21.0 | 236 | 85 |
| Billey Bluff | 220.0 | 35 | 40.0 | 255 | 85 |
| | 220.0 | 80 | 85.0 | 300 | 85 |
| | 220.0 | 88 | 93.0 | 308 | 85 |
| | 220.0 | 144 | 149.0 | 4 | 85 |
| | 220.0 | 355 | 0.0 | 215 | 85 |
| Cape Burks | 223.0 | 96 | 104.0 | 319 | 85 |
| | 223.0 | 123 | 131.0 | 346 | 85 |
| | 226.3 | 128 | 139.3 | 354 | 75 |
| | 223.0 | 310 | 318.0 | 173 | 68 |
| | 223.0 | 312 | 320.0 | 175 | 66 |
| Demas Rg | 226.3 | 55 | 66.3 | 281 | 68 |
| | 226.3 | 180 | 191.3 | 46 | 85 |
| | 226.3 | 278 | 289.3 | 144 | 76 |
| *Kennel Pk* | 226.3 | 128 | 139.3 | 354 | 85 |
| | 226.3 | 130 | 141.3 | 356 | 85 |
| | 226.3 | 85 | 96.3 | 311 | 85 |
| *Mt. Goorhigian* | 226.3 | 64 | 75.3 | 290 | 76 |
| | 226.3 | 76 | 87.3 | 302 | 76 |
| | 226.3 | 83 | 94.3 | 309 | 80 |
| | 226.3 | 85 | 96.3 | 311 | 74 |
| | 226.3 | 130 | 141.3 | 356 | 76 |
| | 226.3 | 315 | 326.3 | 181 | 76 |
| Gilbert Bluff | 223.5 | 88 | 96.5 | 312 | 85 |
| | 223.5 | 131 | 139.5 | 355 | 85 |
| | 223.5 | 144 | 152.5 | 8 | 85 |
| Hermann Ntk | 215.0 | 107 | 107.0 | 322 | 85 |
| Kinsey Ridge | 221.0 | 0 | 6.0 | 221 | 90 |
| | 221.0 | 73 | 79.0 | 294 | 85 |
| | 221.0 | 90 | 96.0 | 311 | 90 |
| | 215.0 | 94 | 94.0 | 309 | 63 |
| | 221.0 | 145 | 151.0 | 6 | 85 |
| | 226.0 | 180 | 191.0 | 46 | 85 |
| | 221.0 | 185 | 191.0 | 46 | 85 |
| | 221.0 | 195 | 201.0 | 56 | 85 |
| Langway | 223.0 | 128 | 136.0 | 351 | 85 |
| Mt Shirley | 218.0 | 124 | 127.0 | 342 | 85 |
| | 218.0 | 185 | 188.0 | 43 | 85 |
| Peden Cliff | 224.0 | 122 | 131.0 | 346 | 85 |
| Mt Prince | 226.0 | 10 | 21.0 | 236 | 85 |
| | 226.0 | 26 | 37.0 | 252 | 78 |
| | 226.0 | 28 | 39.0 | 254 | 85 |
| | 226.0 | 31 | 42.0 | 257 | 85 |
| | 226.0 | 65 | 76.0 | 291 | 85 |
| | 226.0 | 65 | 76.0 | 291 | 85 |
| | 226.0 | 66 | 77.0 | 292 | 85 |
| | 226.0 | 68 | 79.0 | 294 | 85 |
| | 226.0 | 105 | 116.0 | 331 | 85 |
| | 226.0 | 129 | 140.0 | 355 | 85 |
| | 226.0 | 138 | 149.0 | 4 | 86 |
| | 226.0 | 196 | 207.0 | 62 | 74 |
| | 226.0 | 201 | 212.0 | 67 | 78 |
| | 226.0 | 204 | 215.0 | 70 | 76 |
| | 226.0 | 206 | 217.0 | 72 | 79 |
| | 226.0 | 210 | 221.0 | 76 | 81 |
| | 226.0 | 248 | 259.0 | 114 | 73 |
| | 226.0 | 305 | 316.0 | 171 | 86 |
| | 226.0 | 308 | 319.0 | 174 | 85 |

*Tab. 2 (on the left)* - Table presenting the original strike, converted strike, and dip data in right hand rule format Dip values do not change. The function for conversion of strike values for MBL dikes to a reference direction of 215°E (*column 3*) is: Converted strike = $S_C$ = MOD(($S_M$ +(SiteLongit-215)), 360) where (SiteLongit-215) equates with ΔL in the general expression. The function for conversion of strike values for MBL dikes to ANG (*column 4*) is: $S_C$ = MOD((site longitude + $S_M$), 360). In ANG orientation, $S_M$ = 000° (due North) would have a value equal to the longitude. Decimal values that arise in "converted strike" (columns 4-5) due to input of longitude location (column 1) in decimal degrees, are rounded up to the next whole number.

of 345 from the Ford Ranges is distinct from any prevalent strike direction for dikes of the Ruppert Coast. The reverse is also true: the three prevalent directions found in the Ruppert Coast are not strongly evident in the Ford Ranges. Although a scattering of Ford Ranges dikes do have strikes that could fall into the three Ruppert Coast subsets, they are few in number (n<5 for any subset). Within Ruppert Coast, the distribution of the three orientations of dikes seems to be broad (Tab. 2), with 218°E as 226°E. Consequently, careful observation of crosscutting relationships and sampling for absolute age determination will be needed to carry the geometrical interpretations further.

Although the visual difference between the "as measured" strike (Fig. 4, left) and converted strike stereoplots (Fig. 4, middle) might appear to be small or insignificant, careful examination reveals that the conversion serves to tighten the data subsets (rose diagram insets) and correct the angular relationships between dike sets (discussed above). Once the MOD conversion is applied, the MBL data, collectively, can be used for regional tectonic analysis. Use of the MOD function in a spreadsheet application makes it possible to normalize a large structural data set prior to stereographic analysis. Interesting questions that may be addressed in MBL are: 1) Do the mafic dikes have a spatial and geometrical distribution (*e.g.* Fahrig 1987) that would support the hypothesis of a mantle plume beneath MBL in the Late Cretaceous (Weaver et al. 1994)? 2) Does the geometry of the dikes support the interpretation of ~N-S stretching orthogonal to the rifted margin of MBL (Storey et al. 1999) or of transtension oblique to the margin (Siddoway et al. 2005)? 3) Why does the Ford Ranges dike array have a distinct and different geometry than that of the Ruppert Coast region? 4) Do the dike orientations have a geometrical relationship to major faults and fundamental crustal structures that are of consequence for stability of the West Antarctic ice sheet (*e.g.* Dalziel, this volume)? These questions provide examples of the types of tectonic correlation that cannot be carried out without addressing the longitude convergence problem.

## CONCLUSIONS

Opportunities to apply the new normalization technique will increase as detailed structural studies and kinematic investigations continue in Antarctica (*e.g.* Rossetti et al., 2002, 2003; Läufer & Phillips, 2004) and as geophysical coverage of central East Antarctica improves, providing a means to correlate bedrock structures and geophysical lineaments. The modular conversion is generally applicable as a means to convert structural data recorded in terms of a bearing or strike **to** polar stereographic coordinates, for direct comparison with aeromagnetic and other geophysical trends in polar projection. Consequently, the modular arithmetic conversion method may become increasingly valuable for regional comparison of multiple data sets, because it offers a direct means to compare vector data gathered in present-day spatial coordinates at different longitude positions. The aim of this paper is to introduce a simple, generally applicable method for comparison of geometrical data from diverse longitude positions in Antarctica. The authors encourage broad use and rigorous testing of the conversion method, and invite responses from the Antarctic community.

The great utility of the modular arithmetic conversion method is that it overcomes the problem of convergence of the lines of longitude used locally for reference North direction. The method presented is an approximation because curvature of the Earth is ignored. It does not address the question of tectonic or paleomagnetic rotations that may be responsible for the present spatial relationships of contemporaneous features. However, the method does yield an actual angular measurement of the difference in strike or trend of the features being compared that is otherwise impossible to determine. In cases where contemporaneity of features can be demonstrated, the angular measurement might equate with an angle of tectonic rotation. Therefore, put in to general use, this method will allow researchers who have detailed local knowledge of crustal structures (*e.g.* Transantarctic Mountains) to broaden their investigations and explore the significance of characteristic structural trends for a larger region.

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