DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

Rept.Bk.No. 82/31
CLAYS OF THE PALYGORSKITE GROUP-
DEPOSITIONAL ENVIRONMENT, AGE AND
DISTRIBUTION. TO BE PRESENTED
FOR EXTERNAL PUBLICATION.

GEOLOGICAL SURVEY

By

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MAY 1982

DME 169/78

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DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

Rept. Bk. No. 82/31
D.M.E. No. 169/78
Disk No. 10

CLAYS OF THE PALYGORSKITE GROUP - DEPOSITIONAL ENVIRONMENT, AGE AND DISTRIBUTION

(Presented at the 7th International Clay Mineral Conference, Italy, 1981).

ABSTRACT

Major deposits of palygorskite group minerals were initially formed in three environments of different character - (1) as chemical sediments, or early diagenetic transformations of certain smectite group clays, in epicontinental and inland seas and lakes; (2) by diagenesis of materials such as volcanic dust in the open oceans; (3) in calcareous soils by direct crystallization. Subsequently marine deposits were also formed by slumping and turbidity current transport of nearshore materials, and from windblown dust.

Palygorskites which formed in soils, lakes or shallow seas were mostly associated with a Mediterranean to semi-arid climate, not very arid. This is reflected in their distribution in high latitudes. These climatic conditions were present during the Late Devonian and Carboniferous and Late Permian to Triassic in the northern hemisphere, the Early and Late Eocene, Late Oligocene and late Neogene, and possibly Late Cretaceous in both hemispheres. The Late Cretaceous deposits are largely of diagenetic marine origin.

These conclusions were reached by examining Plio-Pleistocene distributions, lithofacies associates and occurrence distributions, plotted on palaeocontinental maps. When the original distribution bias in DSDP data (coincidentally in similar latitudes to continental data) was eliminated, there was little evidence for latitudinal concentration in the oceans. Sampling bias on land is difficult to assess, but there appears to be a concentration between 30° and 40° N and S. There is a distinct concentration between 20°-40°N and 10°-35°S in the late Neogene, for both land and sea deposits.

INTRODUCTION

The palygorskites or fibrous magnesium clays (palygorskite or attapulgite, sepiolite, pilolite, loughlinite, franclandite, etc.) were once regarded as rare minerals, restricted to hydrothermal veins and ore-body alteration zones. They are now known to be widespread in marine and non-marine sediments, and especially in the oceans. The palygorskites are strongly absorbent, very light, and porous, which makes them much sought after as Fuller's Earth, Meerschaum and similar materials, for industrial absorbants, catalysts and ceramics. Structure and composition are summarized in Zelazny & Calhoun (1977) who give adequate references of detailed structural studies.

The geology of these clays has suggested they could be good palaeoclimatic indicators (eg. Weaver & Beck, (1977); Millot, 1964; Wiersma, 1970; Singer, 1979, 1980, 1981; Chamley, 1979; Chamley et al, 1977; Lomova, 1979; among others). Hence an earlier contribution of Callen (1977) has been extended to include the large amount of Deep Sea Drilling Project (DSDP) material, and many new investigations of land deposits.

METHODS

The lithological association of each deposit was recorded, and the location plotted on palaeocontinental maps. For the older deposits, the Eckert projections of Kanasewich et al (1978) are used (Fig. 1), as it is easier to plot on these, and they show the distribution of land and shelf sea. More recent palaeocontinental maps, but using sedimentary palaeoclimatic indicators in addition to independent palaeomagnetic data, have been prepared by Ziegler et al (1979). The latter place Devonian European Russia just north of the equator and Carboniferous Russia further south than the maps of Kanasewitch et al (1978), both being important areas of palygorskite deposition.

For oceanic occurrences the polar projection reconstructions of Firstbrook et al (1979) are used (Figs. 2-6). They have the advantage of being at 10 Ma intervals, with DSDP holes plotted. They are similar to the Smith & Briden (1980) maps with respect to continental positions. The Smith & Briden mercator projections are used to plot continental palygorskites and summarize oceanic occurrences (Figs. 7-13), because they give a better view of latitudinal distribution, and the age of land-based deposits is not so well-defined that narrower time intervals can be considered.

The comments of Scotese (1980) concerning alternative continental configurations must be considered with respect to the reconstructions of Smith & Briden (1980) and Firstbrook et al (1979). The position of New Zealand on the Mercator projections has been adjusted approximately, in line with the suggestions of Scotese (1980). Smith (1981) has recently updated some of his reconstructions. The work of Veevers et al (1980) suggests a somewhat different history for the southern Indian Ocean and the position of Madagascar. It is suggested that Madagascar was attached to Australia, reaching a more northerly location at an early stage. Basically, these adjustments make no major changes in the distribution patterns (Figs. 2-6).

Data for DSDP cruises and onshore studies has been obtained from the project volumes (see references), though there are some important additional analyses published elsewhere (Table 1 and references). The data used are essentially that of oriented <2μ clay analyses; other unoriented <2μ analyses are recorded and plotted but not used in the percentage calculations. A few papers published outside the DSDP series, but using the project cores, do not state the analytical method, but it is assumed these are oriented <2μ samples. Analyses in some 1979-81 DSDP reports and related external studies are in the form of graphs without tabulation of individual sample results, or indication of the depth of each sample on the graph. This makes it difficult to estimate percentages, and only one has been included. Published material on the South Atlantic Ocean is in this form, and was omitted from the percentage abundance studies.

Data from DSDP studies were sufficient to record the approximate abundance of palygorskite plus sepiolite (Figs. 2-6) in each hole for each 10 My time slice. The scheme used to show this on the polar plots is essentially qualitative, and is explained in the figure caption. All the data used in the % abundance and average calculations (Fig. 14 and Table 2) are tabulated (Table 3 includes additional data obtained since these calculations were made).

PREVIOUS WORK

Most significant previous work is summarized and adequately discussed in the reviews by Singer (1979, 1980), Weaver & Beck (1977) and Lomova (1979).

Singer (1980) concluded that palygorskites are typical of arid and semi-arid soils, and one of the few useful palaeoclimatic indicators among the clay minerals. Singer (1979) also specified the conditions of formation of palygorskite and sepiolite, being alkaline pH, high Si and Mg, and low Al activity. He demonstrated that most data suggested neoformation rather than diagenesis. Solid state transformation of smectite to palygorskite as proposed by Weaver & Beck (1977) is not favored as a major mechanism. Singer proposed an essentially detrital origin for deep marine palygorskite, with some of hydrothermal origin, and most deposits being neoformed in the perimarine environment.

Weaver & Beck (1977) include a summary of perimarine environments in their paper on the Georgia-Florida palygorskite mines of U.S.A., concluding they are dominant environments of neoformation.

Lomova (1979) summarizes* some of the DSDP and other coring projects in the oceans as well as much data from the continents, and divides deposits into the following types: terrigenous clastic, chemogenic evaporitic, pyroclastic, volcanic hydrothermal, pedogenic, hydrothermal veins, and contact metamorphic or alteration zones around orebodies. This author includes playa-lake and shallow lacustrine types in the pedogenic group, and favours widespread neoformation in oceans from

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*comments based on partial translation from Russian text by W.V. Preiss, South Australian Department of Mines and Energy.

volcanic detritus and hydrothermal activity. An arid environment for continental deposits in Russia is emphasized and most of the major Russian deposits are discussed in some detail. Lomova believes palygorskites can form in humid areas, provided there is an abundance of basic volcaniclastics Overall there is a greater emphasis on hydrothermal and volcanic influence in genesis than is given most "western" literature. The brief review by Gradusov (1976), however, places more emphasis on a detrital origin in the oceans, with neoformation in soils and peri-marine environments.

Couture (1977,a,b) studied oceanic deposits, and suggested diagenesis from smectite and volcanic detritus, though the evidence for this is not convincing (Beck & Weaver, 1978). Decarreau et al (1975), on the other hand, provide some evidence supporting diagenesis from degraded ferriferous beidellite in restricted marginal marine conditions.

THE PALYGORSKITE-SEPIOLITE FACIES

LATE PLIOCENE - HOLOCENE DISTRIBUTION.

Agricultural investigations have provided large numbers of clay analyses, resulting in the discovery of high percentages of palygorskites in calcareous soils and calcretes over a wide area (Fig. 13). Many of these contain palygorskite as cutanic films of oriented fibres on skeleton grains or joint (ped) surfaces, indicating neoformation in the soil (Perelman, 1950; van den Heuval, 1966; Singer & Norrish, 1974; Eswaran & Barzanji, 1974; Watts, 1981; Hutton & Dixon, 1981). Many others are said to be inherited from underlying material, or added by aeolian transport, though this is likely to have been overemphasized in early studies through lack of knowledge of the submicroscopic distribution within the soil fabric. The derived soils at least demonstrate palygorskites are stable in these environments, though a few show evidence of present day degradation (e.g. Nahon & Ruellan, 1975).

The value of the late Neogene palygorskite occurrences in the present study is to identify the climatic zone in which palygorskites are preserved, and demonstrate that many such occurrences were neoformed within certain latitudinal limits. They also show that these soils are a major source of fibrous clay minerals for the oceans, through erosion. The plots show that all of the soils lie within the present day dry Mediterranean to arid climatic belts. A non-random distribution of original clay sample points can be reasonably assumed, as routine clay analyses of soils are undertaken by most countries, except perhaps in some central African nations, South and Central America and southeast Asia. Frozen ground at latitudes higher than 80^0 would also be a factor preventing sampling.

Many of the soils and calcretes containing palygorskites are probably quite old. The calcretes of the Murray Basin (Hutton & Dixon, 1981) in Australia, for example are most likely several hundred thousand years old (Cook et al, 1976; and unpublished work of the author). Thus, although many of these soils are now at the Earth's surface and even used in agriculture, they are likely to be relic, and may not have formed under the climatic conditions of the present. Calcrete deposits were probably common in the past; Watts (1976) has demonstrated the presence of palygorskite in Triassic calcretes. Pre-Neogene calcrete and soil occurrences have not often been recorded because of the small volume of such materials preserved in the sedimentary record compared with sediments, and also because of the lack of clay mineral studies on such materials and difficulty in recognition of ancient soils. Only recently has it been realized that they can be a major palygorskite-forming environment.

Large amounts of palygorskites are present in Plio-Pleistocene sediments around the Atlantic Ocean in the same latitudes as the soils and playas. In the northern Indian ocean, Goldberg & Griffin (1970, p. 532), from comprehensive coring of bottom sediments, suggested palygorskite was an aeolian imput from N. Africa and South Arabia. If this evidence is coupled with that of windblown dust, and intercalated red desert sands and palygorskite clay in the Atlantic adjacent to northern Africa (Chamley et al, 1977), and evidence from the N. Pacific Ocean (Leinen & Heath, 1981) it is clear many of the late Neogene oceanic deposits are closely related to latitudes in which dry windy conditions and palygorskite-bearing soils prevail. Chamley et al (1977) suggested the palygorskite beds were deposited under more humid conditions than the red sands, which are taken to be indicators of extreme aridity.

It is known from dust analyses that palygorskites can be carried in significant quantities over long distances (e.g. Bain & Tait, 1977), hence the erosion of palygorskitic soils in the arid zones and redeposition in the oceans is a phenomenum of present-day environments.

Soil-derived deposits, whether from windblown dust or stream erosion, are transported into deeper waters by turbidity currents and slumps (Chamley, 1979; Melieres, 1978; Chamley et al, 1979). The distribution of palygorskites with age should therefore give some indication of the drier climatic regions in the geological record, for both non-marine and marine environments. In marine conditions a much more crude distribution would be expected because of the effects of ocean currents.

A number of playa deposits are of comparatively recent origin, or are still forming (McLean et al, 1972; Stoessel & Hay, 1978; Kautz & Porada, 1976), and these also fall within the same latitudinal belt. Occurrences neoformed in lakes and playas are much commoner in many Cainozoic and older sediments (Callen, 1977; Verzelin et al, 1973).

LITHOFACIES OF OLDER PALYGORSKITES

Land-based deposits.

The lithofacies associates of past palygorskites should reveal whether conditions outlined above apply throughout the geologic record. The peri-marine environment has been an important environment of genesis in the past (Table 4), which is poorly represented in modern times.

The study of Weaver & Beck (1977) of marginal marine facies in Florida and Georgia, U.S.A. is the best known example and includes a world-wide summary of peri-marine deposits. Readers are referred to their report for further details.

All the deposits (marine and nonmarine) on present landmasses are dominated by dolomites, limestones, fine or sometimes coarse clastics, and are often associated with evaporites, or phosphates, and chert. Palygorskites apparently precipitate or form within the sediment in conditions less saline than those conducive to gypsum precipitation. The magnesium-clays are often found peripheral to evaporite deposits, or above or below such deposits (Chamley et al, 1978; Hsu et al, 1973; Cita, 1979; Verzelin et al, 1973; Gradusov, 1976). Other deposits are associated with phosphates, particularly in African epeiric seas of Late Cretaceous to Eocene age, and in the Gulf of Mexico region (Millot, 1964; Isphording, 1972; Weaver & Beck, 1977). These phosphates are of the shallow warm shelf type, where nutrients for the phosphatic organisms are replenished by wind-induced upwellings near the edge of the continental shelf (Birch, 1980; Giresse, 1980; Boujo et al, 1980).

The majority of non-marine palygorskites are intimately related to dolomite (e.g. Sittler, 1964; Suguio, 1975; Callen, 1977), and are often associated with anomalous barium and strontium values. These dolomites are frequently of the type formed in the zone of mixing between Mg-charged fresh waters and saline lakes or playas (Muir et al, 1980; Callen, 1977), perhaps in a Coorong-type environment. No comprehensive clay mineral studies have been made on the associated sediments of the dolomite beds in the Coorong and so it is not known whether the suggestion of Wiersma (1970) that this is palygorskite-bearing environment is correct. However, it is known that palygorskites do not occur where carbonates are presently being precipitated in the waters of that environment. Few studies of modern sabkha environments have located palygorskites, and in these it is believed to have been transported from elsewhere (Seibold et al, 1973).

Oceanic Deposits

In the present open marine situation palygorskites are found in three typical sedimentary associations in waters of varying depth:

1. With disturbed sediments or turbidites.
2. Perimarine facies which have subsided into deep water (Enos & Freeman, 1979), or formed in the early stages of opening of oceans.

3. With chalk or the "calcareous ooze" facies of Kidd & Davies (1978).

The first association is typical of Atlantic Ocean palygorskites. There is no doubt that slumps and turbidites play a major role in redistributing shallow continental shelf material into deeper waters. Palygorskites in such deposits are discussed in the references given earlier.

The second association needs no further comment except that conditions in the early oceans would probably have been similar to the Mediterranean Sea during and just after the Messinian (Chamley et al, 1978; Hsu et al 1973; Rouchy, 1980).

The third association is clearly shown by an example from the Indian Ocean. Plotting palygorskite zones (Fig. 15) on the facies-time-depth curves of Kidd & Davies (1978) demonstrates the intervals of palygorskite sedimentation coincide with calcareous ooze (sometimes "other clays"), deposited in water of variable depth, including very deep waters. Thus, as for land deposits, there is a general association with the carbonate facies. A similar association is reported for the Shatsky rise of the northwestern Pacific Ocean (Zemmels, 1973; Zemmels & Cook, 1973, 1976; Matti et al, 1973; Gorbunova, 1972).

SUMMARY

The Plio-Holocene deposits demonstrably formed in alkaline-brackish waters in a Mediterranean/arid climate, hence older deposits may have also formed under similar circumstances. The arid climatic association is confirmed from the lithofacies of older palygorskites, hence palaeolatitudinal plots should reveal past distribution of 'arid' climatic belts. The greater extent of perimarine deposits prior to the Neogene indicates that palaeocontinental plots of results from the Deep Sea Drilling Project would assist in defining latitudinal distributions. Windblown dust is essentially derived from arid areas, and many deep ocean deposits come from slumping of perimarine occurrences (including dust deposits) hence even the deep ocean plots may show a latitudinal distribution related to 'aridity'.

LATITUDINAL DISTRIBUTION

SAMPLING BIAS

The significance of the distributions can only be assessed after determining whether the original samples were randomly distributed or not. Both land and DSDP occurrences are affected by difficulty of access in the polar regions due to ice, hence these zones are not considered in the study. A second factor is introduced by the change in area of each latitudinal slice, which decreases by about 4x proceeding from equator to pole. Thus a specific number of samples in the higher latitudes are of more significance with respect to concentration than the same number near the equator.

Deposits on land must be assessed separately from DSDP results for the following reasons:

1. Deposits on present landmasses are plotted in terms of basins, to avoid the bias that would be caused by repeated studies of the same sort in one series of related beds. Any area once studied tends to attract further studies and refinements. DSDP holes on the other hand, are single spot occurrences.

2. The original sample distribution is known for DSDP holes, whereas it is not for land-based deposits. For the latter, one must assume an even coverage of rocks of all ages in all countries, obviously a rather idealistic assumption (see (3)).
3. The distribution of land deposits depends on the individual efforts of certain groups, often working within certain territorial limits, and also influenced by accessibility. DSDP results are an international effort, with comparatively unlimited access.

Accepting that the two sets of data must be considered separately, another problem arises. The distribution of land and sea varies with latitude and time. For example there is much more land in the northern mid-latitudes, hence one would expect more results from this area. A few occurrences in a belt with little land are more significant than the same number in a belt with much land, and conversely for the oceans.

Phenomena such as the northward drift of India and Australia significantly change the distribution of land and sea with time.

Taking land deposits first, an estimate of the relative concentration per latitude was made by dividing the number of occurrences in terms of basins by the area of each 10^0 latitudinal belt. This was adjusted crudely for land area by dividing by the fraction of land in each belt, estimated by eye from mercator projections of each time interval (using the maps of Smith & Briden, 1980). Different factors were thereby derived for 0^0-30^0 and 30^0-60^0 in the north and south hemispheres. A more accurate result could be obtained by taking 10^0 belts, but this is hardly justified considering the number of data points and the other uncertainties. A different and perhaps more relevant approach could be made by incorporating data on epicontinental seas, which could change the factors significantly, but this has not been accomplished at this stage.

Adding the resulting figures for each time interval, and plotting by latitude, gives Fig. 16A. The result is obviously non random, demonstrating a concentration in latitudes 10^0-40^0N, especially 30^0-40^0N, and 30^0-40^0S. The Pliocene-Holocene results are not included because of the impossibility of recording the extensive soil occurrences as single basins. The significance of these younger deposits has already been discussed.

Taking the oceanic occurrences, essentially from DSDP results, the plot on Fig. 16B is obtained. The palygorskite occurrences have been recorded against latitude on a histogram (Fig. 16C), for DSDP holes, by totalling all holes containing palygorskites for each 10 My time slice in each 10^0 latitudinal belt. The distribution is strongly skewed toward the northern hemisphere, with zones of most abundance between 10^0-30^0N and 30^0-40^0S. However, Fig. 16B demonstrates that the original distribution is biased in the same way towards certain latitudes, these being essentially the same ones as for land-deposits (Figs. 7-13) by coincidence. Thus there is no proof that oceanic occurrences are significantly concentrated in certain latitudes, except possibly in 20-30^0N and 30-40^0S. This latter concentration may be the result of erosion of the 'land' deposits in these same latitudes.

'ANCIENT' DEPOSITS

The scarcity of results from pre-Mesozoic times may be partly the result of lack of ocean floor of this age. In addition, very few deep ocean deposits have been recognized in present continental areas, which is surprising considering the great extent of the palaeo-Pacific Ocean. Those deep sea sediments that have been recognized have no detailed clay mineralogy. Lack of older deposits is also caused by the dissolution of palygorskite above 100^0C (Kulbicki, 1959; Millot, 1964; Couture, 1977b). Thus any metamorphic terrain, unless of very low grade, will not contain primary palygorskite or sepiolite.

All but one of the 'Ancient' occurrences (Fig. 1) are concentrated within 30^0 of the equator in shallow land-locked seas of central and western Russia. However, the Devonian Pripyat basin may be non-marine, and the Siberian occurrence may be of hydrothermal origin (Divina et al, 1978). The most extensive deposits are Devonian to Permian in age, associated with platform dolomites and other carbonates.

It is likely that other such deposits will be discovered, because there are few adequate studies of the clay mineralogy of such sequences. These could radically alter the pattern of this distribution.

MESOZOIC AND CAINOZOIC DEPOSITS

Palygorskites are widely, though diffusely spread through the arid Triassic rocks of north Africa and Europe, (Fig. 1, top left), reaching concentrations of 50% or more in the phosphatic rocks of Morocco (Krumm, 1969). As for the Carboniferous of Russia, they were restricted to a series of shallow landlocked seas and saline lakes, close to the equator.

There are few records from the Jurassic to Early Cretaceous (Figs 2,3), though Early Jurassic and Aptian-Albian deposits are prominent in the newly opened North Atlantic Ocean (Fig. 7), northwest of Austral-Antartica, and in the proto-Pacific Ocean. Environments in the Atlantic Ocean probably resembled those of the Triassic seas and the Late Miocene of the Mediterranean Sea (Hsu et al 1973). Chamley (1979) has given a detailed history of the development of the Atlantic Ocean deposits through to modern times, emphasizing the role of the perimarine environment, and describing how this retreated from the central ocean area as rifting developed. Neoformation later became concentrated in shallow seas like the Gulf of Mexico and Straits of Gibraltar (Figs. 5, 6, 9, 10), from which transport into the deep oceans was effected by turbidity currents. Such transport methods prevented severe breakage of the long palygorskite and sepiolite fibres. Previously the presence of such fibres had been accepted as evidence of in situ genesis (e.g. Gorbunova, 1973). Large amounts of palygorskite dust were probably also finding their way into the seas at this time, though these would be expected to have much shorter fibres. In the southern Indian ocean, the distributions (Figs. 8-12) suggest wind transport from Africa, and there are some deposits in the adjacent east African landmass which could have provided this material.

In the central South Atlantic, a belt of highly concentrated palygorskites may be related to sediments of similar age on the adjacent continents (Figs. 8-10), being the Bauru Basin (Suguio, 1975) of Brazil, and the Point-Noire Basin (Giresse, 1980) of the Congo. In the Late Cretaceous , India had drifted into this same belt and palygorskites were deposited in alkaline lakes in depressions in the Deccan traps (Aneesuddin, 1971).

The Campanian was one of the main periods of palygorskite deposition in the oceans, reaching up to 80% or more of the clay fraction (Table 2; Fig. 14) in extensive thick clay-rich beds

(Figs. 4, 8). This was the time of major deposition, especially in the region equivalent to the Shatsky Rise in the proto-Pacific Ocean. At the same time, major nonmarine and marginal marine deposits were forming in the Fergana Trough of Khurgizstan, a region which has a long history of palygorskite deposition from Late Jurassic to Pliocene. Northern hemisphere occurrences of these times extend to 40^0N of the equator, and are distributed mainly beween 25^0 and 40^0. This was also the beginning of extensive shallow marine epicontinental sea deposition in North Africa, where phosphates were prominent sedimentary associates of palygorskite and sepiolite. These epicontinental seas were comparable to those of Australia in the Late Jurassic to Early Cretaceous, and yet Australia has no Mesozoic palygorskites. This is attributed to its high-latitude position at this time.

In the Maastrichtian to Early Eocene (Fig. 9), zonal distribution is not as clear, spreading further north and south to latitudes 45^0N and 55^0S. The lacustrine deposits of Brazil and southern France were prominent, as were the Indian Ocean and northwest Australo-Antarctica deposits.

The Middle Eocene to Early Oligocene map (Fig. 10) shows an apparent latitudinal distribution. Non marine lacustrine deposits became more abundant, in similar latitudinal belts. The main sites of deposition were around the Tethyan margin and in the Gulf of Mexico area.

During the Middle Miocene, the apparent latitudinal distribution resembled that of the Late Pliocene to present day. There were extensive lacustrine beds in Australia, Europe and Asia (Fig. 11).

The interplay between marine and non-marine environments is well displayed by the deposits of the Mediterranean Sea. Here, palygorskite clays are interbedded with some of the Messinian evaporite-dolomite sequences (Chamley et al, 1978). These were laid down in brackish lake waters of the dry oceanic depression, which contained a variety of shallow saline environments at this time (Rouchy, 1980). After connection with the Atlantic Ocean was re-established in the Pliocene, there was a sudden increase in palygorskite in pelagic oozes and turbidites of the central basins. These younger clays are probably detrital (Chamley et al, 1978), derived either from eroded Messinian, and possibly older deposits of the adjacent landmasses, or neoformed nearshore and carried into deep water during the Pliocene. The former is most likely as marginal Mediterranean sedimentation did not include suitable environments for neoformation in Late Pliocene - Pleistocene times, except in soils along the African and Israeli - Lebanon Coasts.

SUMMARY

A latitudinal distribution is recognizeable in nearly all the Mercator projection plots (Figs. 7-13). In the oceans, this is largely the result of initial bias in sample distribution. The Late Pliocene to present day latitudinal pattern persists back in time at least to the Late Oligocene, and is also visible in the Late Cretaceous. Also, prior to the Late Oligocene, there is a tendency for a greater spread towards the equator in the deposits on present day landmassesa. The incomplete southern hemisphere belt of southern latitudes is probably caused by lack of records from South America and South Africa.

There appears to be a real concentration of palygorskites on 'land', between 30-40^{0} in both hemispheres. The fact that many of these are actually perimarine occurrences suggests a similar distribution ought to be visible in the oceans. This is difficult to determine because most DSDP drilling was done, coincidentally, in these same latitudes. Nevertheless the oceanic DSDP distribution suggests an even scatter in all latitudes, giving no support to the hypothesis that many oceanic deposits were derived by erosion from 'land' deposits.

Non-marine deposits are most evident from the Eocene to Pliocene.

TIME OF PALYGORSKITE ABUNDANCE

The age distribution in the oceans is demonstrated by Fig. 14, a histogram of total and average percentage of palygorskites. Table 5 summarizes the times of greatest abundance of deposits on the continents and oceans as determined from Fig. 14 and Table 4. The DSDP results show that the peaks of simple aggregate percentage for all the holes for each time-stratigraphic Age unit coincides with the average percentage. Only oriented <2μ samples are used, and some data were not included (see Methods section). Some data service largely from many analyses in one or two holes; the caption to the graph shows which peaks come into this category.

In the Late Miocene-Holocene, total abundance is high, but average percentage low, and perusal of the original data confirms a large number of samples of low percentage. This is the result of the large number of intersections, the Quaternary sediments being the most widespread, together with the large number of closely spaced samples from these intersections. The lack of late Neogene peri-marine environments may be the reason for the low average percentage of palygorskites in these occurrences. The older sediments have fewer intersections, because the amount of ocean floor diminishes to zero in the Triassic.

Examination of the data of Robert (1981) and Chamley & Robert (1979) for the South Atlantic, which is not included in the calculations, coupled with data from holes with bulk analyses or non-orientated <2μ samples (Table 3), shows the same distribution as the histogram. It also confirms the existence of the Albian peak.

Table 5

MAJOR INTERVALS OF ABUNDANCE

DSDP	'LAND'
	Cambrian
	Devonian - Carboniferous
	Permian - Triassic
Late Cretaceous, especially Albian and Campanian	
	Late Cretaceous to Eocene (especially Eocene).
Eocene, especially Early and Late	
Late Oligocene to Middle Miocene	Late Oligocene to Middle Miocene, especially Middle Miocene
Pliocene to Pleistocene	Pliocene to Pleistocene

Some of the marine deposits, such as those of the Mediterranean Late Miocene, and early oceans, are best regarded as lacustrine whereas many of the deposits on present landmasses are marginal marine or shelf environments. The results show that from the Late Cretaceous onwards the main intervals of deposition coincide for marine and non-marine deposits, whether located in present day oceans or on landmasses. The palygorskite Late Cretaceous - Paleocene "event" of Callen (1978; see also Singer, 1980) has been resolved into several events, one of which (Campanian) is essentially oceanic, and the importance of three earlier intervals of deposition is recognized.

VEIN DEPOSITS

Vein occurrences are plotted in Fig. 17. Most are associated with basalts, serpentinites or other related basic rocks, and are generally regarded as hydrothermal in origin. The age of most is difficult to establish, and little information is given about overlying rocks. The studies of Watts (1980), Haranczyk & Prochazka (1974) and Barnes et al (1978) suggest that some could be the result of weathering or pedogenesis in a high-Mg^{2+} environment.

Occurrences in caves are also informative. Such deposits, for example those described by Lowry (1964) and Urbani (1975) are joint infillings in limestone, with palygorskite coatings on calcite. The former is in Early to Middle Oligocene shelf limestone of northern New Zealand and is thought to have been deposited under phreatic conditions. The deposit described by Urbani is in late Jurassic dolomite of Venezuela and was derived by weathering of the carbonate. Both plot within the same latitudinal position as sedimentary deposits of their age. It is necessary to investigate whether or not the presence of the veins indicates the presence of sedimentary palygorskite in the host rocks. It is suggested that other vein deposits could also be the result of reconstitution of palygorskites from surrounding rocks, and this also needs to be tested by suitable analyses.

A number of occurrences are of undoubtedly hydrothermal origin, with suitably zoned crystallization sequences, in cracks related to igneous bodies or hydrothemal veins.

DISCUSSION

The latitudinal distribution of palygorskites within the present continental areas (viz. between 20-40^{0}N and S) is unlikely to be the result of biased sampling, though the nature of that sampling precludes rigorous statistical testing. In the northern hemisphere extensive studies of clays from rocks of all ages have been made by the developed nations existing in these regions. The extent of land at latitudes greater than 40^{0}N is great, and yet very few palygorskite discoveries (apart from vein deposits) have been made in rocks younger than Triassic. Thus the 'land' deposits (as against DSDP deposits) are latitudinally controlled, and are thought to reflect past climatic 'aridity' though it is uncertain what type of aridity is involved.

The existence of a climatic belt conducive to palygorskite formation is indicated by events in Australia and India. Figs 9-11 show that as Australia drifts northwards palygorskites are deposited, firstly in the north during the Oligocene and then in southern Australian in the Miocene. Similarly deposition does not begin in India until the Late Cretaceous to Early Eocene, when it had drifted into latitude 20^{o}S (see Powell et al., 1981, for details of the northward drift of Australia and India).

The conclusion is that the climate of the Late Cretaceous was arid, which corresponds with the observations of Frakes (1979). That the Carboniferous and Eocene were also 'arid' is, however, in some conflict with presently accepted views. 'Aridity' may have been a greater factor in certain latitudes at these times than has generally been accepted, particularly for the southern hemisphere.

The results of the Deep Sea Drilling Project suggest palygorskites are probably fairly uniformly distributed in the oceans, and do not reflect the latitudinal constraints apparent in the Neogene. The distribution of palygorskite-bearing DSDP holes is virtually the same as the overall distribution of all holes drilled. This applies for all time intervals back to 110 Ma. Plotting the highest concentration of palygorskite rather than simply its presence or absence produces the same result (Fig. 16C), except that there is a somewhat more exceptional concentration in the 0-20^{0} belt compared with the 20-40^{0} belt. Inspection of the plots shows that it is the north Indian Ocean, Red Sea and Pacific Ocean deposits that have the greatest influence on this, rather than the Mediterranean and proto-Atlantic Seas. Thus the dominant ocean occurrences are not distributed in the same latitudes as the 'land' deposits. The evaporite-associated palygorskites of the Mediterranean and proto-Atlantic are, however in the same latitudes as the perimarine 'land' deposits.

The initial suggestion that oceanic deposits would reflect the zonation apparent on land during the Neogene is not supported. If most oceanic deposits are detrital, whether they be deposited from turbidites or from aeolian dust, then ocean currents have apparently produced a very even redistribution. Alternatively, a different origin for the bulk of these deposits must be proposed.

A different origin is suggested for some of the major deposits, for example the Shatsky Rise in the Pacific Ocean (Figs 8-11). These deposits are not in turbidites, and there were no large 'land' deposits nor suitable perimarine environments known around the margins of the proto-Pacific Ocean to act as a detrital source. Even if such sources for these deposits were found in the future, the distance of the Shatsky Rise from land is such that one would have to entertain a different spreading history, or earth expansion since the Campanian (Shields, 1979), to account for their present position. Gorbunova (1972, 1973,) has suggested they are hydrothermal, a hypothesis supported by the oxygen isotope studies of Church & Velde (1979). An alternative is the diagenesis of montmorillonite and related minerals, suggested by Couture (1977a), whose ideas explain the lack of correlation with ocean rises, as would be expected for hydrothermal occurrences. Conversion of smectite to palygorskite is difficult, however, though Giresse et al (1980) propose it for production of palygorskite in the Paris basin, from beidellite.

If palygorskites were neoformed in the deep oceans on a large scale, they should show an antithesis to the Cretaceous anoxic events of Jenkyns (1980), palygorskite and sepiolite cannot form where high organic matter is present so would not appear in such sediments unless they were detrital. The increase in palygorskites in the Campanian does correspond to the cessation of anoxic conditions on th ocean floor. The main anoxic events are in the Late Barremian to Albian, Cenomanian/Turonian boundary, and Coniacean to Santonian. Concentrations of palygorskite in the Aptian - Albian and the Coniacean, suggest a dominant aeolian detrital origin at these times, as ocean bottom currents would have been relatively inactive.

Analysis of aeolian components in the central Pacific Ocean (Rea & Jancock, 1981) reveal the Aptian/Albian contribution here was volcanic dust; and show the Coniacean and Late Campanian were times of low aeolian input (the Early Campanian is not represented). This reinforce an essentially diagenetic origin for the Campanian palygorskite peak, and also suggests it was not derived from volcanic dust. The other evidence from this study does not support a windblown calcareous dust origin for Pacific palygorskite in the Aptian/Albian and Coniacean, conflicting with deductions from anoxic events. Rather it suggest diagenesis, perhaps from volcanic dust in the Aptian/Albian, or transport in surface waters after erosion of continental or shelf deposits.

The DSDP results suggest a broad agewise coincidence with 'land' deposits, though the main Campanian peak is largely an oceanic feature. Of the four 'land' deposits recorded in the

Campanian-Maastrichtian, only one is definitely of this age. The agewise link for other times can be explained by the influx of detrital palygorskites to the oceans during 'arid' times, in the manner described elsewhere in this paper, supplemented by diagenesis. If oceanic deposits could be more clearly identified as detrital, diagenetic or hydrothermal, and the results plotted, the age distribution might prove different for each type.

In the search for possible explanations of the apparent agewise link, Callen (1978) suggested Mg^{2+} introduced through vulcanism could be a contributing factor, but there is no correlation between volcanic effusive phases (fig. 7, Ronov et al 1980) and palygorskite 'events'. There is an approximate correlation of palygorskite 'events' with the alpinotype orogenic events of Schwan (1980), except for the Campanian phase, which implies volcanic dust in the oceans is not a necessarily a precusor for palygorskite. The lithological association of many deposits with basic rocks is probably an indication that they act as a readily available source of Mg^{2+}. Such a source is not essential because deposits like those of South Australia (Callen, 1977) have no link to rocks of this kind. Thus the times during which palygorskite forms a high percentage of the clay fraction of sediments are not normally connected with vulcanism.

Lack of palygorskites in certain intervals in the oceans, especially the Maastrichtian - Early Paleocene and Early Oligocene, is probably a genuine reflection of climatic conditions. Although these were times of widespread low sedimentation rates and abundant hiatuses (Moore et al, 1978; Worsley & Davies, 1979), such events are unlikely to affect shelf sedimentation and obviously not non-marine sedimentation.

The abundance of palygorskites in nearshore marine environments implies peaks in concentration might coincide with the spread of epeiric seas. Ronov et al (1980) summarized world sediment volumes in geosynclines and shelves, sedimentation rates, and other factors of relevance. Comparing these results there is no obvious correspondence between peaks in palygorskite sedimentation, regressions and transgressions, or extent of seas and platforms. The main peak in abundance in the Campanian is the only one which correlates with a major interval of shelf sedimentation and extent.

On his fig. 3, Jenkyns (1980) plots global transgression curves. These do show a crude correspondence between transgressions and palygorskite peaks, more precisely just before and after the maximum transgressive phase of the Santonian - Coniacean. However, most of the palygorskites of these times were forming in the open oceans, not in epicontinental seas. More detailed studies, such as those of Cooper (1977) are unhelpful as the age ranges of palygorskite peaks are not known with enough accuracy. The general lack of correlation indicates that other factors are more important than the extent of epeiric seas. The prevalence of 'aridity' within the continents at these times may be one such factor.

CONCLUSIONS

1. Late Pliocene to Holocene palygorskite deposits are located mainly between 20^0-40^0N and 10^0-35^0S latitudes in the Mediterranean to arid climatic belts. Oceanic deposits of these times are probably largely derived from windblown dust, with some slumped material and turbidites. Neoformation took place in calcareous soils and pedogenic calcretes, and minor playas and springs.

2. The latitudinal pattern in the Pliocene-Holocene is presnt throughout the Cretaceous and Tertiary. That part of the distribution contributed by the oceans, derived from DSDP results, is essentially coincidental with that determined from onshore deposits, but is the result of initial sample distribution and cannot therefore be used as support for a latitudinal distribution in the oceans. Concentration is largely between 30^{o}-40^{o}N and South.

   Prior to the Cretaceous, the majority of deposits are in the northern hemisphere, within latitude 45^{0}, but are most abundant near the equator. Pre-Jurassic interpretations are somewhat speculative in view of the controversial nature of early reconstructions.

3. Palygorskites in perimarine and intracontinental situations are indicators of semi-arid or seasonally arid conditions, not generally as extreme as for sand dune desert formation and evaporite deposition. This is indicated by the late Neogene distribution, partial coincidence in latitudinal and agewise distribution between marine and non-marine deposits during the Cainozoic, and the lithofacies associates. Deposition took place in brackish alkaline waters.

4. Some continental lacustrine deposits, such as the extensive Australian occurrences, are not associated with volcanic ash, nor were there any basic rocks or metamorphic rocks of any extent in the surrounding catchments. Such deposits demonstrate other sources of magnesium ions are sufficient for palygorskite genesis (in the South Australian basins for example, the only other source is the extensive montmorillonite clay of the Cretaceous).

5. Many deep ocean deposits have a hydrothermal or diagenetic origin, which best explains the Campanian peak in the Pacific Ocean. Alteration could have occurred some time after deposition, which might explain the rather poor correlation with worldwide climatic and tectonic events.

   Others were derived from soils through windblown dust in the trade wind belts, and from nearshore occurrences by slumping and turbidity currents. Some represent foundered peri-marine environments left behind as the continents drifted apart.

6. Vein deposits are mostly hydrothermal in origin, and are characterized by a prevalence of sepiolite and related minerals. Some are probably pedogenic crack or joint infills, some from spring action, or result from the weathering of alteration zones around ore bodies and igneous rocks.

7. Periods when palygorskites are most abundant are:

   Cambrian

   Late Devonian and Carboniferous

   Late Permian and Triassic

   ?Late Jurassic

   Late Cretaceous, especially Albian, Campanian and possibly Coniacian.

   Early Eocene (First major widespread non marine deposits)

   Late Eocene

   Late Oligocene

   Middle Miocene to Pliocene

ACKNOWLEDGEMENTS

The data are presented with the permission of the Director General of Mines and Energy, South Australia. The manuscript was read by B. G. Forbes and G. W. Krieg, W.V. Preiss is sincerely thanked for translation of German and Russian literature, my wife J.H. Callen for French literature, and N. McKellar-Stewart (librarian) for extensive assistance in obtaining references, often obscure, from libraries in various parts of the world. All but J.H.C. are of the Dept. of Mines and Energy, South Australia.

Correspondence with A. Singer (Hebrew University, Jerusalem), C. Weaver (Georgia Institute of Technology), L. Watts (Norske Shell, Utvinningsavdelingen) and R. Couture (Argonne National Laboratorty, U.S.A.) is acknowledged.

Lilian Musich, Scripps Institute of Oceanography, La Jolla, California is thanked for printouts of palygorskite analyses not in DSDP volumes (current to 1978).

RAC:AF

R. A. CALLEN

GEOLOGIST

TABLE 1

PALYGORSKITE REFERENCES-OCEANS
Studies on DSDP cores in order of site number

LEG	SITES	AUTHOR
1	1&3	GORBUNOVA, Z.N. (1979)
2	7-15	GORBUNOVA, Z.N. (1979)
	8,9,12.	KASSOVSKAYA, et al (1975)
	9	GORBUNOVA, Z.N. (1972)
	10	CHAMLEY, et al (1977)
	12	CALVERT, S.E. (1971)
	12B	LOMOVA, O.S. (1975)
	12B, 12C	REX, R.W. (1970)
3	15-17	GORBUNOVA, Z.N. (1979)
	20 & 21	ROBERT, C. (1981)
4	26, 28	CHAMLEY et al (1977)
	29, 29B	REX & MURRAY (1970)
6	46-52	GORBUNOVA, Z.N. (1972)
9	79	CHAMLEY, et al (1977)
10	85-89, 93-97	COOK & ZEMMELS (1973)
	92	CHAMLEY et al (1977)
11	98, 99A, 100, 102 104-106	ZEMMELS, et al (1972)
	105	CHAMLEY, H. (1979)
	105	CHAMLEY, & ROBERT (1979)
	105-110	HATHAWAY & SCHLEE (1968)
12	116-117	GORBUNOVA, Z.N. (1979)
13	124, 125A, 132-134	CHAMLEY, et al (1978)
	125	CHAMLEY, H. (1975)
	125-134	ZEMMELS & COOK (1973)
		CHAMLEY, H. (1975)
		HSU et al (1973)
14	131-138	LOMOVA, O.S. (1975)
	135-138	BERGER & VON RAD (1972)
	135-142,144	GORBUNOVA, Z.N. (1979)
	139-144	POW-FOONG & REX (1972)
		VON RAD & ROSCH (1972)
16	157, 157A, 161, 161A, 163, 163A	ZERMMELS, I. (1973)
17	164	COUTURE, R.A. (1977)
	164, 165A, 166, 167, 169-171	ZEMMELS & COOK (1973)
20	196	COUTURE, R.A. (1977)
	196, 198A	MATTI et al (1973)

22	211-213, 215 & 216	MATTI, et al (1974)
	211-218	COOK, P.J. (1977)
	211-218	VALLIER & KIDD (1977)
23	219-224	VALLIER & KIDD (1977)
	219-230	HEEZAN et al (1965)
	219-230	MATTI et al (1974)
	219-230	STOFFERS & ROSS (1974)
	211-223	WESER (1974)
24	231-238	MATTI et al (1972)
	231-238	VALLIER & KIDD (1977)
25	239-245	MATTI, et al (1974)
	239-245	VALLIER, & KIDD (1977)
26	246-255	VALLIER & KIDD (1977)
	250-253,256	COOK, et al (1972)
	253-255	COOK, P.J. (1977)
27	256-263	COOK, P.J. (1977)
	256-263	VALLIER & KIDD (1977)
	259-262	COOK et al (1972)
28	264	COOK, P.J. (1977)
	264	VALLIER & KIDD (1977)
	264, 266, 272	COOK et al (1975)
29	282	COOK et al (1974)
30	288A & 289	ZEMMELS et al (1975)
31	302	COOK, et al (1973)
32	305, 310, 311 & 313	ZEMMELS & COOK (1975)
33	316 & 317A	COOK & ZEMMELS (1976)
34&34A	319A	FLOOD (1978)
35	323	ZEMMELS & COOK (1976)
37	332-334	ZEMMELS, HARROLD & COOK (1974)
38	343	WHITE, S.M. (1976)
39	356 & 357	ROBERT, C. (1981)
40	354-364	CHAMLEY & ROBERT (1979)
41	366-370	MELIERES, F. (1978)
42&42A	372, 374-376	CHAMLEY, et al (1978)
	374-376	MELIERES et al (1978)
44	390	CHAMLEY & ROBERT (1979)
45	395 & 396	TIMOFEEV, et al (1976)

47	398, 400 399-402	CHAMLEY & ROBERT (1979) CASSAT, G. (1979)
47A	397	CHAMLEY & GIROUD d'ARGOUD (1979)
47B	398	CHAMLEY et al (1979)
	398	LATOUCHE, C. (1979)
48	403-406	LATOUCHE, C. (1979)
50	415-416	CHAMLEY et al (1980)
51-53	417A, D, 418A, B	MANN & MULLER (1977)
54 & 58		SKORNYAKOVA, et al (1979)
58	442, 444	CHAMLEY, H. (1980)

OTHERS

SUBJECTS	AUTHORS
Mid-Atlantic Ridge	HATHAWAY, J.C. & SACHS, P.L. (1965)
Atlantic deep sea sediments	BONATTI, E. & JOENSUU, O. (1968)
11 bores off coast of Morocco. Northern Indian Ocean.	CHAMLEY, H. & MILLOT, G. (1970); GOLDBERG, E.D. & GRIFFIN, J.W. (1970)
Miocene diatomite, Santa Cruz Basin (California).	FLEISCHER, P. (1972)
Western Indian Ocean.	VENKATARATHNAM KOLLA et al (1976)
Off Algeria (Gulf of Arzew)	FROGET, C. & CHAMLEY, H. (1977)
Deep-sea Pacific	CHURCH, T.M. & VELDE, B. (1979)
Book on palygorskites of the world, especially Russia.	LOMOVA, O.S. (1979)
Off Algeria (Gulf of Arzew)	FROGET, C. (1980)

TABLE 2

PALYGORSKITES - TOTAL AND AVERAGE % IN DSDP CORES (Legs 1-58) AS RECORDED IN INIT. REP. DEEP SEA DRILLING PROJ

	Σ x	n	$\bar{x}$	σ_{n+1}	
Hol.					
L.Plei.	200	17	11.8	8.2	
E.Plei.	326	13	25.1	13.5	
Plei.	2828	130	21.8	16.7	
Qu.	3289	155	21.2	16.4	
Plio/Plei.	720	24	30.0	20.7	
L. Plio.	2879	123	23.4	18.3	
E-L. Plio.	642	21	20.6	15.6.	2 holes only
E. Plio.	1300	51	25.5	18.2	
Plio.	5183	210	24.7	17.6	
L. Mio.	2068	79	26.2	19.3	
M-L. Mio.	289	17	17.0	11.4	Nearly all 1 hole
M. Mio.	885	28	31.6	22.2	
E. Mio.	755	26	29.0	21.7	
Miocene	4202	157	26.8	19.6	
L. Mio-Plei.	2210	82	27.0	17	
L. Olig.	120	4	30	23.4	
M. Olig.	1648	46	35.8	18.0	Mostly 2 holes
E. Olig.	265	13	20.4	24.4	
Oligocene	2123	68			
L. Eo.	791	17	46.5	31.0	Mostly 1 hole
M. Eo.	748	29	25.8	15.8	
E. Eo.	874	17	51.4	26.9	
Eocene	2610	67			
L. Pal.-E. Eo.	289	9	32.1	9.6	
L. Pal.	441	19	23.2	9.50	
E. Pal.	189	6	31.5	14.8	
Paleocene	1110	44			
Maast.	495	18	27.5	18.7	
Camp-Maast.	181	8	22.6	19.1	
Camp.	2075	52	39.9	16.7	50% from 1 hole
Sant./Camp)	129	5	25.8	11.8	
Sant.)					
Cont./Sant)	617	17	36.3	22.8	
Con.)					
Tur.	104	2			
Cen. & Cen/Tur	447	20	22.3	24.0	
Late K.					
Alb.)	343	8	42.9	23.8	
Alb-Cen.)	(1143)	(28)	(40.8)	(12.9)*	
Aptian-Alb)	175	6	29.2	14.7	
Aptian)					
Bar-Aptian	9	2			
Early K					
Valang-Tith.	32	2			
Oxfordian	60	2			
Late Jurassic	247	7			

* Estimated from summary log results; individual samples not listed.

DATA FROM "UNORIENTED" SAMPLES

	Σ x	n
M. Miocene-Pliocene	5	1
M. Miocene	16	5
E. Miocene	3	1
Oligocene	12	3
L. Eocene	30	3
M. Eocene	95	13
M-E. Eocene	1	1
E. Eocene	46	10
L. Pal - E. Eocene	75	1
E. Paleocene	7	1
Maastrichtian	1	1
Camp-Maast.	1	1
Campanian	2	1
Coniacean/Sant.	4	1
Turonian	6	2
Cenomanian-Alb. & Albian	58	6
Aptian-Alb. & Aptian	79	7
Bar. - Aptian	7	1

TABLE 3
PALYGORSKITE IN DSDP CORES - DATA BASE
<2μ, ORIENTED. Depths to nearest m, % to nearest whole number.

SITE NO	DEPTH	%	AGE
12	85	Present	Plio.
	97	"	"
	104	"	
	114	"	Eoc.
	162	"	"
12B	113	70	L.Eoc
	119	80	"
	161	94	"
	161	91	"
	162	P73,S5	"
	162	24	"
	215	4	"
	215	P38,S43	"
	215	S4	"
	215	P28,S31	"
85	19-28	2	L.Plei.
	48-52	5	"
	99-108	3	"
	189-190	3	"
	210-212	12	"
	292	3	"
86	257-264	19	L.Plio.
	500-505	14	L.Pal.
	551-553	24	E.Pal.
87	649-650	12	M.Mio.
88	51-59	8	E. Plei.
	99-104	18	L.Plio.
	104-108	10	"
	128-136	17	E.Plio.
89	0-3	9	L.Plei.
	51	5	M.Plei.
	220-228?	20	E.Plio.
93	0	13	L.Plei.
	1	19	"
94	417-418	11	L.Eoc.
	499-500	10	M. Eoc.
	503-504	62	"
	572	75	E.Eoc.
95	332-340	38	M.Eoc.
	363-364	16	L.Pal.
	378-379	13	E.Pal.
	391	26	"
	396	23	E. Camp.
	400	24	"
	416-425	9	L.Sant.

SITE NO	DEPTH	%	AGE
	425	22	E. Sant.
	434	26	"
98	94-98	24	Olig.
	135-138	10	Eoc.
	167-175	10	"
	207-211	14	"
	217-218	11	Pal.
	223-224	7	"
	232-234	16	"
	240-241	9	"
	273-275	56	Sant-
Camp.			
	312	24	"
	349	31	"
99A	0.4-7	12	Plio/Plei
	15-21	9	"
100	204-210	17	Valang-Tith.
	206	15	"
	241	24	L.Jur.
	248	3	"
	259	4	"
	260	41	"
	262	63	"
	267	48	"
	268	64	"
	277	9	Oxf.
	277-279	19	"
	287-291	33	Oxf-Call.
	312-313	27	"
102	512-513	60	E.Plio.
104	306-312	10	M.Mio.
	402	8	"
	616	30	"
106	340-343	10	E.Plei.
125	2-6	27	Plei.
	19	33	"
	24	49	"
	27	41	E.Plei.
	29-34	40	"
	39	44	L.Plio.
	139	51	"
	40	55	"
	46	39	"
	47	18	"

	52	60	"
	53	37	"
	60-62	64	"
	60-62	36	"
	67	49	E.Plio.
	79	41	L.Mio.
	89	14	"
126	36-43	16	Plei.
	76	18	E.Plei.
	78-79	14	"
	105	6	"
127	21	9	L.Plei.
	435	47	E.Plio.
129A,B	39	41	?
	40	65	M.Mio.
	40	8	"
	80	40	L.L.Mio.
	94	5	L.M.-L.L.Mio.
	95	33	"
130	0	16	Quat.
	15	12	"
	16	29	"
	18	16	"
	50	9	"
	53	36	"
	53	20	"
	78	8	"
	79	6	"
	80	20	"
	150	33	"
	411	11	"
	413-417	78	"
131	33	8	Quat.
	49	26	"
	49	10	"
	208	13	"
	210	6	"
	264	16	"
132	0.15	16	L.Plei.
	2	6	"
	15	21	Plei.
	19	9	"
	29	12	"
	33	10	"
	51	17	"
	74-80	8	L.Plio.
	82-86	9	"
	96	10	"
	100-107	11	"
	110	18	"
	118-121	22	"
	127-135	19	E.Plio.
	155-162	16	"
	165	16	"
	166	26	"
	174	33	"
	176	22	"
	176	30	"
	181	19	"
	182	35	L.L.Mio.
	183	14	"
	208	9	"
	209	6	"
	215	7	"
	223	29	"
134	249	15	L.Plio.
	289	12	E.Plio.
	318-321	9	"
135	261	12	M.Mio.
	336	65P,14S	E.Eoc.
	433	38	L.Camp-.E.Maast.
	434	14	"
	565	12	Cret.
	565	34	"
	565	36	"
	565	41	"
	686	27	Aptian
136	131-138	23	E.Plio.
	217-224	28	E-M.Mio.
	237-240	20	E.Mio.
	245-248	54	L.Olig.-E. Mio.
	254	52	?
	263	24	Conn-Sant.
	263	9	"
	281	98	E.Cen.
	289	32	"
137	53-57	19	Tert.
	59	13	"
	100	97	Tert/Cret
	136	61	"
	137	46	"
	139-143	60	"
	166	40	Maast.
	167	29	"
	167	32	"
	218	39	?Turon/Camp.
	219	36	"
	265	6	L.Cen.
	274	4	"
	284	8	"
	285-287	6	"
	302	12	"
	303	5	"
	303	12	"

	306	5	"
	343	6	E.Cen.
	349	9	"
	377	7	L.Albian-E.Cen.
138	111	2	E.Olig.
	111	19	"
	112-115	11	"
	117	6	"
	118	8	"
	184	96	?
	333	19	Camp.
	428	24	Cen.
	429	15	"
	429	17	"
	429	3	Camp.
139	115	7	M.Plio.
	228	12	E.Plio.
	230	27	"
	354	9	M.Mio.
140&140A	?	14	L.Plio.
	151	15	M-L.Mio.
	237	7	M.Eoc.
	239	17	"
	240	14	"
	243	32	"
	313	56	"
	369	61	M or E.Eoc.
	432	90	?Pal/Eoc.
	513	80	"
	588	4	L.Cret-?E.Pal.
	648	15	Maast.
141	7-13	16	E.Plei.
	15-22	23	L.Plio.
	24-31	14	"
	34-41	24	L.E.Plio.
	42-49	24	M-E.Plio.
	51	P29,S6	"
	51	P32,S11	"
	51	P40,S27	"
	60-67	22	"
	80	29	E-L.M.Plio.
	82	33	"
	86	36	"
	102	P65,S14	"
	192	75	?
	193	19	?
	197	24	?
	287	31	?
142	529	15	M-L.Mio.
	531	11	"
	576-579	5	"
144	164	6	L.Camp-E.Maast.
	214	14	L.Cen-.E.Tur.
	215	23	"
	215	35	"
	216	12	"
	217	26	"
	296	20	L.Apt-E.Cen.
	324	15	L.Apt-Alb.
	327	20	"
157&157A	12	19	Holo.
	24	14	L.Plei.
	24	14	"
	28	17	"
158	143	16	L.Mio.
	289	21	M.Mio.
159	6	16	Quat.
	10	11	L.Mio.
161	2	21	E.Mio.
	3	11	"
	4	19	"
	7	33	"
	7	14	"
	9	17	"
	43	16	L.Olig.
	44	14	"
	49	31	"
	53	48	"
	54	42	"
	55	46	"
	56	28	"
	57	44	"
	57	32	"
	58	48	"
	59	51	"
	60	40	"
	61	58	"
	62	54	"
	62	54	"
	64	45	"
	64	61	"
	66	39	"
	67	28	"
	68	51	"
	69	25	"
	70	30	"
	72	30	"
	73	25	"
	74	54	"
	80	41	"
	83	49	"
163&163A	162	31	E.Maast.
	174	48	"

	177	42	"
	180	46	"
	184	28	L.Camp.
	187	44	"
	188	32	"
	190	48	"
	193	51	"
	197	40	"
	199	58	"
	202	54	"
	204	54	"
	210	45	"
	212	61	"
	216	39	"
	221	28	"
	225	51	"
	228	25	"
	231	30	"
	237	30	"
	240	25	"
	242	55	"
	264	41	"
	271	49	E-L.Camp. boundary
164	85-89	38	Camp.
	91	24	?
	113-114	59	Con.Sant.
	116	65	"
	118	60	"
	150	67	"
	159	60	"
	160	59	"
	170	54	Cen./Tur.
	179	20	"
	188	60	"
	207	58	?
	216	67	?
	253	18	?
165A	30	18	L.Olig.
	291	20	L.Camp-E.Maast.
	292	9	"
	344	33	L.Camp.
	371	13	Camp.
	371	17	"
	372	16	"
	397	29	L.Cret.
	399	6	"
	427	13	?
166	222	57	L.Alb-Cen.
	224	70	"
	225	65	"
	230	63	"
	253	32	"

167	697	8	M.Maast.
	808	40	E.Camp.
169	108	27	Camp.
	193	47	Tur.
	193	57	"
170	7	12	L.Olig-E.Mio.
	108	57	M-E.Camp.
	113	39	"
171	2	12	Plei.
	27	38	M.Mio.
	28	24	"
	30	18	"
	33) same	27	"
	33) sample	57	"
	35	39	"
	35	59	"
	35	65	"
	36	60	"
	46	69	E.Mio.
	49	60	"
	52	54	"
	55	20	"
	57	60	?
	59	57	?
	59	57	?
	63	60	?
	66	67	L.Olig.
	68	57	"
	68	70	"
	68	66	"
	69	19	"
	70	63	"
	77	18	"
	77	32	"
	89	20	"
	89	9	"
	105	33	E.Olig.
	113	13	"
	113	17	"
	113	16	"
	121	29	"
	122	6	"
	130	13	M.Eoc.
	226	18	E.Maast.
196	104	44	Camp.
	105	62	"
	107	49	"
	108	30	"
	108	14	"
198A	93	25	L.Cret.
	96	35	"
	97	42	"
	110	20	Camp.

	117	42	E.Camp.
	122	42	"
	123	60	"
	125	10	"
200/201?	29	25	L.Mio.
	29	35	"
	30	42	"
	32	44	"
	32	62	"
	33	49	"
	33	30	"
	33	12	"
	34	20	"
	36	42	"
	37	42	"
	38	60	"
	38	10	"
211	398	15	?
	409	64	L.Camp-. E.Maast.
	419	31	E-M.Camp.
	420	59	"
	428	63	"
212	173	6	E.-M.Mio.
	289	18	?
	320	22	L-M.Eoc.
	412	7	?
	483	7	L.Cret.
	484	21	"
	484	20	"
	489	38	?
	497	52	?
	507	52	?
	508	53	?
213	84	6	L.Mio
	100	13	?E.Eoc- M.Mio.
	117	11	?M.Mio.
	125	30	E.Eoc.
	145	57	L.Pal.
215	74	44	E.Eoc.
	76	88	"
	77	88	"
216	121	31	M.Mio.
	293	92	Pal.
	311	56	"
	346	22	L.Maast.
219	69	14	L.Mio.
	135	37	E.Mio.
220	28	14	E.Plio.
	102	32	L.Olig.
221	149	25	Mio/Plio.
222	23	44	Plei.
	23	88	"
	24	86	"
	26	6	"
	30	13	"
	36	11	"
	37	31	"
	38	30	"
	45	57	"
	52	28	"
	53	6	"
	88	18	L.Plio.
	89	92	"
	95	56	"
	97	22	"
	103	33	"
	105	22	"
	121	15	"
	125	38	"
	126	7	"
	128	31	"
	128	47	"
	131	63	"
	147	7	"
	148	21	"
	148	20	"
	149	38	"
	152	48	"
	155	53	"
223	364	39	E.Plei.
	367)	40	L.Mio.
	367)	48	"
	367) 0.5m	43	"
	367)	40	"
	367)	40	"
	367)	31	"
	370	46	"
	370	27	"
	371	25	"
	386	44	"
	413	11	M.Mio.
	488	47	E.Mio.
	488	65	"
	489	65	"
	496	24	L.Olig.
	497	17	"
	525	12	M.Olig.
	593	7	M.Eoc.
	611	17	"
224	96	40	L.Mio.
	699	18	E.Olig.
	756	8	M-L.Eoc.
	783	4	M.Eoc.
	785	12	"
	786	23	E.Eoc.

225	22	22	L.Plei.
	26	29	E.Plei.
	27	40	"
	40	17	"
	58	29	L.Plio.
	66	18	"
	85	35	"
	88	40	"
	90	33	"
	91	37	"
	96	4	"
	115	22	E.Plio.
	162	13	"
227	28	50	L.Plio.
	48	14	"
	92	8	E.Plio.
	116	30	"
	134	10	"
	142	18	"
	162	8	"
228	37	14	L.Plei.
	161	15	L.Plio.
	222	16	"
	278	6	?
229A	22	22	?Quat.
230	4	10	?Quat.
231	3	41	Plei.
	19	43	"
	278	39	L.Mio.
	397	52	"
	566	64	M.Mio.
232A	219	44	E.Plio.
	242	40	"
	284	29	L.Mio.
232	1	53	Plei.
	1	10	"
	1	8	"
	7	22	"
	7	22	"
	8	22	"
	8	40	"
	9	50	"
	9	14	"
	10	39	"
	11	14	"
	12	17	"
	15	14	"
	15	14	"
	16	28	"
	18	29	"
	20	18	"
	21	14	"
	26	35	"
	27	40	"
	28	8	"
	28	34	"
	28	37	"
	29	4	"
	29	40	"
	31	32	"
	31	13	"
	35	22	"
	35	30	"
	41	37	"
	41	10	"
	43	18	"
	49	5	"
	49	13	"
	49	5	"
	50	3	"
	70	16	"
	85	6	"
	107	50	L.Plio.
	112	40	"
	112	48	"
	112	43	"
	112	39	"
	112	40	"
	112	31	"
	113	46	"
	113	27	"
	113	25	"
	118	44	"
	126	11	"
	126	47	"
	149	47	E.Plio.
	149	65	"
	149	65	"
	151	24	"
	151	17	"
	158	60	"
	160	12	"
	181	7	"
	186	17	"
	213	18	"
	230	8	"
	239	4	"
	239	12	"
	240	23	"
	301	6	L.Mio.
234	2	33	Plio-. L.Mio.
	5	29	"
	85	24	E.Mio.
	241	9	L.Olig. or earlier
235	2	28	Plei.
	32	30	"
	70	38	L.Plio.
	75	23	"

	75	41	"
	75	35	"
	75	44	"
	93	52	Plio/Mio.
	221	16	L.Mio.
	269	29	"
	269	53	"
	270	18	"
236	18	18	Plei.
	19	18	Plio.
	38	19	"
	39	13	"
	44	20	"
	77	18	L. Mio.
	109	14	"
238	5	27	Plei.
	56	16	L.Plio.
239	159	6	?
	163	13	?
	218	10	L.Olig.
	264	41	L.Eoc.
	303	43	E.Pal.
240	4	16	Quat.
	74	15	?Plio.
	76	15	Plio.
	80	14	"
	161	15	Mio.
240A	169	12	L.Mio.
242	0	78	Plei.
	1	33	"
	1	28	"
	1	41	"
	2	29	"
	3	63	"
	6	43	Plio/Plei
6	19	"	
	10	30	"
	13	15	"
	14	21	"
	21	26	"
	21	15	"
	21	74	"
	23	23	"
	23	35	"
	23	52	"
	24	15	"
	26	24	"
	29	70	"
	33	50	"
	33	12	"
	34	5	"
	41	9	"
	41	18	"
	44	61	"

	45	22	"
	48	60	"
	52	20	L.Plio.
	56	62	"
	67	44	E/L.Plio.
	67	4	"
	73	9	"
	74	40	"
	81	21	"
	82	29	"
	82	29	"
	82	18	"
	85	39	"
	86	29	"
	93	9	"
	121	52	"
	137	36	E.Plio.
	151	20	"
	173	64	L.Mio.
	237	19	"
	311	15	"
	410	9	M.Mio.
	480	11	E.Mio.
	559	14	L.Olig.
	602	9	M.Olig.
	609	10	"
	654	26	L.L.Eoc.
	675	45	?E.L.Eoc.
245	8	19	?
	166	63	E.Eoc.
	321	33	L.Pal.
	27	6	?
	59	20	L.Eoc.
	78	39	"
	97	57	M/L.Eoc.
	102	62	M.Eoc.
249	258	37	L.Camp.
	259	46	"
	286	61	"
	289	12	?
	303	22	E.Cret.
	304	8	"
250A	58	7	Quat.
	646	17	?
	664	23	?
	684	33	?
	702	5	Con.
	713	30	?
	720	29	?
251A	453	40	L.Mio.
252	1	18	?L.Mio-. Plei.
	1	16	"
	1	16	"
	2	14	"

	3	19	"
	3	21	"
	5	54	"
	8	6	"
	15	29	"
	16	28	"
	18	33	"
	22	23	"
	23	15	"
	23	15	"
	24	39	"
	24	10	"
	29	57	"
	31	62	"
	33	34	"
	37	24	"
	42	36	"
	44	33	"
	46	20	"
	49	6	"
	49	15	"
	50	13	"
	51	63	"
	51	6	"
	65	15	"
	67	10	"
	72	19	"
	79	37	"
	79	46	"
	80	41	"
	87	61	"
	88	12	"
	90	12	"
	91	19	"
	92	43	"
	92	22	"
	93	18	"
	95	15	"
	96	28	"
	98	33	"
	98	23	"
	110	54	"
	111	59	"
	111	54	"
	116	21	"
	120	55	"
	122	87	"
	124	38	"
	125	9	"
	127	39	"
	146	11	"
	148	27	"
	162	25	"
	170	14	"
	177	12	"
	178	21	"
	179	20	"
	184	9	"
	186	10	"
	191	35	"
	199	26	"
	206	45	"
	229	22	"
	255	23	"
272	1	44	?
	9	23	E.Plio.
	12	14	"
	17	16	L.Mio.
	21	40	"
	24	19	"
	27	10	"
	28	12	"
	29	13	"
	30	15	"
	33	11	M-L.Mio.
	35	7	"
	38	18	"
	41	12	"
	44	11	"
	47	11	"
	53	50	"
	56	23	"
	59	32	"
	61	29	"
	62	11	"
	94	7	"
	111	21	"
282	32	6	E.Mio.
	47	12	"
	49	10	"
	50	14	"
	52	41	"
288A	458	9	E.Olig.
	535	36	L.Pal.
	536	12	E.Pal.
	579	25	M.Maast.
	610	68	?E.-M.Maast.
	649	79	Camp.
	762	15	Con.
	762	8	"
	762	10	"
289	1138	355	E.Pal.
	1194	43	E.Maast.
	1231	77	L.Camp.
	1232	74	Apt-Camp.
	1234	37	Apt.
	1260	55	"
302	140	9	L.Mio.
	163	36	"
	163	12	"
	177	25	"
	186	68	"
	198	79	"
	232) same	15	"

	232)sample	8	"
	232	10	"
	262	8	"
	347	35S	"
	364	43	"
	375	77	"
	375	74	"
	376	37	"
	384	55	"
305	50	7	M.Mio.
	51	7	"
	52	46	L.Olig- E.Mio.
	57	14	L.Olig.
	61	7	"
	67	13	"
	80	24	L.Eoc.
	89	11	M.Eoc.
	94	20	E.Eoc.
	137	17	L.Maast.
	142	5	"
	145	6	"
	156	16	M.Maast.
	184	14	L.Camp- E.Maast.
	212	15	L.Camp.
	552	5	E.Apt-. Barr.
	608	4	"
	618	15	Apt-Haut.
310	69	31	L.Mio.
	79	20	M.Mio.
	89	8	M.Mio-. E.Olig.
	118	11	E.Camp-. E.Maast.
	334	21	E.Camp-. L.Alb.
311	13	7	Plio or . younger.
313	235	21	E- M.Maast.
	306	8	E.Maast.
	400	11	L.Camp-. E.Maast.
316	515	?	L.Pal.
	515	?	"
317A	585	?	M.Camp.
323	4	7	L.Plio.
	15	7	"
	16	7	"
	16	46	"
	17	14	"
	19	7	"
	20	13	"
	21	31	"
	24	20	"
	27)same	8	"
	27)sample	11	"
	29	20	"
	36	11	"
	42	17	"
	43	5	"
	44	6	"
	47	16	"
	56	14	"
	65	15	"
	72	21	"
	93	8	"
	102	21	E.Plio.
	122	11	"
	168	5	L.Mio.
	185	4	"
	188	15	"
332A	69	1	Plei.
	71	1	L.Plio.
	79	9	"
	88	5	"
	98	7	"
	101	14	"
	103	19	"
	104	26	"
332B	141	1	?L.Plio.
333	0	7	L.Plio.
	0	4S	"
	0	5	"
	18	7	"
	19	3	"
	25	7	"
	79	6	"
	154	21	"
	157	21	"
	160	25	"
	169	1	"
	172	1	"
	173	1	"
	174	10	"
	178	67	"
	184	2	"
	186	2	"
	189	4	"
	203	2	"
	205	69	E.Plio.
	214	70	"
334	134	4	L.Mio.
	138	2	"
	149	2	"
	183	10	"

	237	3	"
	243	7	"
335	89	1	L.Plio.
	91	2	"
	92	2	"
	132	9	E.Plio.
	221	4	"
343	2	8	Plei.
	7	11	"
	8	5	"
	10	3	"
	11	6	"
	16	11	"
366	596	1	M.-E.Eoc.
	616	4	E.Eoc.
	649	2	"
	658	1	"
	683	1	"
	693	1	"
	702	1	"
367	306	8P,18S	L.Eoc.
	306	1P,1S	"
	351	10P,4S	M.Eoc.
	351	17P,3S	"
	372	13P	E.Eoc.
	373	17P,11S	"
	392	36P,39S	L.Pal-. E.Eoc.
	620	7P	L.Cret.
	638	4P	E.Tur.
	650	2P	"
368	274	1	E.Mio.
	279	4P,1S	"
	289	28P,3S	?M.Eoc-. E.Mio.
	315	30P,3S	"
	326	63	"
	330	69	"
	371	20	?M.Eoc.
	386	27	L.E.- LM Eoc.
	395	42	E.Eoc.
	408	59	"
	431	63	"
	441	66P,4S	"
	468	43P,5S	"
	517	52P,10S	"
	538	33P,34S	L.Pal-. E.Eoc.
	564	52P,32S	"
	573	55P,35S	"
	585	7P,3S	"
	593	47P,37S	"
	602	27P,8S	"
	612	29P,6S	"
	620	33P,8S	"
	630	28P,18S	L.Cret-. L.Pal.
	640	11P,16S	"
	651	6P,7S	"
	727	2	L.Cret- ?Pal.
	727	7	"
	754	6	L.Cret.
	803	7	"
	841	5	Camp-Con.
369	84	1	M.Mio.
	102	2	"
	102	2	"
	350	2	L.Eoc.
	357	1	M.Eoc.
	378	1	Maast.
	398	1	L.Camp-. E.Maast.
	406	2	Camp.
	418	4	Con-Sant.
	424	2	Alb.
	435	23	Alb.
	447	2	"
	453	2	L.Apt-. E.Alb.
	463	14	"
	473	3	"
	483	14	"
370	105	5	M.Mio-. Plio.
	208	10	M.Mio.
	209	1	"
	220	3	E.Mio.
	325	3	Olig.
	325	3	"
	428	6	"
	466	2	M.Eoc.
	484	8	"
	485?	5	"
	504	6	"
	541	7	"
	551	2	"
	552	1P,1S	"
	552	1	"
	569	16	"
	592	11	"
	608	29P,7S	E.Eoc.
	618	8P,1S	"
	655	5P,2S	E.Pal.
	675	6	L.Alb-. E.Cen.
	684	12	"
	696	13	"
	753	9	?Alb.
	771	28	L.Apt.- E.Alb.
	810	10	"

	828	8	"
	838	7	Barr-. E.Apt.
	877	5	Barr.
	884	5	"
29	138	23S	M.Eoc.
	139	25S	"
	193	42S	"
	195	40S	"
	198	36S	"
	200	34S	"
	202	34S	"
	203	24S	"
	207	25S	"
	210	31S	"
29B	219	23S	M.Eoc.
	220	28S	"
	221	32S	"
241	10	7	Quat.
	18	4	"
	48	6	E.Plei.
	59	5	"
	72	5	"
	137	36	L.Plio.
	145	5	"
	151	20	"
	212	6	L.Mio.
	237	19	"
	296	9	M.Mio.
	297	13	"
	311	15	"
	323	10	"
	380	22	E.-M.Mio.
	410	9	E.Mio.
	480	11	?M.Eoc-. ?L.Olig.
	484	4	E.-M.Eoc.
	531	25	E.Eoc.
	559	14	?Pal-. ?E.Eoc.
	581	19	?Pal.
	585	17	"
	602	9	?Camp-Pal.
	609	10	"
	627	7	Con-Camp.
	654	26	"
	675	45	"
	750	12	"
	837	10	"
	978	4	M.Cen-Tur.
	979	6	"
	980	8	"
	981	8	"
	982	5	Tur.
	983	6	M.Cen.
	1068	5	"
	1070	9	"
	1071	15	"
	1169	26	"
	1170	10	?
	1170	14	?
248	4	16	Plei.
	121	24	L.Plio.
	315	43	L.E.Eoc-. E.Mio.
	361	54	L.E.Eoc.
	363	59	"
	363	54	"
	393	55	"
	399	87	E.Eoc.
	408	50	Pal or E. Eoc.
	416	39	"
398	620-725	Tr,P	L.Pal.- E.Eoc.
	680-725	Tr,S.	"
	725-730	Ave.15%P, 15%S-(up to 25%)	"
	730-750	S only,0-25%, Ave. 15%	M.Pal.
	770	S only.	"
	780-810	P only, 0-15%	L.Maast. -E.Pal
	1000-1045	P 0-15%	L.L.Alb.- L.M. Alb.
	1065-1190	P 0-30% Ave, 10%.	"

CAPTIONS

Fig. 1. 'Ancient' and Triassic occurrences plotted on Eckert Projections simplified from Kanasewich, et al., (1978).

Figs 2-6. DSDP occurrences plotted on polar projections of Firstbook et al.,(1979). See Fig. 2 for abundance key. site numbers shown. Key to references Table 1. Positions approximate for the following: 40 Ma - 138, 171, 288; 50 Ma - 29; 10 Ma - 87, 88, 139, 171, 323, 333.

Figs 7-13. General distribution, plotted as basins on Mercator projections modified from Smith & Briden, 1977. Dots are generalized DSDP and oceanic occurrences, diagonal shading is continental data (M = marine, (M) partly marine), crosshatched areas are soils superposed on basins with palygorskite. Soils distinguish by prefix "D" on Pliocene-Holocene map. Some oceanic occurrences partly non-marine (e.g. Mediterranean Sea - see text).

Some data from the continents appear on more than one map by reason of lack of age definition rather than deposition over a long time span. For Fig. 13, Israeli occurrences are D3, D20, D25, D30, D31, D84. Lebanon D13A. FD = Falcondite.

Fig. 14. Age distribution of palygorskites: total and average % plotted by Ages, Epochs and Periods, for DSDP drilling. See text for method of estimation. 10: Mainly from two holes, 1E: mostly 1 hole, Camp.: 50% data from 1 hole, Albian: dashed peak = data from 1 hole.

Fig. 15. Palygorskites in the Indian Ocean - palaeodepth curves, adapted from fig. 5 of Kidd & Davies, 1978. Note lack of relationship between palygorskite and depth. Palygorskites associated with "calcareous ooze" facies, except in 250, 252 ("other types" = Cretaceous deep sea clay), 223 (Neogene "terreginous sediments"), and 213, 215, 220, 221, 256 (small amounts in Neogene "other types" of clay, "terreginous sediments" and "siliceous ooze").

Fig. 16. Latitudinal distribution of palygorskites in terms of 10^{o} intervals.

A. Continental records in terms of basins. Concentration factor approximately adjusted for latitude and land area. Plio-Pleistocene occurrences not included. See text for method of estimation.

B. All DSDP holes in terms of 10 Ma time slices, totalled.

C. Palygorskites recorded on presence or absence basis for each site per 10 Ma time slices. Stippled area represents sites shown as large dots on drift maps (viz: greatest concentration in <2 μfraction).

Fig. 17. Vein deposits, plotted on present day map.

TABLE 4

PALYGORSKITES LAND DEPOSITS

(veins and soils largely excluded)

Location, Basin	Age	Associated Rocks	Environment	Concentration & extent	P/S
Parana Basin, Brazil	E.Paleocene (Danian)	Mg-limestone, fine sandstone, basalt	Freshwater, lacustrine	Disseminated in sandstone, rarely pure ?180 000 km^2	P,S
Yucatan Peninsula	E.Eocene	Dolomite, caliche, clay limestone	Marine lagoon		P
Cuba	Cretaceous	Serpentinite, saponite, christobalite, talc.	?hydrothermal	Pure veins	S
Negev, Israel	E-L.Paleocene	Marl, chalk, flint, phosphate (in overlying rocks) zeolite, opal, barite, celestite, gypsum	Marine	20-40%, 60-80% in clay fraction	P,S
Jordon Valley, Israel	E-M.Eocene		Marine		P
Central Turkey	Oligocene-L.Miocene	Gypsum, limestone celestite	Marine	9600 km^2	P,S

Location, Basin	Age	Associated Rocks	Environment	Concentration & extent	P/S
South Arabia (central)	Tertiary		Weathering from Tertiary rocks		P,S
Saudi Arabia	Miocene-Pliocene	Limestone gravel	?alluvial	Extensive 6-30%	P
Nevada-Texas High Plain, U.S.A.	Pliocene-Pleistocene	Caliche cap, in alluvium and soils on these rocks. Dolomite chert, volcanic ash.	Lacustrine and soils	Some pure sepiolite in playas	P,S
South Carolina, Georgia, Florida, Georgia Shelf U.S.A.	L.Oligocene to E.M. Miocene	Clay, limestone protodolomite	Transgressive brackish; tidal lagoon.	1-5 m pure, 3-4000km^2	P,S
Green River, U.S.A.	E.-M.Eocene	Oil shale, dolomite, marl, clay, Na-rich evaporites.	Alkaline lake	10,000 km^2	S
Central Portugal, around Lisbon	Palaeogene probably Eocene	Marl, clay sand conglomerate, limestone, dolomite, silicified. Basalt.	?Marine		P
E.Galice, Spain	Miocene Oligocene	Marl, lignite	?Marine	500 km^2 5-10%	S,P
Lebrija, Spain	Pliocene	Limestone, clay	Sedimentary	1-1.5m thick	P
Caceres, Spain	Miocene	Marl, dolomite	Lacustrine	2-5.5m, 80% 200km^2	P,S
Zomora, Spain	Tertiary-Quaternary	-	-	-	P

Location, Basin	Age	Associated Rocks	Environment	Concentration & extent	P/S
Aquitaine (Loir-Atlantica) France	M.Eocene to L.Oligocene	Limestone	Marine?	Pure beds	P
Cambon & Saffre Basins, Brittany, France.	Late Eocene to Pliocene	"	"		P
Pechelbronne Basin & Mullhouse Basin, France	Late Eocene to E.Oligocene	Petroliferous dolomite, clay, limestone, evaporites (anhydrite).	Marginal marine, very tropical	200 km^2, pure and disseminated	P
Languedoc-Mormoiron Basin, Gard Basin (France)	L.Cretaceous to E.Paleocene, E.Eocene	Limestone dolomite, lignite, gypsum, marl, algal mats, vertebrates.	Lacustrine fluvial.		S
Paris Basin (France)	L.M.Eocene E.Oligocene	Dolomite, marl, sandy clay, gritty limestone.	Marine lagoon	60 000 km^2	S,P
Provens (France) Vaix en Provens Basin	L. Eocene to M. Oligo-cene	Gypsum, lignite marl	Fluvio-lacustrine, subtropical & dry seasons.		P,S
Durance basin, Bresse, France.	L.Oligocene	Gypsum, lignite marl	-	-	S
LeLocle (Switzerland)	L.E. to E.M. Miocene	Celestite, volcanic ash, dolomite, fine sand, clay redbeds.	Freshwater lakes, streams savannah	100 km^2	P

Location, Basin	Age	Associated Rocks	Environment	Concentration & extent	P/S
Malvern, England (midlands)	Late Triassic	Marl, dolomite in joints extending from base Triassic into Devonian dolerite, etc. Redbeds, lateritic soil, red marl, in sediments.	Shelf seas, gypsum lakes	Extensive Up to 40% 10 m thick	S
Northwest Scotland	Permo-Triassic	Clacrete, weathering horizon. Red sandstone	Arid, saline lakes?		P
Poland	Tertiary-Quaternary boundary	Weathered basalt	?Ancient soils		P
River Onega Basin (Russia) near Finland	Carbonife-rous	Calcareous redbeds, lime-stone dolomite, marl, clay, sandstone, basic volcanics bauxite.	Nearshore marine fan deposits	60-70% of claystone	P
Fergana Basin (Uzbekhistan, Khirgizhstan, Russia)	Neocomian-Aptian, Albian, Cenomanian, Turonian to Danian. (Palaeogene, Neogene)	Beneath dolomite, over clay sandstone. Gypsum in Cenomanian; commonest in coarse clastics as cement.	Arid, lagoons & alkaline lakes with marine influence	60-80% in clay fraction of 10m thick clay, in Cretaceous (16% total)	P

Location, Basin	Age	Associated Rocks	Environment	Concentration & extent	P/S
Kara-Mazar Mountains (Russia)	?	Cristobalite, calcite serpentinite.	Veins		S
Cherkassk Deposit (Ukraine)	E. Miocene	Clay, sand, some limestone bauxite, amphibolite.	Marine, shallow water, transgressive.	Similar to Georgia, U.S.A.	P
Moscow Syneclise (Russia)	M-L, Carboniferous	Basalt, kaolinite, bauxite	Margins of deeply weathered highs, shallow marine.		P,S
Novilsk, Kureika River, N. Siberian Platform (Russia)	L. Devonian E. Carboniferous (Tournasion) Also middle to upper Carboniferous	Limestone (rare) Coal, clay, sandstone, "aleurite", marl, vertebrates, dolomite, basalt intrusions.	Marine, tropical, low swamp vegetation. Epicontinental sea saline lagoon. Diagenetic, ?hydrothermal.	Concretions in 40 m thick unit. Extensive.	P,S
Rybin Basin, Irkutsk Amphitheatre, Olekmin, Lena River (S. Siberia Platform)	Late Cambrian and M. Carboniferous	Dolomite, fluorite, anhydrite, clay, carbonate primary dolomite	Flat land, shallow marine, with islands. Marginal marine red-beds. Saline lagoon.	1-1½ km extent + many others	P,S

Location, Basin	Age	Associated Rocks	Environment	Concentration & extent	P/S
Western Armenia (Russia)	Pliocene	Transitional to evaporites, explosive volcanics, opal, dolomite, calcite, phosphate.	?Non marine, lakes.	100 km^2 6-30 m thick	P
Mangyshlak Peninsula, Khazhakstan (Russia)	E. Oligocene	Sand, silt, clay manganese dolomite	Beach and shallow marine		P
Kura Basin, Azerbaijan (Russia)	Oligo-Miocene & Plio-Pleis tocene	Molasse-clay, siltstone, sandstone, grit, carbonate, conglomerate	Weak alkaline basin with ferromagnesium minerals in source area. Arid climate. Marine to non-marine.	Disseminated in clay. Very thick sequence.	P
Donets Basin, Russia	M. Carboni-ferous	Karstic solution holes in ankeritized limestone, over coal seam. Calcrete.	Weathering?	Very extensive	P
Pripyat Depression, Russia	Devonian	Shale, evaporites (gypsum), carbonate, volcanics. Oil shale.	Arid ?Non-marine.	Extensive	P
Gao Basin, Maliard Niger, E. Soudan	M. Eocene	Dolomite, clay, phosphate vertebrates, laterite, gypsum	Marine (marginal)	4000 km^2 in thin pure beds.	P

Location, Basin	Age	Associated Rocks	Environment	Concentration & extent	P/S
Senegal Basin	Paleocene-E. Eocene	Chalk, sandstone, marl, phosphate, glauconite	Marine shelf	Rich	P,S
Togo/Dahomey	Eocene	Glauconite, sandstone, clay	Marine shelf		P,S
Lake Kilamanjira, Kenya	E. Quaternary	Interfingers with basalts & coarse clastics. Dolomite, clay, (aeolian) calcrete, gaylussite.	Lake	200 km^2, 60 m thick	S
Metlaoui Basin, Tunisia	L. Paleocene	Phosphate	Marine		P
Taguenout-Haguerat in NE Mali, and E. Nigeria	Paleocene-Eocene	Black clay, blue shale	Tropical		P
Morocco	Maastrichtian to E. Eocene	Marl, dolomite, phosphate	Marine	10 000 km^2	P,S
Morocco (High & Mid Atlas)	Triassic	Clay sand, carbonates, evaporites, volcanics	Arid, Marine	The highest % of the Triassic deposits	P,S
Tarkarooloo Basin South Australia	Miocene Pliocene	Interbedded with and beneath dolomite, in fine clastics. High strontium. Vertebrates	Non marine lacustrine, Time of max. marine transgression. Fresh to alkaline. Savannah, lakes.	50-80% clay fraction; some pure beds, up to 2 m thick.	P

Location, Basin	Age	Associated Rocks	Environment	Concentration & extent	P/S
			semi arid, (alternating very dry and wet?)		
Ipswich Basin, Queensland	L. Eocene	As above, basalt, oil shale.	Freshwater	Thin beds	S,P
Lake Eyre Basin, South Australia	As for Tarkarooloo Basin.			60 000 km^2	P
Pirie-Torrens Basin South Australia,	As for Tarkarooloo Basin			5 000 km^2	P
Eucla Basin-bordering channels (S. Australia, Western Australia)	Miocene	Clay, dolomite	Non-marine in ancient river valleys.	Low to high	S,P
*Polda Trough, Eyre Pen., S. Aust.	?Miocene	Clay, dolomite	?Non-marine	?	S
Mysore, "Deccan Traps" (India)	L. Cretaceous to Paleocene	Calcareous and cherty rocks inter-bedded with basalts.	?Weathering horizons, arid lakes.	Extensive and thick	P
Hyderabad & Andhra Pradesh	"	"	"	"	"
China** (Jiangsu)	Miocene	Basaltic pyroclastics	?		P
" (Sichuan)	Permian	Dolomitic/limestone	?Hydrothermal		P
" (Guangxi Zhuang)	?	Olivine basalt		S	

* Unpubl. (pers. comm. R. Flint, SADME)
**Zhang, this volume.

Location, Basin	Age	Associated Rocks	Environment	Concentration & extent	P/S
" (Jiangxi)	Permian	Cherty limestone, dolomitic limestone, limestone.	Marine	Several thousand km^2	S

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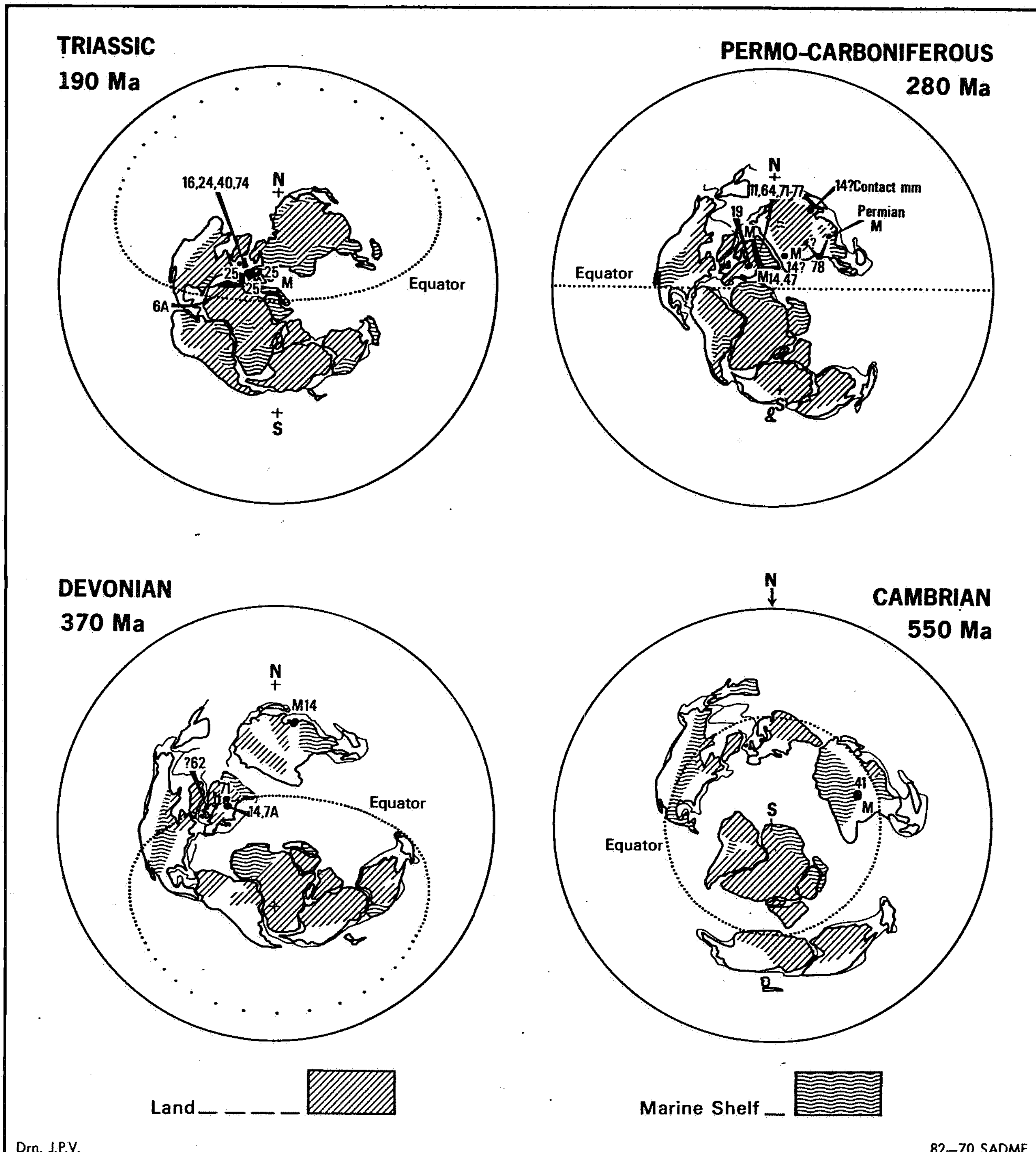

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Fig. 1

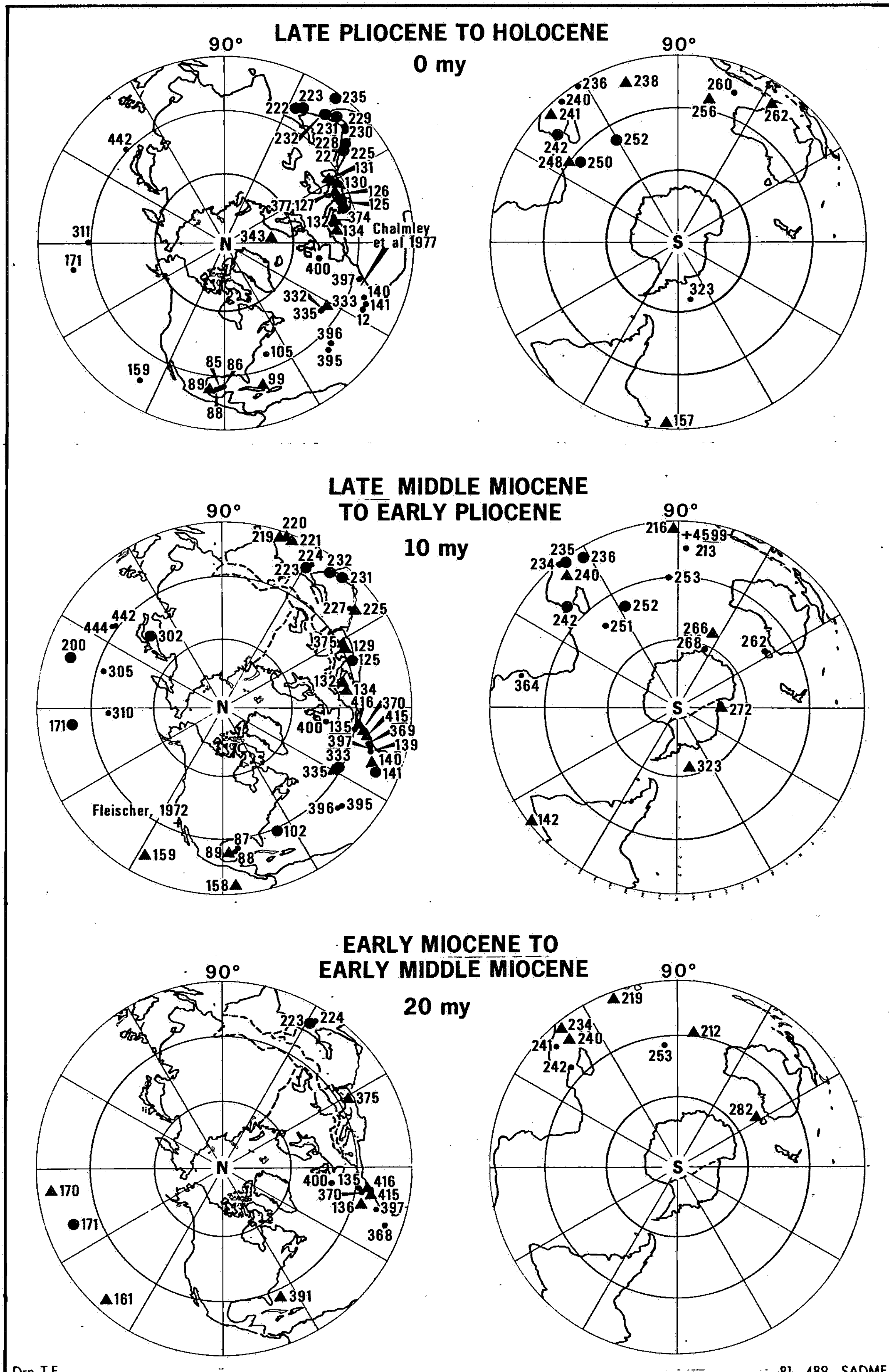

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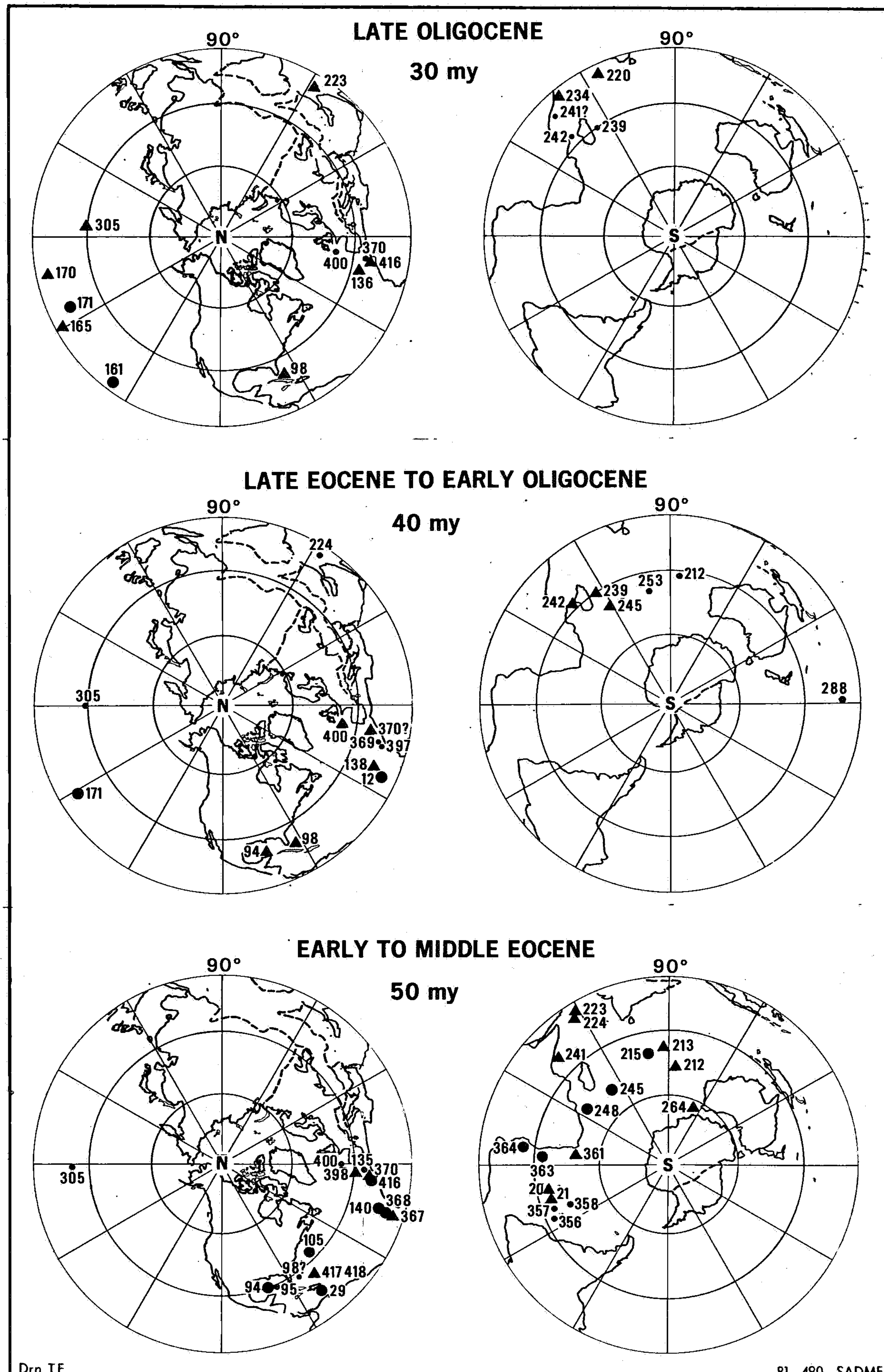
Fig. 2



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165
161
370
400
416
136
98
90°
S
220
234
241?
239
242
LATE EOCENE TO EARLY OLIGOCENE
40 my
90°
N
224
305
171
400
370?
369
397
138
12
94
98
90°
S
212
253
242
239
245
288
EARLY TO MIDDLE EOCENE
50 my
90°
N
305
400
135
398
370
416
368
140
367
105
98?
417 418
94
95
29
90°
S
223
224
241
215
213
212
245
248
264
364
361
363
20
21
358
357
356
Drn T.E.
81–490 SADME

Fig. 3

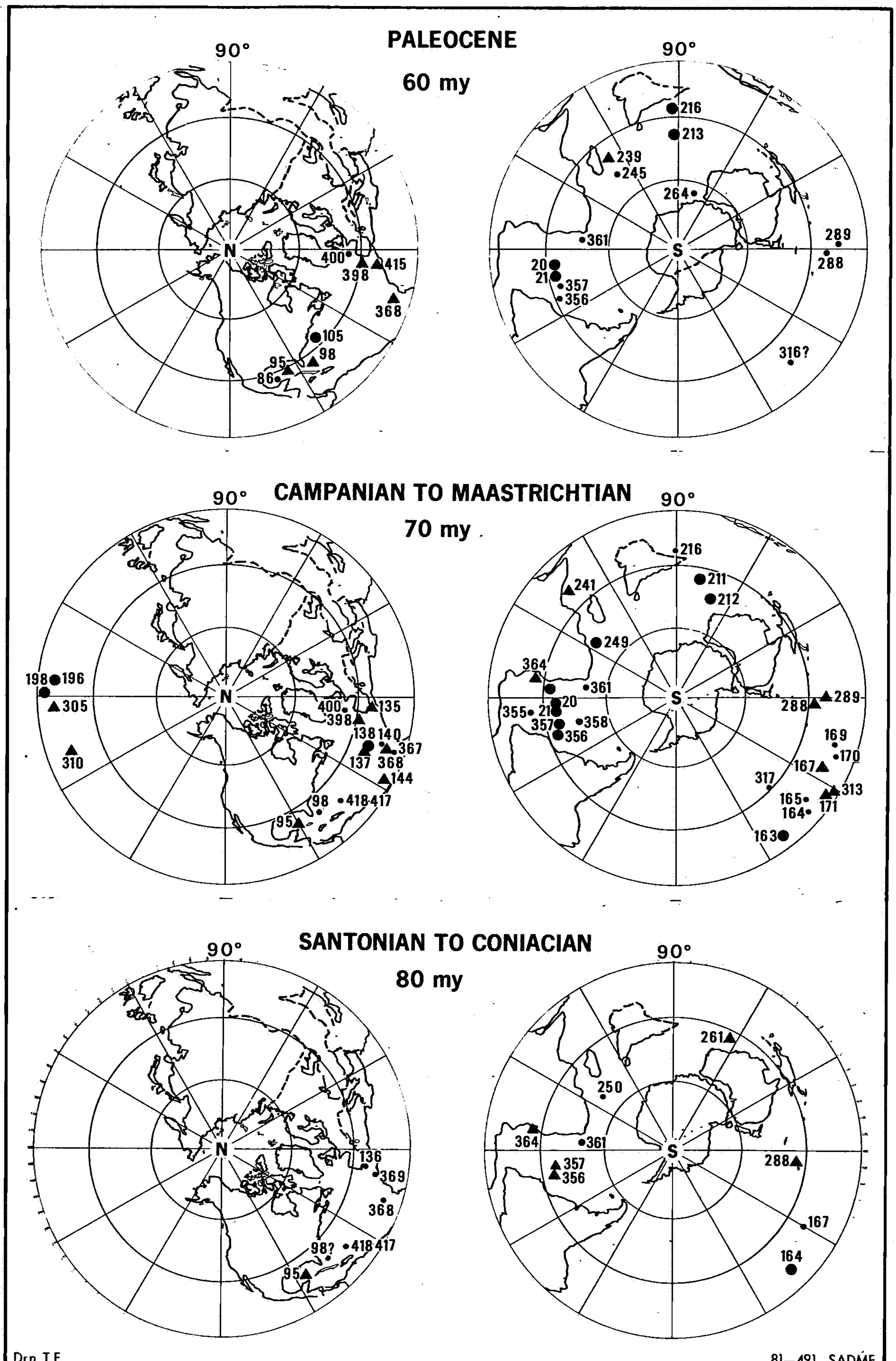

PALEOCENE
60 my
90°
N
400
398
415
368
105
95
98
86
90°
S
216
213
239
245
264
361
289
288
20
21
357
356
316?
CAMPANIAN TO MAASTRICHTIAN
70 my
90°
N
198
196
305
310
400
398
135
138
140
367
137
368
144
98
418
417
95
90°
S
216
211
212
241
249
364
361
20
355
21
357
358
356
288
289
169
170
167
317
313
165
164
171
163
SANTONIAN TO CONIACIAN
80 my
90°
N
136
369
368
98?
418
417
95
90°
S
261
250
364
361
357
356
288
167
164
Drn T.E.
81—491 SADME

Fig. 4

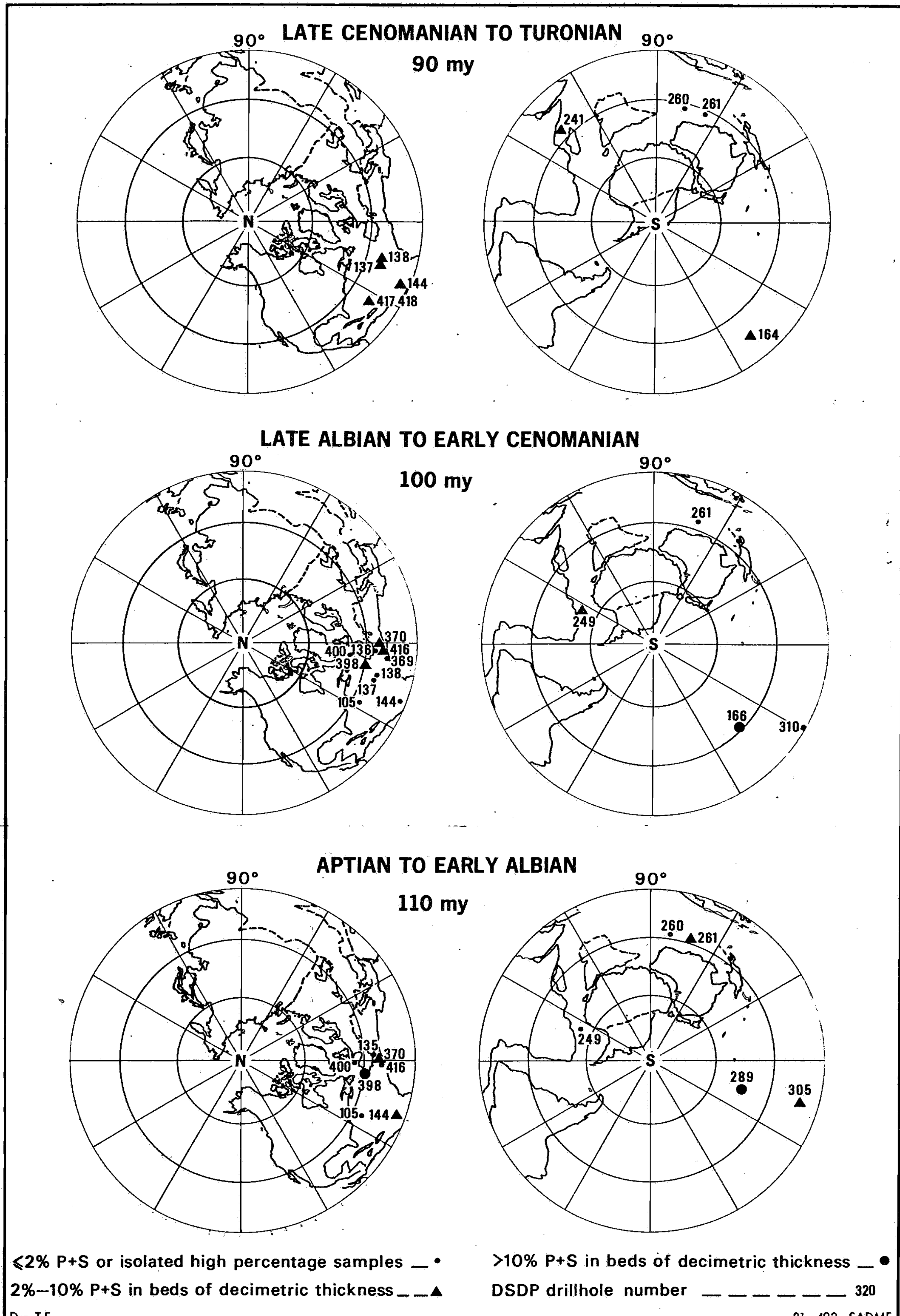

LATE CENOMANIAN TO TURONIAN
90 my
90°
90°
N
S
137
138
144
417
418
241
260
261
164
LATE ALBIAN TO EARLY CENOMANIAN
100 my
90°
90°
N
S
370
400
136
416
398
369
138
137
105
144
261
249
166
310
APTIAN TO EARLY ALBIAN
110 my
90°
90°
N
S
135
370
400
416
398
105
144
260
261
249
289
305
≤2% P+S or isolated high percentage samples — •
>10% P+S in beds of decimetric thickness — ●
2%–10% P+S in beds of decimetric thickness — ▲
DSDP drillhole number — 320
Drn T.E.
81–492 SADME

Fig. 5

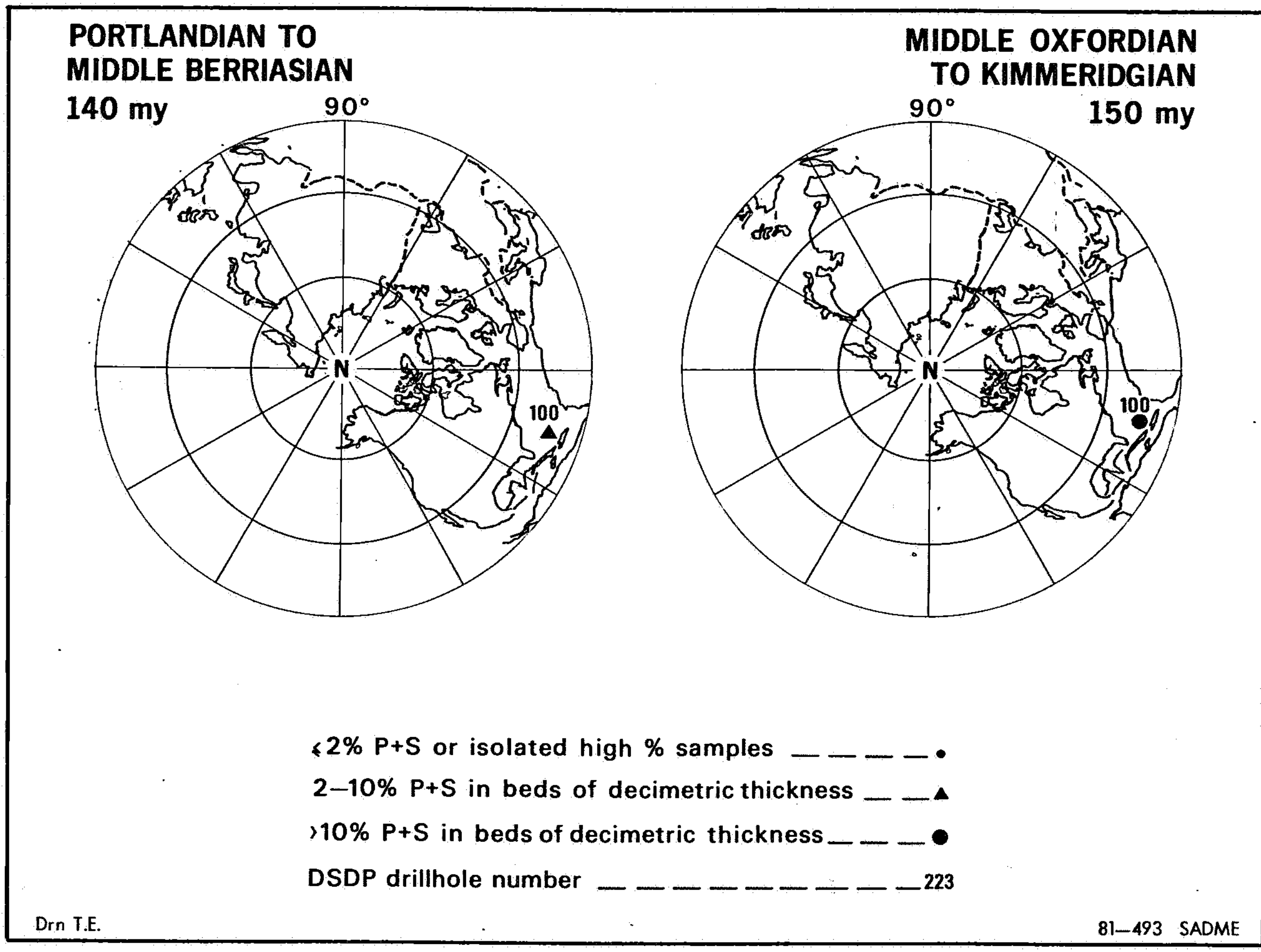

PORTLANDIAN TO
MIDDLE BERRIASIAN
140 my
90°
N
100
MIDDLE OXFORDIAN
TO KIMMERIDGIAN
150 my
90°
N
100
≤2% P+S or isolated high % samples
2–10% P+S in beds of decimetric thickness
>10% P+S in beds of decimetric thickness
DSDP drillhole number 223
Drn T.E.
81–493 SADME

Fig. 6

PALYGORSKITES 0 m.y. LATE PLIOCENE - HOLOCENE

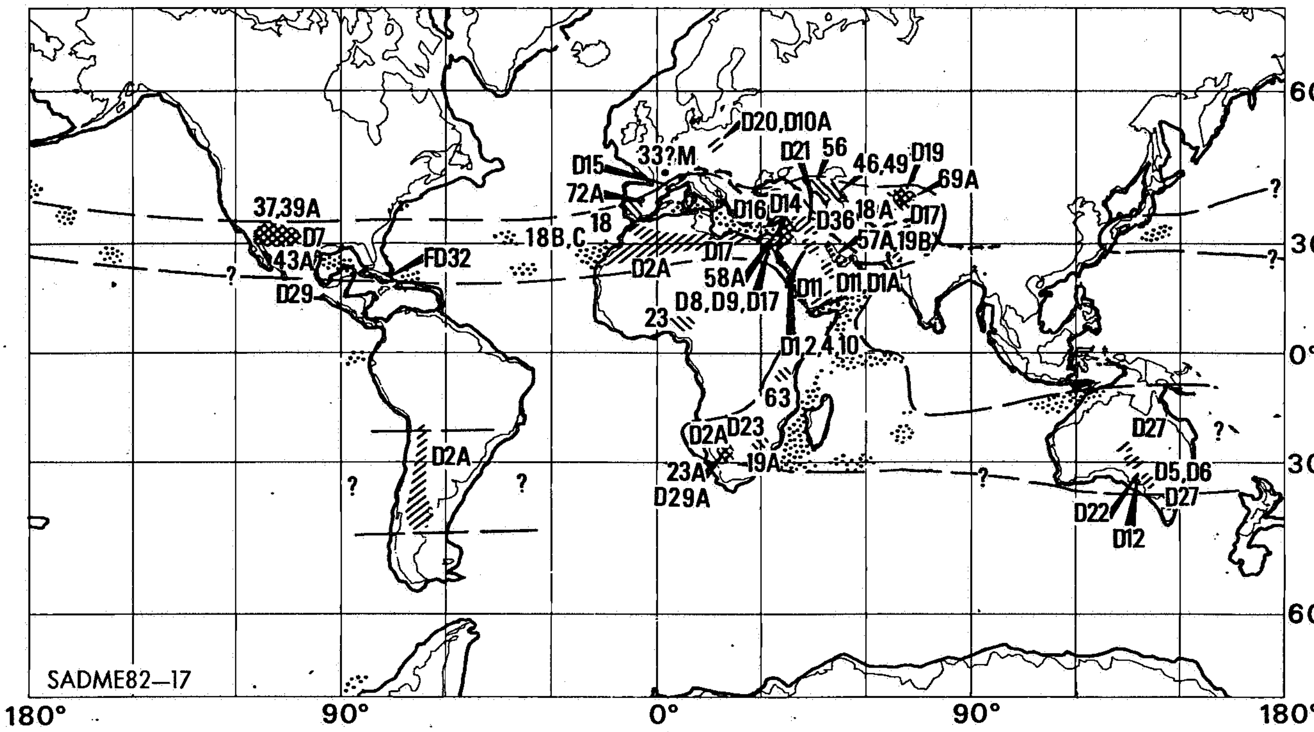


Fig. 7

PALYGORSKITES 10 m.y. MIDDLE MIOCENE - EARLY PLIOCENE

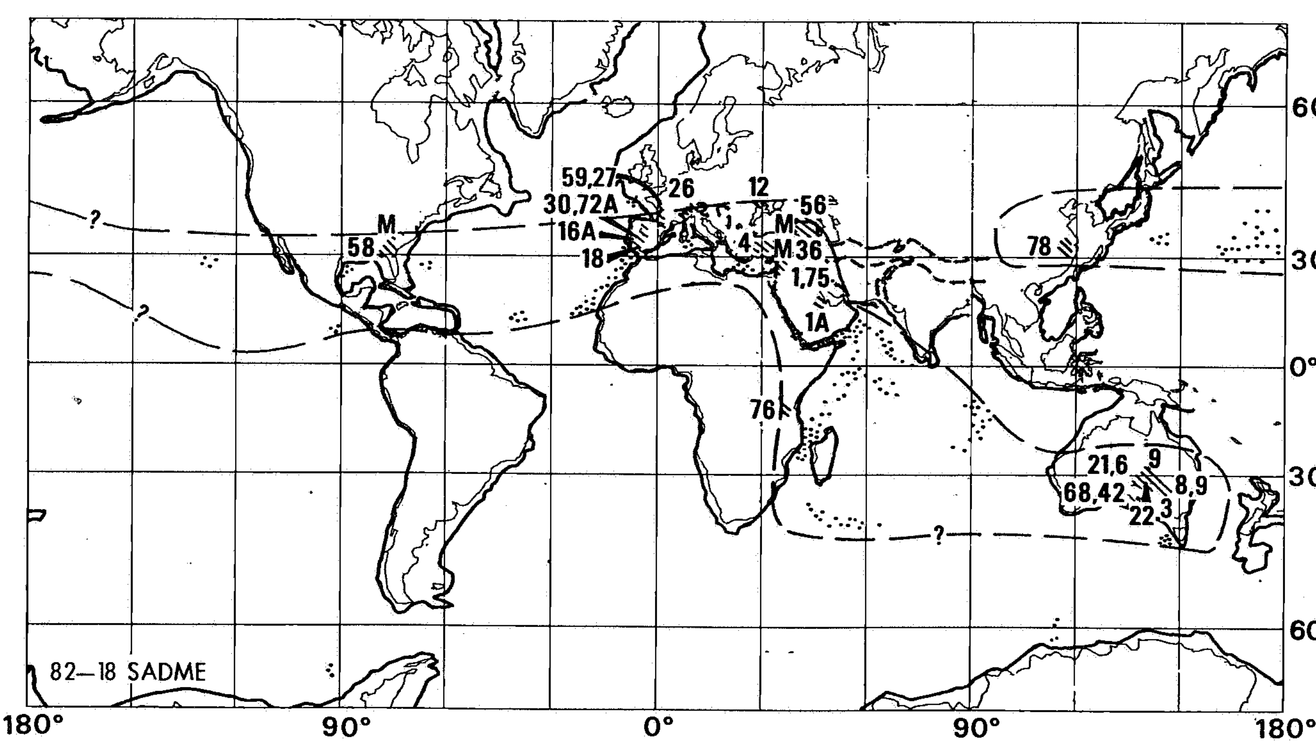


Fig. 8

PALYGORSKITES 20 m.y. LATE OLIGOCENE - MIDDLE MIOCENE

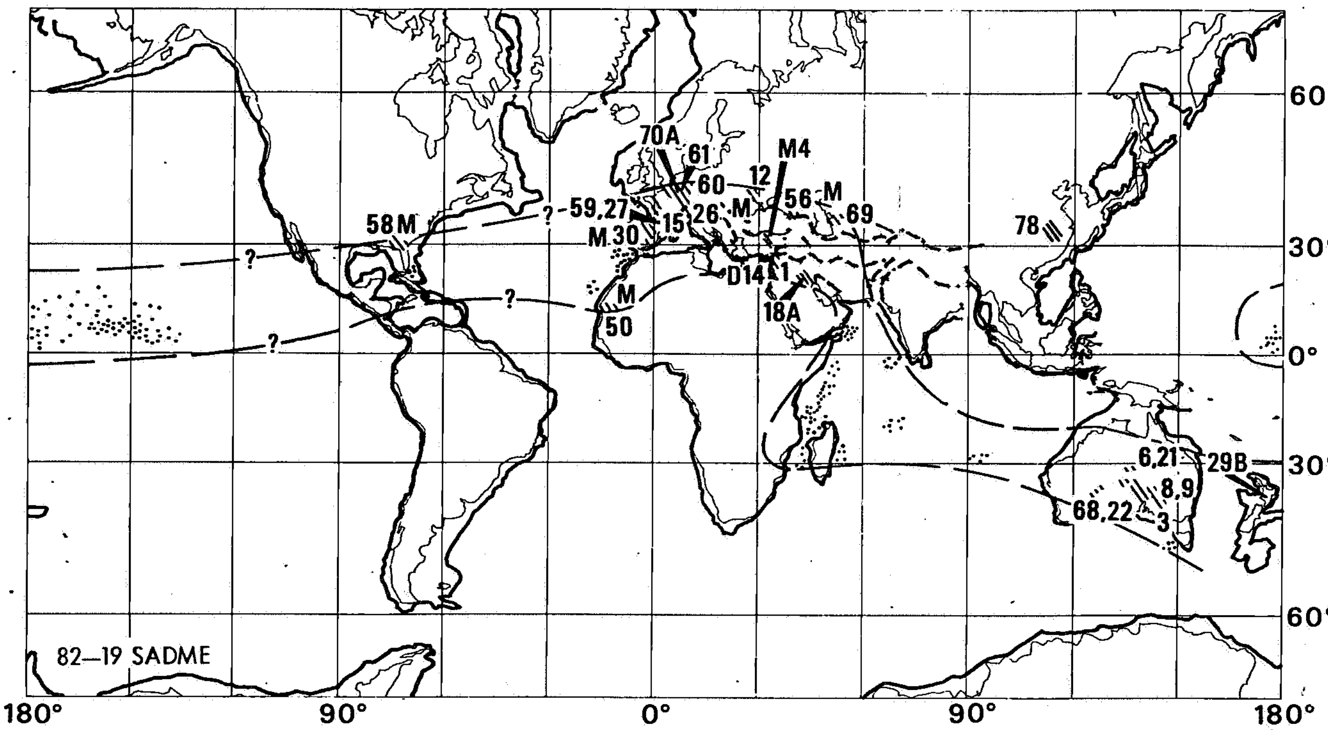


Fig. 9

PALYGORSKITES 40 m.y. MIDDLE EOCENE - EARLY OLIGOCENE

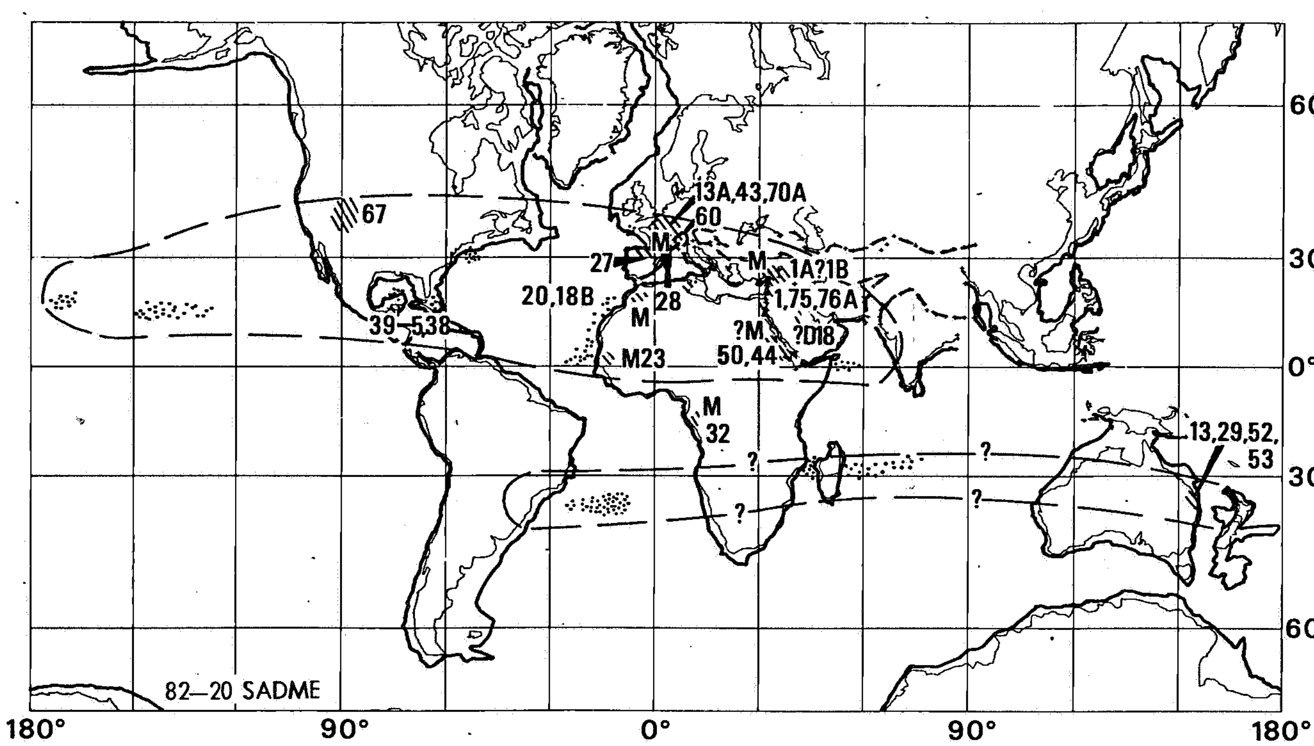


Fig. 10

PALYGORSKITES 60 m.y. MAASTRICHTIAN - EARLY EOCENE

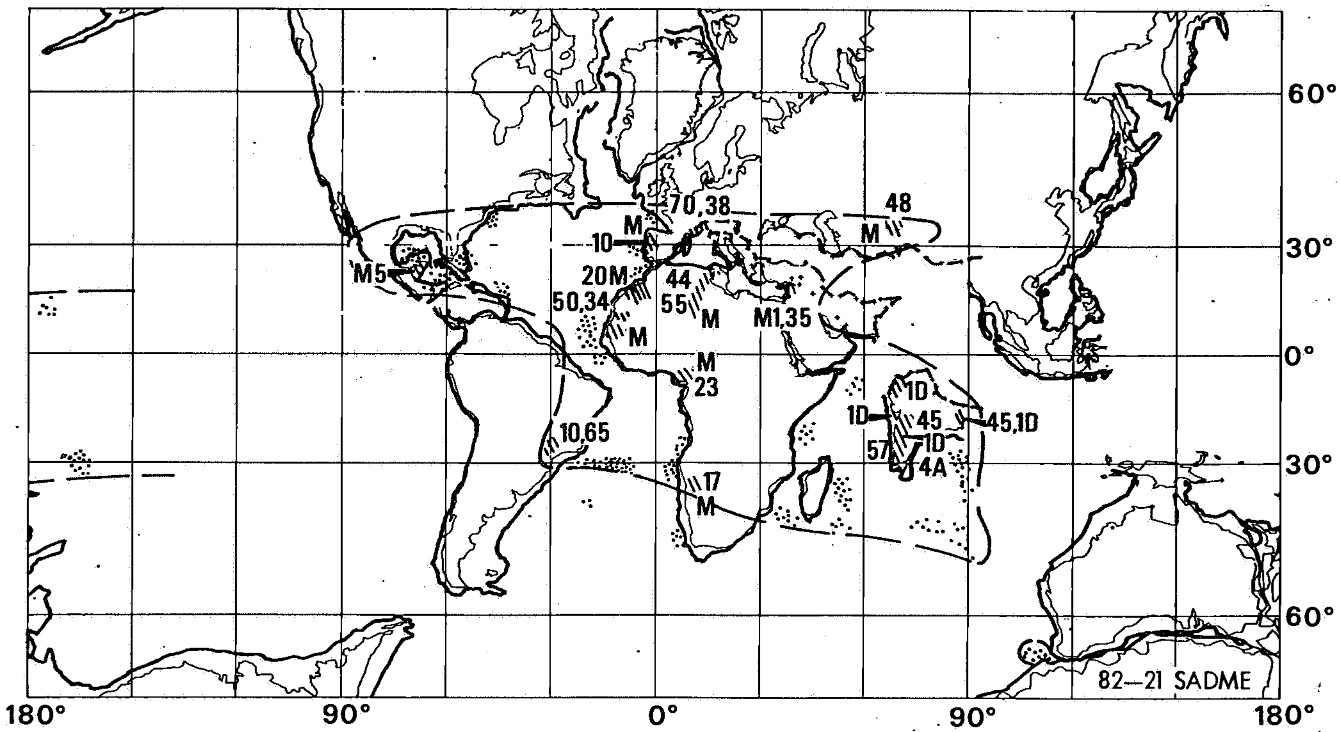


Fig. 11

PALYGORSKITES 80 m.y. CONIACIAN - CAMPANIAN

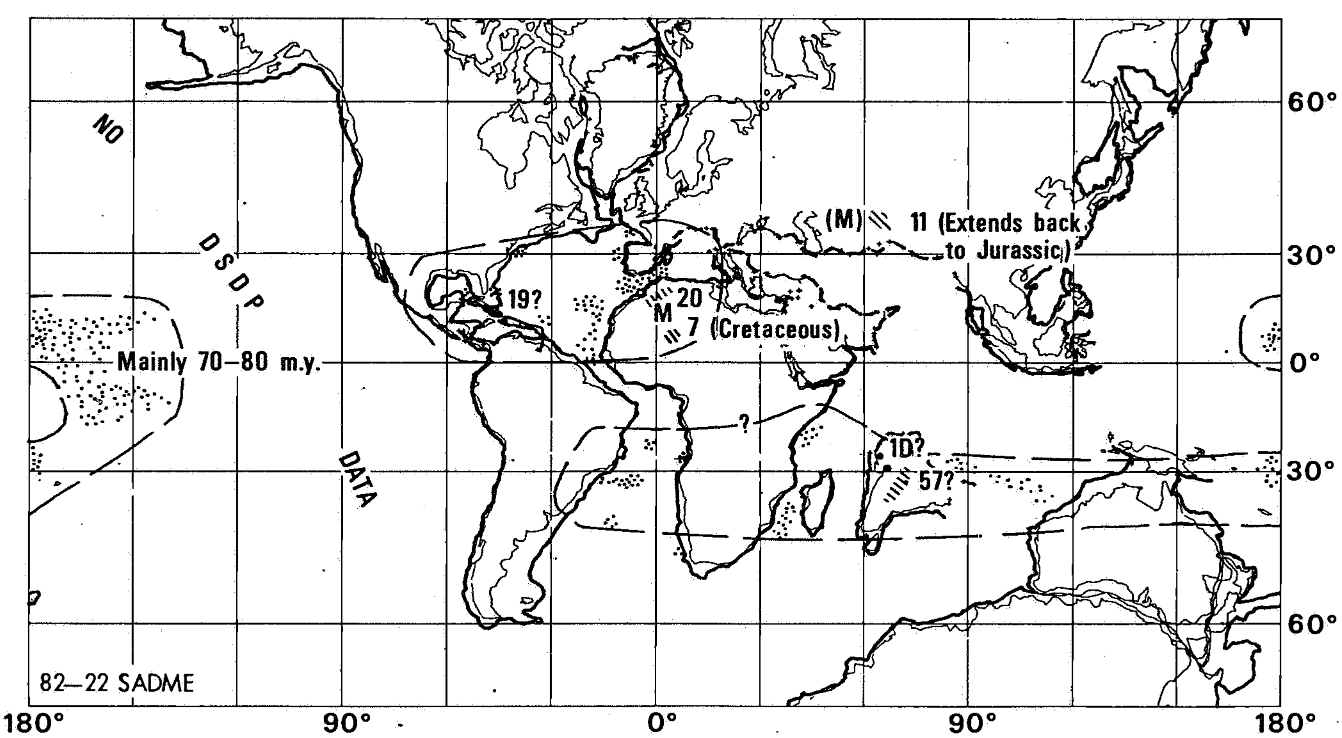


Fig. 12

PALYGORSKITES "VEIN" DEPOSITS

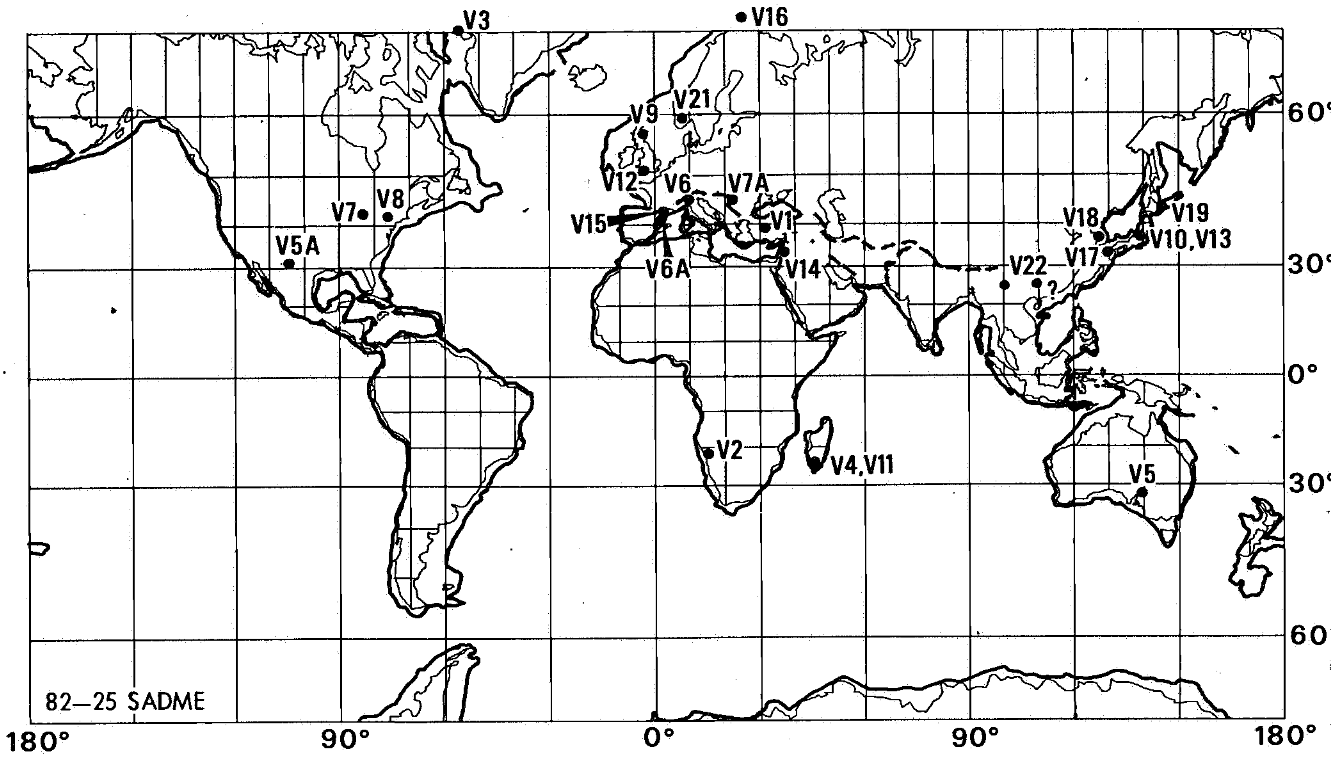
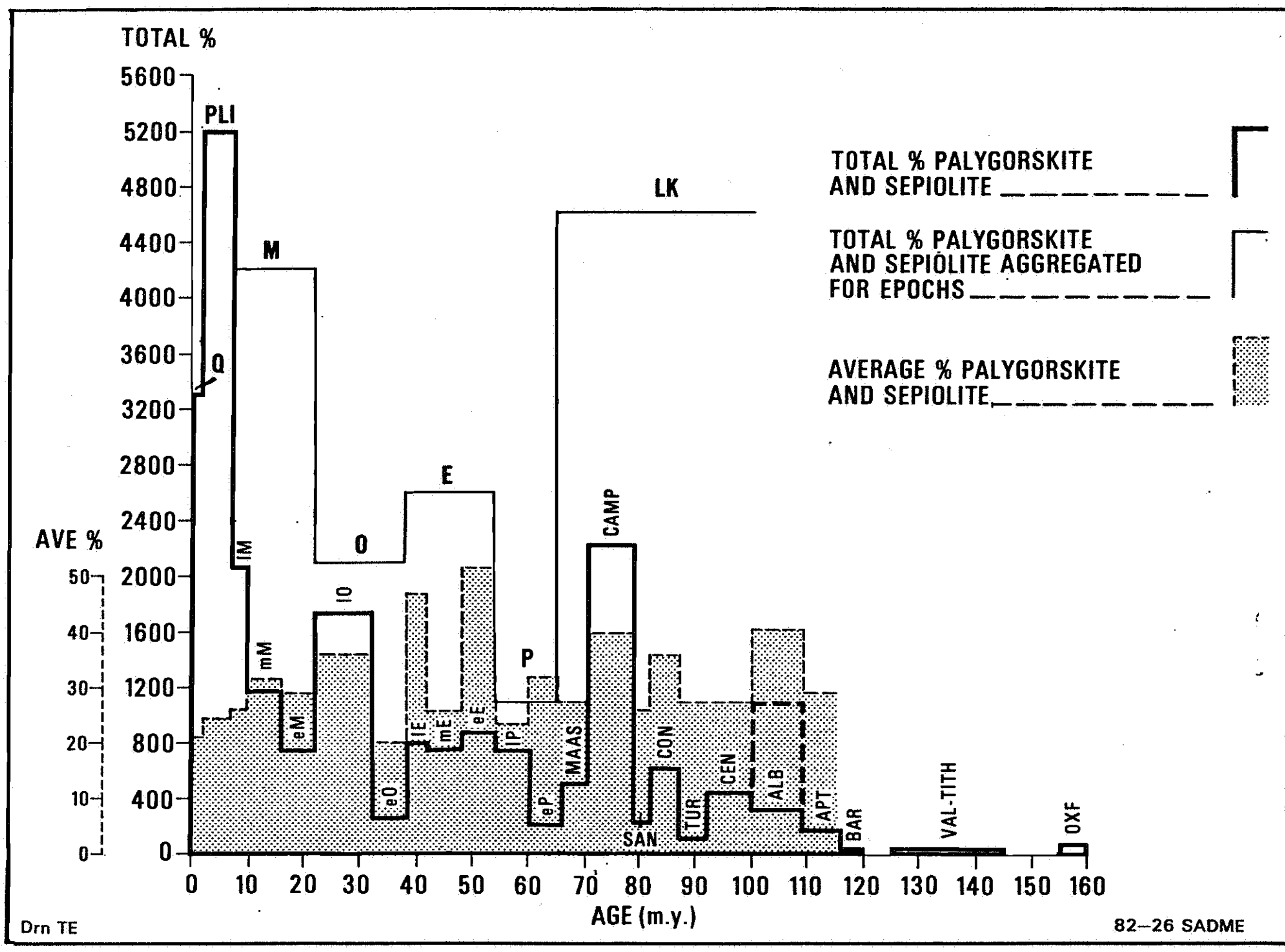


Fig. 13



TOTAL %
AVE %
TOTAL % PALYGORSKITE AND SEPIOLITE
TOTAL % PALYGORSKITE AND SEPIOLITE AGGREGATED FOR EPOCHS
AVERAGE % PALYGORSKITE AND SEPIOLITE
PLI
Q
M
O
E
P
LK
lM
mM
eM
lO
eO
lE
mE
eE
lP
eP
MAAS
CAMP
SAN
CON
TUR
CEN
ALB
APT
BAR
VAL-TITH
OXF
AGE (m.y.)
Drn TE
82–26 SADME

Fig. 14

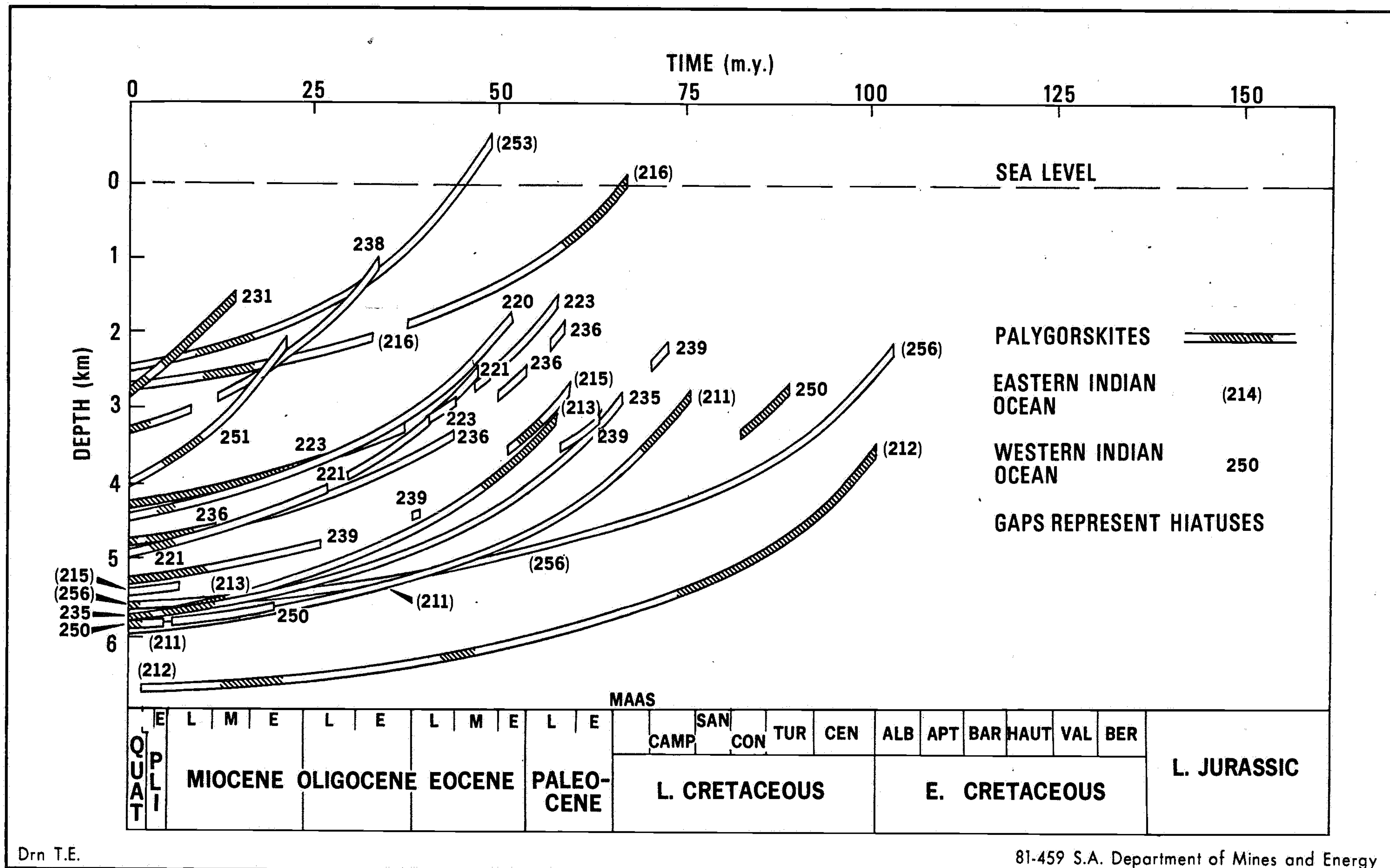

TIME (m.y.)
0
25
50
75
100
125
150
DEPTH (km)
0
1
2
3
4
5
6
SEA LEVEL
(253)
(216)
238
231
(216)
220
223
236
221
236
239
(256)
(215)
(213)
235
(211)
250
251
223
223
236
221
239
236
239
221
(215)
(256)
235
250
(213)
250
(211)
(256)
(211)
(212)
(212)
PALYGORSKITES
EASTERN INDIAN OCEAN
(214)
WESTERN INDIAN OCEAN
250
GAPS REPRESENT HIATUSES
MAAS
QUAT
L
E
PLI
L
M
E
MIOCENE
L
E
OLIGOCENE
L
M
E
EOCENE
L
E
PALEO-CENE
CAMP
SAN
CON
TUR
CEN
L. CRETACEOUS
ALB
APT
BAR
HAUT
VAL
BER
E. CRETACEOUS
L. JURASSIC
Drn T.E.
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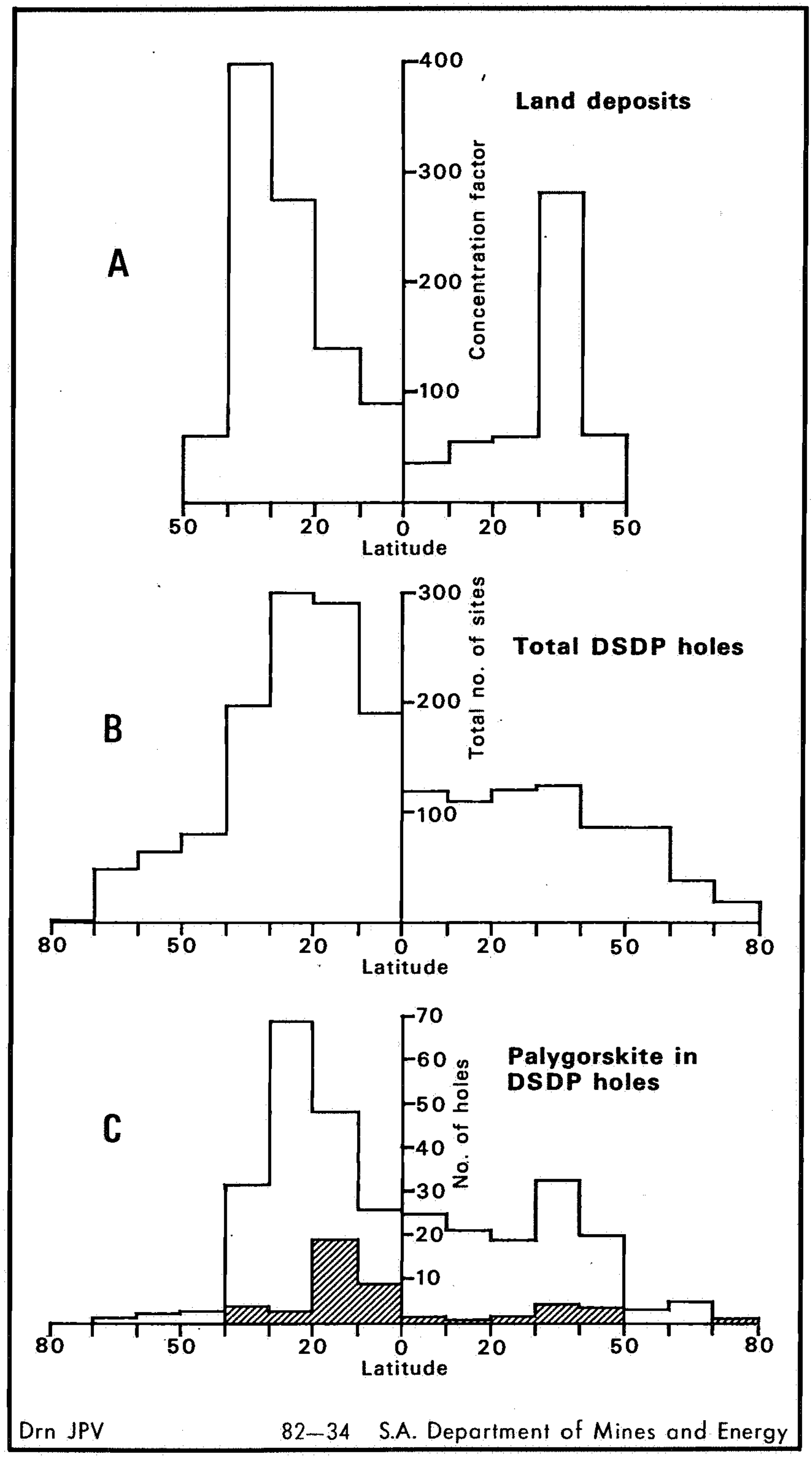
Fig. 15



A
Land deposits
Concentration factor
400
300
200
100
50
20
0
20
50
Latitude
B
Total DSDP holes
Total no. of sites
300
200
100
80
50
20
0
20
50
80
Latitude
C
Palygorskite in DSDP holes
No. of holes
70
60
50
40
30
20
10
80
50
20
0
20
50
80
Latitude
Drn JPV
82—34 S.A. Department of Mines and Energy

Fig. 16