Megaplates, Microplates and Paleomagnetism

David B. STONE

Geophysical Institute, University of Alaska, Fairbanks, AK 99701, U.S.A.

(Received April 2, 1984; Revised September 14, 1984)

1. Introduction

The whole topic of paleomagnetic studies of megaplates and microplates has expanded markedly over the last several years, thus, because of the amount of material and constraints of both time and space, no attempt will be made to make this a comprehensive review. It will simply point out some of the highlights of the subject, with enough references to lead the interested reader into the more specific literature.

There are, of course, many different fields of paleomagnetic study related to the general theme of plate tectonics, but two seem to dominate. One is the continued study of the relative motions of the major cratonic blocks back through time, and the other is the unraveling of the tectonic histories of the fragments, or tectonostratigraphic terranes (see, for example, JONES and SILBERLING, 1979) that have accreted to the margins of these cratons. Both are producing exciting new data, some of which may have dramatic implications to other fields of study such as paleoclimatology. This reference to paleoclimatology comes from an increasing awareness that the simple model of a time-averaged dipole field axis plane coincident with the spin axis of the earth, which has fixed inclination with respect to the plane of the ecliptic, may be overly simple.

2. Global Plate Motions

To attempt to summarize all the work being done in this field would be futile, simply in terms of the volume of material available. Though there are many projects studying many facets of the overall problem, they can be broken down into two of three related approaches. One involves the determination, compilation and selection of paleomagnetic pole positions or virtual geomagnetic poles (VGP) for each craton, from which apparent polar wander (APW) paths can be constructed. Another consists of the reassembly of the paleogeographies based on Euler reconstruction poles derived mainly from magnetic anomaly and transform fault studies. A third involves comparisons of the APW paths and the reconstructed paleogeographies along with the predicted and observed paleoclimates. If all the assumptions involved in these three approaches are valid,
then they should produce similar paleogeographic reconstructions. In practice it is found that there are discrepancies between the results from each technique. There is thus a need to increase the accuracy of VGPs and APW paths, to increase the precision of paleomagnetic reconstructions.

Because APW paths are built up from the published work of many researchers, working in many different areas, on rocks of various ages, it is not possible to pick out individual poles as highlights of the general study, but the reader is simply referred to compilations of pole positions. The most comprehensive summary of the available global paleomagnetic pole position data for Carboniferous through Cenozoic time, and the resulting APW paths, is that of Irving and Irving (1982). As one looks farther and farther back in time, both in geological time and in time of publication, paleomagnetic data are generally more sparse and often lack in precision. Nevertheless, there are individual pole positions and APW paths available for most cratonic blocks from the Precambrian to the present. From these APW paths constraints can be placed on possible relative paleogeographies of the blocks. A review of pre-Mesozoic paleomagnetism is given by Van der Voo (1982) and summaries of the paleomagnetic data for each of the major continental areas of the world are given in McElhinny and Valencio (1981), which include papers on: Africa and Madagascar by Brock; Australia and Antarctica by Embleton; India by Klootwijk and Radhakrishnamurty; South America by Vilas; Europe by Briden and Duff; Southern Europe and the Middle East by Wensink; North America by Van der Voo; and the Soviet Union by Kramov and others.

The basic assumption made for paleomagnetic reconstructions is that the time averaged geomagnetic field is dominantly dipolar, thus there can only be one pair of paleomagnetically determined poles for any given section of geologic time. This allows a first step in paleogeographic reconstructions to be based on virtual geomagnetic pole (VGP) data, since the poles from two different areas of the same age must coincide. Superposing VGPs allows the relative paleolatitudes of the areas sampled to be determined, but does not constrain paleolongitude. Paleolongitude can be constrained by geometry, as for instance in the closing of the South Atlantic, by paleontologic and other geologic constraints, and by the superposition of APW paths. This latter technique works well if there was little or no relative motion between the two areas in question over a period of time long enough to generate a significant APW path. These two paths can then be superimposed to give the relative latitudes and longitudes of the two blocks (see, for instance, Irving, 1983; Scotese et al., 1979).

A number of recent studies have been focussed on comparisons of the reconstructed paleogeographies obtained by different techniques. Some of these studies give interesting and perhaps worrying results. If the differences in the mean geographic pole positions for the reconstructed cratonic blocks are compared with the mean paleomagnetic pole positions for an individual craton (e.g., Irving and Irving, 1982) significant deviations can be seen. An analysis of this problem by Briden et al. (1981) shows that the selection of the
paleomagnetic data, and the time averaging used, can have a marked effect on
the discrepancies observed. A good example is the distribution of paleomagnetic
poles for middle Cretaceous time for North America. In this case the circle of
confidence for North American data (Irving and Irving, 1982) does not overlap
the circle of confidence about the mean pole for the reconstructed land masses
(Firstbrook et al., 1979). It has been argued that this may be due to the
geomagnetic field having large non-dipole components at this time. However,
the high precision (small circle of confidence) for the North American Cretaceous
data, combined with the broad geographic distribution of sampling sites, would
argue against non-dipole fields being the cause. Another possibility is that the
error limits associated with conventional models of determining the
paleogeography, such as the closing of the Atlantic based on magnetic anomaly
and transform fault data, are larger than is generally assumed. It is important
that these discrepancies be resolved, because they are large enough to be impor-
tant in terms of defining reference poles. This is fairly critical for the comparison
of VGPs from relatively small structural blocks, and is especially critical to some
of the Arctic and Antarctic paleoclimatic studies being made, where latitude
changes of the same magnitude as the errors can be very important in terms
of the paleo-sunlight regimes.

3. Polar Wander and Paleoclimates

In many paleomagnetic paleogeographic reconstructions it is not only assumed
that the time-averaged field is dipolar, but it is also assumed that the time-averaged
dipole axis and the spin axis of the earth coincide. The obvious implication of
this is that the magnetic paleolatitude and the overall latitudinal paleoclimatic
indicators should coincide. On long time scales this has been demonstrated to
be true (see, for instance, Irving, 1964; Frakes, 1979). Whether or not dif-
fferences in the location of the time-averaged magnetic and spin axes arise on
time scales of the order of a few million years is more difficult to determine.
Jurdy (1983) argues for about 10° of true polar wander since early Tertiary
time, and also argues that the polar wander is driven by changes in the mass
distribution of the earth due to plate movements. Is it possible that polar wander
and/or separation of the paleogeographic and paleomagnetic poles could account
for the anomalous occurrence of warm climate fossils in rocks of Eocene age
in the Canadian Arctic Islands? Certainly on conventional reconstructions they
are at too high a magnetic latitude (78°N) to allow the presence of the fossil
alligators, tortoises and lizards found (Estes and Hutchinson, 1980; McKenna,
1980). A similar problem arises in some rocks of Cretaceous age. Fossil
dinosaur tracks and fossil plants interpreted to be broad leaved evergreens have
been recovered from the coal bearing mid-Cretaceous aged rocks of Arctic Alaska
(Witte, 1982). If Arctic Alaska is considered to be fixed with respect to North
America, then these rocks were laid down less than 10° from the North American
paleomagnetic pole. If the plants are similar to present day broad-leaved evergreens,
then simple energy considerations prohibit them from surviving several months of darkness each year. Paleomagnetic data from Arctic Alaska indicate that the rocks were deposited further south than their equivalent North American positions would indicate, but the paleomagnetic latitude is still too high for genuine broad leaved evergreens. Very similar conclusions have been drawn from work on Cretaceous rocks from high paleolatitudes in the southern hemisphere (DONN, 1982; DOUGLAS and WILLIAMS, 1982; JEFFERSON, 1982). Since anomalous paleoclimatic latitudes are seen at both polar regions, it seems likely that they must be the result of a global phenomenon. True polar wander and non-coincidence of the geographic and magnetic poles are possibilities, as is a change in the obliquity of the spin axis of the earth. These are fascinating prospects, and deserving of further research.

4. Tectonostratigraphic Terranes

During the course of the last decade the concept that some of the margins of the major cratons consist of fragments rafted in from elsewhere has gained in credibility. It is now generally accepted that much of the Pacific rim is made up of these tectonostratigraphic terranes, defined as fault bounded geologic entities of regional extent, each characterized by a geologic history that is different from the history of contiguous terranes (JONES and SILBERLING, 1979; JONES et al., 1983). It is also recognized that many of these terranes have moved great distances, and much effort is being put into unravelling the dominant northward motion of the terranes of western North America. A good summary of this work can be found in a review by MCWILLIAMS (1983). For other Pacific terranes, the proceedings of the Oji International Seminar, edited by HASHIMOTO and UYEDA (1983) and the proceedings of the Circum-Pacific Terrane Conference (Oji II) edited by HOWELL et al. (1984a) are good basic references. Allochthonous terranes are not, of course, restricted to the Pacific region, and have been recognized elsewhere, particularly along the southern margin of Europe (see, for instance, MARTON and MARTON, 1984; BURCHFIEL, 1980) and in the Middle East (SENGOR and YILMAZ, 1981). As might be expected, there is a tendency for more terranes to be identified where the concept has been acceptable longest, and it is true that the Circum-Pacific Terrane map (HOWELL et al., 1983, 1984b) shows more and smaller terranes for western North America and Alaska than elsewhere, but it also seems that the dominant motion of the Pacific during mesozoic and much of Cenozoic time has been directed northward and eastward (ENGERBRETSON, 1982), thus sweeping the debris on the ocean floor into the northeast corner of the Pacific (MCWILLIAMS, 1983). In the same vein, some of the terranes of China appear to be much larger than those of the eastern Pacific margin, but also seem to be allochthonous. Since these terranes are of "meso" scale, they may produce data with enough resolution to be located in terms of both longitude and latitude (LIN et al., 1984; McELHINNY, 1984).

Most of the paleomagnetic effort of the last few years has gone into tracking
the terranes that have already docked, and attempting to pin down their times of arrival. In a number of these cases the paleomagnetic work has focussed on paleolatitude versus time rather than matching VGPs (see, for instance, Stone et al., 1982). The reasons for concentrating on paleolatitude lie in the observation that many terranes have been rotated, perhaps during the docking process, or perhaps while being transported along transform fault systems (Beck, 1983). In this light, it is of interest to note that several recent studies of active island arc systems have shown parts of them to be currently rotating with respect to other parts (Keating and Helsley, 1984; Fuller, 1984; Fuller et al., 1983).

The next several years will hopefully see efforts continuing to track the various terranes back through time using paleomagnetic techniques, and also to exploring future terranes which are now oceanic plateaus, and to determining what happens to them during the collision-accretion process. In conclusion, the application of geomagnetism to the study of megaplates and microplates is proving to be very fruitful. New data and ideas are continually forcing us to change our models and re-think old ideas making it a very vigorous and exciting area of research.

I would like to thank the many authors who sent me reprints for this review, and I would like to especially thank David Rawley of the University of Chicago for supplying a useful bibliography at very short notice.

REFERENCES


Burchfiel, B. C., East European alpine system and the Carpathian orocline as an example of collision tectonics, Tectonophysics, 63, 31-61, 1980.


