Earth and Planetary Science Letters, 104 (1991) 16–24
Elsevier Science Publishers B.V., Amsterdam

[FB]

Fold test in paleomagnetism: new approaches and reappraisal of data

Mikhail L. Bazhenov and Stanislav V. Shipunov

Geological Institute, Academy of Sciences of the USSR, Pyzhevsky per., 7, Moscow, 109017, USSR

Received April 23, 1990; revised version accepted January 14, 1991

ABSTRACT

It has been shown that any modification of the fold test leads to a definite conclusion about the magnetization nature if several basic assumptions are observed and the statistical test itself is correctly formulated. It has been demonstrated that the test based on comparison of concentration parameters (McElhinny, 1964) is controversial and may lead to erroneous conclusions. Two modifications of the fold test are proposed. The first one is based on the division of the bedding poles distribution into groups, calculation of the corresponding paleomagnetic group-means and their testing by the F distribution. This test is similar to that proposed by McFadden and Jones (1981), but can be used more widely. The second modification is based on correlations of unit bedding poles and paleomagnetic vectors and can be applied to any collection, provided the number of the unit vectors is 10 or more. All three tests were compared with the aid of simulated and real collections and it was shown that the latter two are more sensitive than the first one.

1. Introduction

The reliability of tectonic interpretation of paleomagnetic data depends on solving three problems, namely, complete NRM component separation, dating of these components and accurate determination of their directions. The so-called field tests are very important in this relation. Suggested some decades ago [1], they are widely used now but it does not seem that everything is clear here. The fold test was proposed by Graham [1], and a statistical solution suggested by McElhinny [2] had been widely used later on. However, this solution was recently shown to be inappropriate [3] and it seems to be worthwhile analyzing the fold test once more.

2. Basic assumptions

Apparent simplicity of Graham's idea is deceitful, and it is not so easy to construct a correct statistical fold test because several basic assumptions should be satisfied and a correct mathematical procedure should be applied. These assumptions are as follows: (1) Pre-deformational attitudes of folded strata are known. (2) During deformation, each rock volume was rotated as a rigid body around a horizontal axis. (3) A magnetization is the unicomponent one and it was totally acquired either before or after folding. (4) The magnetization has the same direction in all the rocks studied.

Provided that all the assumptions are satisfied, paleomagnetic directions will be parallel to each other in case of prefolding (postfolding) magnetization after (before) tilt correction. However, if these directions are not parallel, it does not necessarily imply that the magnetization is the sum of several components. Such a situation may stem from violating any other assumption as well. For example, in stratigraphic coordinates, it may occur if the rocks under study had unaccounted-for primary tilts (assumption 1), were rotated around an inclined axis (assumption 2), were totally remagnetized at an intermediate stage of folding (assumption 3), or did not cover a long enough time interval to average out secular variations (assumption 4). It is easy to continue this list. Thus, it is only the parallelism of paleomagnetic vectors that is unambiguous. More data are re-

0012-821X/91/$03.50

quired to determine the cause of deviation from the ideal pattern.

Paleomagnetic data will be invariably blurred due to different sources of dispersion, and a certain statistical procedure must be applied to a real data set. Any correct statistical test should satisfy several conditions. First, the null hypothesis to be checked should be meaningful from the physical point of view. Second, the test's ability to find a deviation from the null hypothesis should increase with the growth of a sample size. Third, such a test should recognize the case(s) when a data set is insufficient for a definite conclusion. These conditions are not as self-evident as it may appear.

In paleomagnetism, four different situations may occur. If a test is positive (null hypothesis is accepted) in stratigraphic coordinates and negative (null hypothesis is rejected) in geographic coordinates, the magnetization is prefolding. If the situation is reversed, the magnetization is postfolding. If a test is negative both before and after tilt correction, one or more basic assumptions are violated; it is just a possibility, though perhaps the most probable one, that the magnetization under study is the sum of several components. Finally, if a test is positive both before and after tilt correction, the age of magnetization in relation to folding cannot be determined. These four situations will be referred to further on as PN, NP, NN and PP, respectively.

3. Procedures

The most widely used test procedure, usually called just "the fold test", is based on comparison of concentration parameters before (K_b) and after (K_a) tilt correction [2]. Such a test (CP test) is well known and there is no need to describe it here. This test has been recently proved to be invalid, on mathemathical grounds mainly, and another test was proposed (further on, it will be referred to as the mean test [3]). However, paleomagnetologists seem to be under the impression that the mean test is only slightly more sensitive and it ought to be applied only if the CP test is inconclusive. If the latter is positive, it can be considered correct. Actually, this is not the case.

The null hypothesis of the CP test is simple: the concentration parameters are statistically identical (for analysis, see [3]). If it is rejected for a data set, it means nothing but the fact that two concentration parameters are different, say, $K_a > K_b$. Indeed, it should be so for a prefolding magnetization. However, such a relation between K_a and K_b is just the necessary but not the sufficient condition. The same may be true if the magnetization under study is the sum of post- and prefolding components provided the latter prevails. And, vice-versa, the null hypothesis is accepted in two cases: (1) if these components are comparable or if the bedding attitude dispersion is too small. In the above-proposed notations, the CP test does not discriminate between the PP situation and the NN situation. Of course, if the K_a/K_b ratio is large, say, 50 or more, there is almost no doubt about the prefolding age of magnetization. But much smaller values are common, 3 or 5 or even less, and it is not possible to find the boundary between "reliable" and "suspicious" values. To construct a correct CP test, one must compare the calculated K_a/K_b value with a certain theoretical value larger than 1. The latter must be estimated independently, the dispersal of bedding attitudes being taken into account. As far as we know, such a test has not been constructed yet.

Another kept-in-mind hypothesis is used jointly with the CP test: if the prefolding component prevails, any postfolding component (or any other distorting factor) will be averaged out. This is true if such a postfolding remagnetization is symmetric in relation to the prefolding component. Otherwise, the result will inevitably be biased, and there seems to be no way to evaluate either symmetry or bias.

There is another reason to disprove the CP test. Actually, what will happen if a data set size grows infinitely? It is clear that the K_a/K_b values closer and closer to 1 will become statistically significant. As stated above, the K_a/K_b value may be close to 1 in two cases: if tectonic corrections are small (PP situation) or if post- and prefolding components are commeasurable (NN situation). In the latter case, the grouping of the data from all limbs considered together does not get worse as the sample size increases, so one is no better able to identify the postfolding remagnetization using the CP test. It is clearly a paradox: the quality of testing decreases with the growth of the sample. The reason is that the null hypothesis of this test is incorrect from the physical point of view.

To overcome this difficulty, the incremental modification of the CP test is used (e.g. [4]) which does allow to discriminate between the NN and PP situations. This approach, however, does not seem to be fully adequate due to several reasons. First, its statistical validity has not yet been properly addressed and, moreover, the criticism of the simple CP test [3] is valid here too. Second, the incremental CP test depends on the adopted way of unfolding. The proportional unfolding is most often used without any geological confirmation of its validity, even for both steep and gentle fold limbs. On the other hand, the test yields arbitrary results if other ways of unfolding are adopted. Moreover, even for purely prefolding remanence, a "better" parallelism of vectors can always be computed with the aid of a differentiated unfolding just because of statistical nature of all data.

The null hypothesis of the mean test [3] is as follows: for a purely prefolding (postfolding) magnetization, mean vectors from different fold limbs should be statistically identical after (before) tilt correction. The means are compared by the F distribution. The test seems to be flawless, but for a certain restriction on the consistency of concentration parameters (for details, see [3]).

Besides, to apply the mean test, a number of sites should be sampled from each monocline limb. If this condition is not met, the test cannot be used. A way to overcome this limitation is presented below, but first let us consider the relationship between "site" and "sample" in paleomagnetism. If samples are taken from a thin bed or lava flow of invariable attitude, then either site- or sample-means can be used for testing. On the contrary, if bedding attitudes are variable within a site and/or a site spans some stratigraphic interval, the sample level is preferable for it does not lead to loss of information. In any case, bedding attitudes are converted into normals to bedding planes (bedding pole, BP). Then, the BP distribution in the stereonet is divided into a certain number of approximately isometrical non-overlapping groups, and mean paleomagnetic vectors are calculated for each group. The set of such group-means is tested as suggested by McFadden and Jones [3]. This group test differs from the mean test by the origin of BP clusters only: it is "hand-made" for the first and natural for the second.

Of course, such division is not unique. When the group test was applied to a number of paleomagnetic collections, as well as the computer-simulated data sets, it was found that the results of testing were almost independent of the number and size of groups, provided these groups were large enough. The minimal number of entries in each group should be 5, preferably more. A certain equilibrium should be maintained, as lesser more "monoclinal" groups include less entries. If a BP deviates considerably from any group and the outliers are not numerous, they can better be omitted; naturally, some information will be lost. Finally, any grouping may be senseless due to a large scatter of BP's. In general, the above-described procedure is quite similar to that used commonly in statistics, e.g. for histogram drawing.

Any data grouping, either natural or "hand-made", inevitably leads to a certain loss of information. Thus, an optimal fold test should deal only with unit vectors. To develop such a test, the null hypothesis must be re-formulated. Actually, if prefolding directions are statistically identical after tilt correction, it means that they are independent of bedding attitudes. In other words, directions of prefolding (postfolding) magnetization do not correlate with unit BP vectors after (before) tilt correction. We contemplated different cases and saw no reason why this new formulation of the null hypothesis is better or worse than the old one. They are just different.

To construct an adequate test, the following procedure was adopted. The principal axes of two sets of unit vectors, i.e., BP's and paleomagnetic directions, are determined and each unit vector is projected on these axes. Intercorrelation coefficients are then calculated for the principal components of the two sets separately. As these variables are not normally distributed, the rank correlation after Spearman [5] is used. Though there are conventional approaches to multi-dimensional normally distributed data processing [e.g. 6], no approaches exist for other types of distribution. We tried to overcome this difficulty in the following way. Certain BP and Fischer-distributed paleomagnetic vector sets were simulated. Nine rank correlation coefficients for these two sets were calculated after tilt correction and nine coefficients before. At first, we tried to develop the test using tabulated critical values of rank correlation coefficients at the 95% confidence level. Such an approach proved to be inappropriate. When simulations *were* repeated manifold the critical values were exceeded far too often due to joint probabilities having been ignored.

To obtain correct critical values, the Monte-Carlo method was used. For any sample size a correlation matrix was calculated several thousand times and the largest coefficient out of nine was selected at each run. Critical values were estimated after [7] and then tabulated for various sample sizes. These values proved to be rather close to those for the one-dimensional case at the 99% confidence level. As the latter values have already been published [e.g. 8] they were used by the authors. We believe that this statistics is over-stringent. In other words, a correct method of multi-dimensional rank correlation may reveal a weak inter-dependency when the proposed statistics fail.

If the group and correlation tests reject the null hypothesis before and after tilt correction it does not mean that the collection should be discarded. Both can be easily adopted for the synfolding magnetization: the tests should just be repeated for each step of unfolding. If the rocks suffered rotations about inclined axes, a more elaborate tectonic correction can be applied and then the data set is to be retested.

4. Numerical evaluation of different tests

The CP, group and correlation tests were compared for a number of computer-modelled collections in the following way. A BP distribution of N vectors was simulated. Then two samples of the same size were drawn at random from two Fischer-distributed populations. The first sample with parameters D_1, I_1, K_1 represented the "prefolding" component. The second one with parameters D_2, I_2, K_2 represented the "postfolding" component and each vector of this population was tilt-corrected using the corresponding BP. Then each "prefolding" direction was contaminated by the corresponding "postfolding" direction. The ratio of intensities of these two "components" varied in a narrow interval during one run but it grew stepwise from run to run. Then all three tests were applied to each "partly remagnetized" collection. Such a procedure was repeated for three different BP distributions, one of which is shown in Fig. 1.

The number of parameters, i.e. BP distributions, declinations and inclinations of components, etc., is so large that it is impossible to analyze all variants. Yet we think that some general conclusions can still be drawn. The capacity of the group and correlation tests to detect small deviations from the null hypothesis, for example, a weak postfolding remagnetization, is comparable and greatly exceeds that of the CP test. During one set of simulations for different stages of remagnetization the K_a/K_b values are 7.2 and 3.6, both being statistically significant, and the mean magnetization vectors are biased from the true prefolding direction by 11° and 17°, respectively. Both the group and correlation tests surely detect

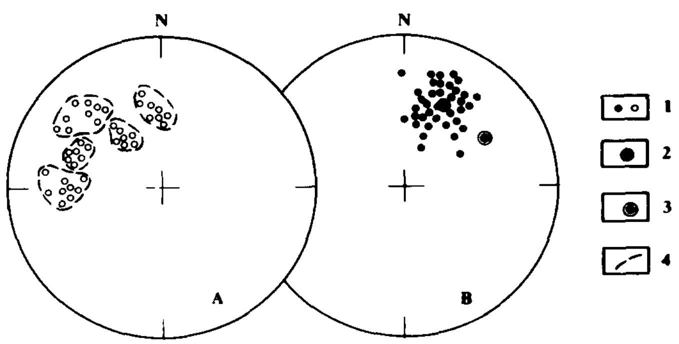

Fig. 1. An example of the simulated result. There are shown one of the BP distributions used (stereonet *A*), and the partially remagnetized paleomagnetic directions, for which the CP test is still positive (stereonet *B*). Legend: (*1*) unit vectors (BP or paleomagnetic); (*2*) mean paleomagnetic direction; (*3*) true mean vector for the prefolding component; (*4*) boundaries of groups. Note the angular distance between (*2*) and (*3*). Here and further on, solid (open) symbols denote downward (upward) pointing directions.

"contamination". Thus, the CP test remains positive when the calculated paleomagnetic means are biased by 12° up to 30°, while for the other two tests marginal bias is about 5–6°, in average.

5. Reappraisal of paleomagnetic results

We applied the group and correlation tests to a number of collections but our results are either published in Russian or are still unpublished. So we decided to re-analyze some data from more accessible journals. Results were chosen if they were based on ten or more independent entries provided both in-situ and tilt-corrected directions were presented for each entry (or bedding attitudes and one set of directions).

The data chosen for analysis are as follows: (1) the high-temperature magnetization isolated in redbeds of the Mississippian Mauch Chunk Formation, Central Appalachians [4]; (2) the characteristic component in the blue-grey limestones of Jurassic age, Jura Mountains [9]; (3) the characteristic magnetization in the Late Permian dykes, Tarim craton [10]; (4) the unicomponent magnetization in the Upper Ordovician volcanics, Nova Scotia [11]; (5) the characteristic magnetiza-

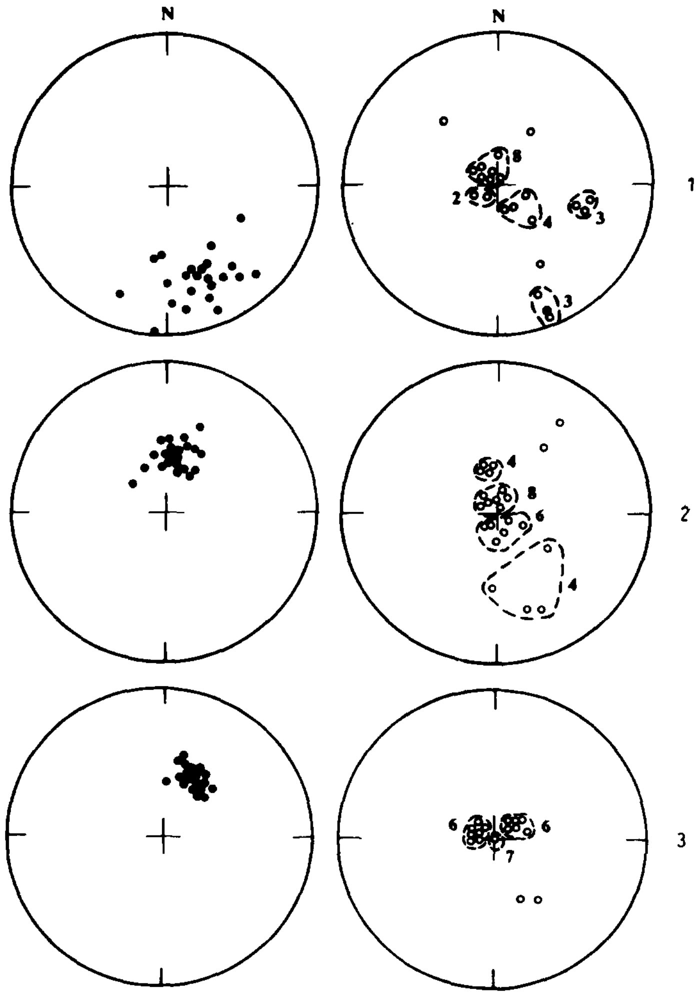

Fig. 2. Tilt corrected paleomagnetic directions (left column) and the corresponding BP distributions with the group boundaries shown as dashed lines (right column) for examples *1*, *2* and *3* (numbers given at the right margin). If both the polarities were present, one of them was inverted through the origin. The unit BP's or paleomagnetic vectors were often identical or very tightly clustered, so the number of points on the stereonets do not match that in Table 1. The numbers of entries in each group are shown in the stereonets.

tion in the Eocene volcano-sedimentary rocks, Central-East Kamchatka [13]; and (6) the unicomponent magnetization in the Eocene–Oligocene carbonates, Southern Apulia, [14]. The corresponding distributions of bedding poles and paleomagnetic directions are shown in Fig. 2. All three tests were applied to each collection and the results of testing are presented in Table 1. Note that some entries were not used in the group test due to significantly deviating BP's.

All three tests yielded the same result for the first two collections. For the third one, the group test for 19 sites out of 21 proved to be insignificant at the 95% confidence level and significant at the 90% confidence level in stratigraphic coordinates. The correlation test for all 21 sites yielded the NN situation, though the calculated value of statistics after tilt correction is next to critical. Thus, the results of the latter two tests are not unambiguous; nevertheless we suspect that some distorting factor could affect paleomagnetic data. As has already been mentioned such a factor is not necessarily a partial postfolding remagnetization, it might as well be the mode of dyke intrusion.

For the Nova Scotia volcanics (4), the CP test was positive, the calculated statistics being much larger than the 95% critical value. Both the group and correlation tests yielded the NN situation thus leading to the conclusion that some basic assump-

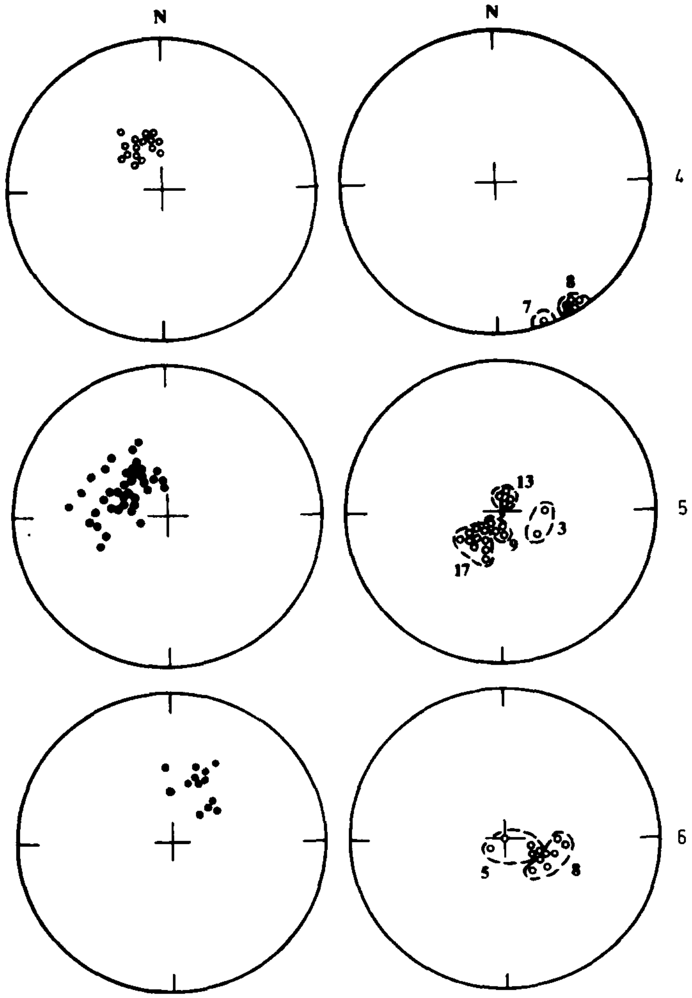

Fig. 3. Tilt corrected paleomagnetic directions (left column) and the corresponding BP distributions (right column) for examples *4*, *5* and *6* (notation is the same as in Fig. 2).

TABLE 1

Results of test application

E	T	$N(n)$	G	DF	BC	AC	CV	OC
1	CP	23		44/44	3.4		1.7	
	G	20(3)	5	8/30	8.2	0.5	2.3	PN
	C	23			0.91	0.25	0.53	PN
2	CP	24		46/46	4.6		1.7	
	G	22(2)	4	6/36	17.1	1.1	2.4	PN
	C	24			0.94	0.39	0.52	PN
3	CP	21		40/40	3.2		1.7	
	G	19(2)	3	4/32	8.7	2.5	2.7(2.1)	PN?
	C	21			0.65	0.57	0.55	NN
4	CP	16		30/30	2.8		1.8	
	G	16(0)	2	2/28	36.7	5.3	3.3	NN
	C	16			0.68	0.67	0.63	NN
5	CP	42		82/82	1.4		1.4	
	G	42(0)	4	6/76	5.9	1.7	2.2	PN
	G	39(3)	3	4/72	5.9	0.9	2.5	PN
	C	42			0.51	0.28	0.38	PN
6	CP	13		24/24	1.7 *		2.0	
	G	13(0)	2	2/22	0.3	2.0	3.4	PP
	C	13			0.45	0.70	0.70	NP?

* $- K_b/K_a$.

E = the number of example as given in the text; T = fold test modifications: CP, as adopted in the text, G, group test, C, correlation test; $N(n)$ = number of independent entries, in brackets, number of entries not used for the group test; G = number of groups; DF = degrees of freedom; BC, AC = the calculated statistics before and after tilt correction, respectively; CV = critical value at the 95(90)% confidence level; OC = result of testing (for G and C only): situations are labelled as in the text.

tion(s) of the fold test had not been satisfied. It is worth mentioning that the mean strikes for two BP groups and the corresponding mean declinations differ by about 12° and 18°, respectively, while the mean inclinations differ by 4° only. Perhaps, steeply dipping rocks there had suffered a certain net rotation [12], but of course, it is just a hypothesis. We would like to point out that the clustering of all BP's ($K = 149$) is much tighter than that for paleomagnetic vectors both before and after tilt correction, $K = 29$ and $K = 79$, respectively. However, it did not hinder testing.

For the Eocene sediments from Kamchatka (5), the CP test is marginal at the sample level. The group and correlation tests yielded the PN situation, thus indicating the prefolding age of magnetization in these rocks. However, one of the groups included three entries only and was rejected. The group test for three larger groups yielded similar results. By the way, the CP test applied at the group-mean level is inconclusive: $K_a/K_b = 1.45$ and the critical value is 4.3.

For the last collection, the clustering of site-means before tilt correction is better than after, but the CP test is inconclusive; the group tests proved to be inconclusive as well (PP situation). However, the correlation test yielded just the critical value. Summing up the obtained results, we think that the postfolding age of magnetization in these rocks is much more probable than the prefolding one. Our conclusion contradicts that suggested by [14], who dismissed the CP test results and proposed the prefolding age of magnetization, relying on the quality of component separation, the presence of both polarities and antiparallelism of the polarity-means.

The incremental CP test has also been carried out for these six collections. For collections 1 and 5 the function of concentration parameter K/degree of unfolding grows steadily. For collection 3 the maximum of K ($K_{max}/K_a = 1.03$) is reached at 90% unfolding. For collection 6 such a maximum ($K_{max}/K_b = 1.03$) is reached at 20% unfolding. These two values differ insignificantly from those for the unfolded and in-situ states. All three tests point to the prefolding age of remanence for collection 2, but the distinct maximum (K_{max}/K_a = 1.18) appears at 80% unfolding. However, this difference is statistically insignificant. Finally, the K value grows steadily from the in-situ to unfolded states for collection 4 in spite of the fact that both the group and correlation tests have found something "suspicious" here. Thus, the incremental CP test did not yield any statistically significant results, and, therefore, is less sensitive than the group and correlation tests. Considering the last two examples together, it seems doubtful that any meaningful conclusions can be drawn from the qualitative interpretation of the K versus incremental unfolding plots as well.

6. Discussion

By the above-presented examples, we tried to illustrate different relationships between three modifications of the fold test (the group and mean tests after McFadden and Jones [3] are treated as one). Naturally, all of them may lead to the same conclusion (examples 1 and 2). The CP test clearly requires much larger dispersion of bedding attitudes than the other modifications (5 and 6). But the most interesting are situations, when the first contradicts the other two (3 and 4) These two cases confirm the prediction that the CP test can be positive when some basic assumptions are violated, e.g., the magnetization under study is the sum of pre- and postfolding components. Unfortunately, we have not found many examples of this kind among publications in the well-known journals, partly because the data presentation was often not complete enough for the group and correlation tests to be used.

It is important to emphasize that there is no "safety line" for the CP test. Rather small values of K_a/K_b can be obtained for purely unicomponent magnetization (example 5), and, vice-versa, larger values may be disproved by more rigorous tests (examples 3 and 4). It was stated [3] that since the CP test "is too stringent it is almost certain that any workers who have claimed the presence of a significant fold test in an investigation will be correct". As shown above, it is not always so and the positive CP test does not imply the reliability of results.

However, the group and correlation tests have a weak point of their own as both require a number of independent entries larger than 10, preferably more. This is another reason why many published data could not be used.

The analysis of test application for real and simulated collections showed that the group and correlation tests lead sometimes to rather different conclusions (see also Table 1). We have never met a case when one test yielded, say, the NP situation, while the other yielded the PN one. It was always the choice between the NN and PP on the one hand, and the NP and PN on the other hand. So, one of two tests was sometimes more sensitive than the other (e.g., examples 3 and 6), and as a rule, it was the correlation test. This is hardly a surprise since the same situation is common for statistics if different criteria based on different null hypotheses are applied to the same data set. One is free to rely on a test he prefers. It may be argued that the same reasoning can be applied to the CP test as well. However, the situation is quite different here, since the latter test is incorrect from both the mathematical [3] and physical points of view.

Nevertheless, we do not think that the CP test should be discarded altogether. It can be used for preliminary analysis. But its main "ecological niche" is testing of small collections where other tests cannot be used, though the results will naturally be of a limited reliability.

We suppose it was shown more or less convincingly that the CP test should be replaced by two more sensitive ones wherever possible. Naturally, it may and sometimes will lead to reappraisal of the results which seemed quite reliable before.

7. Conclusions

It has been shown that the CP test is invalid, thus confirming and strengthening the criticism of McFadden and Jones [3]. We propose two correct modifications of the fold test. The group test based on the division of bedding pole distribution into a number of smaller groups is very similar to the test proposed in [3] but can be used more widely. The correlation test puts no restrictions with respect to the attitudes of the beds sampled since no data grouping is required. Both new tests are more sensitive to deviations from the fold test basic assumptions and may recognize a remagnetization which can pass undetected by the CP test.

Acknowledgements

We wish to express our thanks to S.B. Kul'nitskaya and Dr. G.Z. Gurary for reading and correcting the manuscript. We would like to thank Dr. P.L. McFadden and Dr. E. McClelland for their very helpful and constructive reviews on earlier versions of the paper.

References

1 J.W. Graham, The stability and significance of magnetism in sedimentary rocks, J. Geophys. Res. 54, 131–167, 1949.
2 M.W. McElhinny, Statistical significance of the fold test in palaeomagnetism, Geophys. J. R. Astron. Soc. 8, 338–340, 1964.
3 P.L. McFadden and D.L. Jones, The fold test in palaeomagnetism, Geophys. J. R. Astron. Soc. 67, 53–58, 1981.
4 D.V. Kent and N.D. Opdyke, Multicomponent magnetizations from the Mississippian Mauch Chunk formation of the Central Appalachians and their tectonic implications, J. Geophys. Res. 90, 5371–5383, 1985.
5 M.G. Kendall and A. Stuart, The advanced theory of statistics vol. 2: Inference and Relationship (second edition), 900 pp., Griffin, London, 1968.
6 P.C. Consul, On the exact distributions of likelihood ratio criteria for testing independence of sets of variates under the null hypothesis, Ann. Math. Stat. 38, 1160–1165, 1967.
7 G.A. Barnard, Discussion following a paper by Bartlett, J. R. Stat. Soc. B 25, 294, 1964.
8 G.J. Glasser and R.F. Winder, Critical values of the coefficient of rank correlation for testing the hypothesis of independence, Biometrika 48, 444–448, 1961.
9 R.J.E. Johnson, R. Van der Voo and W. Lowrie, Paleomagnetism and late diagenesis of Jurassic carbonates from the Jura Mountains, Switzerland and France, Geol. Soc. Am. Bull. 95, 478–488, 1984.
10 Yianping Li, M. McWilliams, A. Cox, R. Sharps, Yongan Li, Zhengjia Gao, Zhengkun Zhang and Yongjian Zhai, Late Permian paleomagnetic pole from dykes of the Tarim Craton, Geology 16, 275–278, 1988.
11 R. Van der Voo and R.J.E. Johnson, Paleomagnetism of the Dunn Point formation (Nova Scotia): high paleolatitudes for the Avalon terrane in the Late Ordovician, Geophys. Res. Lett. 12, 337–340, 1985.
12 W.D. MacDonald, Net tectonic rotation, apparent tectonic rotation and the structural tilt correction in paleomagnetic studies, J. Geophys. Res. 85, 3659–3669, 1980.
13 M.L. Bazhenov, V.S. Burtman, O.A. Krezhovskikh and M.N. Shapiro, Paleomagnetism of Paleogene rocks from the Eastern Kamchatka and Komandorsky Islands: implications to tectonics, in prep.
14 M. Tozzi, C. Kissel, R. Funiciello, C. Laj and M. Parotto, A clockwise rotation of Southern Apulia, Geophys. Res. Lett. 15, 681–684, 1988.