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associated rocks. From literature study and his own experience, the author thinks that the slope-eugeosyncline concept of KÜNDIG (1959) seems to be compatible with many observed facts, and could probably be applied to part if not all of the Franciscan rocks.

GUATEMALA

Green radiolarian cherts of ? Albian age associated with ophiolites are reported from the Jalapa area north of Pedro Pinula. This information is drawn from unpublished reports by H. H. WILSON and H. F. JANSEN.

COLOMBIA

Eocene and Lower Oligocene rocks of the Costal Cordilleras in Colombia (GANSSER, 1959), which were deposited during periods of ophiolitic extrusions, are characterised by a high silica content. A connection between silicification and basic igneous rocks can be assumed.

Diabase with small intercalated chert beds occurs in the mountain range of the Central Cordillera (NELSON, 1956, p. 41). A Middle and Upper Cretaceous age is ascribed to the diabase.

Paleocene black cherts and greenish sandstones in the Rio Tulua area are associated with greywacke (NELSON, 1956, p. 43). The cherts often have a fine sandy appearance and probably cannot be regarded as true radiolarian cherts.

U.S.S.R.

Siliceous shales, cherts and radiolarian cherts, which range from Ordovician to Devonian, are found in the Ural Mountains.

Upper Ordovician siliceous shales passing into radiolarites (part of the Bardym Group) attain a thickness of 350 m. Graptolites such as *Climacograptus* sp. are present in this sequence (OVECHKIN, 1959, p. 257).

Silurian and Devonian cherts and siliceous shales occur on the eastern slopes of the Ural. They are hundreds of metres thick, often show a red to pink colour and occasionally contain a high manganese concentration. Graptolite-bearing siliceous rocks are often found associated with diabase-albitophyres (OVECHKIN, 1959, p. 294). The silica concentration is ascribed to the accumulation of tests of radiolaria and to volcanic activity (NALIVKIN, 1962).

In the Altai-Saian province (Kalba) the Upper Silurian is represented by argillites, siliceous rocks and red cherts (OVECHKIN, 1959, p. 308).

## 3. Remarks on the chert problem

A comprehensive and exhaustive discussion of the chert-associated sediment-ophiolite problem is beyond the scope of the present article. A few remarks will be made only on time-stratigraphic, paleogeographic, petrogenetical, sedimentological and structural aspects of these rocks, which follow from a review of their world-wide occurrences, and which are more intended to stimulate interest rather than to present solutions to the problem.

## A. THE STEINMANN TRINITY

In 1905, STEINMANN emphasised the association of deep-sea deposits such as radiolarian chert, deep-sea clay and cherty limestone («Radiolaritkalk») with ophiolites. Twenty-two years later, STEINMANN (1927, p. 640) pointed out that three ophiolite members, serpentinite (peridotite), gabbro and diabase-spilite (including variolite), usually occur together with radiolarian cherts and deep-sea clays, tintinnid-bearing limestones, and shales (argille scagliose) and argillaceous limestones. Although STEINMANN did not introduce a name to describe the three ophiolitic and the three sedimentary members, it would be logical to call them the «Steinmann Ophiolitic Trinity» and the «Steinmann Sedimentary Trinity». In the literature the term «Steinmann Trinity» is not always used in this sense. KÜNDIG (1956, p. 109), for example, called serpentine, pillow lavas and radiolarites the «Steinmann Trinity», which was a rather liberal interpretation of STEINMANN's original thinking. In the light of present knowledge, it would appear that a new nomenclature should be introduced to incorporate the variety of rock-types found in a slope-eugeosynclinal environment. Terms such as Ankara Melange (BAILEY & McCALLIEN, 1953) and Coloured Melange (GANSSER, 1955, p. 286), although useful and concise, cover one aspect only of ophiolitic-sedimentary associations and, moreover, are not precise enough in their meaning to anyone not thoroughly familiar with the subject.

In order to group together different lithologies and other characteristic phenomena, the following nomenclature scheme is proposed:

| | Prefix | End of word |
|---|---|---|
| a. Radiolarian cherts, cherts, interbedded shales | | -silite |
| b. Limestones, marly limestones, marls, and shales | carbo- | |
| c. Breccias, greywackes, sandstones, shales | clasti- | |
| d. Ophiolites | ophio- | |
| e. Turbidity phenomena | turbi- | |
| f. Slumping, sliding | slumpi- | |
| g. Olistostromes, olistoliths | olisto- | |

Ophio should always be used at the beginning of a composed word, silite at the end. Turbi, slumpi, and olisto should be inserted between ophio and carbo or clasti and silite where necessary. Composed words should only be used to designate associations which are more or less synchronous.

Examples:

| | Suggested name |
|---|---|
| Radiolarite-carbonate association in southern Switzerland and northern Italy | Carbo-silite |
| Ophiolite-chert association in France | Ophio-silite |
| Ophiolite-olistostrome-chert association in southern Iran | Ophio-olisto-silite |
| Ophiolite-radiolarite-greywacke-shale association in eastern Australia | Ophio-clasti-silite |

## B. TIME-STRATIGRAPHIC RELATIONSHIPS AND RELATED PROBLEMS

Geological age-dating of radiolarian cherts and ophiolites is a challenging problem, which in many cases may never be solved satisfactorily. This is especially true in tectonically complex areas and in Coloured Melange-type (ophio-olistosilite) outcrops. Even in undisturbed and easily accessible sequences, a subdivision into stages or sub-stages is hardly possible. Age assignments in literature, therefore, are usually rather generalised (e.g. Jurassic, Upper Cretaceous, possibly younger), or, if more evidence is available, indicate a lower and an upper time limit (such as post-Bajocian and pre-Upper Tithonian).

**a. Age-dating of radiolarian cherts.** Radiolarian cherts usually contain no fossils except radiolarians, sponge spicules and some problematica. Since HAECKAL's (1887) classical monograph on the radiolarians collected by the Challenger Expedition and RÜST's (1885, 1888, 1891–92) papers on fossil Mesozoic radiolarians, a number of contributions to the radiolarian problem have been made, among which the following should be mentioned: HINDE & FOX (1895), HINDE (1899), RUEDEMANN & WILSON (1936), ABERDEEN (1940), KOBAYASHI & KIMURI (1944), DAVIS (1950), CAMPBELL (1954), and ELLIOTT (1959). ELLIOTT's (1959) work on various Triassic, Jurassic and Cretaceous radiolarian faunas from sections in Iraq and elsewhere in the Middle East, confirms the existing view that as indicators of age, without associated evidence, these fossils as commonly preserved are of little use, but that in local and regional problems where they are associated with other evidence, they may be of considerable stratigraphic value. These remarks summarise clearly the stage of our present knowledge on radiolarians as time indicators. RIEDEL and FUNNELL (1964), who examined Tertiary sediment cores and microfossils from the Pacific Ocean floor, state that age assignments based on calcareous nannoplankton and radiolarians cannot at present be so precise as those based on the planktonic foraminifera. This appears to be principally a function of the amount of research into stratigraphical distributions that has been carried out and published on the various microfossil groups, rather than of any fundamental differences in the rates of evolution and geographical dispersal of the members of the three groups. Fossil radiolarians as contained in radiolarian cherts are usually poorly preserved, and it is doubtful whether intensified research would shed much new light on the stratigraphic value of these fossils without taking into account additional evidence.

Radiolarian cherts are often interbedded with shales, marls and limestones, which contain diagnostic fossils such as graptolites, belemnites, aptychi and foraminifera. Graptolites usually enable an accurate age determination to be made. The time-range of belemnites and aptychi is somewhat wider, but provides such age assignments as Kimmeridgian-Tithonian. Foraminifera, if not re-worked, are often excellent age indicators, especially for Upper Cretaceous chert formations.– Type-fossils, however, are normally found only in parts of a chert sequence, and therefore do not indicate the time range of the complete sequence.

Chert sequences, which are conformably overlain and underlain by type-fossil-bearing strata, can be fairly well dated, although some minor uncertainties still remain to be solved. Well-dated chert formations in this sense are, for example, those occurring in Morocco, southern Switzerland, northern Italy and Poland. One of the difficulties, however, is to assess whether the transition of the top and bottom layers of a chert formation into fossil-bearing strata, which often consist of limestones and marls with chert nodules, is continuous or discontinuous. A clear-cut answer to this problem cannot be given, as sedimentary conditions in a eugeosynclinal environment are not fully understood.

Radiolarian cherts in Mediterranean areas are usually overlain by tintinnid-limestones, which are generally of Upper Tithonian-Berriasian age. Thus the upper time-limit of the cherts can be fixed as lowermost Upper Tithonian or Lower Tithonian. If a more refined tintinnid stratigraphy were available, a more accurate age assignment of the uppermost part of the Mediterranean chert sequence could be made. A comparison of recent work on tintinnids by DOBEN (1962), BOLLER (1963) and REMANE (1964) shows slightly divergent interpretations of their time range. Further research on a regional basis could probably straighten out these differences.

Isolated chert lenses, which are often found as part of an ophio-olisto-silite, cannot be dated without proper regard to their complex field relationship. In a chaotic block mixture, the age of the blocks is not indicative of the age of the cherts. The Mammonia Formation of Cyprus is a striking example of an erroneous age-dating of the cherts on fossil evidence in an olistolith.

**b. Age-dating of ophiolites.** Dating the ophiolites in relation to cherts and associated sediments still remains a difficult task. Literature evidence on this subject is usually vague, and age assignments such as «pre-Tertiary, probably Mesozoic», or «Jurassic, possibly younger», are often made. KÜNDIG (1956) does not

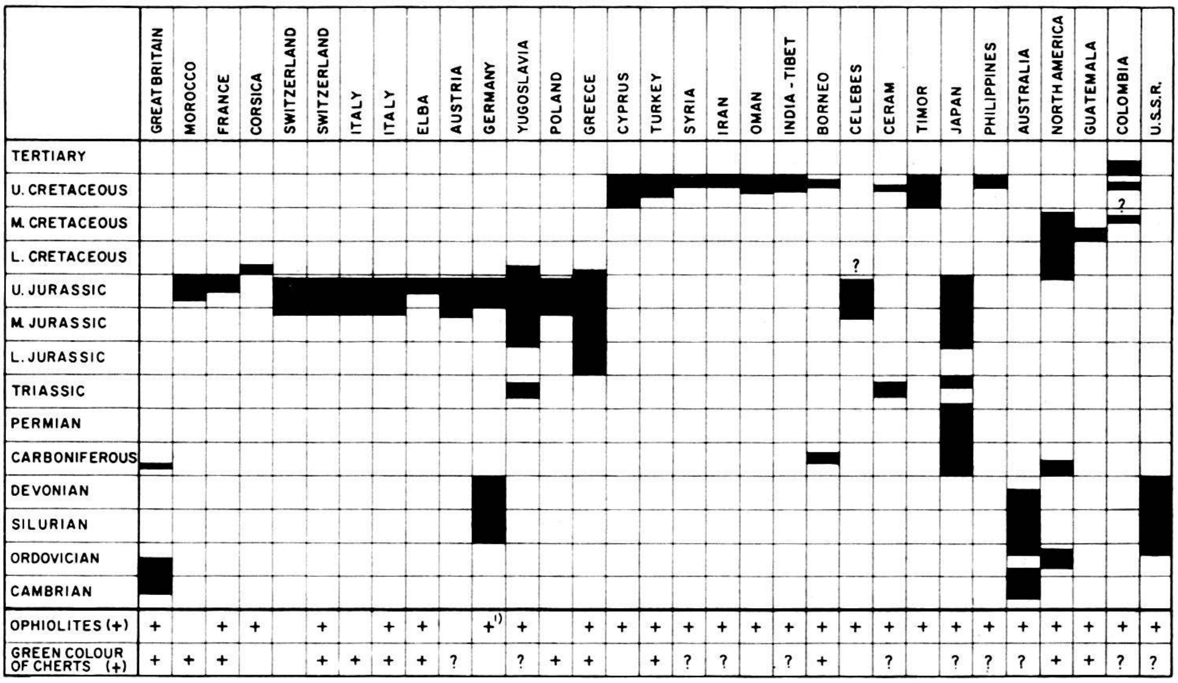


Fig. 5. Geological age of radiolarian cherts, association with ophiolites, and green colour of cherts. This is a simplified version of Plate I.

[1]) Palaeozoic cherts only are associated with ophiolites.

believe that an ophiolitic catastrophe is repeated in an orogenic cycle and therefore considers it improbable that a wide variance in age could exist in the ophiolitic belt of the alpine orogenic system. STILLE (1940b) relates intrusions and extrusions of ophiolites to an initial, simic, geosynclinal phase of magmatism. From a regional comparison of the eugeosynclinal parts of the Tethys geosyncline, an Upper Jurassic and Upper Cretaceous emplacement of the ophiolites could be postulated (see Table 1). It seems, however, that factual evidence is still more convincing than any speculation. What then are the facts?

The upper age-limit of an ophiolite emplacement can be fixed by normal superposition of well-dated sediments or by ophiolite detritus found in associated, younger sediments, which contain diagnostic fossils or which can be compared with sediments of known age. Overlap of Maestrichtian sediments on ophiolites can, for example, be observed in Turkey (KÜNDIG, 1959) and Oman (MORTON, 1959). Sediments containing ophiolitic detritus are reported from Switzerland (GRUNAU & HÜGI, 1957; GEES, 1955), Italy (GÖRLER & REUTTER, 1963; V. D. WAALS, 1946), and other places. GRUNAU (1957 a, b) produces evidence that the green colouration of radiolarian cherts in the south-eastern part of Switzerland (Arosa area) is partly due to fine serpentine detritus. Trace element investigations (GRUNAU & HÜGI, 1957) corroborate this point of view. The world-wide, frequent association of ophiolites with green cherts (Fig. 5), as far as is known to the author, has not been studied in detail. Although it is premature to advance a theory which is not based on a number of reliable observations, it would seem to the writer that the green colour of chert occurrences in California, France, Elba, Italy, Yugoslavia, Greece, Turkey, and Borneo might be caused partly or wholly by ophiolitic particles. This would provide means of dating the upper time-limit of ophiolitic emplacement. The identification of the nature of these particles could help in determining the relative age of different rock types of the ophiolitic suite. It would, of course, be tempting to interpret the absence of green colouration in a chert sequence as evidence that the ophiolites are younger than the cherts. In Oman, for example, this argument might be used to prove that the Semail Ophiolites are younger than the Hawasina Cherts. The author, however, is not inclined to believe that such negative reasoning is really convincing.

The lower age-limit of ophiolites could be established, in theory, from low-grade thermo-contacts with well-dated sediments (GRUNAU, 1947b). Such contacts, where observed, cannot always be interpreted unambiguously. Undisturbed superposition of ophiolite flows on sediments usually gives some indication of the lower time-limit of the ophiolite emplacement. Good examples are known from Syria (DUBERTRET, 1955) and Oman (MORTON, 1959).

The stratigraphic range of radiolarian cherts, associated sediments and ophiolite emplacement, as shown in Table 1 has to be regarded in the light of the aforementioned critical remarks. Time relationships of these occurrences in Europe, the Middle East, Australia and North America seem to be fairly well, although not yet entirely satisfactorily, established. Much work still remains to be done in the Far East, South and Central America in order to eliminate the existing gaps of knowledge and the uncertainties.

## C. PETROGENETICAL RELATIONSHIPS

The association of basic and ultra-basic igneous rocks with radiolarian cherts is so common (see Fig. 5), that the few chert occurrences not related to ophiolites, as observed in the western part of the Mediterranean Tethys geosyncline, can be considered exceptions of a general rule. It is, therefore, not surprising that views and hypotheses on petrogenetical relationships between cherts and ophiolites have been expressed by a great number of authors. As early as 1880 Pantanelli concluded that pillow lavas extruded at the sea-bottom during the deposition of chert and thereby created conditions which destroyed the natural animal enemies of the radiolarians, so that only the latter survived. This is probably the first, albeit somewhat fantastic attempt towards an interpretation of the chert-pillow lava association. LOTTI (1886) believed that during the final phase of ophiolitic extrusions silica- and soda-rich sources originated, which silicified already deposited, originally clayey sediments and at the same time stimulated enormously the development of radiolarians. STEINMANN (1905), one of the first geologists to emphasise the frequent association of ophiolites and cherts, thought that the abyssal sediments such as chert, deep-sea clay and pelagic limestones, were older than the basic and ultra-basic igneous rocks. The magmatic intrusion took place during a phase of uplift of the abyssal sedimentary trough. These early views by PANTANELLI, LOTTI & STEINMANN stressed two fundamental relationships of a chert-ophiolite association, namely the supply of silica and other elements to the sea-water as characteristic for differentiation processes of ophiolitic magmas, and the tectonic history of the basin. The many authors who have contributed to an explanation of the chert-ophiolite association, have produced additional evidence for these fundamental aspects.

The petrogenetical relationships of cherts and ophiolites, especially the problem of material supply, are treated by DEWEY & FLETT (1911), TALIAFERRO (1933), TALIAFERRO & HUDSON (1943), BURRI & NIGGLI (1945), BRAMLETTE (1946), ROUTHIER (1946), GRUNAU (1947 a, b), GEIGER (1948), WENK (1949), CORNELIUS (1951), GRUNAU (1957 a, b), GRUNAU & HÜGI (1957), CONTI (1958), IRELAND (1959), KRAUSKOPF (1959), and NEBERT (1959), apart from remarks and further contributions to the subject contained in papers of more regional interest.

Ophiolite emplacement in relation to eugeosynclinal basin history was discussed especially by STEINMANN (1927), STILLE (1940b), KÜNDIG (1956, 1959), and TRÜMPY (1958b, 1960).

The following remarks on chert-ophiolite associations resulting from the present world-wide review and the author's own experience are not intended to present an exhaustive discussion of the problem.

It would seem appropriate to tackle the chert-ophiolitic problem by attempting to establish mutual time-relationships before any further conclusions are drawn. In structurally complex areas, as for example in eastern Timor, ophiolites and cherts occur in close vicinity. The ophiolites, however, are of Permian or even pre-Permian age, and the cherts, belonging to the Bibiliu Group, are considered to range from ?Upper Cretaceous to Tertiary. No mutual relationship therefore exists, unless it could be proved that Tertiary magmatism took place. In many parts of the world, as for example in Ceram, Celebes, the Philippines, Borneo, and Colombia, no entirely satisfactory age assignment can be given to the ophiolites. Any assumption of silica supply in connection with ophiolitic extrusions in these areas would, therefore, seem highly speculative. In Syria, Turkey, Iran and Oman, good arguments can be advanced to prove that cherts and ophiolites are at least partly synchronous, and the silica could, in this case, have originated from a magmatic source. Ophiolite extrusions and intrusions probably took place in more than one phase in parts of Italy and Switzerland. Upper Jurassic cherts are associated with Jurassic serpentine, and the spilitic pillow-lavas are probably Middle to Upper Cretaceous. Serpentine particles are found in cherts and produce the green colouration of some of them. To what extent silica was supplied, still remains an enigma.

Observations made in Elba, Germany (Devonian and Silurian cherts) and other places, point to a direct relationship between ophiolite and chert thicknesses, which can best be explained by silica exhalations in connection with ophiolite extrusion. In Oman and Iran, the chert facies is restricted to ophiolite occurrences. Synchronous marls and shales are found more distant from any ophiolite influence.

Differentiation of a spilitic magma rich in carbon dioxide, water, other volatiles and soda, may lead to the formation of an end-member rich in silica and soda and other differentiation products rich in iron and manganese (DEWEY & FLETT, 1911; WENK, 1949). These hydrothermal silica-rich and soda-rich solutions and vapours emanate into sea-water, where they trigger off the inorganic precipitation of silica, and create favourable conditions for the development of siliceous organisms. According to NEBERT (1959, p. 14) silica-rich emanations originating also from arrested ultra-basic intrusives could rise along fissures and extrude into sea-water. This differentiation theory would account for the association of synchronous pillow lavas and serpentines on the one hand and siliceous sediments on the other. Inorganic precipitation of silica and silicification of bottom sediments would be the result of silica-rich emanations into sea-water, irrespective of bathymetry. Stimulation of the growth of radiolarians, however, seems only conceivable if the majority of them are forms which live close to the sea-bottom. Silica-rich emanations in deep water, for example, may hardly have any influence on radiolarians living at shallow depths. Determination of the depth range of radiolarians found in cherts, therefore, would be important in proving whether the silica supply theory, in connection with differentiation processes in ophiolitic magmas, can be applied to certain cases. As, however, the depth range of fossil radiolarians can only be established by comparison with recent species, any depth range assigned to fossil radiolarians is of restricted validity, since the depth ranges of fossil and recent radiolarians may not necessarily be identical.

The theory of decomposition of silicate minerals originating from eroded ophiolite bodies as a source of silica would be applicable in many cases, although its mechanism is not yet understood.

Carbon dioxide exhalations in connection with magmatic differentiation could explain the absence of carbonate in many chert sequences.

Hydrothermal solutions rich in iron and manganese may account for hematite and manganese concentrations in cherts. The majority of the hematite found in cherts, however, is probably derived from ferritic products of weathering in the source area, which were possibly altered at the place of deposition.

The pre-orogenic relationship between cherts and ophiolites as outlined by KÜNDIG (1956, 1959) and TRÜMPY (1960) seems to have a world-wide application. In the Tethys geosyncline, which extends from western Europe to the Indonesian archipelago, for example, ophiolites usually occur on continental slopes and continental edges. The prevalence of tensional stresses in the areas between the continental shelf and the deeper, eugeosynclinal parts may have led to the development of fissures, along which the rise, intrusion and outflow of ophiolitic magma took place. This could have happened during an initial, intermediate or final phase of a eugeosynclinal stage, which in itself may have extended through geological periods or may have been as short-lived as an epoch (for example: Upper Cretaceous in Oman), preceded and succeeded by miogeosynclinal stages. The mechanism of ophiolite intrusion and its relationship to extrusive phenomena is still somewhat controversial, and will not be discussed here. The author would not deny that ophiolites may also occur in areas not related to continental slopes.

From the foregoing the impression is gained that the chert-ophiolite petrogenetical relationship is one of the most challenging, but still imperfectly understood problems of geology and petrology.

## D. SEDIMENTOLOGICAL ASPECTS

The colour of radiolarian cherts, the carbonate proportion in a chert sequence, and the association of turbidites with radiolarites merit special attention in a regional context. Problems of a more specific nature such as diagenetic processes

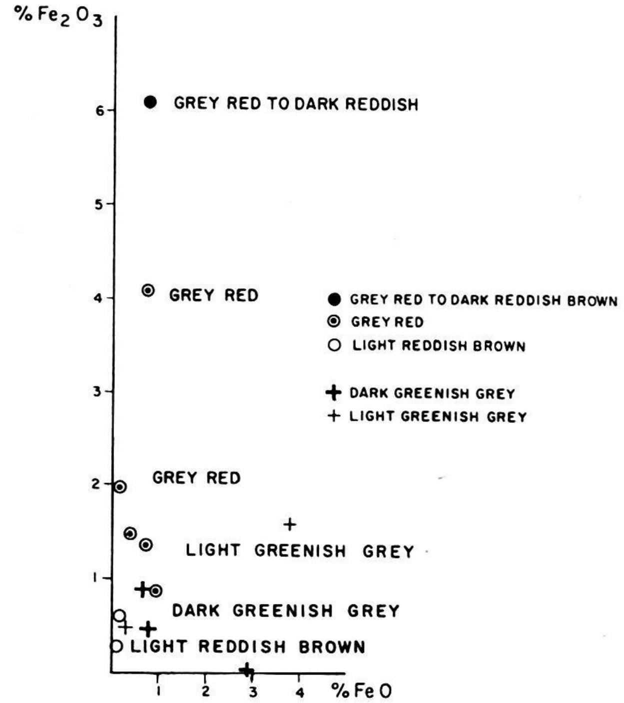


Fig. 6. Ferric-ferrous iron content in relation to colour of chert. Analyses by Grunau, Hügi and Rüfenacht (GRUNAU, 1959).

(IRELAND, 1959; GIANNINI, PIERUCCINI & TREVISAN, 1950) are not within the scope of this paper.

**Colour.** One of the most characteristic features of a chert sequence is its wide variety of colours, ranging from all shades of grey-red, red and reddish brown over dark green, light green, greenish grey to white-grey, dark grey and black, apart from the brown, orange and purple hues which occasionally occur. The relationship between colour on the one hand, and mineralogical and chemical composition on the other hand is not yet fully understood. Chemical analyses or partial analyses, especially of the ferric and ferrous iron content, are rather scarce (DAVIES, 1918; NIGGLI, DE QUERVAIN, & WINTERHALTER, 1930; GRUNAU, 1959) and do not provide a comprehensive answer to the colour problem. Mineralogical analyses of cherts are found sporadically in literature, but accurate colour descriptions of cherts in relation to chemical analyses and mineral content are practically non-existent. Fig. 6, which is based on analyses by GRUNAU, HÜGI and RÜFENACHT (GRUNAU, 1959, p. 126), clearly shows that light red hues become gradually darker with increasing ferric iron (hematite) content. Green colours are due to ferrous minerals such as chlorite. A comparatively high ferrous and low ferric iron content produces dark green colours. A rather astonishing fact is that cherts having almost the same ferric-ferrous iron content can be either red or green. The red or green rock colour is in such cases determined by the relative size and the density of the colour pigment.

The possible derivation of pigment in red beds is fully discussed by VAN HOUTEN (in NAIRN, 1961). Four main possibilities are considered:

1. Erosion of red soil containing anhydrous ferric oxide pigment.
2. Erosion of red bedrock containing anhydrous ferric oxide pigment.
3. Dehydration of goethite, aging of hydrohaematite, alteration of ilmenite-magnetite or biotite.
4. Precipitation of anhydrous ferric oxide or of hydrated ferric oxide later dehydrated.

VAN HOUTEN's review refers to continental and shallow marine red beds. The author would like to add a few remarks on eugeosynclinal red beds, although he is not in a position to make any straightforward nor yet definite statements:

Chert sequences deposited in the Tethys geosyncline are predominantly red. Their age is usually Upper Jurassic in the Mediterranean area and Upper Cretaceous in the Near and Middle East and south-eastern Asia. Upper Jurassic and Upper Cretaceous in the Tethys belt were periods of moist tropical or subtropical climate. Ferric oxide probably originated in red upland soils, and was subsequently washed into the Tethys geosyncline. Oxidising conditions at the bottom of eugeosynclinal basins preserved the red colour.

Red colours are reported from Palaeozoic chert sequences in Great Britain, Germany, the Urals, Eastern Australia, and North America. From literature evidence it is not clear to what extent the red colour is present, but it appears that the same palaeoclimatic reasoning as above could be applied for Ordovician, Silurian and Devonian red cherts.

Hydrothermal solutions connected with ophiolite extrusions might be an additional source of ferric iron. The author, however, is inclined to believe that the original source of hematite is from lateritic weathering on a mainland, since cherts which are not associated with ophiolites also show red colours.

The possible origin of green colour minerals is an even more delicate problem than the derivation of red pigment. In a few cases (see p. 42) it can be shown that ophiolitic particles cause the green colour of cherts. This, however, is not a general rule, and considerably more investigation is required before a more precise explanation can be given.

**Carbonate proportion in a chert sequence.** Only a few chert sections are accurately described in literature, so that little reliable data is available with regard to the carbonate-silica proportion of chert sequences in general, especially if they occur together with ophiolites. The hypothesis of carbon dioxide exhalations in connection with basic magma extrusion, which would have kept calcium carbonate in solution, undoubtedly appears attractive in order to account for the lack of, or small percentage of, carbonates in a number of chert sections all over the world. Some cherts which are not associated with ophiolites, however, such as Upper Jurassic radiolarites in the Bavarian Alps, are practically carbonate-free, but probably due to different reasons. In this context, the results of modern deep-sea research in the Pacific Ocean are of special interest. In considering the general lithology of two middle Tertiary cores from the western tropical Pacific, OLAUSSON (cited in RIEDEL & FUNNELL, 1964, p. 308) tentatively concluded that the release of magmatic volatiles into the bottom-water might have been responsible for a decrease in the calcareous content in the upper part of one of these Tertiary sequences. RIEDEL & FUNNELL (1964) conclude that the absence of contemporaneous calcareous microfossils from pre-Quaternary sediments containing apparently indigenous siliceous microfossils can be interpreted in two ways: (i) either decalcification took place by submarine leaching, or (ii) it may be reasonable to assume that the sediment accumulated below the calcium carbonate compensation depth at the time of deposition.

For fossil radiolarian chert sequences free or almost free from carbonates, it could by analogy be argued that they were deposited below the compensation depth, which at present in the Pacific lies between 4000 and 5000 m. Carbo-silites on the other hand were in most cases deposited above the compensation depth of that time. Compensation depth in this context refers to the depth below which the rate of solution of calcium carbonate exceeds the rate of its supply to the sea floor.

The author is not inclined to attribute a minor value to the carbon dioxide exhalation theory in favour of the depth theory or vice versa. Both theories are applicable, have a high degree of probability and do not exclude each other.

**The association of turbidites with radiolarites.** Radiolarian cherts interbedded with coarse clastics and sandstones are known from many parts of the world (for example, from California, Switzerland, Austria, Cyprus, and Australia). Graded beds in breccias were also observed (GRUNAU, 1959, p. 90). Tectonic activity, followed by slumping and slow mass-gliding movements down the continental slope into the deeper parts of a eugeosynclinal basin, provides a most satisfactory explanation to account for the clasti-silite association, which is in line with modern thoughts on turbidites (BOUMA & BROUWER, 1964). These views were held by KÜNDIG (1959) and TRÜMPY (1960) in full appreciation of the meaning of turbidites. The writer can only corroborate this interpretation as a general principle of world-wide significance.

In 1964, the author observed graded-bedding in oolitic lime grainstone (Fig. 3) alternating with chert at the base of the Upper Cretaceous Hawasina Cherts in Wadi Miaidin on the south flank of Jebel Akhdar (Oman). The oolitic grainstone, which was deposited originally in very shallow water, must have been reworked and slid as a turbidite down the slope into the chert basin. A similar oolitic lime grainstone intercalated in red cherts was noticed by the author in the Kevan area in south-eastern Turkey, north-west of Diyarbakir, on an excursion with M. RIGO DE RIGHI and M. SHEPHERD.

KÜNDIG's (1959) schematic cross-section through a geosyncline at an early stage is a most valuable contribution to illustrate the relationship between shelf, slope and eugeosynclinal sediments, which in KÜNDIG's scheme are presented as being more or less syntemporaneous. In many cases, the isochronous slope equivalents of the radiolarian cherts are nowhere exposed or may even be non-existent. A turbi-slumpi-clasti-phase often precedes or succeeds the perennial eugeosynclinal phase, which is usually characterised by chert deposition. In southern Switzerland, for example, Liassic, Lower Dogger and lowermost Biancone Limestone show turbidity or slump phenomena, whereas no turbidity or slump characteristics can be observed in the Upper Jurassic radiolarian cherts. In southern Iran, the Upper Cretaceous ophio-olisto-silites of Makran are succeeded by an Eocene-Oligocene flysch sedimentation. Similar observations are known from many other parts of the world, e.g. Japan and New Guinea. A careful and detailed analysis of the chert-turbidite associations would provide valuable palaeogeographic indications of the shifting of major sedimentary basins in space and time.

## E. BASIN CONFIGURATION AND BATHYMETRY

The present world-wide review of radiolarian cherts and associated rocks clearly demonstrates that radiolarian cherts were deposited in huge eugeosynclinal basins, flanked by continental slope and shelf regions. In the Tethys geosyncline, two major basins existed at different times: the Upper Jurassic Mediterranean basin and the Upper Cretaceous Middle East-Far East basin, which can be traced over a distance of thousands of kilometres. The extent of Palaeozoic eugeosynclinal basins was probably much less.

The two Tethys eugeosynclinal basins were differentiated into deeper zones and submarine swells which controlled sedimentation to a certain extent. The existence of systems of island arcs in the eugeosynclinal basins no longer seems convincing.

The absolute depth of eugeosynclinal basins is still a matter of speculation. The author would consider deposition in 1000–5000 m-deep water highly probable. In any case, all faunistic and sedimentological evidence points to an environment much deeper than neritic.

### F. POST-OROGENIC TECTONIC POSITION AND STRUCTURAL STYLE

Radiolarian cherts and associated rocks usually occur in the internal zones of mountain systems. They are often part of structurally complex units, characterised by faulting, thrusting, gravity-sliding and large-scale overthrusting. Epi-metamorphism is also observed.

Vertical tectonics and gravity-sliding play a major role not only during the eugeosynclinal stage of a basin but also characterise the orogenic history. Major basinal downwarps in tectonically active zones are followed by major uplifts, and the extreme difference in relief is compensated by tectonics.

The chaotic puzzle presented by an ophio-olisto-silite is difficult to untangle, as basinal and orogenic history are closely interwoven. The incompetent structural style of a chert sequence can be interpreted as resulting from slumping in the basin, disharmonic folding due to compression or post-upheaval gravity-sliding. In most cases no really convincing argument can be produced in favour of any particular one of these interpretations.

Radiolarian chert-ophiolite belts have a structural style of their own representing a complex, comparatively short-lived eugeosynclinal phase of a long miogeosynclinal basin history. Where chert-ophiolites are exposed, the impression of major diastrophic events is created. It should not be overlooked that the structural style of older and younger sediments in the vicinity of ophio-silites is usually completely different. In some areas a simple anticlinal belt can hide a complex ophiolite-chert body, which itself can be underlain by large, competent folds. Ophiolite-chert associations can be considered therefore as crustal layers distinguished by a difference in their behaviour as a result of basinal and orogenic deformation as compared to the overlying and underlying strata of different lithologic composition.

## 4. Conclusions

From a world-wide literature review of radiolarian cherts and associated rocks and the author's personal experience, the following conclusions may be drawn:

1. The impression is gained that radiolarian cherts and associated rocks, in comparison with continental and shallow marine sediments, have been inadequately investigated and are not fully understood. Many uncertainties regarding their petrographic characteristics, geological age, field relationship and genesis still exist, so that an attempt at even a partial synthesis of the chert problem seems premature. In this context the following remarks have to be considered.

2. Radiolarian cherts and associated sediments such as pelagic limestones, siliceous shales, graded lime-grainstones, sandstones, greywackes and coarse clastics, which occasionally show graded bedding, were deposited in the eugeosynclinal part of major geosynclines. In accordance with KÜNDIG's views, the eugeosynclinal sedimentary fill can be subdivided into perennial cherts, pelagic limestones and siliceous shales, and catastrophic olistostrome-turbidite rocks. Sedimentological and faunistic evidence points to deposition in rather deep water, thus confirming concepts held by MOLENGRAAFF (1900), the STEINMANN school, and more recently by COLOM (1955), KÜNDIG (1959), TRÜMPY (1960) and others.