Sedimentologie und Stratigraphie der Oligozän-Miozänen Molassesedimente in der Umgebung von Steyregg, Oberösterreich.

SEDIMENTOLOGY AND STRATIGRAPHY OF OLIGOCENE-MIOCENE MOLASSE SEDIMENTS, NEAR STEYREGG, UPPER AUSTRIA.

eingereicht von

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KURZFASSUNG

Die Molassesedimente im Gebiet von Steyregg (Oberösterreich) können in zwei Abfolgen gegliedert werden, nämlich in eine gemischt terrigen-karbonatische Abfolge (Steyregg) und den siliziklastischen Linzer Sanden. Die stratigraphische Ausbildung, geographische Verteilung, Mächtigkeiten, Lithologie, die Beschaffenheit der Kontaktflächen der Schichten und die räumlichen Beziehungen zwischen den verschiedenen Lithologien werden im Detail beschrieben und erklärt. Rasche laterale und vertikale lithologische Veränderungen in den Ablagerungen werden über verschiedene Lithofazies- und Sublithofaziestypen genauer untersucht.

Die Sedimente der gemischt terrigen-karbonatischen Abfolge bestehen hauptsächlich aus nichtkalkigen, kalkig-klastischen sandig und kiesigen Lithofaziestypen und schwach verfestigten Kalkareniten (bioklastische Arenite, sandige Biokalkarenite und Biokalkarenite). Sie wurden während der Transgression des Meeres nach Norden über das schwach abgesenkte und nach Süden einfallende Grundgebirge der Böhmischen Masse in einem Ablagerungsraum zwischen Strand-Vorstrand und Brecherzone mit Rampengeometrie sedimentiert. Diese Sedimente werden im Gebiet von Steyregg diskordant von pleistozänen Ablagerungen überlagert. Die Linzer Sande hingegen enthalten nur nichtkalkig-siliziklastische Lithofaziestypen (Kiese, Sande und Tone) und wurden im Bereich des Strand-Vorstrand bis zur oberen Brecherzone im Zuge einer Transgression des Meeres nach Norden über die Böhmische Masse akkumuliert. Der Kontakt mit den im Hangenden folgenden pliozänen Sedimenten ist erosiv. Die einzelnen Lithofazies- und Sublithofaziestypen werden allgemein durch erosive Diskordanzen begrenzt. Die Phasen der Erosion und Nichtablagerung während der Absenkung des Meeresspiegels wurden zum Teil durch eustatische Meeresspiegelschwankungen kontrolliert.

Fossilien sind nur in der verfestigten Kalkarenit-Lithofazies der gemischt terrigen-karbonatischen Abfolge zu finden. An Makrofossilien dominieren Fragmente von corallinen Algen (*Lithothamnium*), Austern und anderen Muscheln. Die Mikrofossilien werden vor allem von benthischen Foraminiferen dominiert. Diese können jedoch nicht als Leitfossilien verwendet werden. Daneben findet man als einzige Spurenfossilien vertikale und horizontale Röhren von *Ophiomorpha* in den Sedimenten der Linzer Sande.

Die primären Sedimentstrukturen in der gemischt terrigen-karbonatischen Sequenz umfassen hauptsächlich Schrägschichtung, Linsenschichtung, Rinnenfüllungen und Scour-und-Fill Strukturen. In der Abfolge der Linzer Sande jedoch sind Horizontalschichtung, wellige Schichtung, Schrägschichtung, Rinnenfüllungen, Scour-und-Fill Strukturen, Bioturbation, massive Bänke und Trockenrisse die häufigsten Sediment-Strukturen. Diese wurden meist unter dem Einfluß von welleninduzierten Strömungen, in Form von ebenen, schräggeschichteten Sandkörpern und Großrippeln auf großen Flächen eines flachen, seichten Meeresboden gebildet.

Die Petrographie der einzelnen Sedimente beider Abfolgen wird im Detail beschrieben, diskutiert und in Tabellen und Diagrammen zusammengefasst. Variationen in der Art und Menge der terrigenen Komponenten (Kiese, Sande und Tone), der Bioklasten, der mikritischen Grundmasse und des Zements dienen zur Unterscheidung der Lithologie in beiden Abfolgen. Darin eingeschlossen ist auch die Korngrößenverteilung, Sortierung und die Abrasion der siliziklastischen und bioklastischen Komponenten. Für Modalanalysen in der verfestigten Kalkarenit-Lithofazies wurde eine spezielle Klassifikation für gemischt terrigen-allochemische Sedimente verwendet.

In der gemischt terrigen-karbonatischen Abfolge von Steyregg gehen die bioklastischen Komponenten in den verfestigten Kalkareniten vor allem auf coralline Algen (*Lithothamnium*), Austern, benthische Foraminiferen und in geringerem Ausmaß auf Mollusken, Brachiopoden, Bryozoen und Echinodermen zurück. Die siliziklastischen Komponenten umfassen hauptsächlich Quarz, Feldspat (K-Feldspat überwiegt gegeuüber Plagioklas) und granitische Gesteinsbruchstücke. In kleinen Mengen kommen Schwer- und Tonminerale vor. Die wichtigsten nicht opaken Schwerminerale sind Sphen, Zirkon, Apatit und Disthen. Diese liegen als detritische Körner vor und stammen von Gesteinen des Grundgebirges der Böhmischen Masse. Ein Teil der Minerale der Montmorillonitgruppe wurde in einem marin-diagenetischem Umfeld aus anderen Tonmineralen gebildet. Tonminerale der Illitgruppe werden teilweise auf Bodenbildungen im Oligozän und Miozän zurückgeführt. Der größte Teil der Glaukonite bildete sich unter spezifischen Bedingungen aus Tonmineralen der Montmorillonitgruppe. Diese kommen in den verfestigten Kalkareniten vor. Die Porenräume sind generell mit Orthosparit und mit unterschiedlicher Matrix, vor allem Mikrit gefüllt.

In den Sedimenten der Linzer Sande bestehen die siliziklastischen Komponenten hauptsächlich aus Quarz, Feldspat (K-Feldspat > Plagioklas), gewissen Anteilen an granitischen Gesteinsbruchstücken und kleinen Mengen von Schwer- und Tonmineralen. Die transparenten Schwerminerale umfassen vor allem Zirkon, Sphen, Disthen und Apatit. Diese werden ebenfalls von Gesteinen des Grundgebirges der Böhmischen Masse hergeleitet. Große Mengen an Tonmineralen der Kaolinit- und Illitgruppe, die von Bodenbildungen im Oligozän und Miozän stammen, sind vorhanden. Minerale der Montmorillonitgruppe, die durch diagenetische Umwandlung gebildet wurden, kommen in diesen Sedimenten ebenfalls vor. Die Porenräume in diesen Sedimenten sind allgemein offen.

Die stratigraphischen Profile zeigen in Verbindung mit Korngrößenanalysen die vertikalen Variationen in den kompositionellen und texturellen Eigenschaften in den Abfolgen. Diese werden zur Bestimmung der relativen Wasserenergie im Ablagerungsraum der einzelnen Lithofazies- und Sublithofaziestypen verwendet. Die Sedimente beider Abfolgen sind in einem Ablagerungsraum mit einer mäßigen bis hohen Wasserenergie abgelagert worden. Transgressive Zyklen konnten festgestellt werden.

Dazu kommt, daß die ursprünglichen Sedimente der Kalkarenite von Steyregg durch metastabile Magnesiumcalzit-, und weniger häufig Aragonitskelettelemente dominiert wurden. Diese Fragmente wurden syndiagenetisch am, oder knapp unter dem Meeresboden in stabilere Mineralphasen umgewandelt. Große Mengen an biogenen Aragonit wurden noch vor der Lithifikation der Sedimente aufgelöst. Der Aragonit wurde nur dort nicht aufgelöst, wo im Sediment anaerobe Bedingungen herrschten. Die Körner, die aus Magnesiumcalzit bestanden, wurden ohne texturelle Veränderungen über inkongruente Lösung durch Calzit ersetzt. Gelöstes Karbonat wurde als Zement in angrenzenden oder benachbarten Sedimenten gefällt.

Zum Schluß werden die Molassesedimente im Arbeitsgebiet dargestellt. Es wird versucht ein Modell des Ablagerungsmilieus während der Bildung und des Ablaufes der Sedimentation aufzustellen.

ABSTRACT

The Molasse sediments in the Steyregg area (Upper Austria) are divided into two sequences, terrigenous mixed carbonate (Steyregg) and non-calcareous Linz sand. The stratigraphic definition, distribution, thickness, lithology and contacts of beds, and the three dimensional relationships between different lithologies, are described and figured in detail. Rapid lateral and vertical lithologic variations in strata are accommodated by recognition of several lithofacies and sublithofacies.

Sediments of the terrigenous mixed carbonate sequence include mainly non-calcareous, calcareous terrigenous (sand and gravel) lithofacies and slightly consolidated calcarenites (bioclastic arenite, sandy biocalcarenite and biocalcarenite). They were deposited in environments between beach-foreshore and shoreface, ramp setting conditions, as the sea transgressed towards the north over a slight topographically subdued the Bohemian Massif basement sloping towards the south. The contact with the overlying Pleistocene sediments is unconformable in the Steyregg area. On the other hand, the Linz sand sediments consist only of non-calcareous terrigenous lithofacies (gravel, sand and mud), were accumulated in beach-foreshore to upper shoreface environments when the sea also transgressed towards the north over a very low gradient peneplain of the Bohemian Massif basement. The contact with the overlying Pliocene sediments is unconformable. Lithofacies and sublithofacies in both sequences are commonly bounded by disconformities. They record periods of erosion or non-deposition during downward shifts in base level controlled partly by eustatic sea-level changes.

Fossils are found only in consolidated calcarenite lithofacies of the terrigenous mixed carbonate sequence. Macrofossils are dominated by fragments of coralline algae (*Lithothamnium*), oysters and bivalves. Microfossils are mainly benthic foraminifers, and can not be used for age indications. Whilst, burrowed *Ophiomorpha* shafts and tunnels are the only trace fossils in the Linz sand sediments.

Primary sedimentary structures in the terrigenous mixed carbonate sequence include mainly cross-stratification, lenticular-like stratification, channels and cut-and-fill structures. In the Linz sand sequence, however, thinly bedded wavy-stratification, cross-stratification, channels, cut-and-fill structures, bioturbation, massive beds and shrinkage cracks are evident. They were mostly formed under the influence of wave-generated currents, and also by the spreading and/or interfering of sand sheets and sand waves across extensive areas of a flat shallow sea floor.

The petrography of individual sediments in both sequences is described and illustrated in detail, and summarized on tables and pie diagrams. Variations in the type and content of terrigenous grains (gravel, sand and mud), bioclasts, micrite and cement serve to distinguish the lithology in both sequences including the kind and quantity of size, sorting, abrasion of siliciclastic and bioclastic grains. A specific classification for terrigenous mixed allochemical sediments is also used for modal analyses of the consolidated calcarenite lithofacies.

In the terrigenous mixed carbonate sequence, bioclastic grains (only in the consolidated calcarenites) are derived principally from coralline algae (*Lithothamnium*), oysters, benthic foraminifers and, to a lesser extent, from molluscs, brachiopods, bryozoans and echinoderms. Siliciclastic grains include mainly quartz, feldspar (K-feldspar much more than plagioclase) and granitic rock fragments, with small amounts of heavy and clay minerals. The principal non-opaque heavy minerals are sphene, zircon, apatite and kyanite. They were detritally inherited from the rocks of the Bohemian Massif basement. Some amounts of montmorillonitic clay minerals formed from the marine diagenetic transformation of other clay minerals are also present. Some quantities of illitic clay minerals derived from Oligocene-Miocene soils have been observed. Major amounts of glauconite developed from montmorillonitic clay minerals under specific environmental conditions are present in the consolidated calcarenites. Sediment pores are generally filled with granular orthosparite cement and by a variety of matrix including micrite.

In the Linz sand sediments, siliciclastic grains include mainly quartz, feldspar (K-feldspar > plagioclase) and some granitic rock fragments, with small amounts of heavy and clay minerals. The transparent heavy minerals are mainly zircon, sphene, kyanite and apatite. They were detritally derived from the rocks of the Bohemian Massif basement. Major quantities of kaolinitic and illitic clay minerals derived from Oligocene-Miocene soils are present. Other quantities including some amounts of montmorillonitic clay minerals formed by the diagenetic transformation are also found in this sediment. Pore-spaces in this sediment are generally empty.

Stratigraphic columns show the vertical variation in compositional and textural properties (in conjunction with grain-size analyses) through the sequences. They are used to interpret the relative energy level of the depositional environment of individual lithofacies and sublithofacies. Sediments of both sequences accumulated under environmental energy conditions ranging from moderate to strongly agitated waters. Transgressive cycles are evident.

In addition, the primary calcarenite sediment of Steyregg was dominated by metastable magnesium calcite and, less abundant, aragonite skeletons. These skeletons underwent syndiagenetic stabilization reactions at, or just below, the sea floor. Large quantities of skeletal aragonite were dissolved from the sediment before lithification. Aragonite was preserved only where anaerobic conditions were maintained in the sediment. Stabilization of magnesium calcitic grains involved the texturally non-destructive process of incongruent dissolution, which yielded a replacement product of calcite. Dissolved carbonate was precipitated as cement in adjacent or nearby sediment strata.

Finally, the Molasse sediments in the Steyregg area are outlined. A synthesis of the environment of formation and depositional history is established.

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CONTENTS

CHAPTER 1
INTRODUCTION

During the late Oligocene to early Miocene, the area east of Linz (Upper Austria) was characterized by the slow encroachment of a shallow sea onto a relatively low-lying landmass formed by rocks of the Bohemian Massif. The sediments are mainly shallow marine clastic sediments, and are relatively thin. These commonly consist of sandy gravels, slightly gravelly sands and consolidated calcarenites (cf. Folk, 1968, 1980) This thesis describes the stratigraphy and sedimentology of a predominantly transgressive sequence which is exposed in a small area east of Linz. These sediments belong to the Molasse of the Alps (Van Houten, 1969, 1973, 1974 and 1981).

1.1 Geographic location and map coverage.

The area covered in this work includes nearly 35 square kilometres east of Linz, Upper Austria. The Molasse sediment cropouts discontinuously throughout this region so that in more general terms the thesis may be defined as including the study of all subaerially exposed rocks of the Molasse in the area between the towns, **St.Georgen an der Gusen** in the east and **Steyregg** in the west (Fig. 1.1). Some additional lithological and stratigraphical information was obtained from outside of this area. The term **"Steyregg Area"** has been used as a general regional name for the study area. Important localities, roads, rivers and quarries, as mentioned in the text, can be seen on Figs. 1.1 and 2.1.

The Steyregg area is covered by a topographic map BMN 5803; Sheet No. 33 - Steyregg, published in 1988 at a scale of 1:25000 of the Lands and Survey (Landesaufnahme) of Austria. A grid for the field-map is obtained by extrapolating the reference lines from the published BMN 5803-Series topographic sheet. All grid coordinates should be, therefore, regarded as approximate. General geological maps with cross-sections, a scale of 1:1500000 edited by the

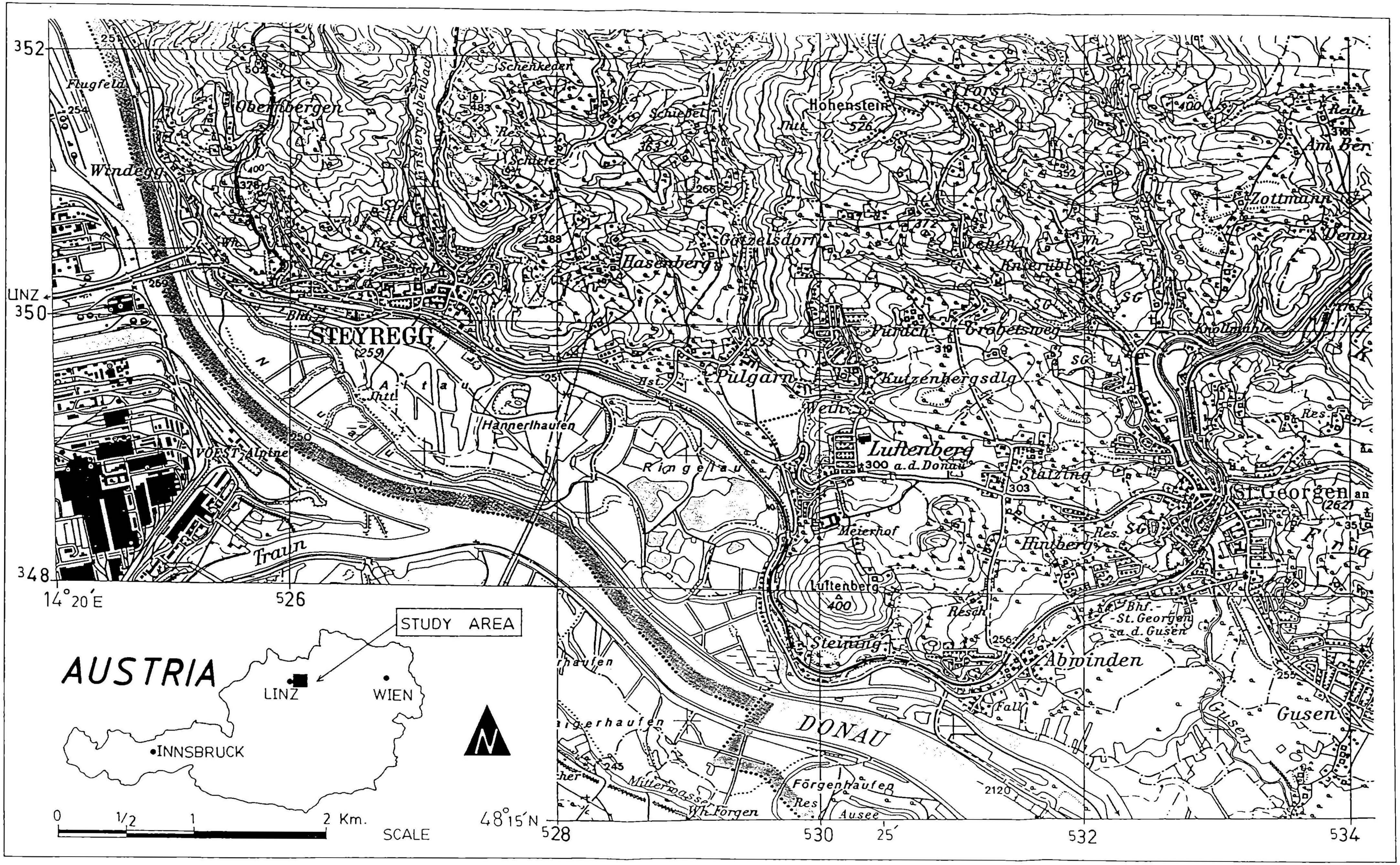

Fig. 1.1 Topographic map of a scale 1:25000 showing the more important place-names, roads and rivers in the Steyregg area refer to the text.

Geological Survey in Vienna (compiled by Beck-Mannagetta, P. and Matura, A., 1980, then it was modified by Demmer, W., 1991) together with a structural map of Austria (Fig. 1.3) of Janoschek and Matura (1980), geologic cross-sections in Steininger et.al. (1986) and a geological sketch-map of the Bohemian Massif in Austria of Matura (1979; in Janoschek and Matura, 1980, based on Fuchs and Matura, 1976), have been used as a regional geological overview for the research area.

1.2 Purpose and scope of the study.

The major task of the present study was to define and trace the patterns of lithologic variation, both vertical and horizontal, within the Molasse sediment in the Steyregg area, and thereby attempt to reconstruct in some detail the history and environment of the formation of the sediments as a whole.

The stratigraphic terminology applied to the Molasse in the other areas made it necessary to establish a detailed lithostratigraphy unified on a regional, Steyregg area, scale with respect to both nomenclature and correlation. To this end, field-work consisted mainly of measuring and describing 12 stratigraphic sections whose locations are shown in Fig. 2.1, and of collecting representative samples for laboratory study. Rock and sediment specimens were normally collected at every obvious lithologic change, and where lithologies appeared uniform, at 0.5-1.5 m intervals.

Field-work provided information on gross lithology, geometry and contact relationships of rock units, sedimentary structures and general microfaunal characteristics of the sediments. In the laboratory, detailed faunal lists were prepared and used in establishing the age of the sediments and assisting in paleoecological interpretations. In fact, however, few planktonic assemblages are controlled by ecological factors and are very rare or absent, most species being long-ranging, and are not age-diagnostic in this study.

Petrographic thin-section, grain-mounted slide, Scanning Electron Microscopy (SEM), X-Ray Diffraction (XRD) and Electron Microprobe analyses were used extensively for detailed study on compositional, textural, microfabric and diagenetic properties of the samples, particularly of the consolidated calcarenites. Considerable attention was paid to the possibility of characterizing major lithologic units by the nature of their insoluble residues and, in particular, the significance of textural parameters derived from mechanical analyses of insoluble residues from consolidated calcarenites and also non-calcareous Linz sand sediments. The mineralogy is defined with a special reference made about the nature and origin of clay minerals, heavy minerals and glauconites in the sediments. Conclusions from the above data are finally integrated in terms of the origin, environment of formation and history of sediments of the Molasse in the Steyregg area.

In the study, the Molasse sediments are divided into two major sample-groups, non-calcareous Linz sand sediments and terrigenous mixed carbonates of the Steyregg area. The "non-calcareous Linz sand sediments" are located in the area around St.Georgen an der Gusen town, Quarries B to F (Fig. 2.1). In contrast, the term "terrigenous mixed carbonate sequence" (cf. Mount, 1984, 1985; Nelson et.al., 1988; Martini et.al., 1992) is used for a combination of non-calcareous terrigenous sediments, calcareous terrigenous sediments and consolidated calcarenites, and only outcrops throughout near Steyregg town, Quarry A in Fig. 2.1.

Sample numbers used in the text and in reference to several stratigraphic columns refer to thin-sections, sedimentological analyses and/or specimens lodged in the petrographic collection of the "Institut für Geologie und Paläontologie, Universität Innsbruck (Österreich)". Additionally, the extra-number of samples were collected, and may be determined from cross-grid references presented in Appendix 8.

1.3 Previous work.

Previous geological work on the Molasse in the Steyregg area has not been carried out in detail. Most of the previous knowledge of stratigraphy and structural geology of the Molasse zone and its basement in Austria was the result of detailed paleontology and facies studies, geophysical work and drilling in the search for crude oil and natural gas, and has normally been included within the far wider framework of a regional geological survey, in which the construction of regional stratigraphy and paleogeography and also a geologic map were the main purpose (see Aberer, 1957; Braumüller, 1959, 1961; Janoschek, 1961, 1964; Brix et.al., 1977; Brix and Götzinger, 1964; Fuchs, 1976, 1980; Janoschek and Matura, 1980; Wagner, 1980; Malzer, 1981; Lengauer et.al., 1987; see also Tollmann, 1986; Menzl, 1989). Most of these earlier workers were concerned with general lithological and paleontological descriptions of the strata and of gross stratigraphic relationship between rock-units as a whole in the Austria area. On a regional scale, Van Houten, 1981; Rögl and Steininger, 1984; Pfiffner, 1986; Hamor and Berczi, 1986; Homewood, 1986; Homewood et.al., 1986; Steininger et.al., 1986; Allen et.al., 1991; Platt and Keller, 1992; Sauer et.al., 1992; Dercourt et.al., 1993, provided useful lithological data for the Molasse in the form of facies, sequence stratigraphy interpretations and paleoenvironmental conclusions. Füchtbauer (1967), Kurzweil (1973) and Roetzel et.al. (1983), in addition to stratigraphic work on the Molasse in the Austria area, made extensive use of insoluble residue studies in characterizing depositional environments and undertook petrographic analysis of consolidated calcarenites of the Molasse to established, detailed facies-relationships within the group in their study to document shifts in sediment's source area and in orientation of paleoslope in response to local patterns of differential tectonic movement.

1.4 Molasse overviews.

"Molasse" was emphasized by de Saussure (1976; its literature was found in Rutsch, 1971). Molasse is a formal stratigraphical name in the northern Alpine domain (Van Houten, 1969, 1973, 1974). Sedimentary Molasse basin is a classical peripheral elongated foreland trough (Dewey and Bird, 1970; Dickinson, 1974) extending from southeast-France in the west through Switzerland to the Linz-Vienna area of Austria in the east, over distance of about 700 kilometres in length (Allen et.al., 1985, 1986; Platt and Keller, 1992) and 75 to 125 kilometres in width (Van Houten, 1981). The southern margin is marked by the frontal thrusts of the Alpine belt whilst the northern feather-edge is bulged between the Variscan Massif Central and the Bohemian Massif (Van Houten, 1981; Allen et.al., 1991; Sinclair and Allen, 1992). These Massifes represent the Eurasian (European) plate and their structures were completed mainly during the Hercynian orogenesis (Malkovsky', 1987; Sauer et.al., 1992). The recent stage of deformation was the result of the collision of the European plate with the African plate (Flügel and Faupl, 1987; Nachtmann and Wagner, 1987; Ziegler, 1987a,b, 1989).

According to the intensity of influence by Alpine-Tectonic movements, northward moving thrust-sheets of the Flysch and Helvetic zones during a later orogenic phase (Ziegler, 1987a,b, 1989), the regional Molasse zone can be distinguished into three major parts (Fuchs, 1976; Rögl et.al., 1978; see also Steininger et.al., 1976):-

- Foreland Molasse (Undisturbed or Autochthonous Molasse).
- Disturbed Molasse (Folded and erected on the southern rim)
- Sub-Alpine Molasse (Strongly folded, imbricated and thrust-faulted or parautochthonous to allochthonous Molasse).

1.4.1 General stratigraphy.

Most of the Molasse is of syn-orogenic origin, some portions are post-orogenic, clastic wedges. It is a distinctive sedimentary facies consisting of continental and shallow marine clastic deposits derived from a source area undergoing rapid uplift and erosion (Aubouin, 1965; Mazarovich, 1972), characterized by an interdependence between sedimentation and tectonism (Dickinson, 1974; Allen and Allen, 1990).

The Molasse sequence was divided into four main units (Homewood, 1986; Homewood et.al., 1986; Pfiffner, 1986; Steininger et.al., 1986; Allen et.al., 1991), two comprising dominantly marine deposits and another two consisting of continental facies (Figs. 1.2, 1.4) in stratigraphic ordering as follows:-

- Upper Freshwater Molasse (Obere Süßwasser Molasse, OSM).
- Upper Marine Molasse (Obere Meeres Molasse, OMM).
- Lower Freshwater Molasse (Untere Süßwasser Molasse, USM).
- Lower Marine Molasse (Untere Meeres Molasse, UMM); includes North Helvetic Flysch.

In detail, seven megacycles have been identified in the Molasse of the northern Alps (Füchtbauer, 1967) and each coarsening upwards cycle reflected a separate tectonic pulse (Van Houten, 1974, 1981). However, variations in the rates of uplift and erosion in the source area and of subsidence and sedimentation in the basin can cause fining or coarsening upwards sedimentary cycles with or without internal syn-depositional folds and unconformities (Miall, 1978). Moreover, differential compaction has created some structural features (cf. Aniwandter et. al., 1990).

1.4.2 Austrian Molasse.

The Molasse in Austria comprises a sequence of detrital sediments of late Eocene to Miocene age overlying unconformably the foreland basement, the Bohemian Massif and

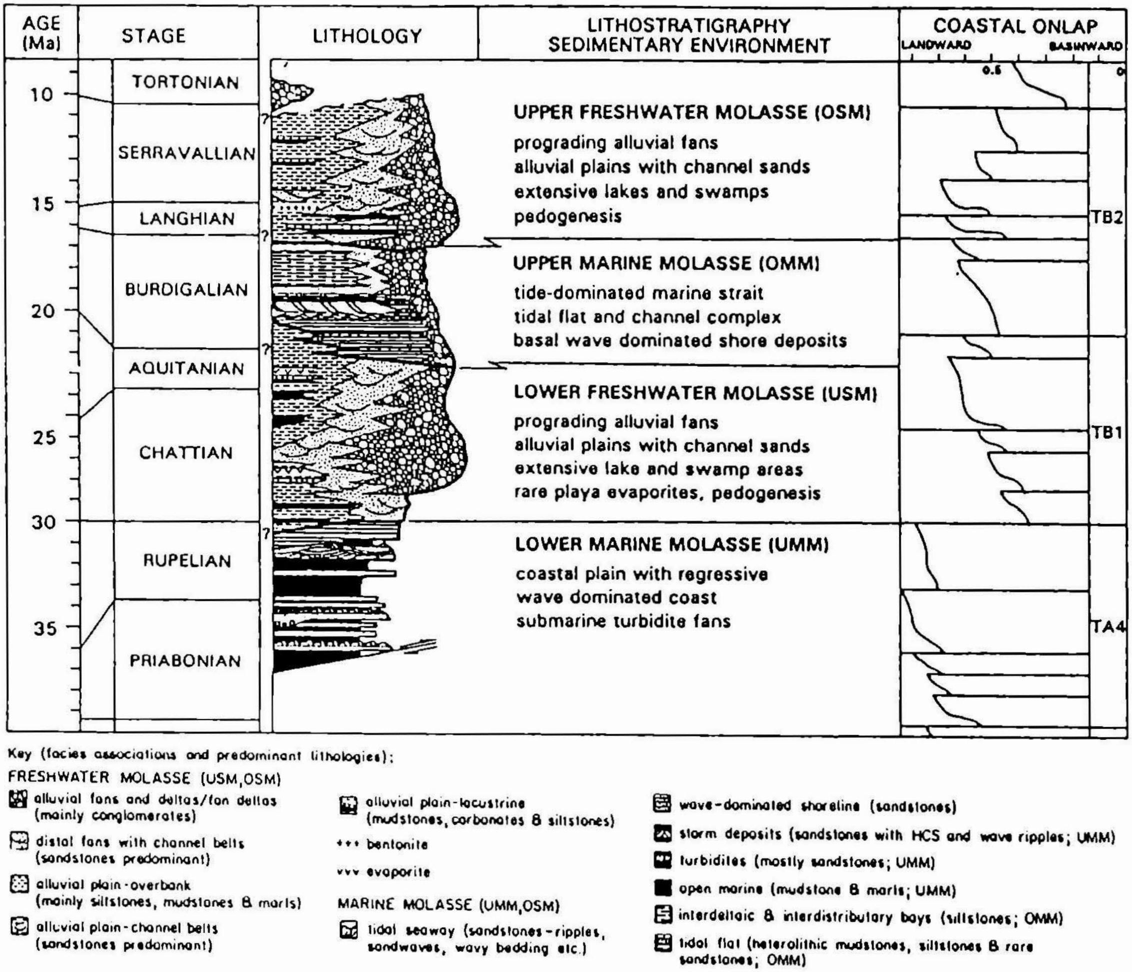

Fig. 1.2 A general stratigraphy of the Molasse sequence (Platt and Keller, 1992 based on Keller, 1990)

partially late Paleozoic to Mesozoic rocks (Janoschek, 1961; Kapounek et.al., 1967; Brix et.al., 1977; Wessely, 1987).

The Bohemian Massif is a branch of the Variscan Orogenic System, extending from Bavaria and Czecho-Slovakia to the northern part of Austria (Tollmann, 1977; Malkovsky', 1987; Fuchs and Matura, 1980). It forms, in Austria, essentially medium to high grade metamorphic rocks of Precambrian to Paleozoic age and extensive Variscan granite plutons (Sauer et.al., 1992), and is divided into three main units (Fig. 1.3): the Moravian zone at the eastern rim, the Moldanubian zone (the major part) in the centre and the Bavarian zone at the southwestern rim (Fuchs and Matura, 1980). This Massif dips southward below the Molasse sediments and further continues below the Alps (Nachtmann and Wagner, 1987; Sinclair and Allen, 1992). A considerable erosional phase in the early Palaeogene has formed a peneplain, sloping to the south and southwest, on which the sea advanced northward and eastward (Braumüller, 1961; Wagner, 1980; Lengauer et.al., 1987).

The Molasse sediments were deposited under marine, brackish-water and fresh-water conditions (Fig. 1.4), associated with coals or lignites, marine algal limestones, bituminous marls and shales as well as conglomerates, sandstones, siltstones, claystones and marlstones (Steininger et.al., 1986). According to Janoschek and Matura (1980), the Austrian Molasse can be divided into five main regional parts. However, only a small area within the Molasse zone situated between the rivers Salzach (and Inn) in the west and the area of Amstetten in the east (No. 2 in Fig. 1.5A) has been investigated in this study.

During the late Eocene to Miocene, this area formed a part of the Alpine foreland basin, three phases of depositional facies of the Molasse are recognized and described as follows (Janoschek, 1964; Kollmann, 1977; Oberhauser, 1980; Roetzel and Kurzweil, 1986; Steininger et.al., 1986; Allen et.al., 1991).

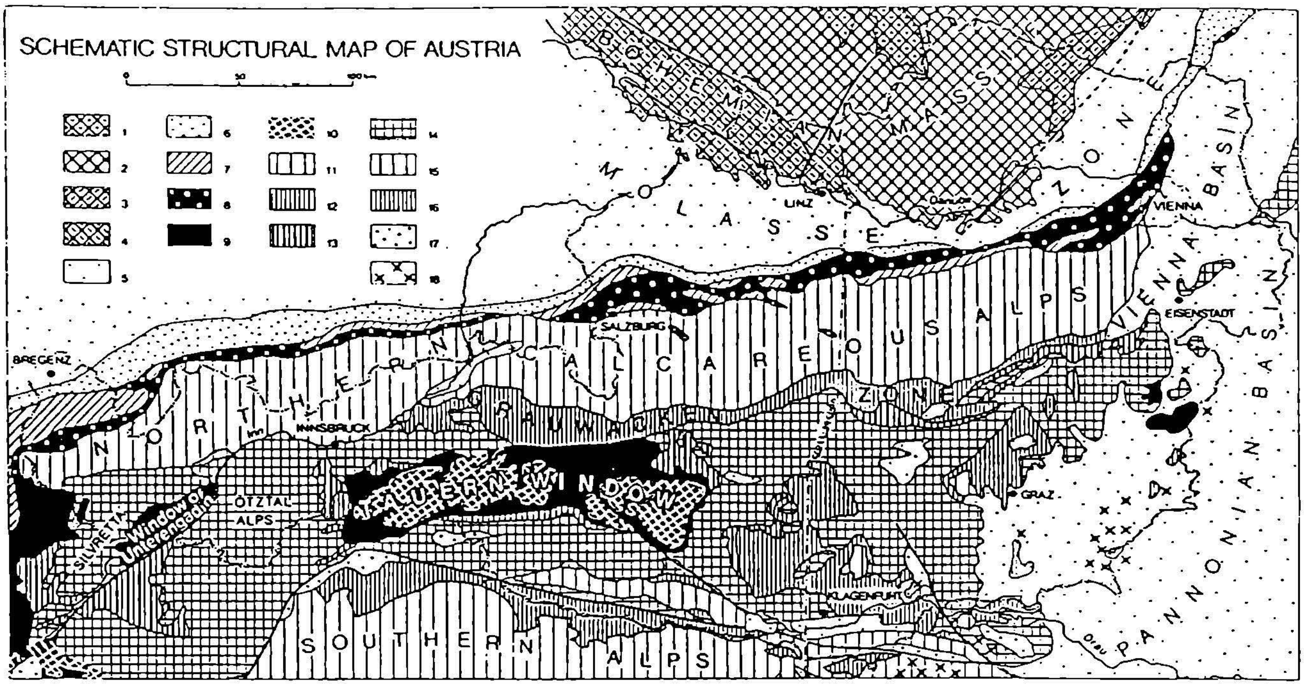

Fig. 1.3 Schematic structural map of Austria (Janoschek and Matura, 1980 based on Beck-Mannagetta and Matura, 1980).

1—4 = Bohemian Massif:
1 = Post-Variscan sedimentary cover; 2 = Moldanubian Zone; 3 = Moravian Zone; 4 = Bavarian Zone; 5 = Tertiary basins; 6 = Subalpine Molasse; 7 = Helvetic and Klippen Zone; 8 = Flysch Zone; 9 = Metasedimentary rocks of the Penninic Zone; 10 = Crystalline basement of the Penninic Zone; 11—14 = Austro-Alpine Unit; 11 = Permomesozoic in North-Alpine facies; 12 = Palaeozoic; 13 = Permomesozoic in Central Alpine facies; 14 = Crystalline basement ("Altkristallin"); 15 = Permomesozoic of the Southern Alps; 16 = Palaeozoic of the Southern Alps; 17 = Periadriatic intrusive masses; 18 = Neogene andesites and basalts.

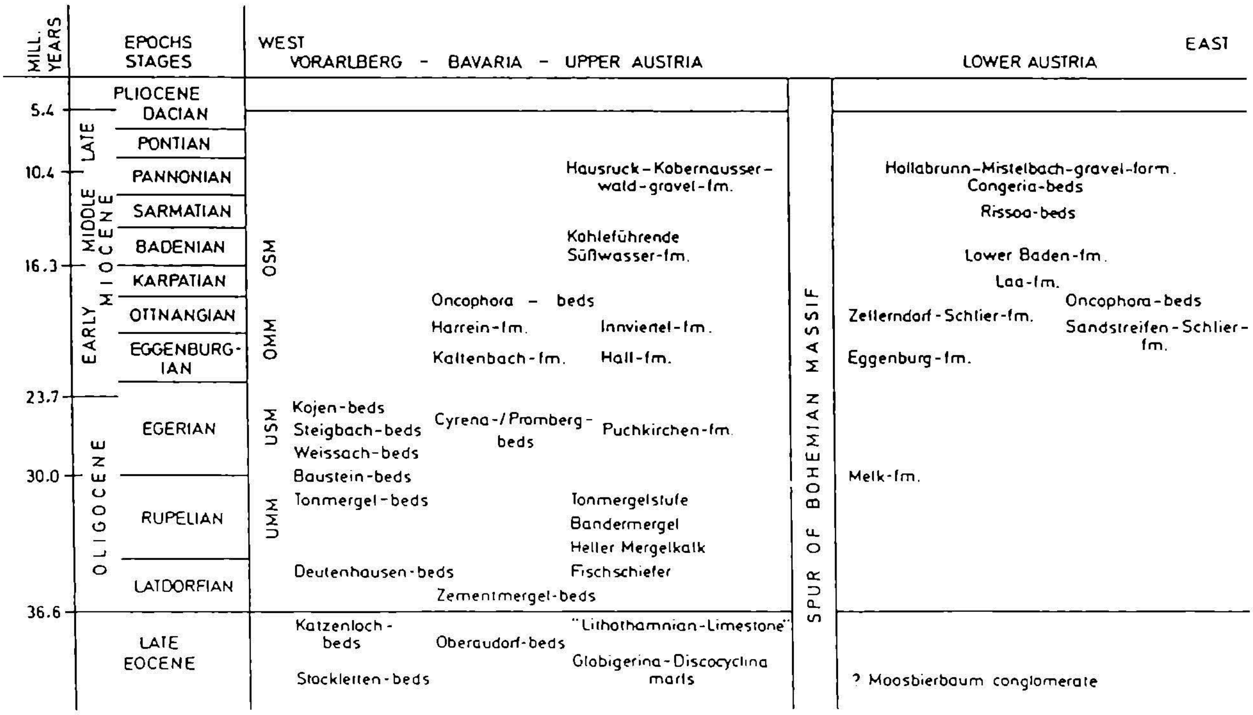

Fig. 1.4 Stratigraphic units of the Molasse sequence from Western Austria across Bavaria to Upper and Lower Austria (Based on Steininger, et.al., 1986):-

UMM = Untere Meeres-Molasse (Lower Marine Molasse)
USM = Untere Süßwasser-Molasse (Lower Freshwater Molasse)
OMM = Obere Meeres-Molasse (Upper Marine Molasse)
OSM = Obere Süßwasser-Molasse (Upper Freshwater Molasse)

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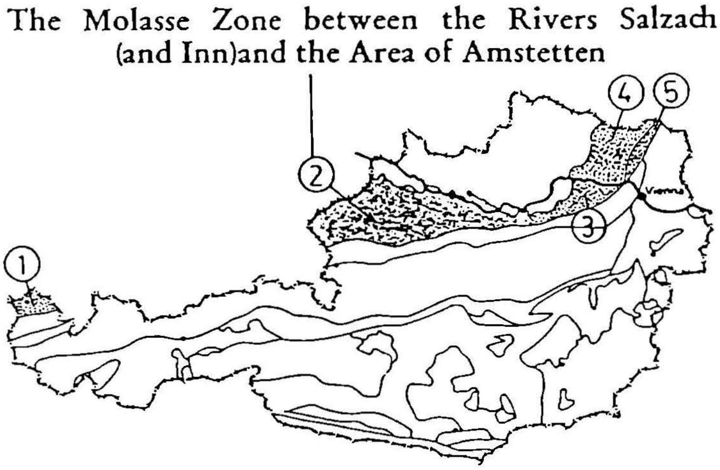

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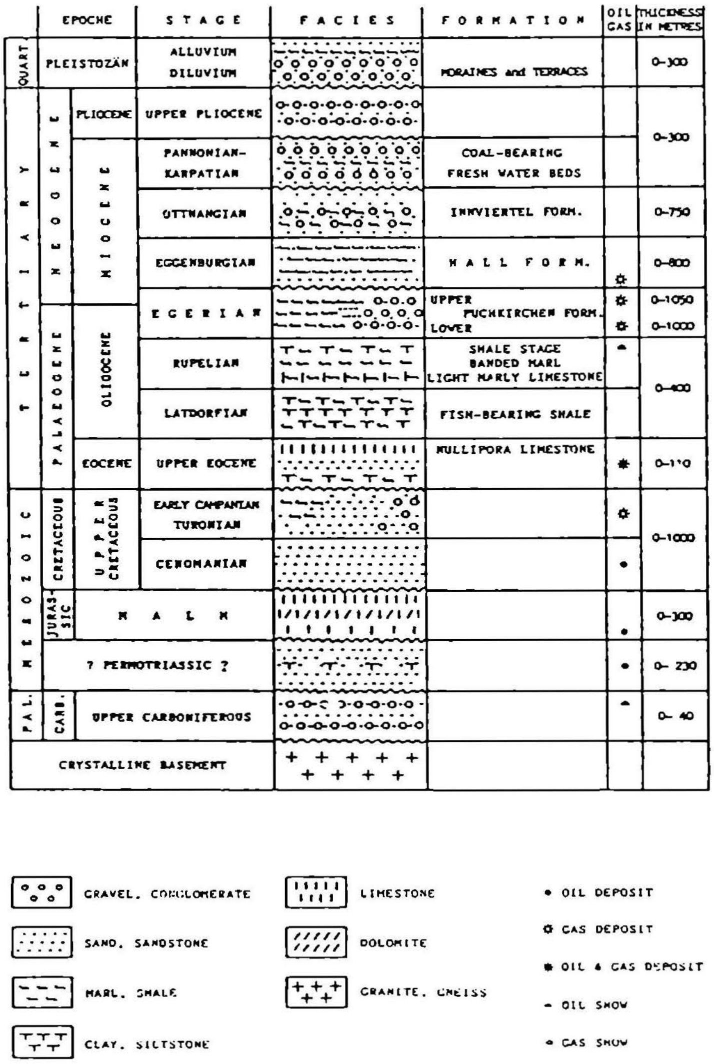


Fig. 1.5 A. Distribution map of five Molasse main parts in Austria.
B. Stratigraphic diagram of the Molasse zone between the rivers Salzach (and Inn) and the area of Amstetten.
(Janoschek and Matura, 1980 for both figures)

1. Late Eocene to Middle Oligocene (Lower Rupelian stage).

During the last Eocene to early Oligocene, rapid subsidence of the Molasse basin (Wagner, 1980) due to flexural down bending of the crust under the load of the advancing Alpine nappes induced the development of a dense network of essentially basin-parallel to synthetic and antithetic normal faults (Nachtmann and Wagner, 1987). Thin lacustrine, lagoonal and neritic sediments of the upper Eocene indicate the beginning of the Molasse epoch (Kollmann, 1977, 1980). The lacustrine series with various graded clays and intercalation of sandstone and coal are limited to the southern and middle regions, while shallow marine facies (Fig. 1.5B), such as Nullipora Limestone facies become more prominent towards the north (Janoschek and Matura, 1980). The Fischschiefer facies (fish-bearing shale) of the Latdorfian stage indicates depositional conditions of deeper water (Braumüller, 1961; Steininger et.al., 1986), the Heller Mergelkalk facies (light marly limestone) and the Bändermergel facies (banded marl) of the Rupelian stage show conditions of a sedimentation in shallow water (Braumüller, 1961; Steininger et.al., 1986). The sediments are possibly derived mainly from the Bohemian Massif as suggested by Woletz (1963) and Kurzweil (1973).

2. Middle Oligocene (late Rupelian stage) to middle Miocene (Ottnangian stage).

From bottom to top, four main Formations form the typical Molasse sediments (Figs. 1.4, 1.5B):-

a. Tonmergelstufe Formation (shale facies; upper Rupelian stage)

Thin alternating shales and fine sandstones are deposited in the relatively rapid subsiding Alpine foreland basin (Füchtbauer, 1964). They represent the oldest sediments in typical Molasse facies (Janoschek and Matura, 1980). In the southern part of the area, intercalations of sands and sandstones as well as gravels and conglomerates mainly occur (Braumüller, 1961; Kollmann and Malzer, 1980).

b. Puchkirchen Formation (Egerian stage).

In lower and upper parts of the formation, argillaceous beds prevail in the north. To the east, a wide belt of Linz sand (a light quartz-sand) indicates the position of the shoreline (Braumüller, 1961). The Linz sands represent a basal transgressional level of the northwards advancing Molasse sea (Oberhauser, 1980; Roetzel and Kurzweil, 1986). During this stage, a last climax movement of Alpine southward subduction took place (Van Houten, 1981).

c. Hall Formation (Eggenburgian stage).

The Formation spreads unconformably over the foreland Molasse, and consists of steaky marls with intercalated sands and sandstones (Janoschek and Matura, 1980). The sediments are derived mainly from the south as noted by Kurzweil (1973).

d. Innviertel Formation (Ottnangian stage).

The Formation conformably overlies the Hall Formation. Sands and gravels predominate in the west, while in the east the occurrence of fine sands is common (Oberhauser, 1980; Rögl and Steininger, 1984). The marine history of the Molasse in this area also ends with this Formation (see also Wessely, 1987). Locally, Oncophora Beds of the late Ottnangian formed within a brackish to lacustrine environment (Rögl and steiniger, 1984).

3. Late Miocene to early Pliocene.

During this period fluviatile and lacustrine sediments were deposited (Steininger et.al., 1986), resting unconformably upon the earlier Tertiary beds (Braumüller, 1961; Kollmann, 1977). At the base, lignite-bearing clays are found, overlain by gravels and conglomerates. A fauna of mammals and terrestrial gastropods was observed (Oberhauser, 1980). This succession is an equivalent to the upper Freshwater Molasse in the west (Fig. 1.4; Steininger et.al., 1986).

In general, deposition of the Tertiary Molasse in this area started in late Eocene and ended upto early Miocene (Ottnangian stage). Toward the east, it began during late Oligocene or even early Miocene and ended about the middle Miocene (Brix et.al., 1977).

1.4.3 Fault system and fuel-exploration.

The pre-Eocene fault system was developed during the Laramide inversion phase, and was partly reactivated during the Oligocene and early Miocene phases of the Alpine orogeny (Schröder, 1987). The young fault planes mainly follow the strike of the original faults, NW-SE and NNW-SSE trends, within the basement and a few that dip into opposite directions (Nachtmann and Wagner, 1987). The reactivation of pre-Tertiary faults is generally of minor importance, compared with the Oligocene tensional faults. Other faults are the NE-SW trends (Schermann, 1966; Thiele, 1970; see also Tollmann, 1985). The resulting structures contain important oil and gas accumulations.

Oil and gas were discovered in Eocene and upper Cretaceous sandstones in the Austrian Molasse (Kollmann and Malzer, 1980; Ladwein, 1988), such as the Upper Austrian region and the north of the river Danube (see Malzer, 1981). The oil is mainly connected to the Malm Formation of Jurassic age, shown by upper Cretaceous and upper Eocene reservoir rocks (Fig. 1.5B), and also the Gresten Formation (Lias Formation). Gas deposits are mainly found in the upper Eocene, in the Puchkirchen Formation of the upper Oligocene, the Hall Formation and the Oncophora Formation of the lower Miocene (Kollmann, 1977).

1.5 General geology of the Steyregg area.

The geological map of a scale 1:10000 presented in this thesis represents a compilation of field research data (see map in map-pocket for references). An attempt has been made to specify the geological boundary of the Molasse sediments in the area. Field work at times enabled exact positioning of upper and lower contacts of the Molasse sediments in the study area, occurrences of possible non-conformity underlying Bohemian Massif rocks and disconformity overlying Pliocene-Pleistocene sediments are recorded. It is hoped that the present map will assist in the current Austrian Geological Survey programme of preparing 1:10000 geologic maps.

The oldest rocks in the area are mainly granites, and some gneissic-granites, and referred to hereafter as the Bohemian Massif basement rocks. Two contrasting regional lithofacies are locally widespread and recognized on either side of the study area (See Fig. 2.1). To the west, Steyregg, sediments belong to the **"terrigenous mixed carbonate sequence"**. These sediments are approximately 90 metres thick. It is commonly characterized by the presence of a micro- and macro-fauna. In contrast to the east, St.Georgen an der Gusen, the sediments are assigned to the regional non-calcareous **"Linz sand sequence"** (see Janoschek, 1961; Oberhauser, 1980; Steininger et.al. 1986); are thinner and less indurated than that of the sediments in the west. They are non-fossiliferous, and characterized by an abundance of bioturbation.

The terrigenous mixed carbonate sequence of Steyregg and the Linz sand are characterized by dips varying from 5° to 30° to the south-southeast. Variations in dip are the result of broad, simple warping interrupted by differential elevation and gentle tilting of large basement-blocks. Depositional dips of more than a few degrees are also recorded in occasional cross-bedded units. Folding is not evident in either sequence.

Faulting occurs in the Steyregg area. The main strike directions are between N10°W to N50°W and N20°E to N70°E, and lie parallel or subparallel to the major strike of the Bohemian Massif faults (see Schermann, 1966; Thiele, 1970; Tollmann, 1985; Wessely, 1987; Schröder, 1987; Nachtmann and Wagner, 1987). The present pattern of faulting is attributed mainly to late Tertiary movements of the Alpine orogenesis, in that faulting effects equally most of the Oligocene-Miocene rocks (Nachtmann and Wagner, 1987).

In addition, variations of the consolidated calcarenites and their associated terrigenous sediments in the terrigenous mixed carbonate sequence (Steyregg) are probably related to short-term fluctuations of relative sea-level changes. To this end, the author suggests that these sediments are possibly part of the Hall Formation of Eggenburgian age (Upper Marine Molasse; Figs. 1.4, 1.5B). On the contrary, the non-calcareous Linz sand sediments are laterally equivalent to the Puchkirchen Formation and Melk Formation of Egerian stage, Lower Freshwater Molasse, due to Oberhauser (1980) and Steininger et.al. (1986).

CHAPTER 2
STRATIGRAPHY AND SEDIMENTARY STRUCTURES

Terrigenous mixed carbonate (cf. Mount, 1984, 1985; Nelson et.al., 1988; Martini et.al., 1992) and Linz sand sequences cropout discontinuously throughout the Steyregg area (Fig. 2.1). Lithologies of the terrigenous mixed carbonate sequence (Steyregg) consist mainly of non-calcareous, calcareous-terrigenous sandy and gravelly sediments with subordinate consolidated calcarenites (cf. Folk, 1968; 1980), while that of the Linz sand sequence are composed only of non-calcareous terrigenous sandy and gravelly sedimemts. Despite gross lithological simplicity of the lithofacies terminology applied to these sediments is both difficult and confused, the reasons for this include:-

1. A general partly calcareous nature of strata, such as in the terrigenous mixed carbonate sequence (Steyregg), and lack of continuous marker horizons, eg. in the Linz sand sequence.
2. Miscorrelations due to the vertical repetition of similar lithofacies and sublithofacies.
3. Failure to appreciate fully the rapid lateral and vertical lithologic variations (facies changes) in the sediments eg. in the Linz sand sequence.
4. The application of paleontological ages in establishing lithostratigraphic units.

In this chapter a detailed sedimentological description of the terrigenous mixed carbonate (Steyregg) and the Linz sand stratigraphic sequences in the Steyregg area will be presented. The reader desiring only basic stratigraphic information is referred to Figs. 2.2, 2.4 for important general stratigraphic columns and Fig. 2.3 for the overall relationships between the major lithofacies units in the terrigenous mixed carbonate sequence, including Fig. 2.5 for the Linz sand sequence (see also Appendices 3 and 4).

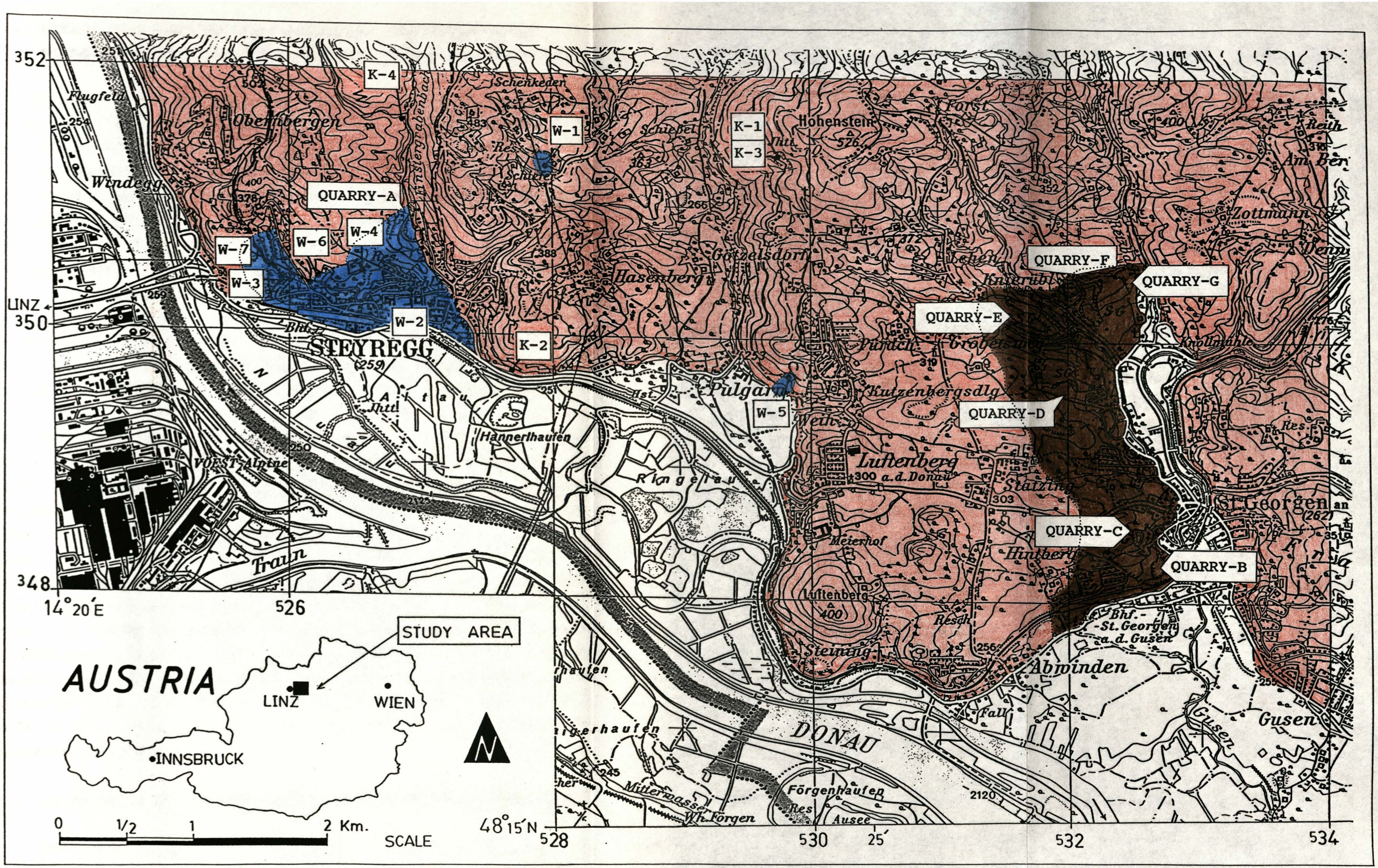


Fig. 2.1 Location of outcrops of the terrigenous mixed carbonate sequence (light blue), the Linz sand sequence (light brown) and the Bohemian Massif, granite (red) of a scale 1 : 25000.

2.1 Lithofacies terminology adopted for the terrigenous mixed carbonate (Steyregg) and the Linz sand sediments.

In order to establish a more detailed stratigraphy, into which could be incorporated the results of paleontological, petrographical and sedimentological analyses of the samples, a major sedimentary sequence has been divided into a number of lithofacies and sublithofacies. Although, the various usages, definitions and implications of the word "facies" are the subject of a number of articles (eg. Flügel, 1982; Walker, 1984; Reading, 1989; Tucker et.al., 1990; Swift, 1991), it appears that the desired meaning of the term is best defined by each worker. Accordingly, in this study, lithofacies are lateral and/or vertical subdivisions of mapable lithostratigraphic units that are characterized by certain physical, mineralogical and petrographical attributes. Indirectly, these attributes may aid in paleoenvironmental reconstructions. Paleontological components are simply regarded as a part, and very often a significant part, of the lithological character of the sediment. Each lithofacies may be referred to, by use of combinations of the abbreviation letters and/or symbols shown. Variations in lithofacies thickness are the result of interplaying between the basement paleorelief and the relative sea-level fluctuations, the tectonic subsidence and rates of sediment supply during sedimentation. Proximal lithologies, near source rocks, commonly exhibit rapid lateral and vertical variations, and pass vertically and distally into the lithology typical characteristic of the bulk of the formation as in the terrigenous mixed carbonate sequence (Steyregg).

2.2 Lithofacies of the terrigenous mixed carbonate sequence.

The terrigenous mixed carbonate sequence investigated mostly at Quarry A area near Steyregg (Fig. 2.1, Photos. 2/1, 2/2) shows a maximum thickness in the north-northwest, measuring approximately 90 metres (Fig. 2.2), and thinning to a minimum of about 35 metres to the south-southeast (Fig. 2.3

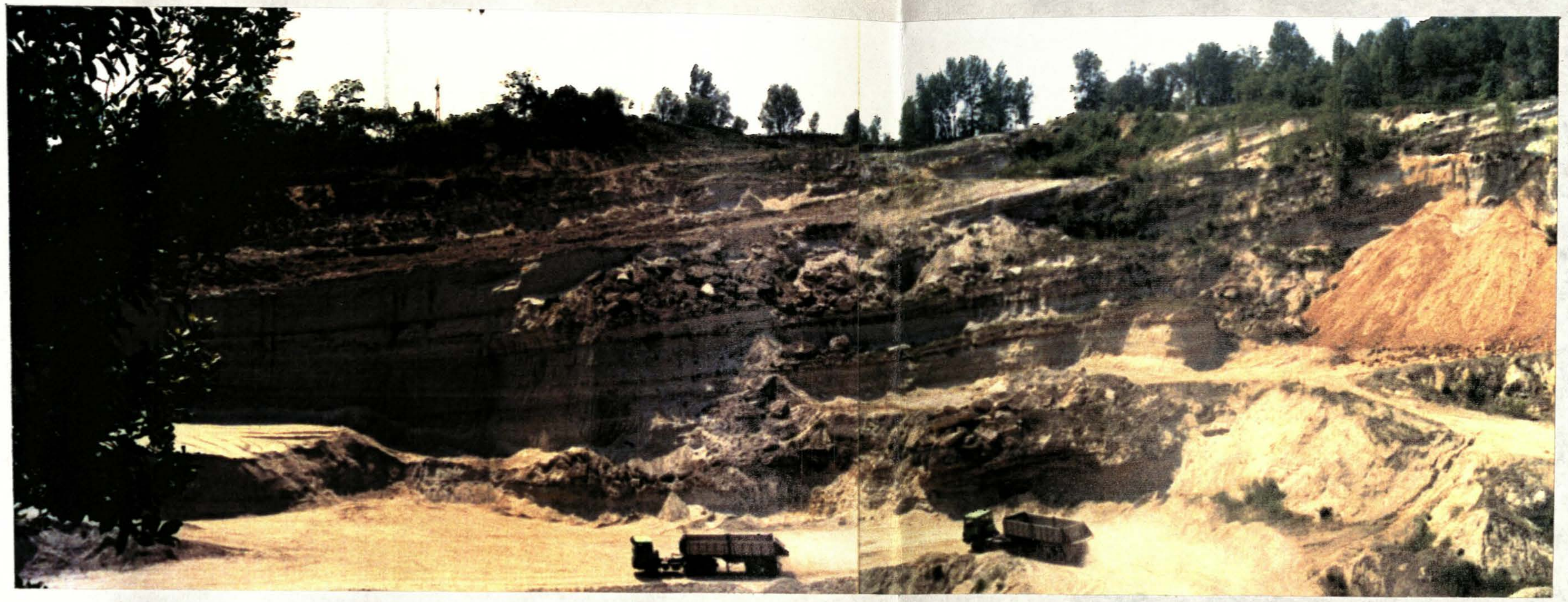


Photo 2/1 The terrigenous mixed carbonate sequence at Quarry A, Steyregg, looking W-SW.

Photo 2/2 The terrigenous mixed carbonate sequence at Quarry A, Steyregg, looking SE.

Both photographs show the variation in lithology, thickness and seaward dipping of the sequence. Note that the terrigenous sediments (light colour beds) intercalated in the consolidated calcarenites (dark colour beds) increase in thickness towards the N-NW (Photo 2/1).

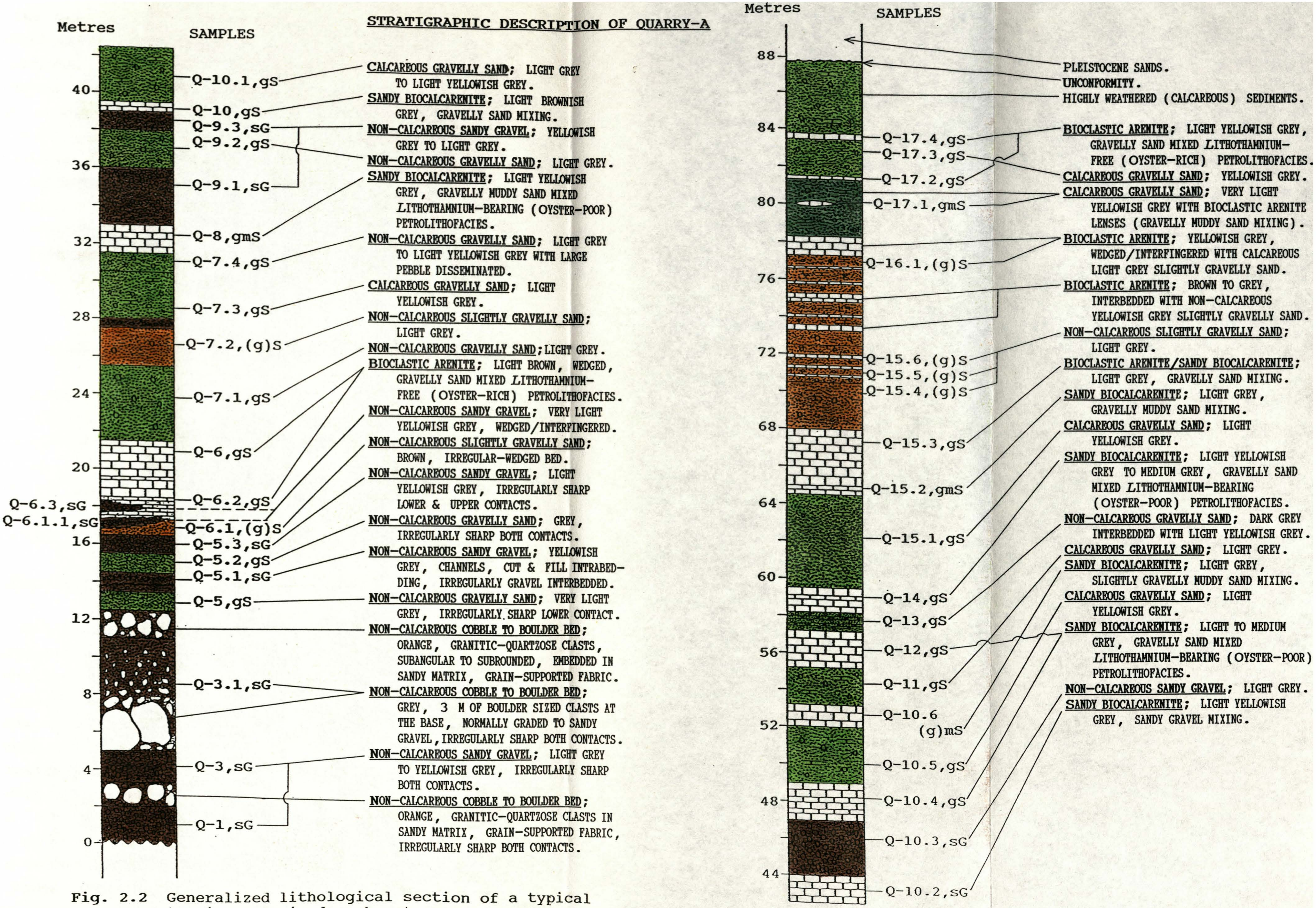
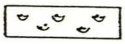
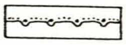
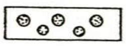
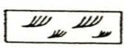
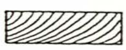
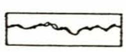
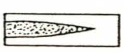
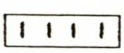
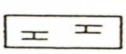
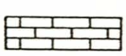
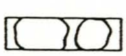
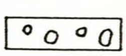
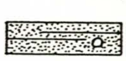


Fig. 2.2 Generalized lithological section of a typical terrigenous mixed carbonate sequence, Steyregg (from Section I of Quarry A).

LEGEND	DESCRIPTION
	SMALL CHANNELS, CUT AND FILL STRUCTURES
	SHALLOW CHANNELS, CUT (SCOURED) AND FILL STRUCTURES
	BIOTURBATED, BURROWED TUNNELS
	UNCONFORMITY
	INTERFINGERING CONTACT
	SMALL-, MEDIUM-SCALE CROSS-BEDDING
	LARGE-SCALE CROSS-BEDDING
	IRREGULAR, THIN-BEDDING
	CLASTIC OR CARBONATE LENSES
	BIOTURBATED, BURROWED SHAFTS WITH IRON-OXIDE
	CALCAREOUS NATURE OF SEDIMENTS
	THIN BEDDED, SLIGHTLY CONSOLIDATED CALCARENITES
	MEDIUM BEDDED, SLIGHTLY CONSOLIDATED CALCARENITES
	COBBLE-BOULDER SIZED
	PEBBLE SIZED
	SANDY GRAVELS
	MUDDY SANDY GRAVELS
	GRAVELLY SANDS
	GRAVELLY MUDDY SANDS
	SLIGHTLY GRAVELLY MUDDY SANDS
	SLIGHTLY GRAVELLY SANDS
	SANDS
	MUDS
	COVERED

in the map pocket). The sequence consists of three major lithofacies; a non-calcareous terrigenous lithofacies, a calcareous terrigenous lithofacies and a consolidated calcarenite lithofacies, which possibly lie stratigraphically near an unconformity developed on the basement rocks of the Bohemian Massif and below the Pleistocene sediments. Each lithofacies is divided into several sublithofacies, ranging in thickness from a few centimetres to a few metres. Systematic vertical and horizontal variations of these sublithofacies tend to repeat within the sequence. Additionally, lithofacies and sublithofacies terminologies using in this section are present in sections 2.6, 3.3 and 4.2.

2.2.1 <u>Lithofacies A</u>: **Non-calcareous terrigenous sediments.**

Sediments of this type are generally very light grey (N8), horizontally bedded, quartzo-feldspathic sandy gravel, gravelly sand and slightly gravelly sand; and locally cross-bedding. Several small channel fill structures within these beds are present. Fossils are not evident throughout the lithofacies. This lithofacies can be divided into three sublithofacies types, which will be described below.

<u>Sublithofacies A-1</u>: Gravel.

This sublithofacies typically consists of granitic and quartzose gravels. Content of clasts is more than 80 %. The clasts are subangular to subrounded, and are embedded in a scattered dark yellowish orange (10YR 6/6) sandy matrix (Photo. 2/3). Some beds are composed predominantly of cobbles as large as 20 cm across, others consist exclusively of boulders as large as 1.8 m in diameter. Generally, graded bedding within an individual bed is rarely observed, and if seen, the largest boulders tend to be lying on a basal bed and grain size decrease upwards the top. The contacts of this bedded sublithofacies are generally erosional and sharp in cross-sections. This sublithofacies may be deposited adjacent to, or rested directly near, the basement rocks,

Photo 2/3 Clast-supported fabric occurs in a very thick gravel bed (Sublithofacies A-1). Clasts are mainly cobble to boulder-sized, and are subangular to subrounded. They are embedded in sandy matrix, and overlain by gravelly sand (gS); Quarry A, Section I at 12 m., looking NW.

Photo 2/4 A general sandy-matrix supported fabric occurs in a thick sandy gravel bed (sG, Sublithofacies A-2). Gravels are granule to pebble-sized, and are angular to subangular. Sorting is poor. The gravel bed is overlain by slightly gravelly sand ((g)S); Quarry A, Section I at 16 m., looking NW.

although the direct evidence of such a contact cannot be examined in the study area.

<u>Sublithofacies A-2</u>: Sandy gravel.

This poorly sorted sublithofacies type is composed mostly of granitic, quartzose and feldspathic gravels. Gravel content ranges from 30 % to 80 %. Clasts are angular to subangular, granule to pebble sized. The groundmass is light grey (N7) to yellowish grey (5Y 7/2, Photo. 2/4). Normal grading is rarely recorded within an individual bed (Photo. 2/21). Individual beds are arranged to fining upwards sequence. Locally, individual sandy gravel beds are interfingered and intercalated with sand sublithofacies types. Thickness of individual gravel beds ranges from 10 cm upto 1.3 m.

<u>Sublithofacies A-3</u>: Gravelly sand.

Gravelly sands contain gravels ranging between 5 % and 30 % and less than 10 % mud. Slightly gravelly sands contain less than 5 % gravels. They are generally very light grey (N8) to light grey (N7) in colour, occasionally yellowish grey (5Y 8/1). The medium to very coarse grained quartzo-feldspathic sand contains granitic granule and pebble. Individual beds are horizontally stratified, sometimes cross-bedded. Small channel fill structures also occur. Locally, this sublithofacies type grades into other sublithofacies types.

<u>Sublithofacies A-3-1</u>: Bedded sand.

Individual beds of this sublithofacies are generally medium (30 cm) to thick (90 cm), and described by normal grading with some gravels occuring at the base (Photo. 2/5). Sorting is generally moderate to poor. Contacts between individual beds are rather gradual than sharp.

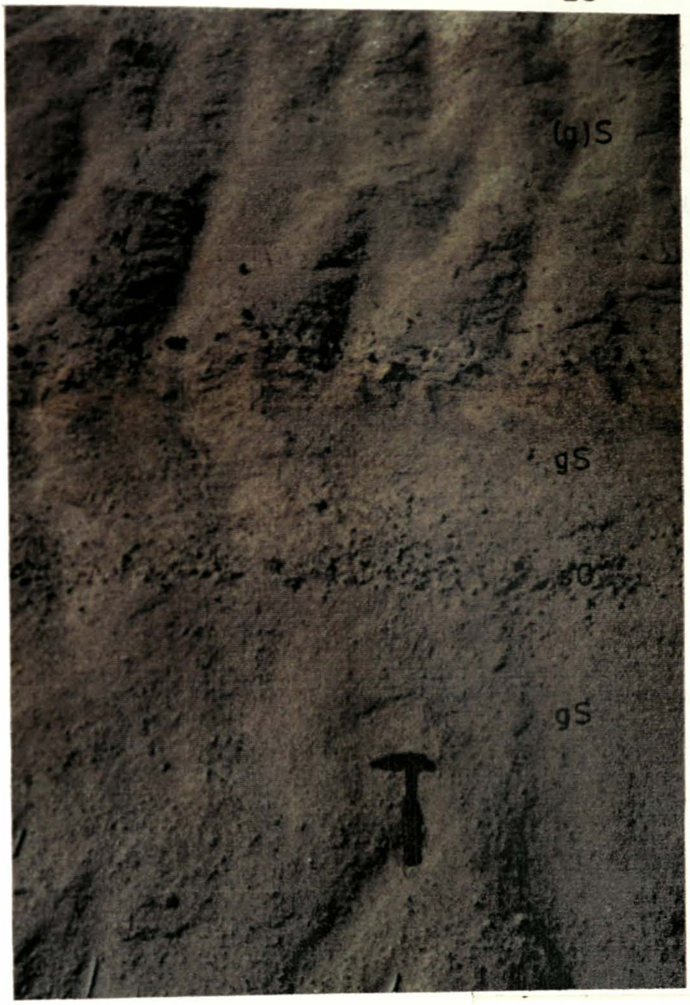


Photo 2/5 Thick to very thick bedded gravelly sand (gS) and slightly gravelly sand ((g)S) of Sublithofacies A-3-1 are interbedded with a thin bed of sandy gravel (sG, Sublithofacies A-2). The beds show normal grading and scattered pebbles; Quarry A, Section IV at 5 m., looking E.

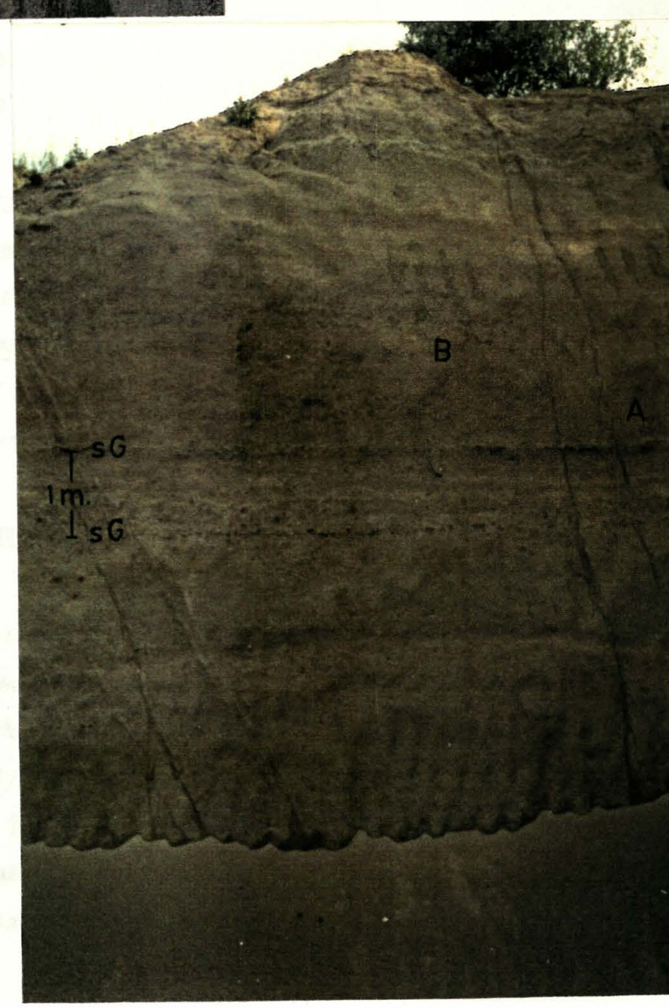


Photo 2/6 Medium scale tangential (A) and trough (B) cross-bedded gravelly sand (gS) and slightly gravelly sand ((g)S), Sublithofacies A-3-2. The contacts of cross-bedded units are sharp, marked by thin bedded sandy gravel(sG); Quarry A, Section IV at 6 m., looking N.

Sublithofacies A-3-2: **Cross-bedded sand.**

This sublithofacies type is typically medium to large scale tangential, tabular and rare trough cross-bedded. Bed thickness ranges from 3 m to 1 m. Contacts of cross-bedded units are marked by a basal gravel lag (10-20 cm thick), although clasts of different size are also common at the base of individual cross-bedded sets (Photos. 2/6, 2/7). Cross-bedded sands are intercalated with horizontally stratified slightly gravelly sand with thickness up to 50 cm (Fig. 2.3). Pebble-sized quartz and feldspar grains are concentrated on the toesets. Within an individual set grain size decreases upwards. The base of cross-bedded sets is generally sharp. To the southeast, the foresets dip with very low angles. Foresets dip more or less oblique to the postulated shoreline. Other transport directions, indicated by smaller foresets, are towards the west.

Sublithofacies A-3-3: **Channel fill sand.**

Isolated small channels and cut-and-fill structures are a typical feature of this sublithofacies. Channels are cut into slightly gravelly sands rather than gravelly sands (Photo. 2/23). Individual channels are small, symmetrical, of U or V-shape, approximately 20-25 cm wide and 5-20 cm deep in cross-section. Channels are filled by very coarse sand to fine pebble, and display normal grading. The direction of the axis of the channel averages around N55°E, although long dimensions are never exposed.

2.2.2 Lithofacies B: **Calcareous terrigenous sediments.**

This lithofacies is texturally similar to the non-calcareous terrigenous sediments of the Lithofacies A, and is mainly composed of quartzo-feldspathic gravelly sand. They are yellowish grey (5Y 8/1) to light brownish grey (5YR 6/1), medium to thick bedded, interfingered with other lithofacies, and locally associated with lenses of consolidated calcarenites of Lithofacies C. Cross-beds and small channel

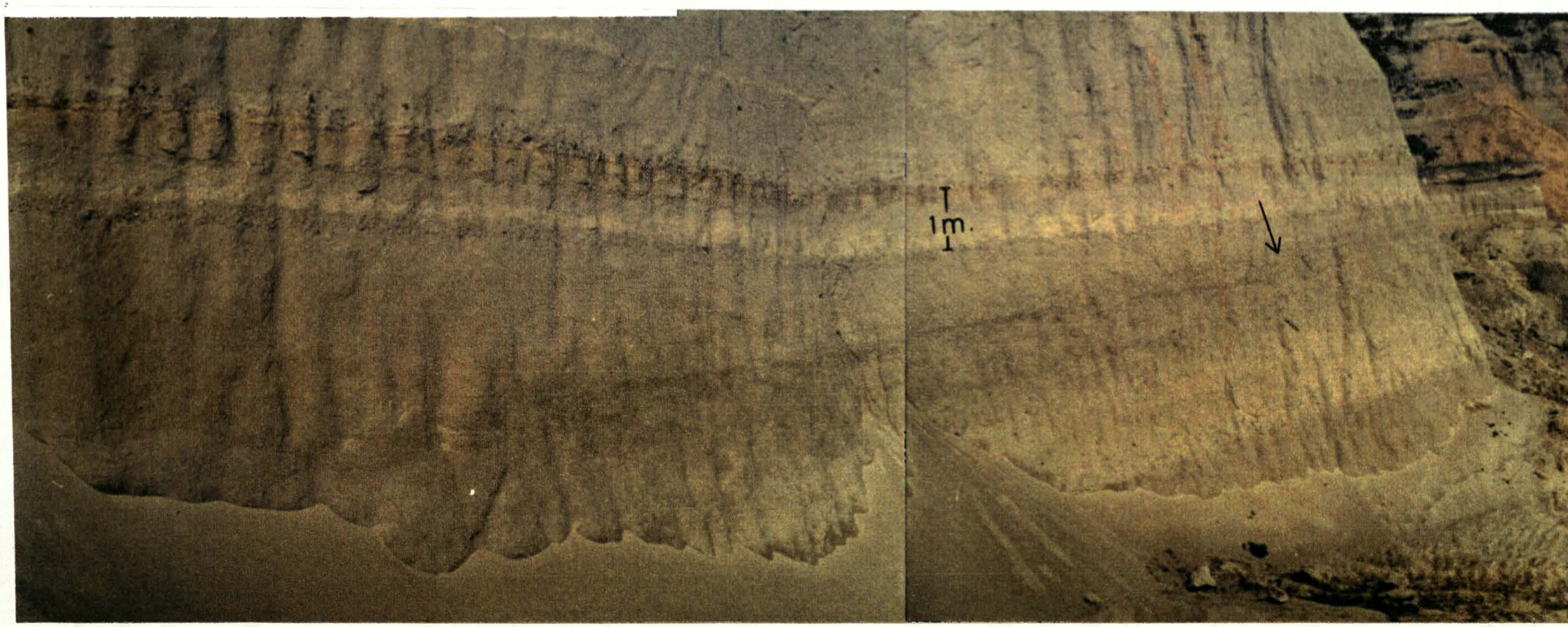


Photo 2/7 Large scale, low-angle tabular cross-stratification in gravelly sand (gS) and slightly gravelly sand ((g)S) of Sublithofacies A-3-2, thickness of this unit decrease towards NW; Quarry A, Section IV at 17 m., looking SW.

structures are not present. Moreover, this lithofacies is a transitional facies between the non-calcareous terrigenous lithofacies A and the consolidated calcarenites lithofacies C (Photos. 2/8 to 2/10).

2.2.3 Lithofacies C: consolidated calcarenites.

The consolidated calcarenites are generally light grey (N7) to white (N9) and light brownish grey (5YR 6/1). Individual beds are wedge-shaped and interfingered with other lithologies. They contain fragments of oysters, echinoderms and brachiopods which are locally associated with unidentified trace fossils and small coalified fossil plant fragments. The terrigenous constituents are variations. This facies type is mostly composed of quartzo-feldspathic gravelly sand and gravelly muddy sand, less common of slightly gravelly sand, slightly gravelly muddy sand and sandy gravel with rare muddy sandy gravel. This lithofacies can be divided into three sublithofacies due to petrographical data (see section 3.3.1) and field observations: (1) bioclastic arenite, (2) sandy biocalcarenite and (3) biocalcarenite. These sublithofacies types are either *Lithothamnium*-bearing (oyster-poor) or *Lithothamnium*-free (oyster-rich, see section 3.5), and are generally interbedded with non-calcareous and calcareous terrigenous sediments of other lithofacies types.

Sublithofacies C-1: Bioclastic arenite.

The coarse to very coarse grained bioclastic arenite are generally composed of 50-90 % terrigenous sand and gravel, 10-50 % bioclastic grains and less than 10 % micrite plus terrigenous clay. Bioclastic grains consist mostly of large oyster rather than *Lithothamnium*-fragments and benthic foraminifers. The colour is light brownish grey (5YR 6/1) to light brown (5YR 6/4, Photos. 2/9, 2/10). Generally, they form medium to very thick beds (20-120 cm), and locally pinch out and are interbedded with non-calcareous sandy gravel and

Photo 2/8 Medium bedded calcareous terrigenous sediments (Lithofacies B) are interbedded with thin bedded consolidated calcarenites (Lithofacies C). They are generally intercalated within very thick bedded non-calcareous terrigenous sediments (Lithofacies A); Quarry A, Section III at 13 m., looking NW.

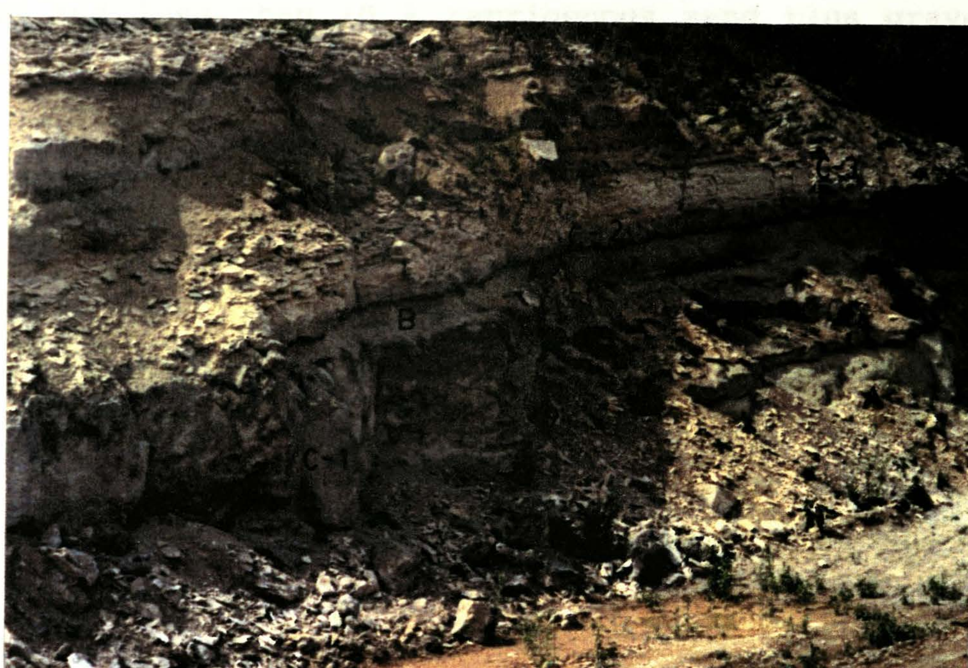


Photo 2/9 Typically brownish grey surface and medium to very thick wedged, bioclastic arenite (Sublithofacies C-1) is intercalated with non-calcareous terrigenous sediments (Lithofacies A) and calcareous terrigenous sediments (Lithofacies B). Sandy biocalcarenites (Sublithofacies C-2) show a gradual change to upper biocalcarenite (Sublithofacies C-3); Quarry A, Section III at 20 m., looking NW.

calcareous gravelly sand. The bioclastic arenites are typically intercalated within the lower and upper parts of the terrigenous mixed carbonate sequence (Steyregg).

<u>Sublithofacies C-2</u>: **Sandy biocalcarenite.**

The sandy biocalcarenite sublithofacies comprise 50-90 % bioclastic grains (high contents of *Lithothamnium* fragments and benthic foraminifers), 10-50 % terrigenous sand and gravel, and less than 10 % micrite. They are commonly light grey (N7) to very light grey (N8), medium (20 cm, Photos. 2/10, 2/11) to thick bedded (60 cm), intercalated and interfingered with either non-calcareous or calcarous terrigenous sediments of other lithofacies. Siliciclastic grains are sparely scattered throughout the sediments.

<u>Sublithofacies C-3</u>: **Biocalcarenite.**

Biocalcarenites are composed of more than 90 % bioclastic grains and less than 10 % terrigenous sand plus gravel and micrite. They are typically thin to medium bedded (Photo. 2/11), very light grey (N8) to white (N9), contain high amounts of benthic microfossils and few amounts of *Lithothamnium* fragments. Sandy biocalcarenites of the previous facies type grade upwards into biocalcarenite. Both facies types laterally interfinger with non-calcareous or calcareous terrigenous sediments.

2.3 <u>Cycles in the terrigenous mixed carbonate sequence</u>.

An attempt to identify cycles is made in this study. The terrigenous mixed carbonate sequence (Steyregg) can be divided into five cycles. Each cycle can be traced laterally in the area (Fig. 2.3, in the map pocket). An individual cycle ranges in thickness from a few metres to several tens of metres, showing lateral and vertical lithologic variations of several sublithofacies. Each cycle is composed of the different lithofacies from bottom to top.

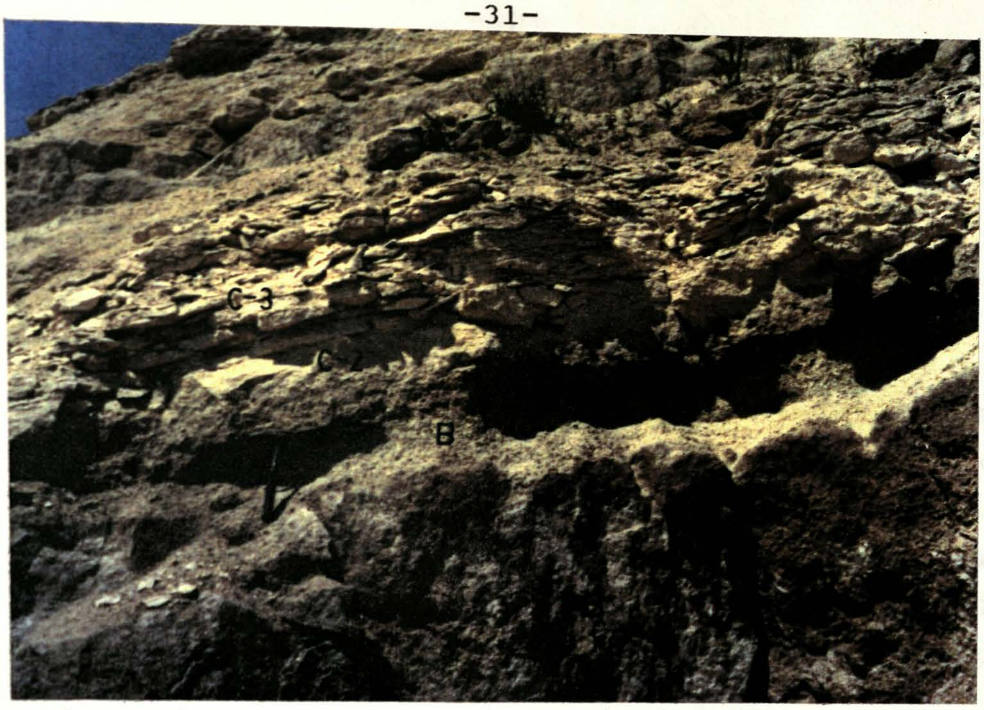


Photo 2/10 Three petrographical distinctions of bioclastic arenite (Sublithofacies C-1), sandy biocalcarenite (Sublithofacies C-2) and biocalcarenite (Sublithofacies C-3) are physically defined by different weathering surfaces. Contact between the calcareous terrigenous sediments (Lithofacies B) and the consolidated calcarenites (Lithofacies C) are generally sharp; Quarry A, Section III at 20 m., looking NW.

Photo 2/11 Lenticular-like structures (above hammer) occur in thin to medium bedded biocalcarenite (Sublithofacies C-3). The layer-thickness varies irregularly from zero to about 5-10 cm, some 15 cm to the left. This feature can be used to separate biocalcarenite from sandy biocalcarenite (Sublithofacies C-2) and bioclastic arenite (Sublithofacies C-1); Quarry A, Section III at 22 m., looking NW.

<u>CYCLE A</u>: This type of cycle is composed of gravel at the base, with upward grade into horizontal stratified or cross-bedded sands and consolidated calcarenites on top. Thickness of cycle A is up to approximately 20 m. Laterally, the sediments show rapid facies change and interfinger with other lithofacies types.

<u>CYCLE B</u>: This type of cycle consists of sandy gravel and gravelly sand at the base, overlain by cross-bedded and channel fill sand. Then, the sediments upward grade into slightly gravelly sand with horizontal stratified and intercalated fine gravelly sands and of consolidated calcarenites at the top. The base of the cycle is sharp, but not erosive.

<u>CYCLE C</u>: This cycle starts with sandy gravel at the base, grading upward into gravelly sand with horizontal stratification. Up these follow horizontally stratified siliciclastic sands will increasing carbonate content upwards. On top of the cycle, consolidated calcarenites are developed.

<u>CYCLE D</u>: This cycle starts with gravelly sand at the base, grading upward into slightly gravelly sand with horizontal stratification. Compared to cycle C, the cycle D contains thick consolidated calcarenites on top which laterally interfinger with calcareous siliciclastic sand and gravel.

<u>CYCLE E</u>: This cycle is formed of gravelly sand at the base, overlain by slightly gravelly sand, interbedded with consolidated calcarenites. They show horizontal stratification. This cycle is erosively overlain by Pleistocene sediments, particularly sand.

2.4 <u>Lithofacies of the Linz sand sequence</u>.

The siliciclastic Linz sand sequence investigated from Quarries B to G in the St.Georgen an der Gusen (Fig. 2.1) shows a maximum exposed thickness of about 40 m at Quarry E section and a minimum of approximately 20 m at Quarries B and C. The sequence includes all textural lithologies (see section 4.2.2) which are referrable to several lithofacies: sandy gravels including a local pebble and cobble bed near the base of Quarry D section, slightly gravelly sand, gravelly sand, sand and slightly gravelly mud (Fig. 2.4). The individual lithofacies occur as tabular beds, ranging in a few tens of centimetres to a metre. The lateral and vertical lithofacies variation is shown in Fig. 2.5 (in the map pocket). The individual lithofacies are slightly uniform in thickness throughout the area. An individual lithofacies type occurs at different locations, making a correlation between adjacent sections very difficult.

2.4.1 Lithofacies 1: **Gravel and sandy gravel.**

Two different sublithofacies can be recognized in this lithofacies. The most abundant lithology is sandy gravel, with locally present intercalated gravel sublithofacies.

Sublithofacies 1-A: Gravel.

Gravel beds are 80-100 cm thick composed of large gravel sized clasts, and is only found near the base of the Quarry D section. Gravels generally range from pebble to cobble size, averaging 15 cm and 20 cm across. Clasts are commonly subrounded to rounded, and obviously composed of yellowish grey (5Y 8/1) indurated sand with all preserved internal cross-beds. The matrix is composed of moderate reddish brown (10R 4/6) sand (Photo. 2/12). Upper and lower contacts of the bed are irregular and sharp. The gravel beds are under and overlain by white (N9) to light grey (N7), slightly gravelly sand. Within the bedded gravel sublithofacies, normal grading is observed. The lower contact of the gravel beds is frequently scoured.

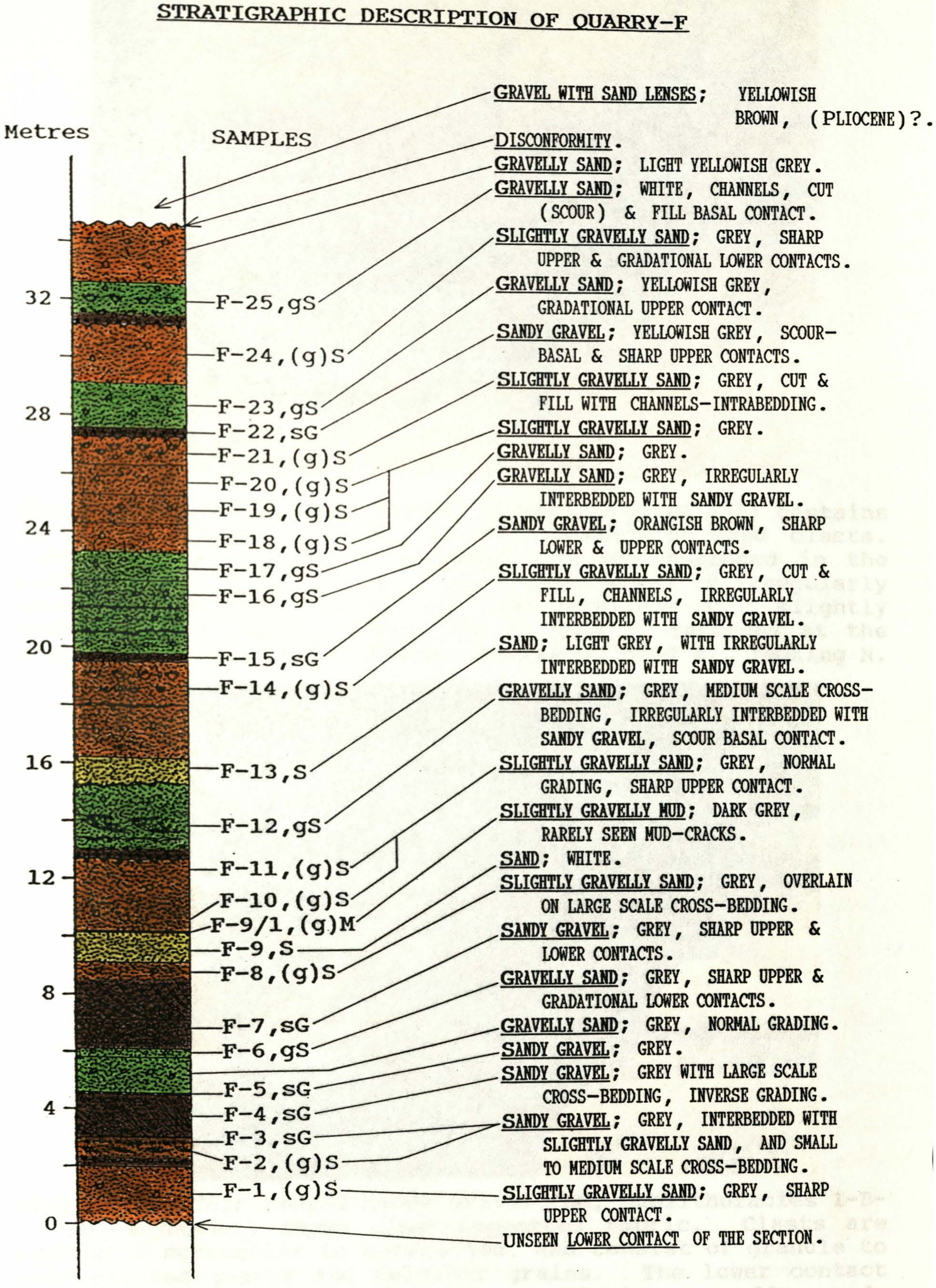


Fig. 2.4 Generalized lithological section of a typical Linz sand sequence, St.Georgen an der Gusen (Quarry F).

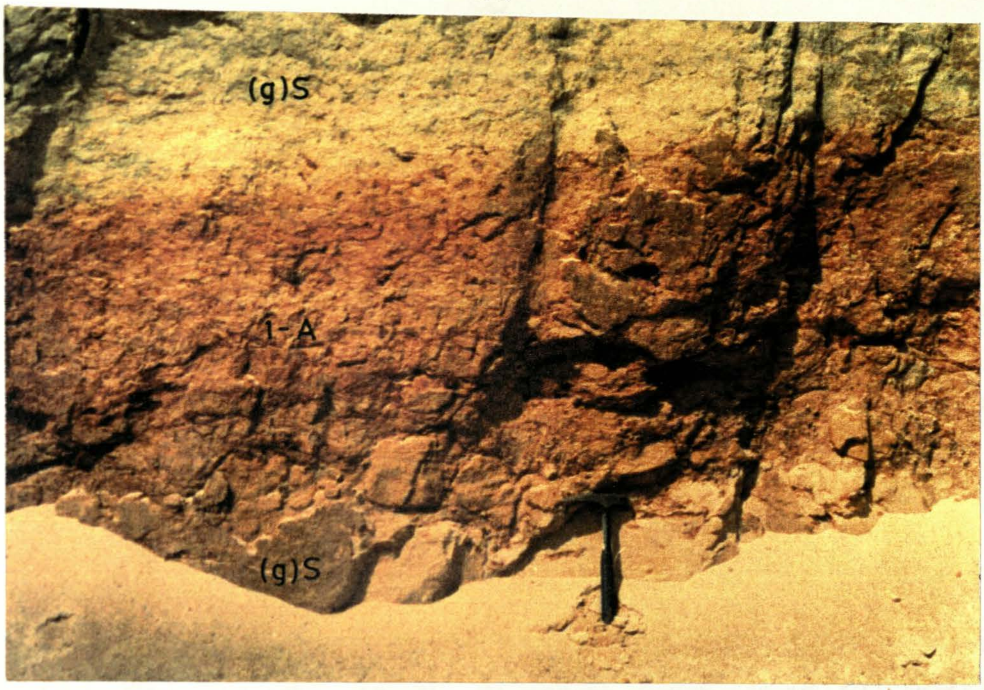


Photo 2/12 Thick bedded gravel (Sublithofacies 1-A) contains pebble to cobble-sized of slightly indurated sand clasts. Clasts are subrounded to rounded, and are embedded in the reddish brown sandy matrix. The lower contact is irregularly sharp or scoured, lying on (and overlain by) slightly gravelly sand ((g)S). This bed is locally recorded at the base of the Linz sand sequence; Quarry D, at 2 m., looking N.

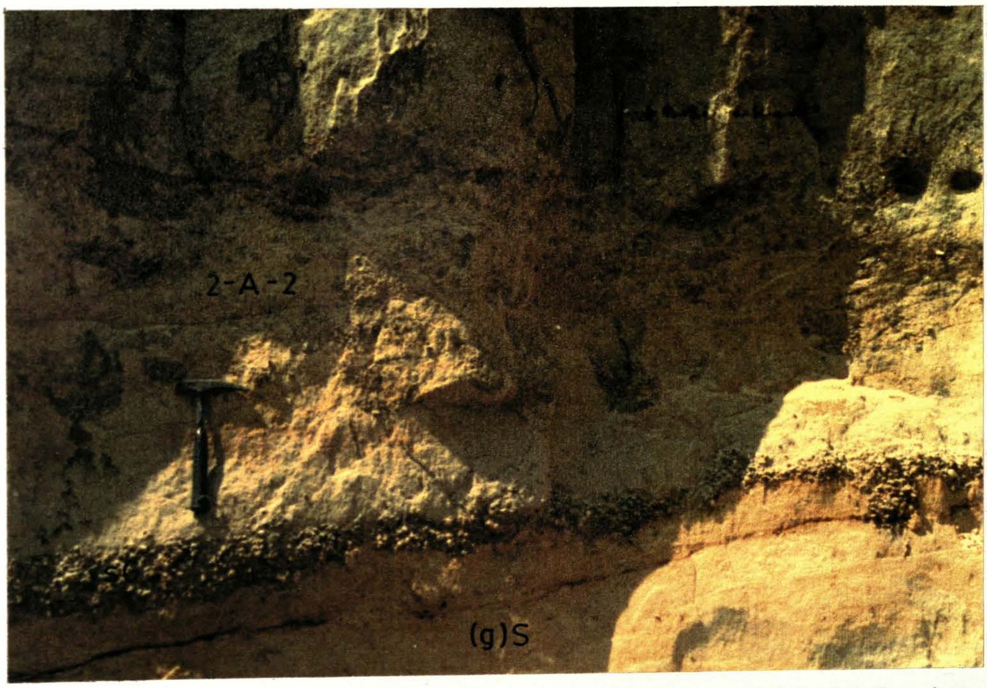


Photo 2/13 Thin bedded sandy gravel (sG, Sublithofacies 1-B-1, below hammer) shows clast-supported fabric. Clasts are typically subangular to subrounded, and consist of granule to pebble-sized quartz and feldspar grains. The lower contact of the bed is slightly cut into slightly gravelly sand, (g)S . Overlying sediments are slightly gravelly sand (Sublithofacies 2-A-2) with present small channels; Quarry B, at 9 m., looking NW.

<u>Sublithofacies 1-B</u>: Sandy gravel.

Sediments of this sublithofacies are generally very light grey (N8) to yellowish grey (5Y 8/1), occasionally light brown (5YR 6/4) to pale reddish brown (10R 5/4). Modal grain size is 1.5 cm. Clasts are either quartz or feldspar. Granite rock fragments are very rare. The matrix is composed of fine sand and mud. According to the sedimentary structures, the following types can be distinguished.

<u>Sublithofacies 1-B-1</u>: Bedded sandy gravel.

This sublithofacies is characterized by thin (5 cm) to thick (80 cm) bedded sandy gravels that consist mostly of granule to pebble sized clasts, subangular to subrounded, rarely well rounded. Sorting is poor to moderate. The matrix is formed by medium sand (Photo. 2/13). Bedded sandy gravels tend to be rhythmically repeated at a vertical interval of a few metres. They are typically separated from underlying beds by an erosional surface, shallow channels. Upper contact is either irregular and sharp or gradational. Obviously, several thin sandy gravel lag beds are irregularly intercalated with other sublithofacies. In some, they are concentrated near the basal contact of beds and within small channels.

<u>Sublithofacies 1-B-2</u>: Cross-bedded sandy gravel.

This sublithofacies accounts for sandy gravels in the lower part of the sequence. Individual beds are typically thick to very thick (60-120 cm), tabular cross-bedded with medium to large scale cross-stratification (Photos. 2/14, 2/24). Gravels are composed mostly of quartzose granule to pebble sized clasts. Granitic pebbles are also present. Gravels are abundant on toesets. The clasts are angular to subangular and locally show inverse grading within beds. High angle cross-bedding is a common sedimentary structure in this sublithofacies, where it occurs in sets tens of centimetres to more than a metre thick. The foresets dip

<u>Photo</u> 2/14 Multiple units of small to medium scale cross-bedded sandy gravel (sG, Sublithofacies 1-B-2), associated with slightly gravelly sand ((g)S), showing well developed paleocurrent directions; Quarry F, at 2.5 m., looking NE.

<u>Photo</u> 2/15 Burrowed traces generally extend down into the underlying slightly gravelly sand ((g)S, Sublithofacies 2-A-1). They are filled with the overlying sediments, showing up as rounded tunnels and cylindrical shafts in cross-section; Quarry D, at 11.5 m., looking SW.

predominantly towards the southeast, away from the postulated shoreline. Some foresets dip towards the southwest, probably oblique to the shoreline, and towards the northwest in an onshore direction.

2.4.2 Lithofacies 2: Sand.

The most abundant textural lithologies in this lithofacies are slightly gravelly sand, gravelly sand and minor pure sand. They are generally light grey (N7) to white (N9) and yellowish grey (5Y 7/2), medium to thick bedded, and commonly bioturbated. Channels and shallow scour-and-fill structures are the most common sedimentary structures. Gravels occur both disseminated and graded bedding within an individual bed.

Sublithofacies 2-A: Bedded sand.

This sublithofacies generally shows normal grading from thin sandy gravel, to gravelly sand, slightly gravelly sand and sand at the top. An individual bed is medium to very thick bedded (50 cm to 1 m), and locally associated with gravelly sand and sandy gravel lenses. Gravels are dominantly angular to subangular, granule to pebble sized and embedded in a sandy groundmass. Lower contact of beds is generally marked by cut and fill structure, forming irregular and sharp scoured surfaces. Near the upper contact, the sediments are generally bioturbated. The burrows are filled with sediment which is different in composition and texture from the surrounding sediments. Small individual channels and cut-and-fill structures are also recorded within several beds. These beds are irregular in thickness and observed by irregular, sharp upper contacts. Bedded pure sand-sized lithologies are rare. Sand-grains in this sublithofacies are common quartz and feldspar, medium to coarse sand sized, with some pebbles sparely dispersed throughout the sediment. The sorting is poor to moderate, sometimes moderately well. This sublithofacies mostly occupies the upper part of the sequence, and will be described in detail below:-

Sublithofacies 2-A-1: **Bioturbated sand.**

This sublithofacies is typically characterized by bioturbation in form of shafts and tunnels, and is mostly preserved in very light grey (N8) to light grey (N7) slightly gravelly sands (Photos. 2/15, 2/27). These sediments are normally fine to medium sand sized with some gravels disseminated. The sediments are moderately well sorted and medium to thick bedded. The upper most part of an individual bed has been extensively burrowed, forming a thick 30 cm zone of tunnels rather than shafts. Primary sedimentary structures have been completely destroyed. Good exposures at Quarry E sections show that the bioturbated sediments occur in the upper part of small channels. The contact between the bioturbation and the underlying sediment is sharp. Obviously, these burrowed traces are infilled with sediments of the overlying bed. At Quarry C sections, the slightly gravelly sand only recorded a complete shaft, possibly *Ophiomorpha*.

Sublithofacies 2-A-2: **Channel fill sand.**

A typical feature of this sublithofacies are channels in slightly gravelly sand beds and scour-and-fill structures at the base. A general lithology is previously discussed. These channels and scour-and-fill structures are generally abundant at or near the lower contact of beds, and sporadically decreasing upwards (Photo. 2/16). Very shallow scoured surfaces on the underlying sediments may be created by wave-generated currents, and filled by pebble lag deposits. The presence of these thin lag deposits, 10-15 cm thick, suggests a short period of very rapid deposition of pebbles (Blatt et.al., 1980).

Sublithofacies 2-A-3: **Massive sand.**

This type is typically characterized by uniform thickness of white (N9) to very light grey (N8) slightly gravelly sand that are more resistant than other beds (Photo. 2/17). They

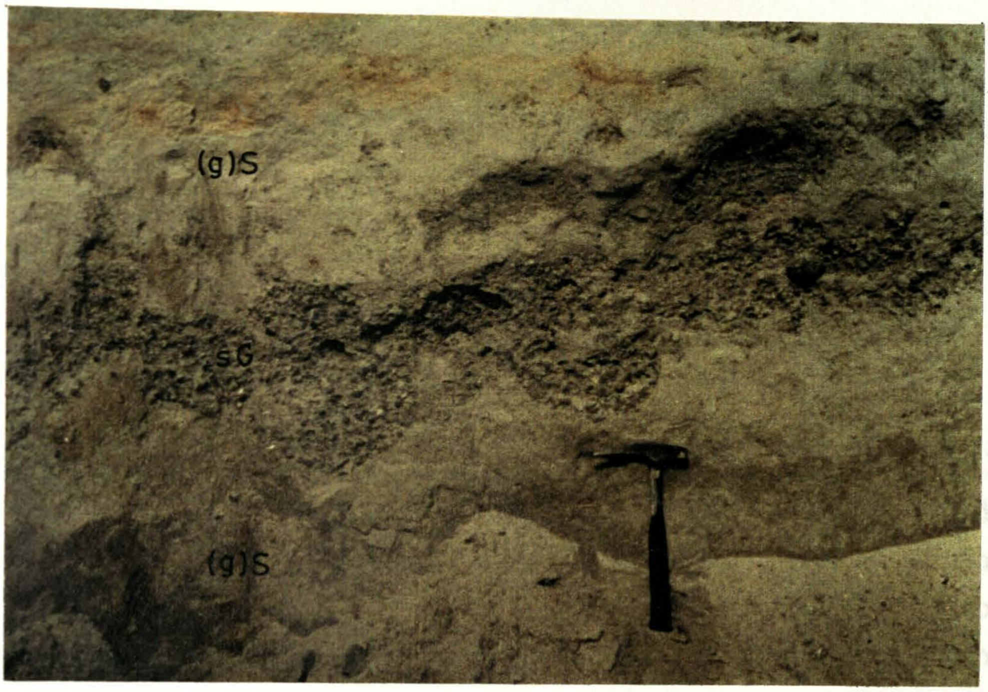


Photo 2/16 Cut and fill structures in slightly gravelly sand ((g)S, Sublithofacies 2-A-2), filled with sandy gravel (sG, Sublithofacies 1-B); Quarry E, Section II at 21.5 m., looking NW.

Photo 2/17 Stratification of massive, slightly gravelly sand ((g)S, Sublithofacies 2-A-3) is enhanced by different weathering due to different intensity of possible cementation and bioturbation within 3.5 m thick; Quarry F, looking NE.

consist of about 96 % sand, 3 % gravel and 1 % mud. Sands are generally fine to medium grained, moderately well sorted, and commonly contain disseminated granule to pebble sized clasts. Locally, these sediments are associated with small channels, cut-and-fill structures and a few irregular thin sandy gravel intracalations. Trace fossils are absent in this sublithofacies.

Sublithofacies 2-B: Cross-bedded sand.

This sublithofacies commonly is composed of a small to medium scale cross-bedding. Individual sets of cross-bedding consist of gravelly sand and slightly gravelly sand (Photo. 2/18). This sublithofacies is similar to the previously described cross-bedded sandy gravel sublithofacies, although the scale is different. Locally well developed inclination of foresets varies from south-southeast to north-northwest and in east-west bidirections (herringbone cross-bedding). The lower contact of cross-bedded units is sharp, while the upper contact is either sharp or gradational. Bioturbations are not evident in this sublithofacies.

2.4.3 Lithofacies 3: Mud.

This lithofacies is characterized by dark grey (N3), very thin to thin bedded, slightly gravelly mud. This type occurs mostly in the lower part of the sequence. The sediment contains very small amounts of gravel and sand but a very high content of mud. Bedding is either irregular or slightly undulated with shrinkage cracks on the top. The contacts of beds are clearly sharp according to the difference in grain-size and colour to overlying and underlying sediments (Photo. 2/19). A few quartz-granules are disseminated in the muddy groundmass, locally forming thin laminae.

2.5 Major subdivisions in the Linz sand sequence.

The Linz sand sequence can be divided into two major parts, lower and upper parts, due to the massive sand bed

Photo 2/18 Multiple sets of small to medium scale, low angle (tangential) cross-bedding occur locally in the thick bedded gravelly sand (gS) and slightly gravelly sand ((g)S) of Sublithofacies 2-B with well preserved paleocurrent directions; Quarry D, at 4.5 m., looking N.

Photo 2/19 Very thin to thin bedded (dark grey) slightly gravelly mud ((g)M, Lithofacies 3) is locally present in the lower Linz sand sequence. The minor normal fault at the middle right; Quarry F, at 10 m., looking NW.

which acts as a marker bed (see Fig. 2.5, text section 2-A-3 and Photo. 2/17).

The lower part is dominantly composed of cross-bedded sandy gravel and gravelly sand. Locally small channels and bioturbation in slightly gravelly sand, gravelly sand and sand are observed. Thin dark grey slightly gravelly muds are rarely intercalated. The lower part is mostly preserved in the north and the northwest of St.Georgen an der Gusen.

The upper part is typically composed of small sandy gravel channel fill sediments, and common scour-and-fill structures. Intercalated beds are irregular beds of sandy gravel, bioturbated slightly gravelly sand and sand. The thickness of beds is medium to thick like in the lower part. Cross-bedded and muddy sediments are not evident in the upper part.

In general, an individual thickness of each major part in the Linz sand sequence is uniform throughout the area, although lateral lithologic variations may be present.

2.6 Sedimentary structures.

Different sedimentary structures reflect different modes of deposition, and their characteristics are useful in assisting an interpretation of depositional environments like relative water energy, water depth and current flow directions. The major sedimentary structures recognized in the Steyregg area include horizontal stratification, wavy-lenticular stratification, irregular (channels and cut-and-fill structures) stratification, cross-stratification, massive deposits, bioturbation and shrinkage cracks. Local occurences of graded bedding are conspicuous at a few horizons.

2.6.1 Horizontal stratification.

Well defined horizontal stratification is prominent in the sequence of the Steyregg area, and ranges from thin (3-10 cm), medium (10-30 cm), thick (30-100 cm) to very thick beds (over a metre thick; see Collinson and Thompson, 1989). Medium to thick beds occur most commonly as texturally distinctive units, such as in the Linz sand sequence (Photo. 2/17), and/or as repeatedly interbedded units of similar or contrasting lithology, eg. in the terrigenous mixed carbonate sequence of Steyregg (Photo. 2/20). More rarely, uniform textures and lithologies are shown within horizontal beds throughout the area. Contacts between beds are either even on top or gently undulating, and may be either sharp and well defined or transitional.

According to Champbell (1967) and Pettijohn (1975), horizontal stratification results from spatial and time variations in the rate and kind of sediment supply or from the differential setting of grains initiated by changes in current velocity or abrupt change in depositional conditions.

Additionally, normal graded bedding occurs locally in both sequences. Granule to pebble sized quartzose and granitic fragments, which may rest on a scoured substrate, pass rapidly up into successively finer grain sizes (Photo. 2/21). Most normal graded units have been formed from a gradually waning current, such as might have resulted from the sudden flooding across a low-lying sediment (Nelson, 1982). Inverse graded units have not been commonly recorded.

2.6.2 Wavy-lenticular stratification.

In the Linz sand sediments, thin bedded (10-15 cm thick) slightly gravelly sands interbedded with very thin light grey muds, rarely show broadly undulating, parallel and small hummocky bedding surfaces (Photo. 2/22). However, close observations show that an internal bedding is structureless. Many of these thin wavy terrigenous beds are themselves laterally discontinuous. The author likewise suggests that these surfaces resulted from unequal reaction to loading.

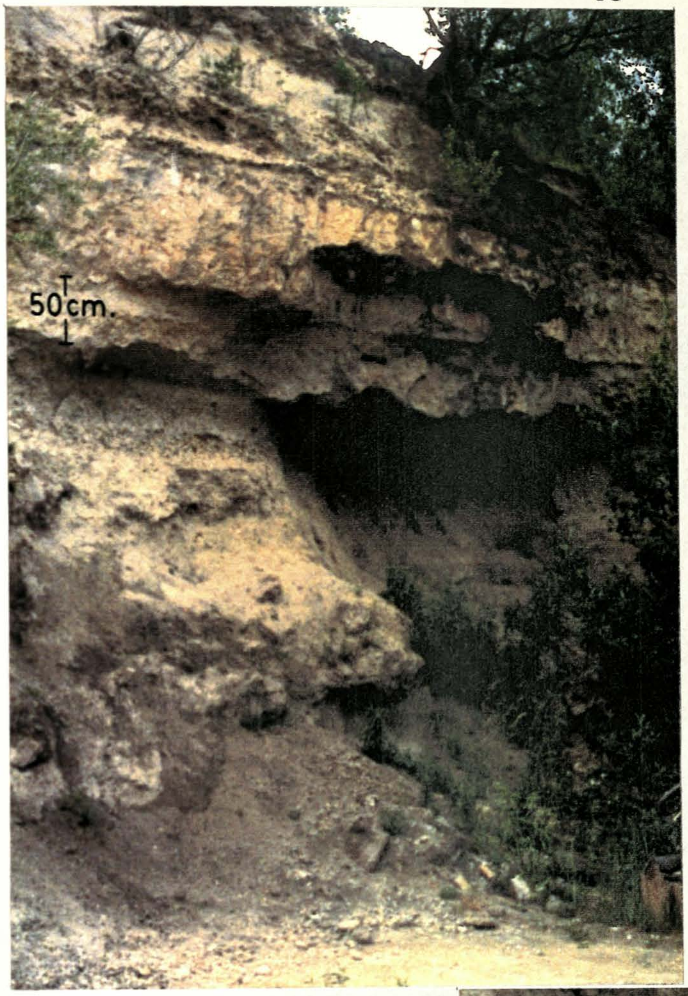


Photo 2/20 Stratification is remarkably uniform and flat. Bedding is defined by alternating layers of consolidated calcarenites and terrigenous sediments. Note that the terrigenous beds do preserve small irregularities and undulations. In exposed outcrops,the terrigenous bed is preferentially weathered, and the consolidated calcarenite bedding is well defined; Quarry A, Section III at 10 m., looking NW.

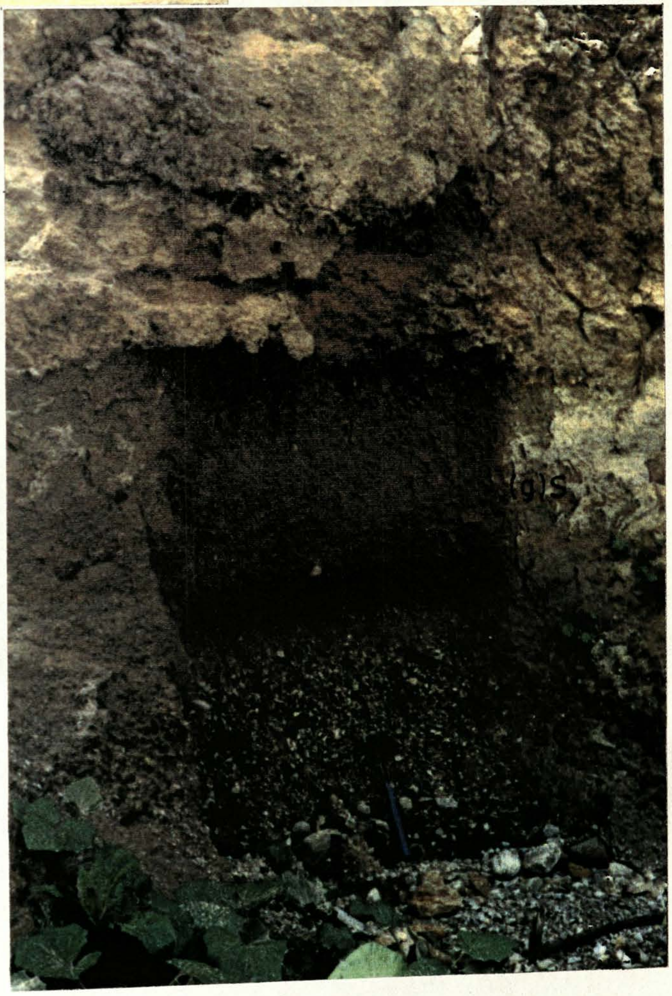


Photo 2/21
Normal grading in sandy gravel (sG, Sublithofacies A-2) with the overlying slightly gravelly sand ((g)S) in the terrigenous mixed carbonate sequence, Steyregg; Quarry A, Section III at 9.5 metres, looking NW.

Photo 2/22 Wavy stratification occurs in the lower Linz sand sequence. Note that the low amplitude relief in few layers simulates a kind of ripple marks, although the obvious ripple cross-lamination is absent within beds; Quarry G, Section II at 9 m., looking W.

Photo 2/23 Small channels form lenses of gravelly sand (gS) and sandy gravel (sG) with normal grading. They are a typical characteristic within slightly gravelly sand ((g)S, Sublithofacies A-3-3) of the terrigenous mixed carbonate sequence (Steyregg) and Sublithofacies 2-A-2 of the Linz sand sequence; Quarry A, Section IV at 14 m., looking NW.

On outcrop scale, lenticular beds (streaks and wisps of the terrigenous sand or gravel mixed carbonate) are occasionally common in the consolidated calcarenites of Steyregg (Photo. 2/8). Smaller scale, lenticular-like structures vary in thickness from 1-2 cm to about 10 cm, and show quite irregular and swirled patterns (Photo. 2/11). Layers rarely extend laterally for more than a metre, and more commonly for only a few tens of centimetres. Again, however, slabbed specimens are generally featureless. The author suggests that these features possibly resulted from an unequal reaction to loading and from differential weathering characteristics of fine-grained sediments.

The occurrence of both wavy bedding in the Linz sand sediments and irregular lenticular bedding in the consolidated calcarenites is, according to Nelson (1978) and Boggs (1992), consistent with deposition in a shallow marine, current-agitated environment, and is a characteristic of sediments deposited at or above fair weather wave base.

2.6.3 Irregular stratification.

Irregular stratification (Boggs, 1987,1992), structures appear to have formed as a result of erosion of unconsolidated beds followed by an episode of sedimentation. Structures of this kind can be called simply erosional structures, include channels and cut-and-filled structures. These structures are very common in both the Linz sand sequence (Photos. 2/13, 2/16) and pure terrigenous sediments of the terrigenous mixed carbonate sequence, Steyregg (Photo. 2/23).

2.6.3.1 Channels.

Channels (Boggs, 1987) are sediment-filled troughs that show a U- or V-shape in cross-section, and that cut across previously formed beds. Channels exposed in sequences of the Steyregg area range in width and depth from 5 x 20 cm to 10 x 25 cm across, being single lens-like in cross-section (Photo.

2/23). They are commonly filled with sandy gravel that is texturally different, commonly coarser, than that of the underlying bed. The long profiles of the channels are not exposed in any outcrop for measurement of paleocurrent directions. These structures may have been formed by small currents, and are particularly common in fluvial and nearshore sediments (Boggs, 1992).

2.6.3.2 Cut (or scour) and fill structure.

In contrast to channels, cut and fill structures occur closely spaced in a row as the soles of beds, generally being more asymetrical-shaped in cross-section (Boggs, 1987,1992). They show great variation in depth. These structures are formed by current. The current always cut or scoured in sand, and subsequently filled with coarser material as current velocity decreased (Photo. 2/16).

2.6.4 Cross-stratification (also called cross-bedding).

Three types of cross-bedding have been observed: tangential, tabular and trough cross-bedding (Allen, 1982). Cross-bedded units are generally 1-3 m thick, and in particular composed of slightly gravelly sand. Cross-bedding developed locally in the lower part of the terrigenous mixed carbonate sequence (Steyregg) and more common in the lower Linz sand sequence. The angle of dip of foreset beds ranges from 5° to 20°, and averages about 10°. The coarse grains (granule to pebble sized quartz and granitic fragments) lie at the base of individual foresets (Photos. 2/24, 2/25). The individual cross-bedded unit represents successive foreset beds, added to an advancing sediment front. These cross-beds probably formed by the periodic migration of submarine sand-waves an across relatively flat substrate of the sea-floor under the influence of current and/or wave actions (Chamley, 1990). They are typical of beach sediments, and particularly of the foreshore environments (Davidson-Arnott and Greenwood, 1976). The foresets, which may have either flat or undulatory upper and lower bounding surfaces, vary from a few

Photo 2/24 Large scale cross-stratifications in sandy gravel (sG, Sublithofacies 1-B-2) are associated with slightly gravelly sand ((g)S) and gravelly sand (gS) of the lower Linz sand sequence. Foreset dips 15-20° towards the south-southeast; Quarry G, Section II at 3.5 m., looking NW.

Photo 2/25 Several units of small to medium scale cross-stratifications occur in the slightly gravelly sand ((g)S, Sublithofacies 2-B), and are associated with sandy gravel (sG) of the lower Linz sand sequence. Cross-bedded units are defined by gently dipping foresets of slightly gravelly sand with parallel series of horizontal slightly gravelly sand beds or erosional surfaces; Quarry F, at 2.5 m., looking NE.

to several tens of centimetres in thickness, are laterally continuous, and may show well defined foreset beds. In some cases, individual tabular cross-stratified sets interfere with one another, and appear wedge-shaped like in the lower Linz sand sequence (Photos. 2/14, 2/18), as a result of erosion followed by deposition.

Paleocurrent directions of the small scale cross-bedded units indicate current flowing from east to west (Photo. 2/6) for that in the terrigenous mixed carbonate sequence (Steyregg), and from south-southeast to north-northwest (Photos. 2/14, 2/25) and from east to west (Photo. 2/18) for that in the Linz sand sequence.

An average trend of these cross-strata in the terrigenous mixed carbonate sequence (Steyregg) indicates current flowing towards the southeast (Photos. 2/6, 2/7). Current directions in the Linz sand sequence are observed toward the south-southeast.

2.6.5 Massive deposits.

Few thick strata of the terrigenous mixed carbonate (Steyregg) and the Linz sand sequences are structureless. This is most frequently seen in moderately to well sorted sands, where sedimentary structures cannot be delineated by textural variations (Selly, 1988). The massive nature of these lithologies is probably the result of continuous rapid deposition of sediments (Collinson and Thompson, 1989), of more or less similar grain-size and composition under relatively uniform environmental conditions, coupled perhaps with the texturally homogenizing influence of burrowing organisms.

2.6.6 Bioturbation.

Ichnofossils are particularly useful in paleoenvironmental analysis because there are biogenic features that clearly formed in place (Ekdale, 1978; Ekdale et.al., 1984; Basan, 1978). In contrast, body fossils can be transported from one environment to another, and can be reworked from older sediments.

Biogenic structures, identified only in the Linz sand sequence, are recognized as burrows. General descriptions of these structures are branched burrow systems of straight to gentle curved shafts (Photo. 2/26) and horizontal to gentle inclined closely spaced. The tunnels are circular shaped in cross-section with clayey walls 2-5 mm thick. The walls are smooth on the interior surface and distinctly mammilated on the exterior surface. Exterior diameter of the burrow ranges from 1-3 cm with an average of about 2 cm for well developed tubes. No apertural necks are observed. Burrows are generally filled with sediments of the overlying bed which is different from the surrounding matrix (Photos. 2/15, 2/27). This burrowing structure may likely be identified as *Ophiomorpha*.

Gentle erosion of the Linz sand by wind and rain often reveals the presence of small and extremely delicate trace fossils in form of tunnel and shaft-burrows. Obviously, burrows of *Ophiomorpha* are never common, probably, because special conditions of slow erosion with cliff overhang protection are needed to reveal the wall burrows (Seilacher, 1967; Frey, 1973; Curran, 1985).

The burrows of *Ophiomorpha* shafts were undoubtedly constructed to support dwelling/feeding activity. The recent *Callianassid* burrows are very similar to *Ophiomorpha* shafts and tunnels (Weimer and Hoyt, 1964; Frey et.al., 1978; Curran, 1985a). They are shallow-water forms, prefer sandy substrate, and likely burrow in high energy-littoral environment (Crimes and Harper, 1970).

2.6.7 <u>Shrinkage cracks</u>.

The term "shrinkage cracks" (Collinson and Thompson, 1989) encompasses a broad suite of sedimentary structures, having

Photo 2/26 Burrows of *Ophiomorpha* shafts (in a circle) occur in slightly gravelly sand ((g)S, Sublithofacies 2-A-1) of the Linz sand sequence. Burrows are filled with sediments of the overlying bed. Shaft's orientations are generally at right angle to the bedding surface; Quarry C, at 15 m., looking NW.

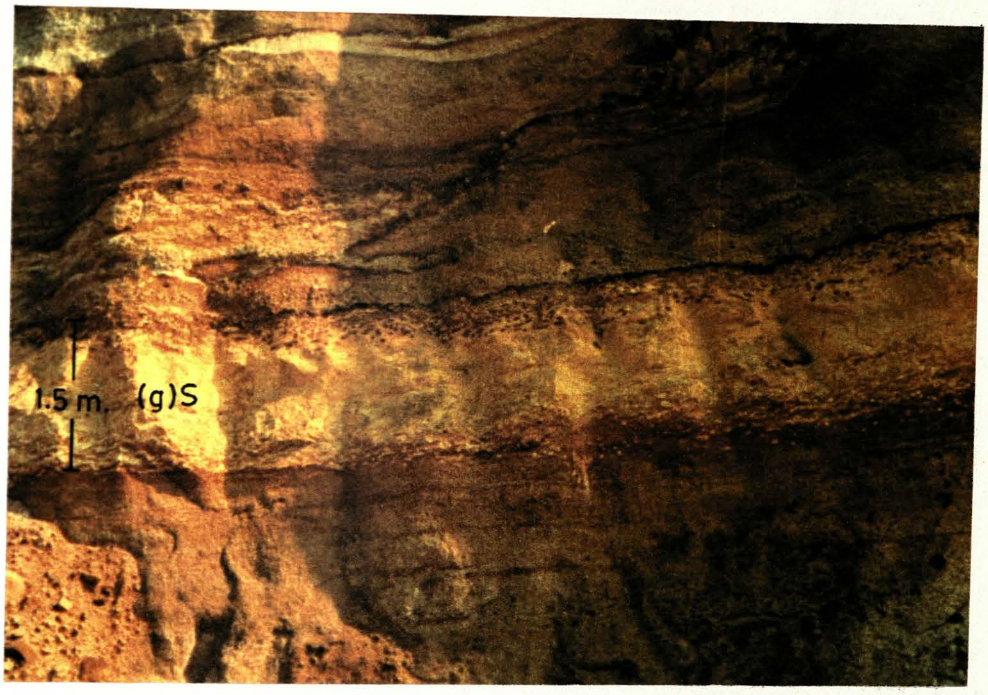


Photo 2/27 Well developed *Ophiomorpha* tunnels are shown by circular marking and close spacing in cross-section. Burrowing zone is commonly 30 cm thick on the top most of bed. They are a typical structure of slightly gravelly sand (Sublithofacies 2-A-1) of the Linz sand sequence; Quarry E, Section II at 5 m., looking NE.

various origins. They are found locally in the muddy lithofacies of only the Linz sand sequence, and may indicate a short period of pond-like depositional environment periodically subject to subaerial exposure and/or desiccation. However, these cracks can form also at the sediment-water (subaqueous) interface or substratally by synaeresis processes (Plummer and Gostin, 1981; Collinson and Thompson, 1989). Thus, confidence in interpreting subaerial exposure from shrinkage cracks also depends on finding other associated sedimentary structures diagnostic of exposure which are absent in the Linz sand sequence.

CHAPTER 3
PETROGRAPHY: THIN-SECTION

One of the principle purposes of this work was to document in detail the petrographic character of consolidated calcarenites in terrigenous mixed carbonate sequence (Steyregg) and non-calcareous Linz sand sediments in the study area. The highly calcareous nature of the consolidated calcarenites demanded some knowledge of the modern nomenclature and classifications applied to these sediments. A realization of the petrographic properties deemed useful in interpreting the genesis and environment of the deposition of these sediments. Although most of the petrographic terms used in this thesis are defined in the literature, their specific definitions are included in the following pages because their usage has not always been fixed. The methods of study are also briefly outlined.

The petrographic character of twenty-six samples of the consolidated calcarenites (Steyregg) and four samples of the slightly consolidated Linz sand sediments was determined by using thin-sections. One end of carbonate thin-sections was partly stained with "Alizarin-Red" and "Potassium Ferri-cyanide" in order to observe in detail the carbonate varieties and the distribution of terrigenous clay and sand size grains (see Friedman, 1959; Dickson, 1965,1966; Wolf et.al, 1967).

Results of the basic textural, compositional and diagenetic properties of many thin-sections investigated were summarized on petrographic data sheets in Appendix 7, Table 3.1 and Fig. 3.7. The percentage abundance of bioclastic, terrigenous, matrix and cementing materials was estimated by the ocular-grid counting method. Grain-size in thin-sections was measured with an ocular micrometer (cf. Textoris, 1971).

Throughout this chapter, bioclastic grains were identified in petrographic thin-section according to Bathurst (1971), Flügel (1982), Adams et.al. (1984) and Tucker et.al., (1990).

3.1 Descriptions of the sediment's constituents.

3.1.1 Terrigenous, allochemical and orthochemical constituents.

Following the terminology of Folk (1959, 1968 or 1980) the components of the sediments may be grouped under the three following headings:

a. **Terrigenous constituents**: those materials derived from the erosion of a land area "outside" the basin of deposition and transported as solids into the basin; eg. quartz grains, detrital clay minerals and rock fragments.

b. **Allochemical constituents**: those materials formed by chemical and biochemical precipitation "within" the depositional area and showing evidence of subsequent transport; eg. shell fragments and intraclasts.

"**Intraclasts**" are fragments of penecontemporaneous consolidated or slightly consolidated carbonate sediments which have been eroded from adjoining parts of the sea bottom and redeposited to form a new sediment.

c. **Orthochemical constituents**: those materials chemically precipitated "within" the depositional area and showing no evidence of post-precipitation transport; eg. sparry calcite cement.

"**Grains**" are discrete particles which, in this work, are conveniently regarded as being larger than about 0.06 mm (cf. Bissell and Chilingar, 1967). They form the rock framework or, more rarely, are subordinate to smaller particles in the rock. The term "**detrital** or **clastic**" is applied to any particles that have suffered mechanical transportation before final deposition; in particular the name "**siliciclastic** and **bioclastic**" are used.

Siliciclastic constituents are mechanically transported particles of essentially non-calcareous character eg. quartz, feldspar and detrital glauconite.

Bioclastic constituents are mechanically transported, variably abraded and broken particles with an essentially calcareous composition eg. transported fossil (or bio-) fragments.

3.1.2 Intrinsic and extrinsic constituents.

The former pore spaces in consolidated calcarenites may be conveniently regarded as of two types:

a. Interparticle pore space is that pore space "between" the prominent grains in sediments where lithification proceeds via the diagenetic addition of new material or modification of pre-existing material. Because these sites are more or less essential to the lithification process, they are called "**intrinsic pore space**" and are infilled by "**intrinsic material**".

b. Intraparticle pore space is that pore space "within" the allochemical grains of a deposit, and includes in particular the chambers and cavities of fossil shells. Since they are not essential sites for lithification of the sediment, they are called "**extrinsic pores**" and are infilled by "**extrinsic material**".

In the consolidated calcarenites, the main intrinsic and extrinsic materials include sparite, calcilutite, glauconite, and pyrite.

"Sparite" is a non-genetic, purely descriptive term for any transparent or translucent crystalline calcium carbonate. Possible origins of sparite include (Chilingar et.al., 1967):-

1. **Physicochemical precipitation** within the voids of a deposit, in which case the sparite is distinguished by adding the genetic prefix "ortho-", ie. orthosparite. Since the bulk of the sparite in the consolidated calcarenites, in this study, appears to be a physicochemical precipitate (see

section 5.5) the names orthosparite and sparry (calcite) cement are used synonymously.

2. **Neomorphic alteration** (Folk, 1965), which includes the processes of recrystallization and replacement of pre-existing materials. In this case, the sparite is distinguished by adding the genetic prefix "pseudo-", ie. pseudosparite.

The term "microsparite" is used if the crystal size falls in the 0.004 to 0.016 mm range.

"**Micrite**" (Folk, 1959) is unconsolidated or consolidated clay-sized (smaller than 0.004 mm) carbonate materials of either physicochemical, biochemical or detrital origin.

"**Matrix**" is defined as fine terrignous materials which has been mechanically transported or infiltrated. The larger grains in a sediment are embedded in the matrix. A preponderance of silt-sized terrigenous detritus (0.004-0.063 mm) in the matrix is indicated by the name "**silt-matrix**", while clay-sized terrigenous detritus (finer than 0.004 mm) is generally called "**clay-matrix**" and included in micrite-contents in this study.

3.2 General properties of the sediments.

Grain-size: The grain-size scale proposed by Wentworth (1922) is used in a sedimentary petrographic study. The terms "calcirudite, calcarenite and calcilutite" (cf. Grabau, 1960; Folk, 1968, 1980) are applied for impure allochemical sediments (cf. Folk, 1980). The calcilutite class may be further divided into "calcisiltite" (silt-sized fossil debris and/or carbonate particles) and "micrite" (clay-sized carbonate particles).

As a result of the common usage of "-ite" as a rock suffix in geology, the author accepted the use of the terms such as arenite, arkose and subarkose as compositional names for the unconsolidated Linz sands.

For orthochemical minerals (mainly pore-filling cement), the grade scale proposed by Folk (1959, 1962) is used.

Sorting: The degree of sorting was estimated in the thin-sections by comparision with a series diagram of Folk (1968, 1974 or 1980) and Harrell (1984).

Shape: The shape of terrigenous grains in thin-sections was estimated by comparison with diagrams of Folk (1968, 1980; based on Powers, 1953). For the shape of bioclastic grains, the diagram of Folk (1962) and Flügel (1982 based on Pilkey et.al., 1967) was also used. It is further important to observe whether bioclastic grains were broken before or after abrasion.

Washing: It is important to observe the proportion of cement to intrinsic micrite in order to gain additional information on current activity at the site of deposition. A progressive increase in the amount of cement over micrite in the specimen is generally interpreted as being due to an increase in the current action.

Textural maturity: As the sediment suffers a progressively greater input of mechanical energy through the abrasive and sorting action of waves or currents, they pass sequentially through a number of textural stages (Folk 1951, 1962). Flügel (1982 based on Plumley et.al., 1962) proposed an energy index scale for limestones which essentially parallels Folk's scheme. Both schemes are used in this study.

Porosity: In the consolidated calcarenites of Steyregg, the classification of porosity types by Choquette and Prey (1970) and Moore (1989) is used, and can be described as follows:

a. **Fabric-selective porosity** (primary origin) consists of interparticle, intraparticle, some intercrystalline, moldic and growth-framework porosities.

b. **Not fabric-selective porosity** (secondary origin) forms as a result of fracturing and/or solution, eg.fracture, channel, vug and cavern porosities.
c. **Fabric-selective or not porosity** includes both primary and secondary origins that involve solution collape or tectonism, eg. breccia, boring, burrow and shrinkage-porosities.

On the other hand, porosity in the Linz sand sediments is rather different from that in the consolidated calcarenites in terms of origin, evolution and preservation. Most of porosity types in the Linz sand are primary, depositional, interparticle porosity, although secondary porosity is also present (cf. Chilingarian and Wolf, 1975, 1976).

3.3 Systems of classification by petro-compositions.

3.3.1 Carbonate and terrigenous mixed carbonate classification.

Ham and Pray (1962) reviewed several of the important carbonate rock classifications, among which those of Folk (1959, 1962), Dunham (1962), Leighton and Pendexter (1962), Plumley et.al. (1962) and Bissell and Chilingar (1967 modified by Füchtbauer, 1974). Zuffa (1980), Lewis (1984) and Mount (1985) proposed a mixed terrigenous-carbonate classification which is used in this work.

However, consolidated calcarenites in this study normally contain more than 50 % carbonate materials (determined by acid digestion; see Appendix 3A). Many classifications, except that of Lewis (1984), yield insufficient differentiation of the terrigenous mixed carbonate sediments because they are concerned only with the framework grains.

Composition and texture of the consolidated calcarenite were investigated by the ocular grid counting method of twenty-six thin-sections. Modal analyses are presented in Appendix 7A. The average mineralogical and compositional values of the sediments are shown in Table 3.1. In general, the twenty-six samples consist of 51 % bioclastic grains, 29 % terrigenous grains, 3 % matrix, 2 % micrite, 13 % cememt (sparite) and 2 % porosity (average values).

The sediments were classified using the scheme of Folk (1974, 1980; see Fig. 3.1). The consolidated calcarenites are clearly separated into three lithological groups: Allochemical rocks (**A** = 6 samples), Impure Allochemical rocks (**IA** = 15 samples) and Terrigenous rocks (**T** = 5 samples). The gradual increase in gravel and sand content is evident by shifting of the points towards the terrigenous end-member.

The classification scheme of Lewis (1984) is used in this study, and has end-members as follows:

1. **Bioclasts** (bioclastic grains) - eg. calcirudite, calcarenite or all allochems (When the allochems are dominated by eg. intraclasts, the prefix intra- would replace bio-, such as intracalcarenite).
2. **Siliciclasts** (siliciclastic grains) - eg. all terrigenous gravel and sand.
3. **Micrite** - eg. clay sized carbonate particles.

It was not possible to distinguish between (detrital and authigenic) terrigenous clay matrix and (detrital and authigenic) micrite, therefore they are included in the micrite (end-member) in Fig. 3.2 (see also in Table 3.1 and Appendix 7A). Any cementing materials are not calculated for the plot. For convenience, bioclastic and siliciclastic grains are assumed to be mainly of sand size, as is most common in the calcarenites in the area studied, so that the names biocalcarenite and arenite can be used throughout the triangle. However, other names, eg. biocalcirudite, could be inserted when appropriate. Micrite can also be replaced by sparite, when applicable, as proposed by Lewis (1984).

In general, the sample contains less than 5 % micrite, and varying amounts of bioclastic and siliciclastic grains ranging from 5 % to 95 %. The verbal naming of sediments

Table 3.1 Summary of average values of the petrographic constituents for the consolidated calcarenites of Steyregg and the non-calcarenous Linz sand.

		CONSOLIDATED CALCARENITES (STEYREGG)	NON-CALC. LINZ SAND SEDIMENTS
	All bioclastic grains (%)	Σ 50.83	
	Benthic foraminifers %	18.84	
	Planktic foraminifers %	0.03	
	Calcareous algae		
	- Lithothamnium fragments %	26.96	
	- Other algae %	rare	
	Echinoderms %	0.89	
	Bryozoans %	rare	
	Ostracods %	0.12	
DETRITAL CALCAREOUS (ALLOCHEMS)	Molluscs		
	- Bivalves %	3.48	
	- Gastropods %	0.44	
	Brachiopods %	0.07	
	Intraclasts (%)	rare	
	All terrigenous grains (%)	Σ 28.79	88.88
	Total quartz %	12.22	55.83
	- Monocrystalline %	11.30	51.73
	- Undulatory extinction %	2.37	13.10
	- Non extinction %	8.94	38.63
	- Polycrystalline %	0.92	4.10
	- less than 3 crystals %	0.36	2.38
	- more than 3 crystals %	0.55	1.73
	Total feldspar %	6.37	26.58
	- Alkali feldspar %	5.66	20.83
DETRITAL NON-CALCAREOUS GRAINS	- Orthoclase %	1.51	15.33
	- Microcline %	4.15	5.50
	- Plagioclase %	0.71	5.75
	Total rock fragments %	9.44	4.83
	- <2 mm unstable rk.frag. %	0.49	-
	- >2 mm unstable rk.frag. %	7.12	-
	- >2 mm stable rk.frag. %	1.84	-
	Muscovite %	rare	0.20
	Biotite %	0.69	0.95
	Transparent heavy minerals %	0.03	0.20
	Opaque minerals %	0.04	0.30
	Matrix (%)	2.50	1.35
	Micrite (%)	2.21	-
	Cement (%)	13.41	-
	Other authigenic minerals %	0.05	-
	Observed porosity (%)	2.22	9.78

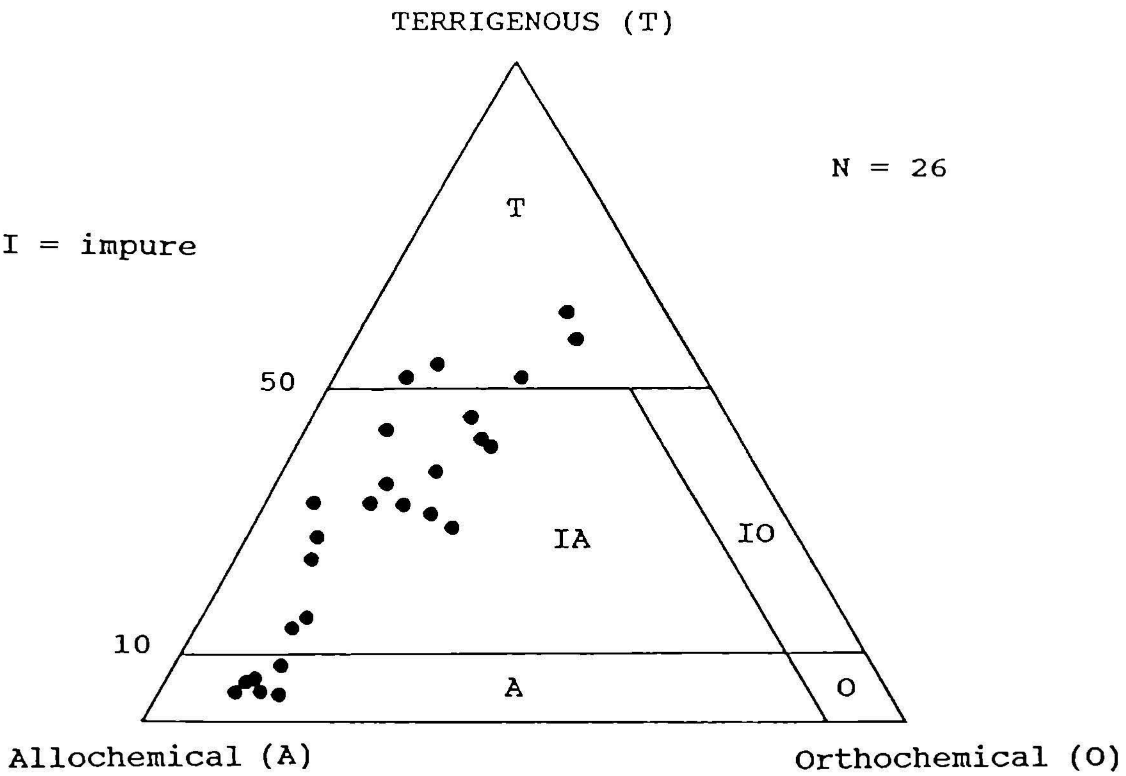


Fig. 3.1 Modal composition of twenty-six selected samples of the consolidated calcarenites of Steyregg, samples plotting on a primary diagram of Folk (1974) are
- Allochemical rocks (field **A** = 6 samples),
- Impure allochemical rocks (field **IA** = 15 samples)
- Terrigenous rocks (field **D** = 5 samples).

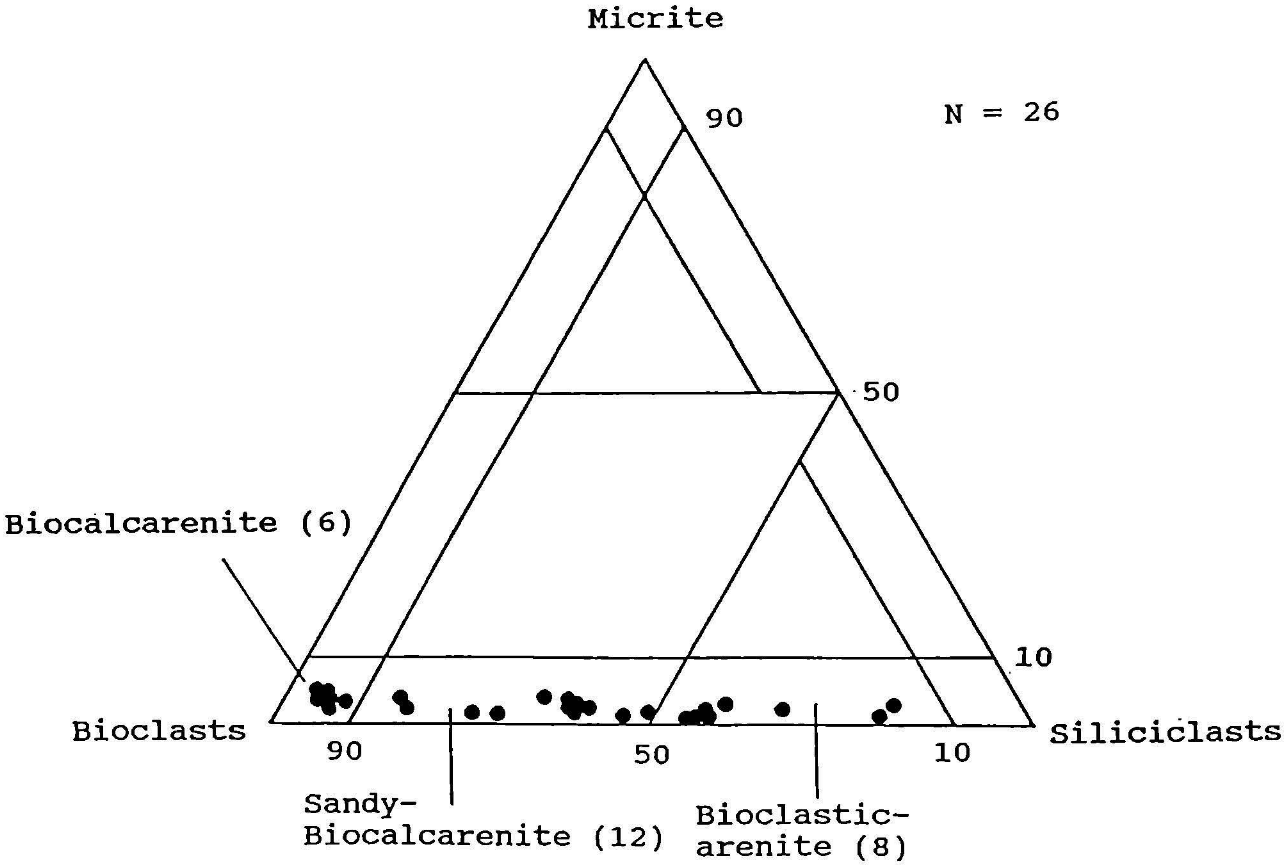


Fig. 3.2 Twenty-six samples of the consolidated calcarenites (Steyregg) are plotted on a diagram of Lewis (1984) for a tentative classification of the terrigenous mixed carbonate sediments.

using the classification of Lewis (1984) has clearly three groups (Fig. 3.2):

- Biocalcarenite (6 samples).
- Sandy biocalcarenite (12 samples: 10 arenite and 2 rudite)
- Bioclastic arenite (8 samples: 7 arenite and 1 rudite).

3.3.2 Sandstone classification.

The classification scheme used for sandstone composition presented in this study is that of McBride (1963). Most terrigenous sand grains are detrital quartz, feldspar and unstable rock fragments. End-members of the diagram used for the study are as follows:

Total quartz - including both monocrystalline quartz and polycrystalline quartz grains.

Total feldspar - including both detrital plagioclase and alkaline feldspar grains.

Unstable rock fragments - generally common as polycrystalline lithic fragments of magmatic, metamorphic and sedimentary origin.

Any appearance of granule to fine gravel grain size in the samples is not included for the plot of both sandstone classifications and provenances.

Thus, a ternary diagram is constructed in which these three components of any arenite may be quantitatively plotted. Note, for the Linz sand sediments, that the classification used only the main constituent as a classification parameter and rock-name. So, the author accepts the use of the terms as previously discussed. In general, the Linz sands are composed of 89 % terrigenous grains, 10 % primary porosity (on an observe) and 1 % matrix according to the thin-section study.

An average value (see Table 3.1) of the main terrigenous sand sized grains in the four Linz sand thin-sections is 65 % quartz (range 52 to 75 %), feldspar 30 % (range 22 to 39 %)

and sand-sized unstable rock fragments 5 % (range 2 to 9 %). On the other hand, the average value of the main terrigenous sand size grains in the twenty-six consolidated calcarenite thin-sections is 67 % quartz (range 51 to 83 %), feldspar 30 % (range 13 to 47 %) and sand-sized unstable rock fragments 3 % (range 0 to 7 %).

Classification schemes of the terrigenous Linz sand and terrigenous sand in the consolidated calcarenite are given in Fig. 3.3. The plots of both sample groups fall across the boundary between arkose and subarkose (McBride, 1963; see also Pettijohn et.al., 1987).

Arkose and subarkose, in general, contain less than 90 % quartz, more feldspar than unstable rock fragments and minor amounts of other minerals, eg. micas and heavy minerals. They are typically medium to coarse sand size, and are characterized by subangular to angular shaped, eg. the terrigenous grains in the consolidated calcarenites. They are texturally immature or submature. Arkose and subarkose typically occur in cratonic (fluvial, lacustrine), transitional-marine and stable shelf settings, where they are associated with conglomerates and carbonate rocks (Boggs, 1992). They are originated mainly by weathering of feldspar-rich acid (felsic) to intermediate crystalline rocks either plutonic rocks or feldspar-rich metamorphic rocks. Dickinson and Suczek (1979) and Dickinson (1985) suggested that feldspar-rich sandstones are derived especially from fault-bounded, uplifted basement areas in continental block provenances.

Arkose and subarkose in the consolidated calcarenites of Steyregg appear to have been deposited as clastic wedges very close to their source (see Chapter 2). Pettijohn et.al. (1987, pp. 152) suggested that a few arkoses being in-situ by disintegration of coarse crystalline rocks. However, less detrital matrix in the studied samples indicates that these arkoses have been transported for some distances.

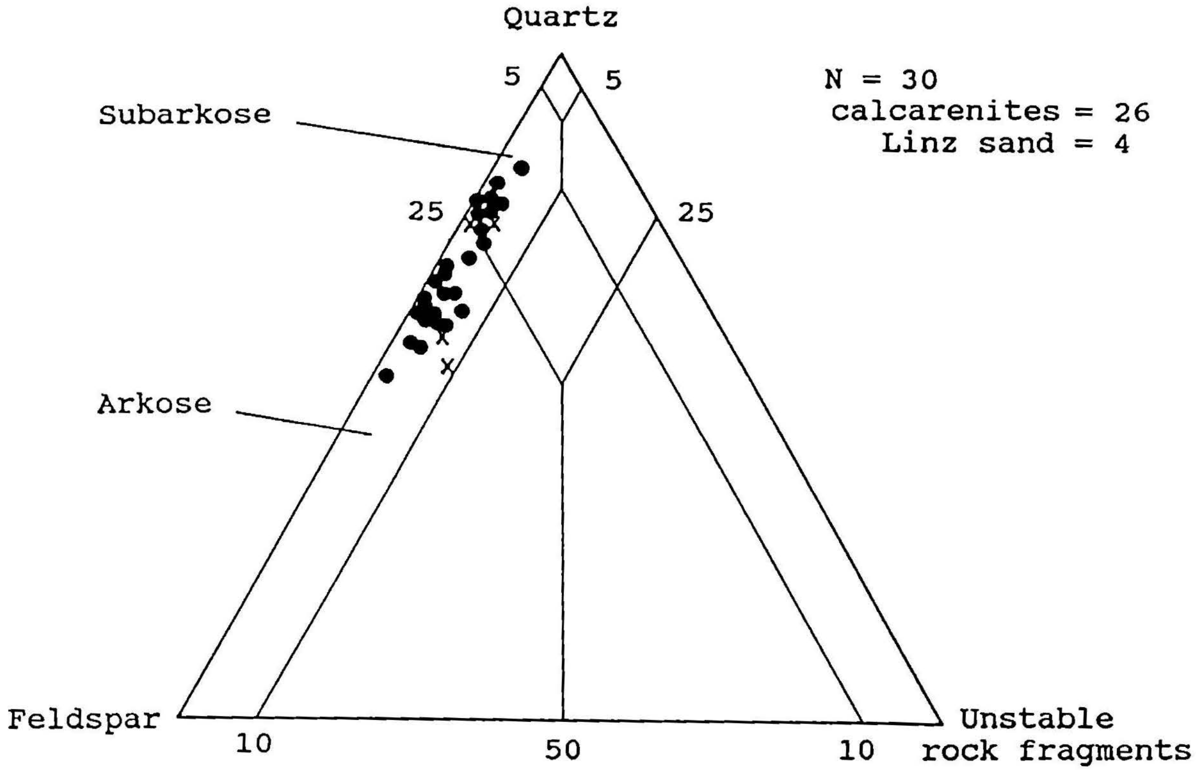


Fig. 3.3 Twenty-six samples of terrigenous sand-sized sediments from the consolidated calcarenites (Steyregg) and four Linz sand samples are plotted on a diagram (Quartz, Feldspar and Rock fragments end-members) for the classification of sandstone due to McBride (1963).

On the other hand, the arkosic Linz sand sediments may have been transported for much greater distances. This is indicated by better sorting, lower matrix content and better rounding of the grains compared with the terrigenous grains in the consolidated calcarenite samples (see Table in section 3.4.2 and also Appendix 7B).

3.4 Provenance of the terrigenous sand grains.

The composition of terrigenous sand grains reflects the influence of provenance (Blatt, 1967), tectonism (Dickinson and Suczek, 1979), climate (Basu, 1976) and sedimentary processes within depositional basins (Davies and Ethridge, 1975). The most informative components of terrigenous sand grains for these interpretations are generally quartz, feldspar, rock fragments and heavy minerals (see section 4.5.2). Diagenetic processes acting after final deposition may also modify the compositional attributes of sediments (see Chapter 5). Do the major kinds of igneous, metamorphic and sedimentary rocks unfortunately contain unequally different suites of minerals that provide a distinctive provenance signature? Are these characteristics preserved in sediments?

3.4.1 Source-rock lithology.

Quartz is the most stable constituent among the common rock forming minerals. Its properties have been considered as significant for provenance, eg. undulatory extinction, monocrystallinity, polycrystallinity and nature of subgrain-contacts (Folk, 1974, 1980; Young, 1976; Mach, 1981). The relative abundance of polycrystalline and strained (undulatory) quartz may be indicative of a metamorphic origin. Plots of Basu et.al. (1975) may prove in provenance determination of the terrigenous sand from the petrographic thin-sections of twenty-six unconsolidated calcarenites (Steyregg) and four Linz sand sediments in this study.

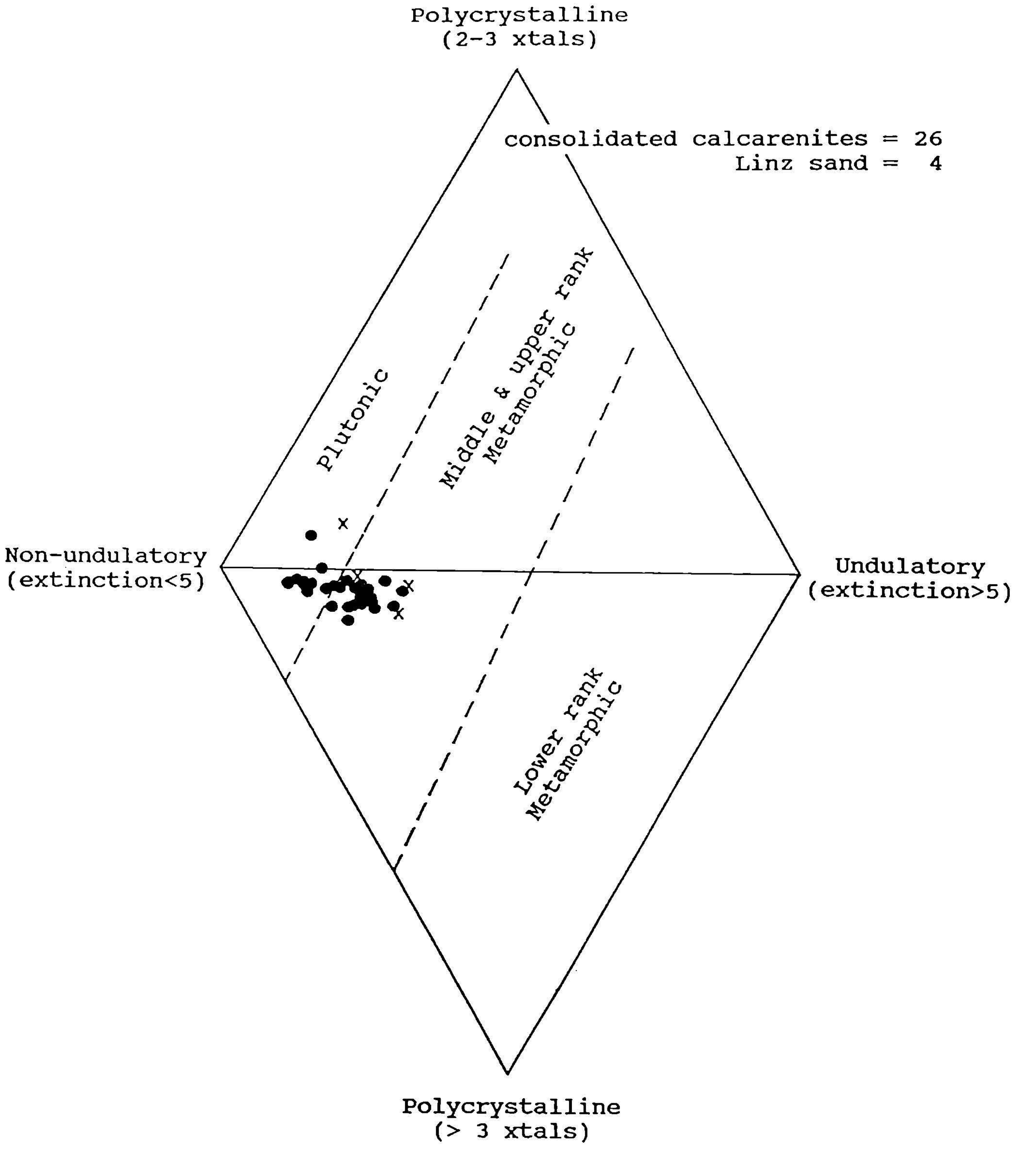


Fig. 3.4 Quartz populations of twenty-six samples of terrigenous sand-sized from the consolidated calcarenites (Steyregg) and four Linz sand sediments indicate that they have been derived from a similar rock-source, middle to upper rank metamorphic and plutonic rocks.

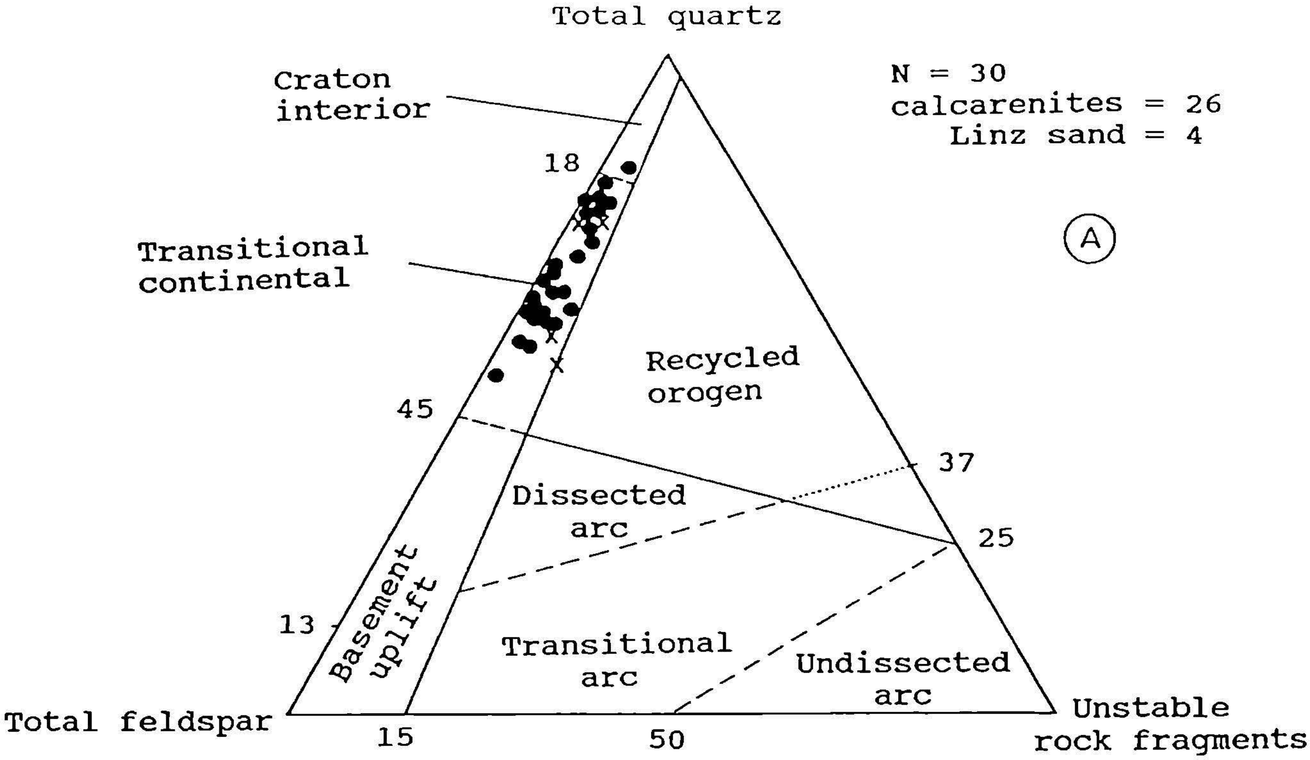
Results of this study (Fig. 3.4) indicate that most of the terrigenous sands are derived from middle to upper rank metamorphic rocks and some plutonic rocks. This interpretation is also supported by heavy mineral analyses (see section 4.5.2.1).

3.4.2 Tectonic provenance.

To develop a full understanding of provenance and paleogeography, the relationships among source area, depositional basin and the regional tectonic framework are required (Schwab, 1981; Cavazza, 1989; Critelli et.al., 1990). The basic assumption is that terrigenous mineralogy reflects not only source-rock lithology but also the general plate-tectonic setting (Girty and Armitage, 1989; Boggs, 1992). Dickinson and Suczek (1979), Dickinson et.al. (1983) and Dickinson (1985, 1988) suggested that all tectonic provenances can be grouped under three main types: continental blocks, magmatic arcs and recycled orogens.

Twenty-six arkoses to subarkoses (from the consolidated calcarenites) and four arkoses to subarkoses (from the Linz sand sediments) were plotted on the two different triangular compositional diagrams of Dickinson et.al. (1983 as seen in Figs. 3.5A,B).

Plotted results of both sediment's groups mostly fall in the transitional continental provenance field. It can be interpreted as a derivation of terrigenous sediments from weathered basement rocks. Evidently, arkose and subarkose lithologies in the consolidated calcarenites rest near the Bohemian Massif basement rocks, gneissic-granite and granite. This is supported by the presence of very coarse clasts of the basement rocks in a few horizons (see section 2.2.1). However, the scarcity of these clasts in the Linz sand arkose and subarkose suggests that any exposures of basement rocks were local, and did not have enough substantial relief (see next section 3.4.3). It can be also suggested that the terrigenous Linz sand may have been transported over long



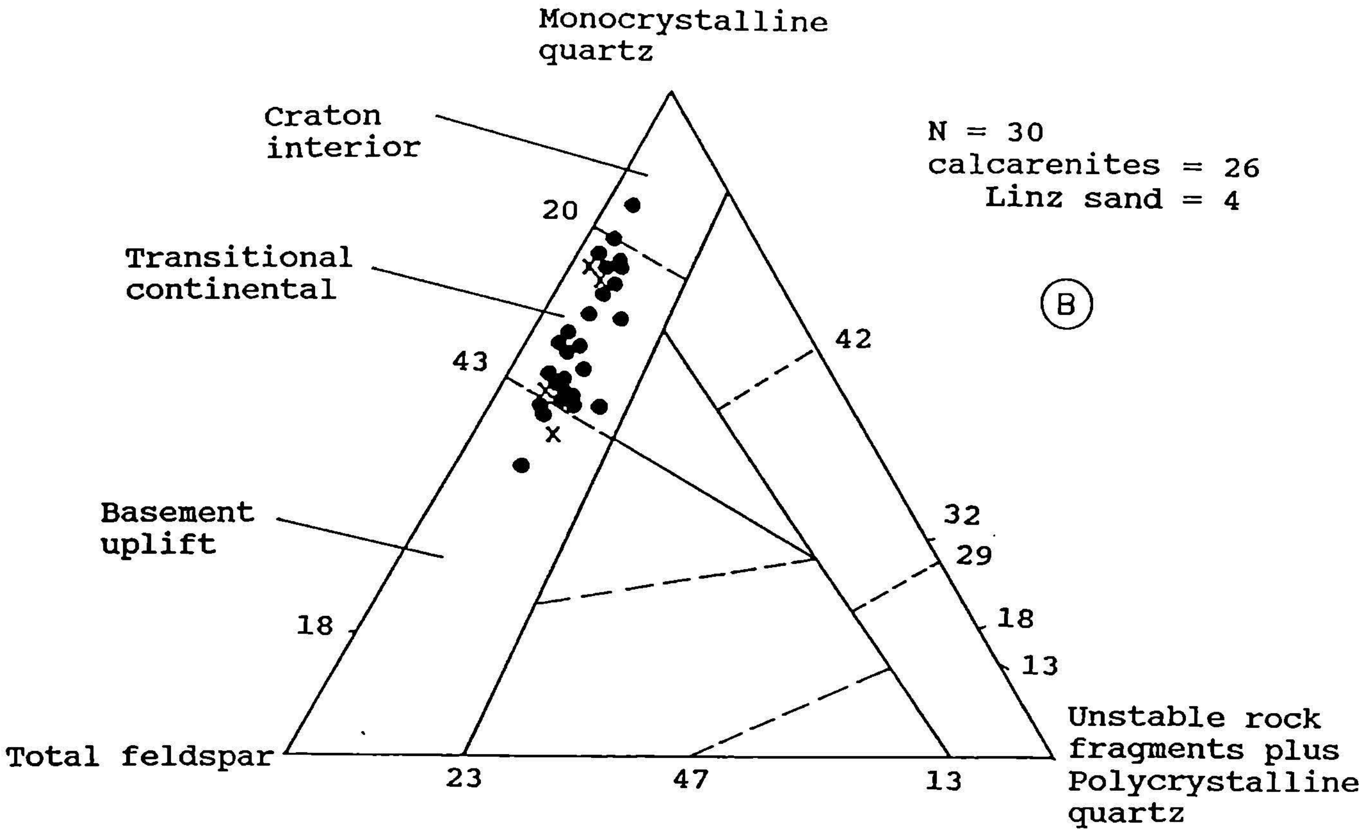


Fig. 3.5 Showing relationships between terrigenous sand-sized grains and tectonic setting as proposed by Dickinson, et.al. (1983). Twenty-six samples from the consolidated calcarenites of Steyregg and four Linz sand sediments are plotted:

A. On total quartz, total feldspar and unstable rock fragments diagram.
B. On monocrystalline quartz, total feldspar and unstable rock fragments plus polycrystalline quartz diagram.

distances on cratons of low relief. Whilst, the terrigenous sediments of the consolidated calcarenites (Steyregg) probably have been deposited without much transport in nearby interior basins. This is indicated by a high content of rock fragments which are very angular to angular shaped (see Table below: based on data in Appendix 7 and Chapter 4).

Comparison table of some sedimentary parameters that characterize the sediments of the terrigenous mixed carbonate sequence (Steyregg) and the Linz sand sequence (St.Georgen an der Gusen) for provenance interpretations.

Parameters	Terrigenous mixed carbonate sequence (Steyregg)	Linz sand sequence (St.Georgen an der Gusen)
Textures:		
- Sorting	Very poor-poor	Poor-moderate
- Roundness	Angular-subangular	Subangular-subrounded
Granitic rk-frag.	Abundant	Rare
- Max. sized	Boulder	Very fine pebble
Micas	Biotite>Muscovite	Muscovite>Biotite
Heavy minerals	Sphene>Zircon>Apatite	Zircon>Sphene=Kyanite
Clay minerals	Montmorillonite>Illite	Kaolinite>>Illite
Glauconite	Common	Non
Textural maturity	Immature-submature	Submature-mature
$CaCO_3$ content	Moderate to high	Rare
Major cement	Carbonate	Rare
Source area	Proximal	Distal
Environments (see Ch. 6)	Beach-foreshore to shoreface, ramp setting	Beach-foreshore to shoreface

3.4.3 Climate and relief of source area.

Folk (1974, 1980; pp. 84-85) suggests that climate and relief of ancient source areas can be evaluated on the basis of the relative size, degree of roundness, of quartz and feldspar and the degree of weathering of feldspar. However, it is very difficult to evaluate because grain-roundness may be inherited from a previous sedimentary cycle and feldspars may become altered during diagenesis as well as during weathering.

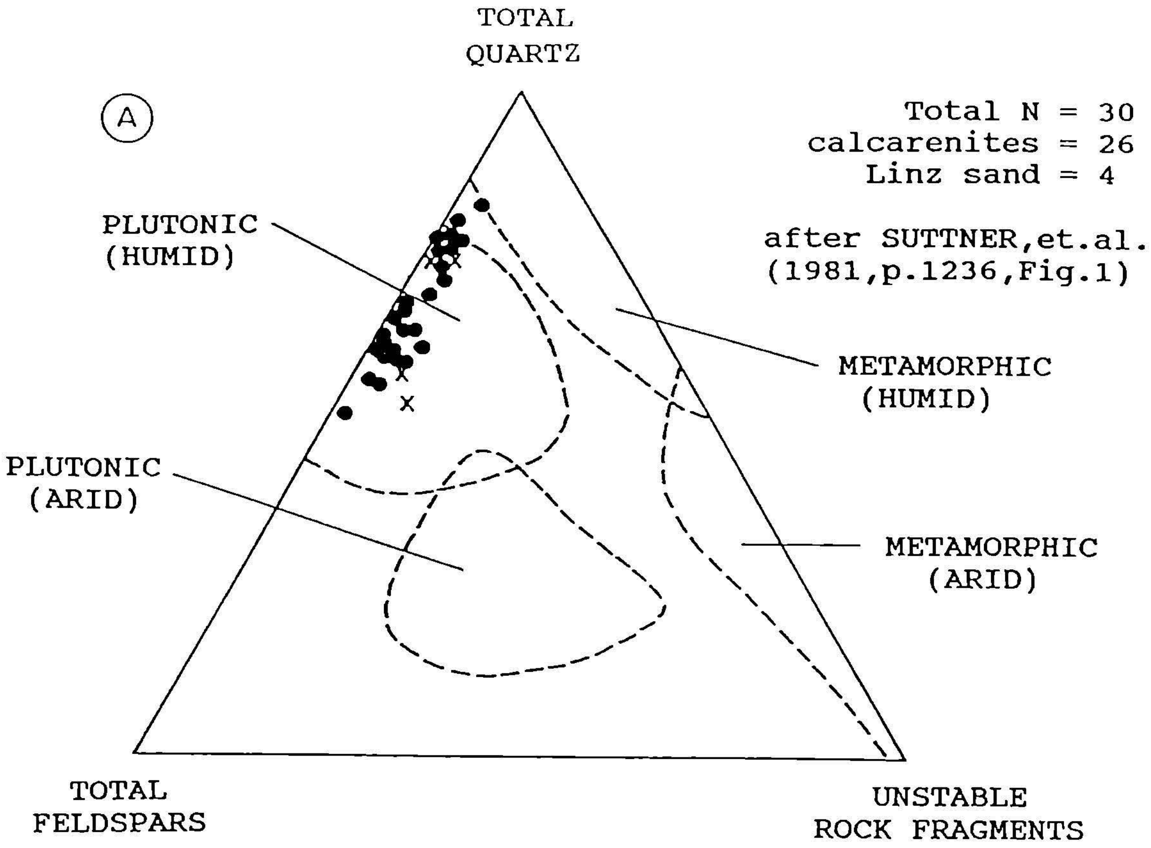
Young et.al. (1975) and Basu (1976) studied composition versus size of first-cycle sands derived from metamorphic and plutonic rocks in semiarid and humid climates. They concluded that weathering in semiarid climates generates greater amounts of rock fragments, feldspars and accessory minerals. Weathering in humid climates produces relatively more polycrystalline and monocrystalline quartz because less stable minerals and rock fragments are more easily destroyed by chemical weathering under humid conditions. In addition, Suttner and Dutta (1986) suggested that systematic variations in compositional maturity can be related to changing climate conditions during deposition.

Potter (1978, 1986), Fraser and DeCelles (1992) suggested that geomorphology, relief and rainfall influence the relative volumes of sediment of different facies composition produced during weathering (see Table below).

Summarized relationships of sand production to climate and relief as proposed by Potter (1978: pp. 444)

		Relief	
		High	Low
Rainfall	High	Large volume of lithic arenites	Small volume of quartz arenites
	Low	Small volume of lithic arenites	Small volume of variable composition eg. quartz, lithic or feldspathic arenites

However, when relief is extreme, a wet climate may simply enhance the volume of sediment rather than alter its composition. Basu (1985) argued that it is actually slope angle, not relief, that controls the residence time of sediment in soil horizons. If a hill slope exceeds the angle of repose and the residence time of all slope soil is low, even hot and humid climate would not be as effective to achieve advanced decomposition of bed rocks. Grantham and Velbel (1988) additionally proposed that rock fragments are the most sensitive indicators of cumulative weathering



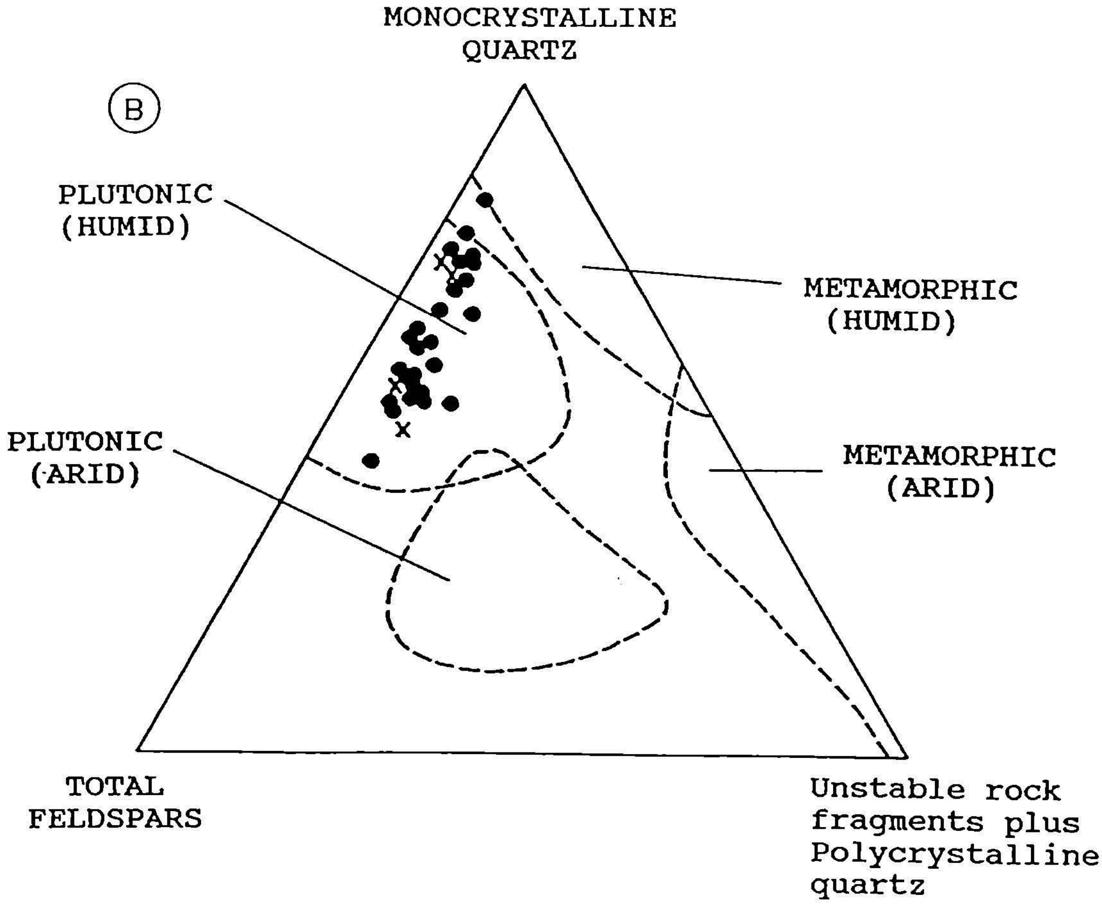


Fig. 3.6 Compositions of terrigenous sand-sized grains of twenty-six samples from the consolidated calcarenites (Steyregg) and four Linz sand sediments are plotted on a standard QRF-diagram of Suttner, et.al. (1981) for source-rock distinctions and climatic conditions.

A. For total quartz, total feldspar and unstable rock fragments end-members.

B. For monocrystalline quartz, total feldspar and unstable rock fragments plus polycrystalline quartz end-members.

effects. They maintained that abundance of rock fragments in detritus entering a fluvial transport system does not correlate directly with climate, but correlates with total or cumulative chemical weathering in the source area.

In this study, the amount of quartz, feldspar and unstable rock fragments of the "terrigenous sand-size grains" from the consolidated calcarenites (Steyregg) and the Linz sand sediments was plotted in the standard diagrams of Suttner et.al. (1981, pp. 1236) for source rock distinction and climatic conditions (Figs. 3.6A,B). Suttner et.al.'s diagrams can be subdivided into four main sources; plutonic (humid and arid) and metamorphic (humid and arid). The plotting results show that modal composition of the terrigenous sand from the consolidated calcarenites and the Linz sand sediments mainly derived from similar parent rocks, plutonic source, which were controlled by humid climatic conditions. This interpretation was supported by interpretations of both clay minerals (section 4.5.1) and heavy minerals (section 4.5.2). Moreover, the abundance of kaolinite in the marine Linz sands (eg. sample F-9/1) suggests that continental erosion at the time of its deposition was strong, caused by humid or wet climatic conditions.

3.5 Petrography of the consolidated calcarenites (Steyregg).

The consolidated calcarenite lithofacies is petrographically distinctive because of:

a. The importance of *Lithothamnium*, oyster and benthic foraminifers in the bioclastic fraction.
b. At least bimodal grain size distributions within both terrigenous and bioclastic fractions.

These two main parameters remain more or less vertical characteristic features of the consolidated calcarenites. Within this lithofacies, it may show considerable variations in the ratio of bioclastic to siliciclastic grains, represented by bioclastic arenite, sandy biocalcarenite and

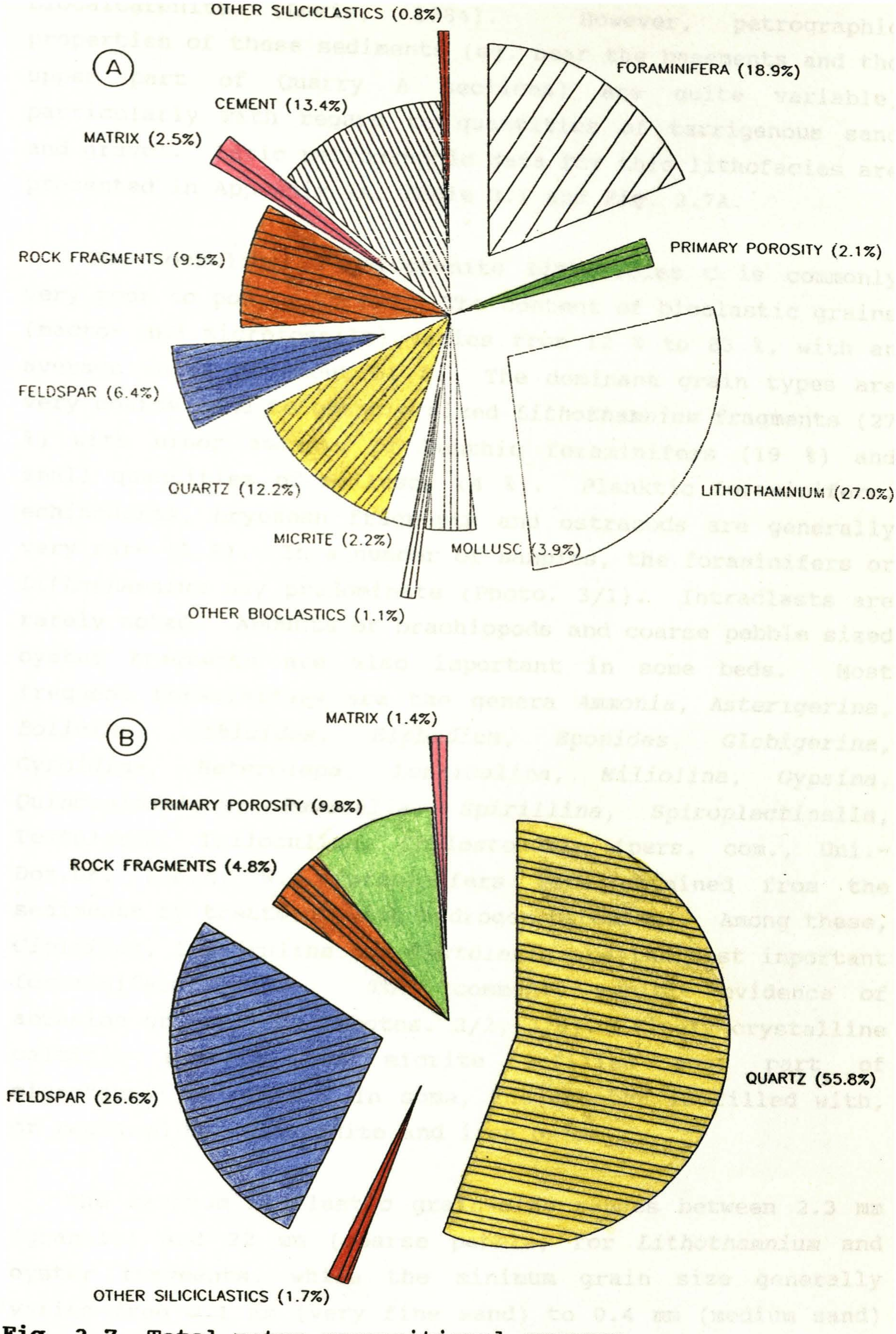


Fig. 3.7 Total petro-compositional summary.
A. Twenty-six samples of the consolidated calcarenite.
B. Four samples of the non-calcareous Linz sand.

biocalcarenite (Lewis, 1984). However, petrographic properties of these sediments (eg. near the basements and the upper part of Quarry A sections) are quite variable, particularly with regard to quantities of terrigenous sand and gravel. Basic petrographic data for this lithofacies are presented in Appendix 7A, Table 3.1 and Fig. 3.7A.

The consolidated calcarenite Lithofacies C is commonly very poor to poorly sorted. The content of bioclastic grains (macro- and microfossils) varies from 12 % to 83 %, with an average value of about 51 %. The dominant grain types are very coarse sand to granule sized *Lithothamnium* fragments (27 %) with minor amounts of benthic foraminifers (19 %) and small quantities of molluscs (4 %). Planktic foraminifers, echinoderms, bryozoan fragments and ostracods are generally very rare (1 %). In a number of samples, the foraminifers or *Lithothamnium* may predominate (Photo. 3/1). Intraclasts are rarely noted. Amounts of brachiopods and coarse pebble sized oyster fragments are also important in some beds. Most frequent foraminifers are the genera *Ammonia*, *Asterigerina*, *Bolivina*, *Cibicides*, *Elphidium*, *Eponides*, *Globigerina*, *Gyroidina*, *Heterolepa*, *Lenticulina*, *Miliolina*, *Gypsina*, *Quinqueloculina*, *Reussella*, *Spirillina*, *Spiroplectinella*, *Textularia*, *Triloculina*, *Chilostomella* (pers. com., Uni.-Doz.Dr. Resch, W.; foraminifers were obtained from the sediments by treatment with hydrogen peroxide). Among these, *Cibicides*, *Lenticulina* and *Textularia* are the most important foraminiferal genus. They commonly exhibit evidence of abrasion or breakage (Photos. 3/2, 3/5). Finely crystalline calcitic sparite and micrite infilled most part of microfaunal chambers. In some, the chamber is filled with, or replaced by, glauconite and iron oxide.

The maximum bioclastic grain-size ranges between 2.3 mm (granule) and 22 mm (coarse pebble) for *Lithothamnium* and oyster fragments, while the minimum grain size generally varies from 0.1 mm (very fine sand) to 0.4 mm (medium sand) for foraminifers and bryozoan skeletons. A modal bioclastic-size is nearly very coarse sand but considerable bimodal

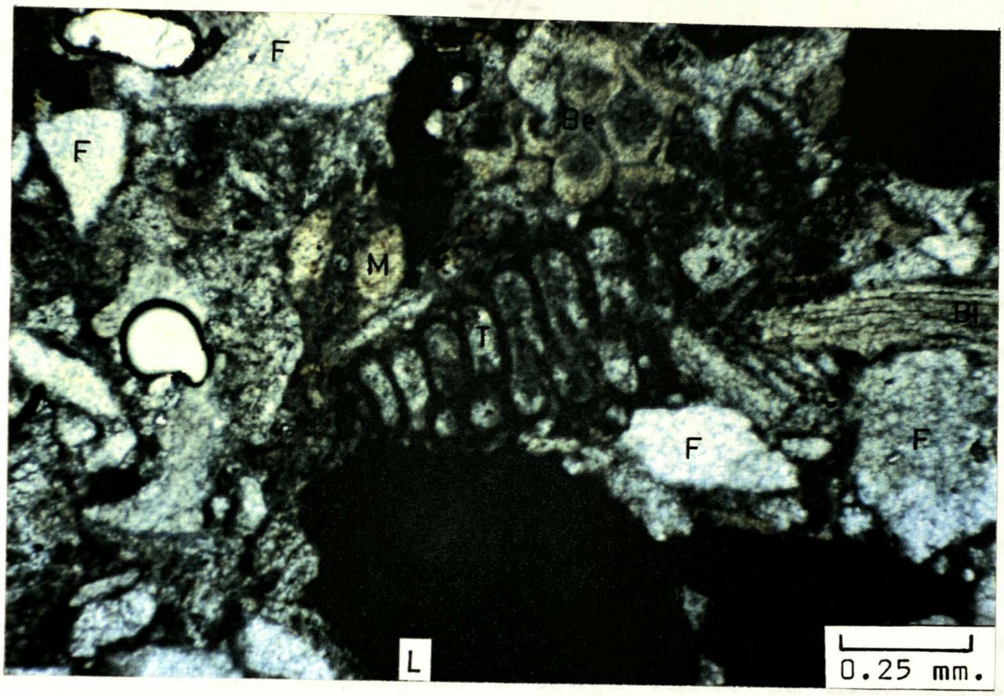


Photo 3/1 Bioclastic and terrigenous grains are tightly packed in sandy biocalcarenite, and are cemented by finely crystalline (granular) sparry calcite (*Lithothamnium* = L, Bivalve = Bi, Textulariina = T, Miliolina = M, Feldspar = F, Benthic foraminifera = Be); Quarry A, Section III at 21 m., sample St-30, plane polarized light.

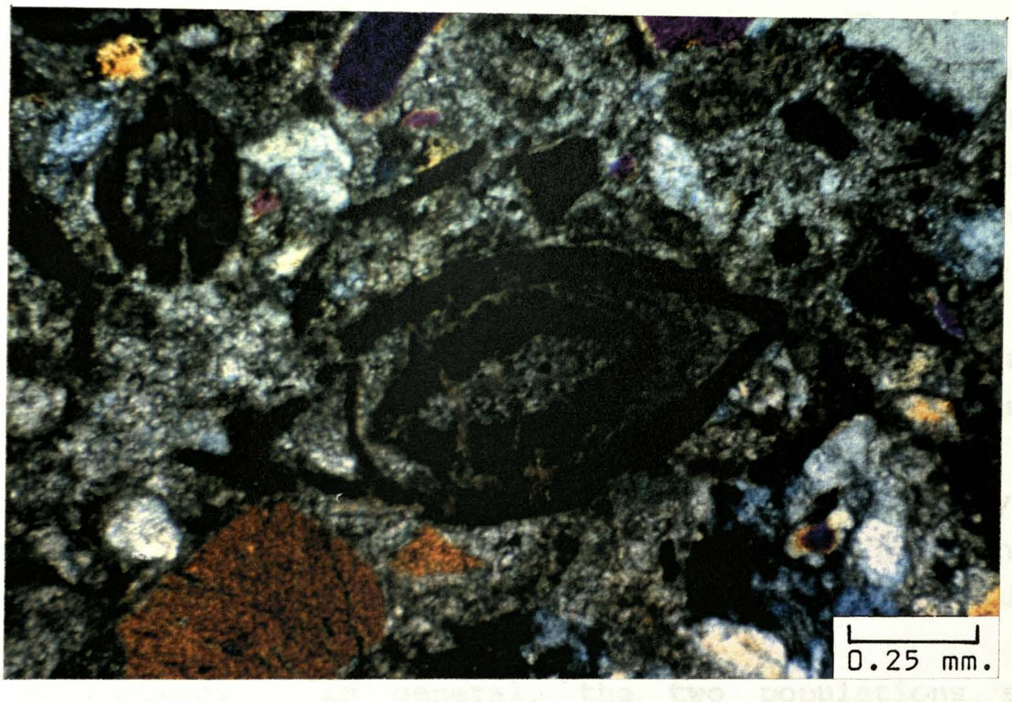


Photo 3/2 Breakage of Rotaliina (*Lenticulina*) in bioclastic arenite, test-chambers are filled with very fine crystals of sparry calcite and micrite. Echinoderm's spine section shows on the upper left; Quarry A, Section I at 21 m., sample Q-6, crossed nicols.

variations are evident. Most skeletons show moderately to strongly abraded and/or broken, low to moderate sphericity, and are very poorly to poorly (very rare moderately) sorted.

The quantity of terrigenous sand plus gravel varies from 4 % to 57 %, in most cases is below 50 %, with an average value of about 29 %. Siliciclastic grains are dominated by medium sand-sized quartz (more monocrystalline than polycrystalline quartz), an average value of about 12 % (ranges from 3 % to 20 %). The siliciclastic grains are subdominated by coarse-sand sized alkaline feldspar with rare plagioclase, ranging between 1 % and 17 % with an average value of 6 %. The sediment generally consists of granitic rock fragments coarser than 2 mm, making an average value as high as about 10 % (ranges from 1 % to 24 %). While, the rock fragments smaller than 2 mm are rare (in general, less than 1 %). Micaceous, non-opaque and opaque minerals are very rare (less than 1 %). At least, bimodality of grain size distribution within this fraction is more or less constant for the entire lithofacies, and occurs between very coarse sand-sized angular grains and granule subangular grains. The size and shape difference between the two populations is highly diagnostic. Sorting of both fractions is extremely variable. In general, however, the finer population is better sorted (poorly to moderately sorted) than the coarser one (very poorly to poorly sorted). Variations in the amount of siliciclastic grains are due mainly to variations in the quantity of the granule sized mode. The ratio of abundance between the two size-populations slightly shows systemmatic vertical variations through the lithofacies, due to the fining upwards trend. However, terrigenous grains may be randomly mixed with the bioclastic fraction. This can be segregated into terrigenous rich and poor beds, or sorted on a microscale into terrigenous layers rich in one of the two size populations. In general, the two populations show contrasting mineralogical compositions. Whereas the finer fraction is dominated by single quartz grains with subordinate feldspars and less rock fragments, the coarse sizes contain composite quartz grains with subordinate feldspars and more rock fragments coarser than 2 mm in diameter. The feldspars are generally unfresh due to sericitization and/or kaolinization, partial dissolution (Photo. 3/3), and replacement by calcite is observed. In a few thin-sections, sedimentary rock fragments are conspicuously rare (eg. F-2, W-2; Photo. 3/4). Traces of detrital glauconite are found in most slides (eg. A-9, Q-6, Q-10.4). Glauconite is mainly important as an extrinsic filling in bioclastic cavities such as sample W-2.

The amount of micritic materials in the consolidated calcarenites characteristically ranges between 1 % and 4 %, with an average value of 2.2 %. Small amounts of micrite plus terrigenous clay are present in the pore space between the grains. The average value of sparry calcite cements is about 13 %, varies from 2 % to 28 %. Whilst, the content of terrigenous silt-sized matrix is about 3 %, varies from 1 % to 6 %. The adherence of matrix to grains suggests that much of the sparry calcite was precipitated after washing of micrite from the sediment; resulting in very small amounts of an observed porosity of the sediment (average 2 %). This sparite has precipitated in original intrinsic voids (Photo. 3/5) and generally fine to medium crystal-sizes (Photo. 3/6). Orange-brown patches suggest iron contamination, derived, perhaps, from alteration of biotite. Skeletal cavities are commonly infilled with either micrite plus terrigenous clay, drusy sparite, glauconite or some combination of these. Diagenetic alteration phenomena in the terrigenous and bioclastic grains are relatively common in the consolidated calcarenites (Steyregg). A detailed description of diagenetic features is given in Chapter 5.

In addition, gross petrographic characteristics of bioclastic arenite, sandy biocalcarenite and biocalcarenite sublithofacies (see section 2.2.3) are entirely more or less similar to the general features and the rapid vertical and lateral variations (see Fig. 2.3) that do exist. These features can be explained by proximity to the source area and the basement (paleorelief) control on sedimentation. The

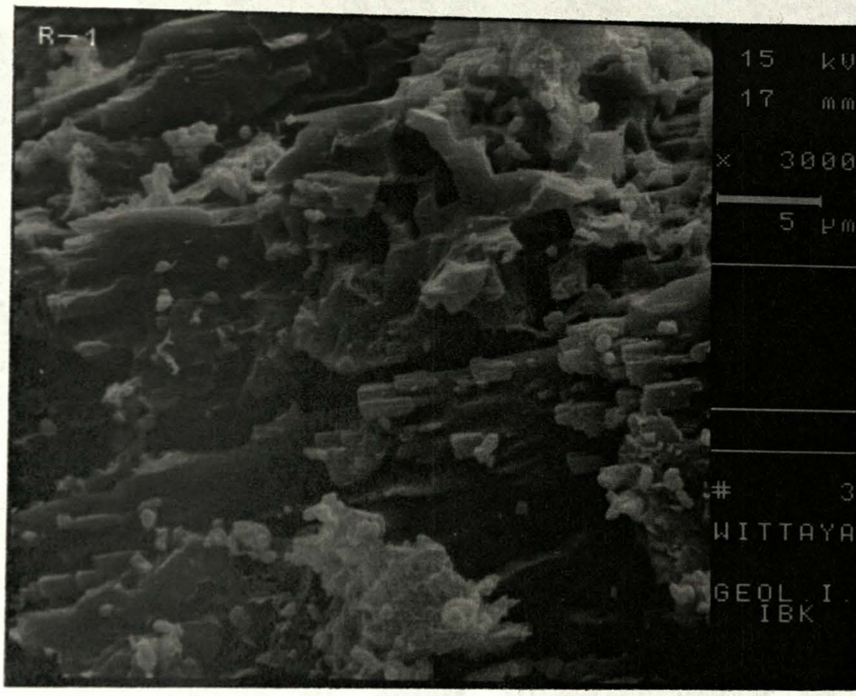


Photo 3/3 SEM photomicrograph of sandy biocalcarenite (rudite) showing that feldspar was dissolved, seen as roughness of the surface, and partially illitized (?); Quarry A, Section III at 33 m., sample R-1.

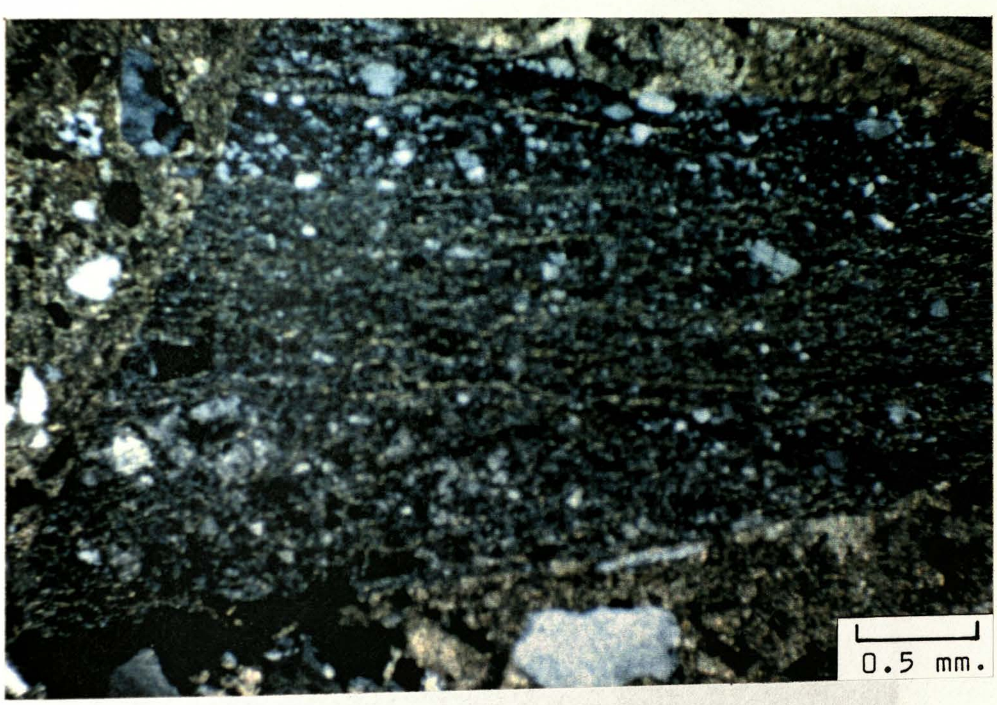


Photo 3/4 Rock fragment of fine grained sandstone is conspicuous in bioclastic arenite of the terrigenous mixed carbonate sequence (Steyregg); Quarry A, Section III at 6.5 m., sample F-2, crossed nicols.

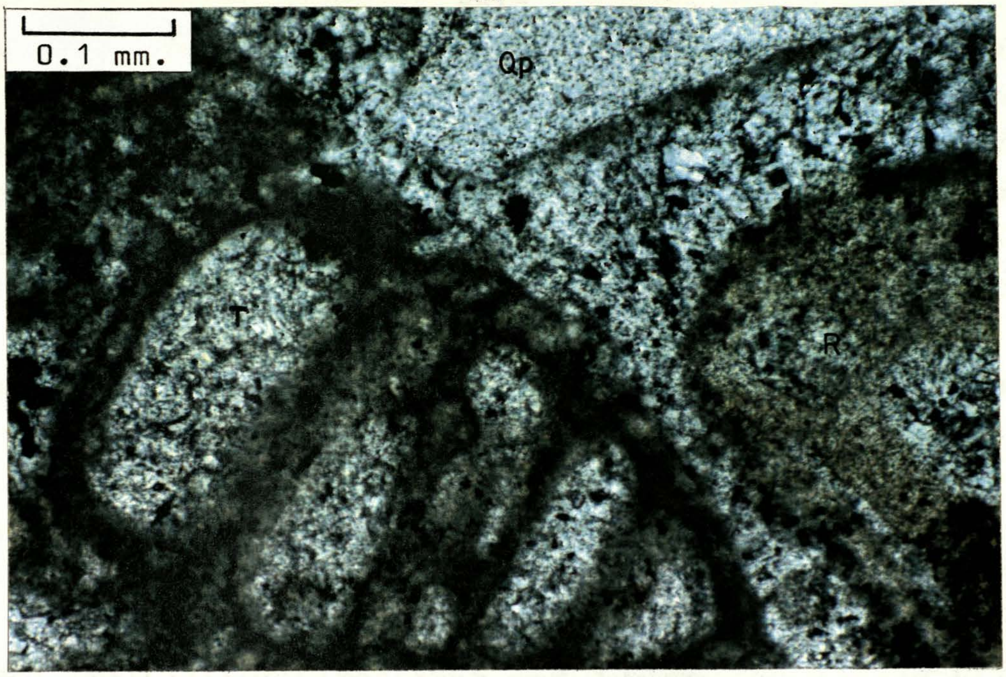


Photo 3/5 Advanced cementation within intrinsic and extrinsic pore-spaces of sandy biocalcarenite by fine to medium crystalline (granular) sparry calcite. Note that dark dusty rim is poorly preserved as surface boundaries of bioclastic and terrigenous grains (Textulariina = T, Rotaliina = R, Polycrystalline quartz = Qp); Quarry A, Section III at 21 m., sample St-30, plane polarized light, enlarged from Photo 5/6.

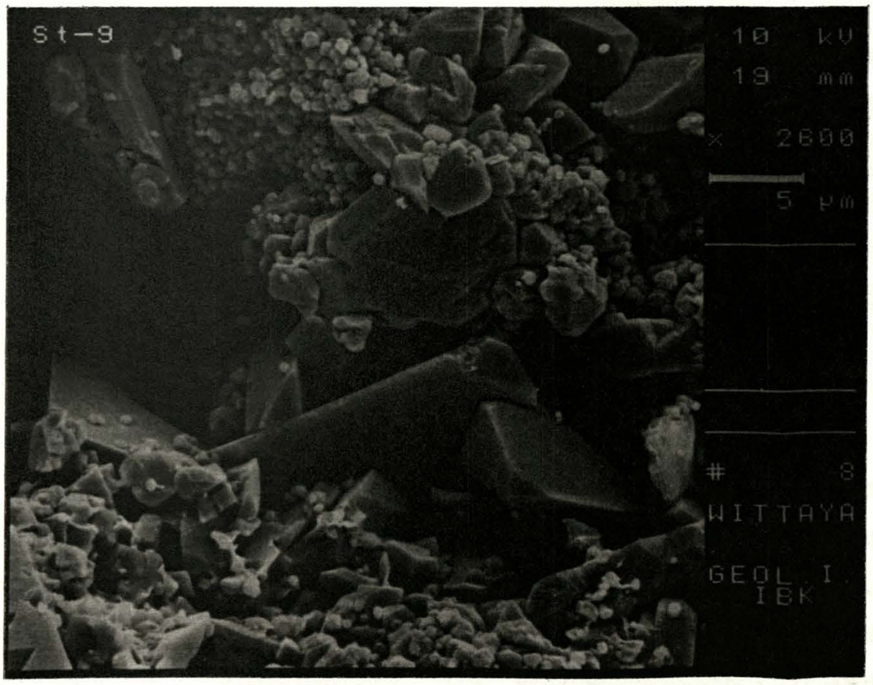


Photo 3/6 SEM photomicrograph showing that the pore space in biocalcarenite has partially been filled with sparry calcite and micrite; Quarry A, Section III at 14 m., sample St-9.

content of consolidated calcarenites (bioclastic arenite) near the base and at the top of the Quarry A sections tends to be higher and coarser than that of the middle part where sandy biocalcarenite dominate. In the middle part, biocalcarenite are interbedded with sandy biocalcarenite and bioclastic arenite sublithofacies (see Quarry A, section-III). From north to south, these sublithofacies are laterally graded into thin-bedded bioclastic arenites and/or pure terrigenous sediments.

3.5.1 Petrolithofacies analyses and environmental interpretations.

Two petrolithofacies-types are recognized and identified from twenty-six thin sections of the consolidated calcarenite Lithofacies C. The distribution of which is presented in the lithostratigraphic cross-section (Fig. 2.3). Petrolithofacies data is summarized in Table 3.2 and Fig. 3.8.

3.5.1.1 Petrolithofacies 1: *Lithothamnium*-bearing, oyster poor calcarenites.

This petrolithofacies is generally very light grey (N8) to white (N9) coloured, and distinguished by trace amounts of sand-sized oyster fragments and small quantities of terrigenous grains. Biocalcarenite and sandy biocalcarenite dominate in many thin sections, although bioclastic arenite (and/or rudite) and sandy biocalcarenite are also present in few thin sections (eg. R-1, St-35, W-3). In general, bioclastic grains form about 59 % of the sediment, and are dominated by very coarse sand-sized *Lithothamnium* fragments (35 %) with subordinated fine sand-sized benthic foraminifers (19.4 % with excluding planktic forms), and small quantities of other bioclastic grains (see Table 3.2 and Fig. 3.8A). Most bioclastic grains are disarticulated and fragmented, and are angular to subangular in shape. Terrigenous grains constitute approximately 24 %, and are composed of small amounts of granule-sized rock fragments (8 %) and quartz (9 %), although in a number of samples either the granule-sized

Table 3.2 Summary of average values of the petrographic constituents for two different petrolithofacies.

		LITHOTHAMNIUM	
		-BEARING, Oyster-poor	-FREE, Oyster-rich
	All bioclastic grains (%)	59.26	27.94
	Benthic foraminifers %	19.43	12.94
	Planktic foraminifers %	0.40	v.rare
	Calcareous algae		
	- Lithothamnium fragments %	35.43	-
	- Other algae %	rare	v.rare
	Echinoderms %	1.75	0.53
	Bryozoans %	v.rare	-
	Ostracods %	0.43	0.95
DETRITAL CALCAREOUS (ALLOCHEMS)	Molluscs		
	- Bivalves %	1.82	7.27
	- Gastropods %	-	5.65
	Brachiopods %	v.rare	0.60
	Intraclasts (%)	rare	rare
	All terrigenous grains (%)	23.53	43.07
	Total quartz %	9.41	17.09
	- Monocrystalline %	8.48	15.60
	- Undulatory extinction %	1.67	3.70
	- Non extinction %	6.81	11.90
	- Polycrystalline %	0.93	1.49
	- less than 3 crystals %	0.47	0.55
	- more than 3 crystals %	0.46	0.94
	Total feldspar %	5.33	9.20
	- Alkali feldspar %	4.51	8.24
DETRITAL NON-CALCAREOUS GRAINS	- Orthoclase %	1.57	1.34
	- Microcline %	2.94	6.90
	- Plagioclase %	0.82	0.96
	Total rock fragments %	7.56	15.13
	- <2 mm unstable rk.frag. %	0.42	0.77
	- >2 mm unstable rk.frag. %	5.46	11.15
	- >2 mm stable rk.frag. %	1.68	3.21
	Muscovite %	v.rare	v.rare
	Biotite %	0.83	1.00
	Transparent heavy minerals %	v.rare	0.35
	Opaque minerals %	0.40	0.30
	Matrix (%)	2.32	2.87
	Micrite (%)	2.51	1.23
	Cement (%)	9.83	20.75
	Other authigenic (%)	v.rare	1.20
	Observed porosity (%)	2.54	2.95

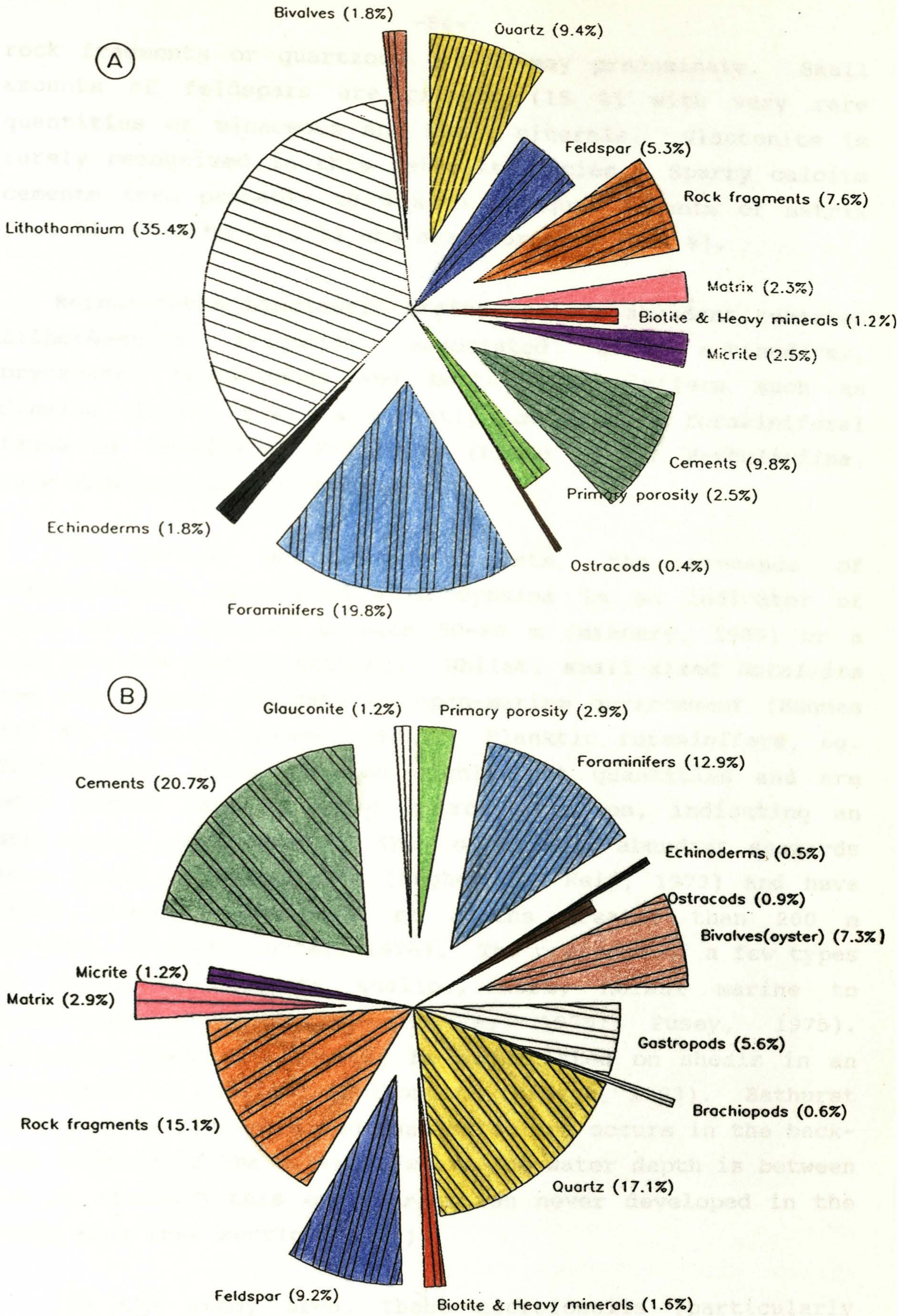


Fig. 3.8 Summary of associated petrolithofacies in the consolidated calcarenites (Steyregg).
A. Nineteen samples of the *Lithothamnium*-bearing, oyster-poor, petrolithofacies.
B. Seven samples of the *Lithothamnium*-free, oyster-rich, petrolithofacies.

rock fragments or quartzose grains may predominate. Small amounts of feldspars are present (15 %) with very rare quantities of micaceous and heavy minerals. Glauconite is rarely recognized in this petrolithofacies. Sparry calcite cements form probably 10 % with subequal amounts of matrix (2.3 %), micrite (2.5 %) and also porosity (2.5 %).

Recognizable bioclastic grains include abundant reworked *Lithothamnium* fragments associated with echinoderms, bryozoans, brachiopods and benthic foraminifers such as *Gypsina* (Photo. 5/4), a slightly low diverse foraminiferal fauna of *Rotaliina*, *Miliolina* (Photo. 3/7), *Textulariina*, rare *Globigerina* and Ostracods.

In modern marine environments, the presence of *Lithothamnium* associated with *Gypsina* is an indicator of water depths ranging between 50-80 m (Minnery, 1989) or a very shallow marine setting. Whilst, small-sized *Rotaliina* and echinoderms indicate an open-marine environment (Hughes and Keij, 1973; Haynes, 1981). Planktic foraminifers, *eg. Globigerina*, occur in some significant quantities and are more common than in other petrolithofacies, indicating an open-marine environment. They occur more abundant seawards at a depth of over 100 m (Hughes and Keij, 1973) and have their greatest abundance at depths greater than 200 m (Walton, 1964 and Hunter, 1976). The presence of a few types of *Miliolina* suggests shallow, warm, normal marine to restricted environments (Ebanks, 1975; Pusey, 1975). *Miliolina* tests may locally be accumulated on shoals in an intertidal to subtidal environment (Mresah, 1993). Bathurst (1971, 1975) also reported that *Miliolina* occurs in the back-reef lagoons of the Bahamas, where the water depth is between 2-6 m, although this environment was never developed in the study area (see section 6.4.1).

In the study area, these microfossils (particularly *Gypsina* and *Lithothamnium*) were reworked and transported within the sedimentary basin. However, they may represent a very shallow marine, near-shore, environment (cf. Nelson,

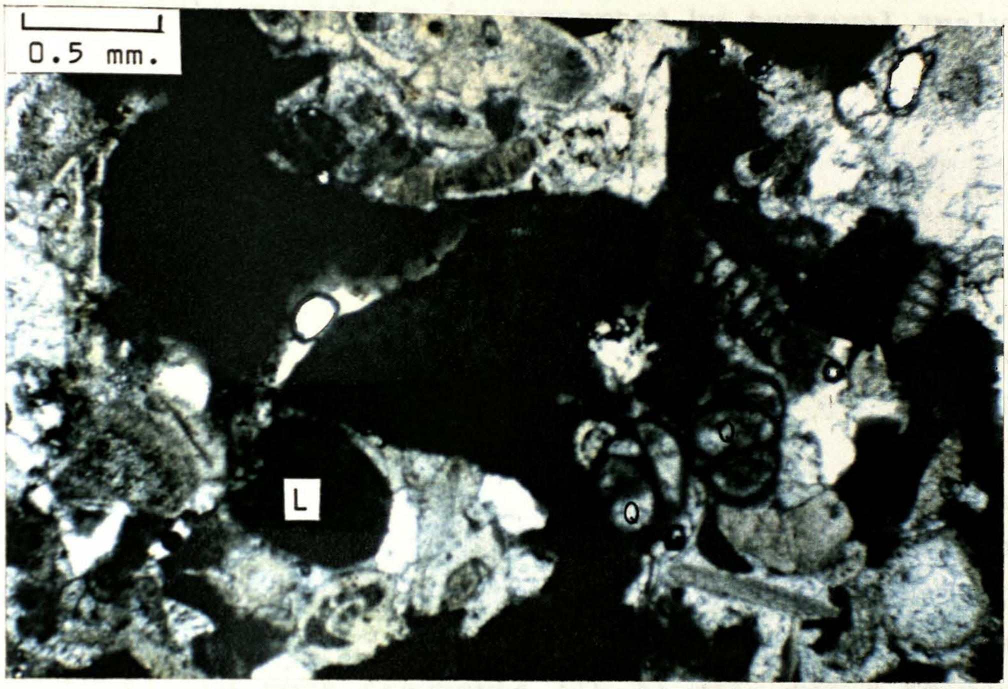


Photo 3/7 *Lithothamnium* (L), Miliolina (*Quinqueloculina* = Q) and other forms of benthic foraminifera are commonly reworked, occurring in a low terrigenous content of sandy biocalcarenite. Sediments are cemented by finely crystalline (granular) sparry calcite; Quarry A, Section III at 34.5 m., sample St-33, plane polarized light.

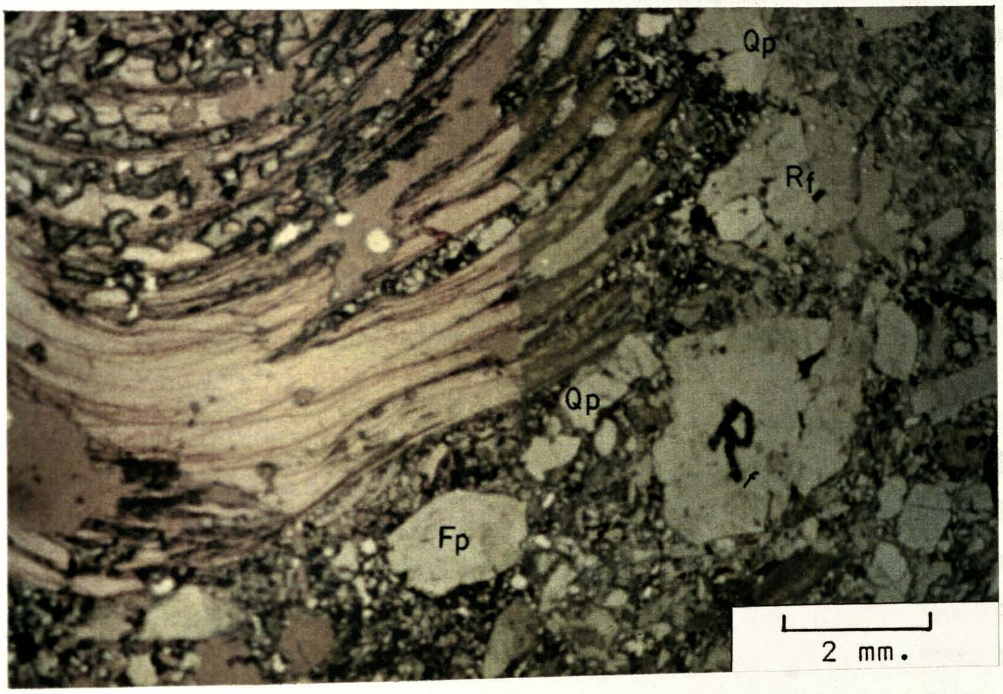


Photo 3/8 Reworked large oyster fragments (with boring features) are present in a high terrigenous content of bioclastic arenite (Rock fragments = Rf, Polycrystalline quartz = Qp and Polycrystalline feldspar = Fp); Quarry A, Section III at 6.5 m., sample F-2, Alizarin-Red staining on the half left and unstaining on the right, plane polarized light.

1988). This interpretation is supported by textural analyses of the sediments (see section 4.4).

3.5.1.2 Petrolithofacies 2: *Lithothamnium*-free, oyster rich calcarenites.

This petrolithofacies is represented by light grey (N7) to very light grey (N8) coloured, consisting of bioclastic arenites and few sandy biocalcarenites (eg. A-9, W-2). This type is characterized by large amounts of coarse pebble sized terrigenous and coarse to medium pebble size oyster fragments. *Lithothamnium* and *Gypsina* fragments are absent. The average amount of terrigenous grains is about 43 % (see Table 3.2, Fig. 3.8B), and is composed of subequal amounts of quartz (17 %) and rock fragments (15 %) with minor feldspars (9 %) , and small amounts of micaceous and heavy minerals (2 % for both). Bioclastic grains range to approximately 28 %, and consist of abundant benthic foraminifers (13 %), subequal amounts of bivalves (oysters, 7 %) and gastropods (6 %) with small quantities of echinoderms, brachiopods and ostracods. Planktic foraminifers and bryozoans are almost absent. Glauconite (1 %) is of both detrital and authigenic origins, and more common (eg. W-2) than in petrolithofacies 1. The content of matrix (3 %), micrite (1 %) and porosity (3 %) remain more or less constant throughout both petrolithofacies types. Very fine to coarse crystalline sparry calcite is abundant, averaging 21 %.

The presence of large oyster fragments and a rather low diverse fauna of small-sized *Textulariina*, *Rotaliina*, *Miliolina* and very rare planktic foraminifers, echinoderms and ostracods in this relatively coarse-sized terrigenous petrolithofacies (Photo. 3/8) suggest that deposition occured in a higher energy environment compared to petrolithofacies type 1. High energy conditions are also indicated by the state of the skeletal materials, eg. oyster fragments and benthic foraminifers, which appear intensely abraded, broken and mixed with other siliciclastic grains. Again, these conditions are likely to occur in a very shallow environment.

3.5.2 Lateral and vertical variations of the petrolithofacies.

For a better understanding the lateral and vertical variation of the two petrolithofacies in the Steyregg Quarry A is shown in Fig. 2.3 (in the map pocket). These petrolithofacies reflect slightly different depositional conditions. An overall picture suggests changing of depth and sedimentary type from the base upwards to the top, and also from the north to the south of the Quarry A. The sedimentary sequence is dominated by a transgressive trend. Indeed, this is not the norm according to Wilson (1975) that carbonate sedimentation is generally regressive in nature. Transgressive direction of the sea-level seems to have shifted landwards from southeast to northwest (see also sections 2.6.4, 6.3.3 and 6.4.1).

The presence of the *Lithothamnium*-free petrolithofacies in the lower and the upper part of the sequence in Quarry A with *Lithothamnium*-bearing petrolithofacies in the middle part, helps to define, at least, three major cycles (see Fig. 2.3, Section I, based only on petrographic data):-

1. Lower part, cycle A: between the base of section and 21.5 m, an overall transgression.
2. Middle part, cycles B,C,D: between 21.5 m and 59.5 m, an overall transgression with several transgressional-regressional episodes.
3. Upper part, cycle E: between 59.5 m and the top, several short periods of transgression- regression episodes.

3.5.2.1 Lower and upper part of the sequence.

In the lower (cycle A) and the upper (cycle E) part of the terrigenous mixed carbonate sequence (Steyregg), the sediments are characterized by bioclastic arenites (*Lithothamnium*-free, oyster-rich petrolithofacies) interbedded with terrigenous sediments. The sediments attain the greatest thickness in the north-northwest of the Quarry-

A. Biocalcarenites and bioclastic arenites (*Lithothamnium*-bearing, oyster-poor petrolithofacies) are occasionally present in the upper part of cycle A (eg. in stratigraphic section III). The depositional environment is dominated by a high energy shoal, very shallow marine environment (see sections 2.3, 4.4, 6.3). The presence of large oyster fragments, gastropods and ostrocods supports a very shallow marine environment. This interpretation is also indicated by the association of macro- and microfossils together with the textural relationship of bioclastic and terrigenous grains (see Appendices 3B, 4C). The sedimentary cycles indicate an overall transgression which is interrupted by regressional events.

3.5.2.2 <u>The middle part of the sequence</u>.

The middle part of the sequence is characterized by sandy biocalcarenites and biocalcarenites (*Lithothamnium*-bearing, Oyster-poor petrolithofacies) interbedded with terrigenous sediments. An overall transgressive trend is occasionally interrupted by the regression. *Lithothamnium*, *Gypsina* and other bioclastic grains are fragmented and abraded. This suggests that they have been reworked by currents within very shallow marine environments (see sections 2.3, 4.4, 6.3).

3.6 <u>Petrography of the Linz sand sediments</u>.

The Linz sand sediments are clearly classified as arkose to subarkose (McBride, 1963; Pettijohn, 1987). Basic petrographic data are presented in Appendix 7B, Table 3.1 and Fig. 3.7B.

Within this arkose (to subarkose), the medium to coarse sand sized grains are angular to subangular shaped. Well rounded grains are also present (Photo. 3/9). Quartz content varies from 48 % to 61 % with an average of about 56 %. They are dominated by monocrystalline quartz (much more non-undulatory than undulatory quartz) with an average percentage of 52 %, ranging from 41 % to 59 %. Polycrystalline quartz

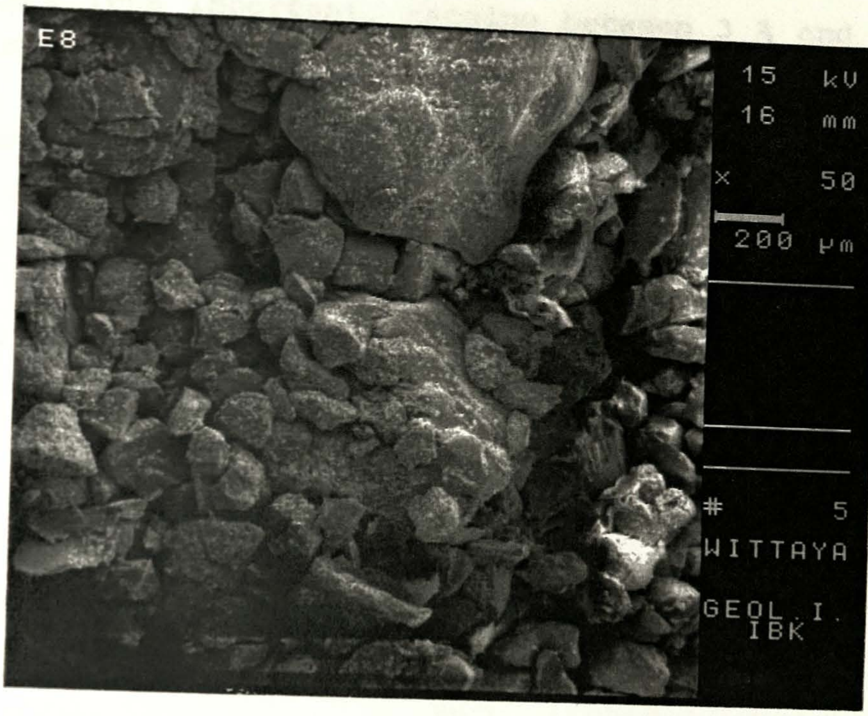


Photo 3/9 SEM photomicrograph of fine to coarse sand sized arkose to subarkose shows angular to subangular grain-shape with open packing and porosity. Clay minerals occur on the surface of grains, may be developed after deposition; Quarry-E, Section I at 13 m., sample E-8 (slightly gravelly sand).

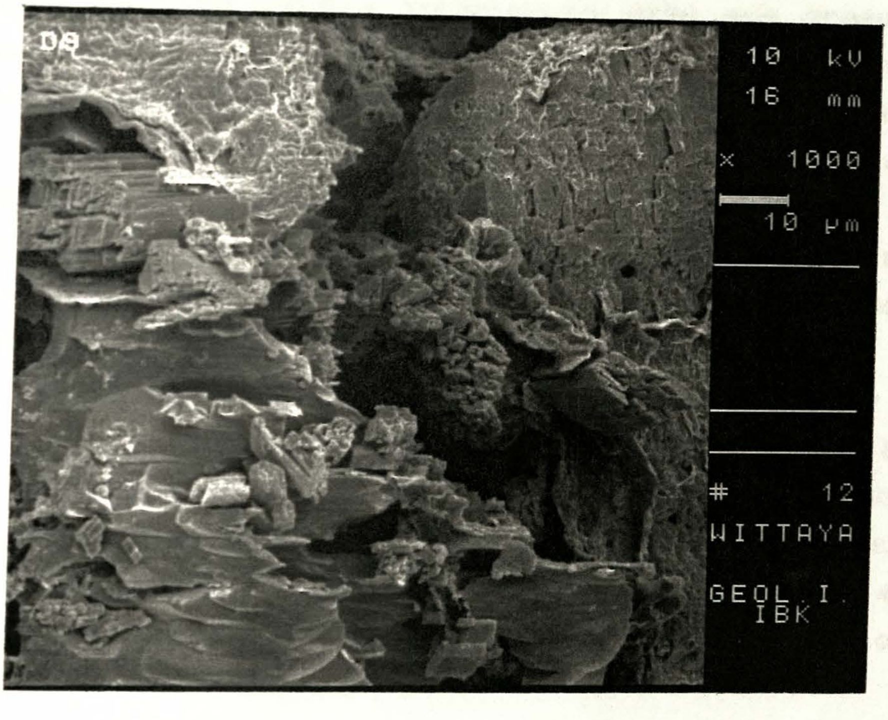


Photo 3/10 SEM photomicrograph shows a slightly sericitized (and dissolved) feldspathic grain to kaolinite with embayed by sparite and matrix. Precipitational patch is conspicuous on the upper left; Quarry D, at 9 m., sample D-9 (slightly gravelly sand).

grains are less important, ranging between 3 % and 7 % with an average of 4 %. Feldspars are subdominant constitutions, ranging from 19 % to 35 % with an average of 27 %. Monocrystalline alkaline feldspar of very coarse to medium sand size, subangular to subrounded, and much more orthoclase than microcline, are the most abundant feldspar types (an average of 21 %). Most detrital feldspar grains are slightly to moderately sericitized or kaolinized (Photo. 3/10). Some fine sand sized plagioclases are also present, averaging amounts of 6 %. Granitic rock fragments of very coarse sand to fine pebble size are a minor framwork constituent, showing an average content about 5 % (2 % to 9 %). Muscovite, biotite, non-opaque and opaque heavy minerals are constitute about 2 %.

Sorting in the arkose and subarkose is extremely variable. In the fine grained arkose and subarkose, the degree of sorting is better (eg. D-4 is moderately to well sorted, Photo. 3/11) than that of the coarser one (eg. G-7) which is poorly to moderately sorted (Photo. 3/12). Occasionally, a few grains of fine pebble to granule size are present. In some samples, grain size distributions are characterized by the bimodal grain-size with modes at fine sand and very coarse sand (eg. E-13, F-6 and G-7). Matrix contents (terrigenous clay plus silt) are generally very small, averaging about 1.5 % (1 % to 2 %). No cementing material has been observed under the microscope. Observed porosity of the sediment is about 10 % (ranging from 5 % to 17 %). However, Scanning Electron Microscopic study of a few samples (Photo. 3/13) indicate that sparry calcite crystals are present in very small amounts. The sediment is characterized by a grain-supported framework with point contacts and long contacts being most abundant (Photos. 3/11-12, 3/14). At least, the sediment underwent some compaction as indicated by slightly bent micaceous minerals.

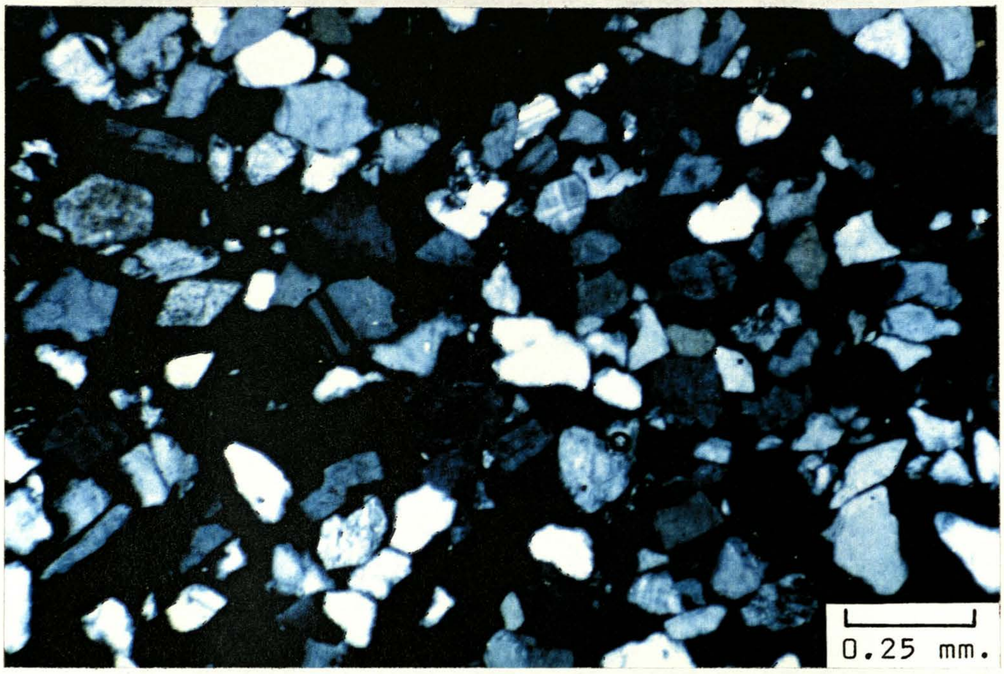


Photo 3/11 Typical characteristics of fine sand sized subarkose are moderately to well sorting with open pore-spaces (dark groundmass). Several feldspar grains are commonly sericitized to clay minerals, seen as dusty surfaces; Quarry D, at 18 m, sample D-4 (sand), crossed nicols.

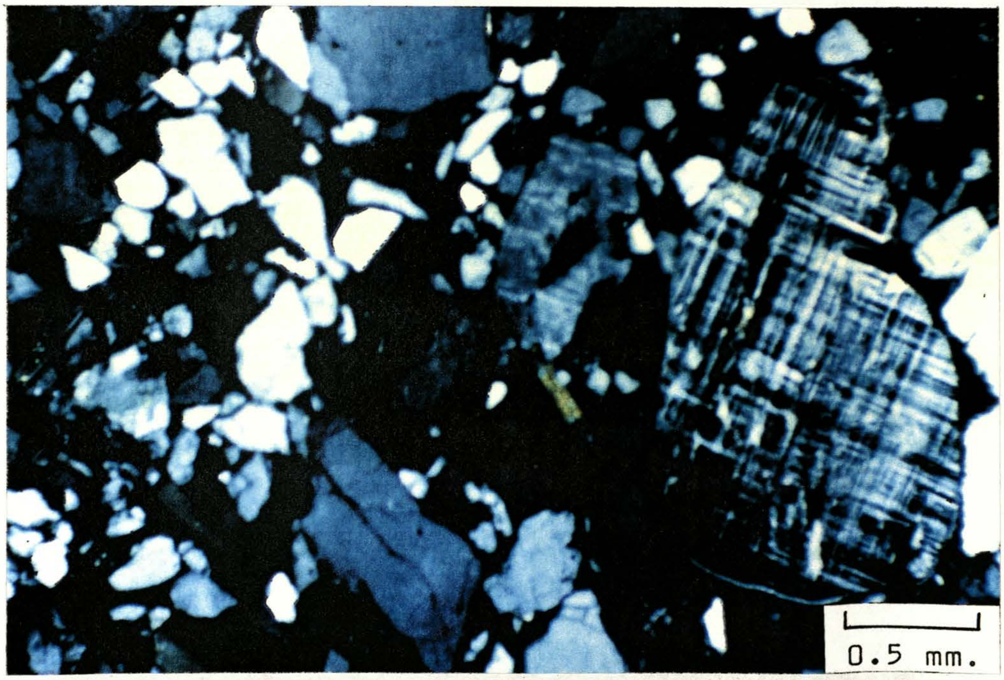


Photo 3/12 Very coarse sand sized arkose shows generally poor sorting with open pore-spaces (dark groundmass). Well rounded microcline grain with grid-twinning is on the right; Quarry G, Section I at 4 m., sample G-7 (slightly gravelly sand), crossed nicols.

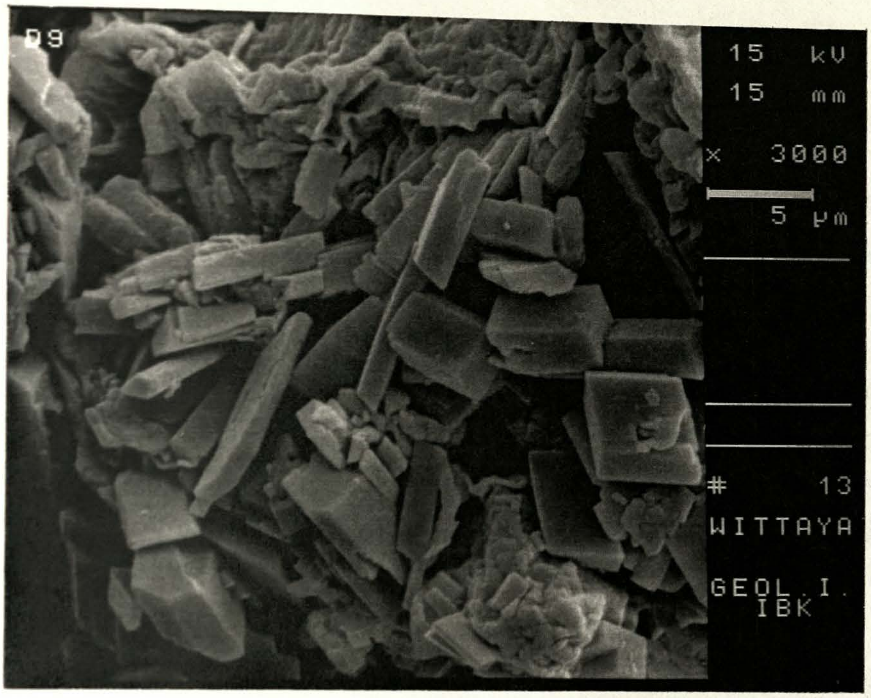


Photo 3/13 SEM photomicrograph showing that interparticle pore spaces in arkose to subarkose of the Linz sand sediment are partly filled with sparry calcite. Note that clustures of finer crystals forming an incipient peloidal-like texture are on the lower right corner; Quarry D, at 9 m., sample D-9 (slightly gravelly sand).

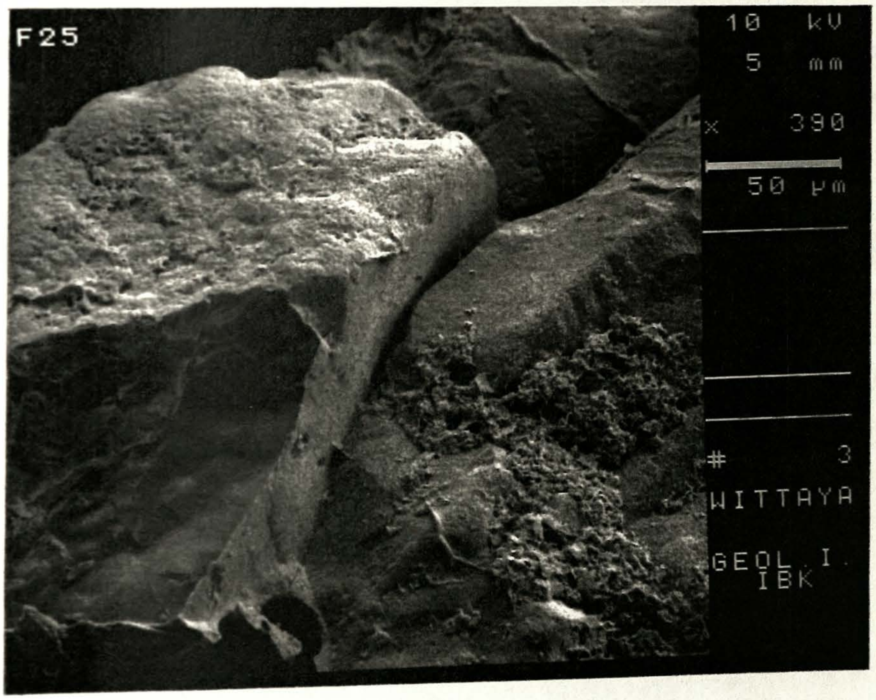


Photo 3/14 SEM photomicrograph showing that grain to grain relationships are commonly characterized by long contact. Note that clay minerals occur on the surface of grains; Quarry F, at 32 m., sample F-25 (gravelly sand).

CHAPTER 4
GRAIN SIZE ANALYSES

Representative calcareous terrigenous sediments and slightly consolidated calcarenites (Steyregg) were treated by acid digestion to determine their carbonate percentages (see Appendix 1 for the procedure). On the other hand, non-calcareous terrigenous sediments, and also insoluble residues after acid digestion, were directly sieved to establish their grain-size distribution characteristics. Ultimatly it was hoped that the results would be sufficiently diagnostic to aid in distinguishing between various lithofacies and to provide information on the depositional mechanisms of the sediments. The textural analysis of these sediments has been attempted independently to relate the grain-size distribution of siliciclastic and calciclastic components such as in the consolidated calcarenite samples.

According to physical and chemical properties the samples in the study area can be divided into three major groups:-

- Unconsolidated and non-calcareous terrigenous sediments.
- Unconsolidated and calcareous terrigenous sediments.
- Consolidated calcarenites.

4.1 Physical and chemical properties of the sediments.

In order to illustrate the variations in textural (grain-size) and chemical (carbonate) properties of the calcareous sediments in the terrigenous mixed carbonate sequence (Steyregg), the quantity of carbonate, gravel, sand and mud is plotted in Fig. 4.1 (see also Appendix 3A). End-members in the diagram are defined in the following manner:-

<u>Carbonate</u> - that portion (%) of a sample soluble in 1:3 to 1:4 acetic acid (CH_3COOH) which, in the sediments under investigation, may be regarded wholly as carbonate content. It therefore includes all allochthonous, authochthonous and authigenic carbonate materials.

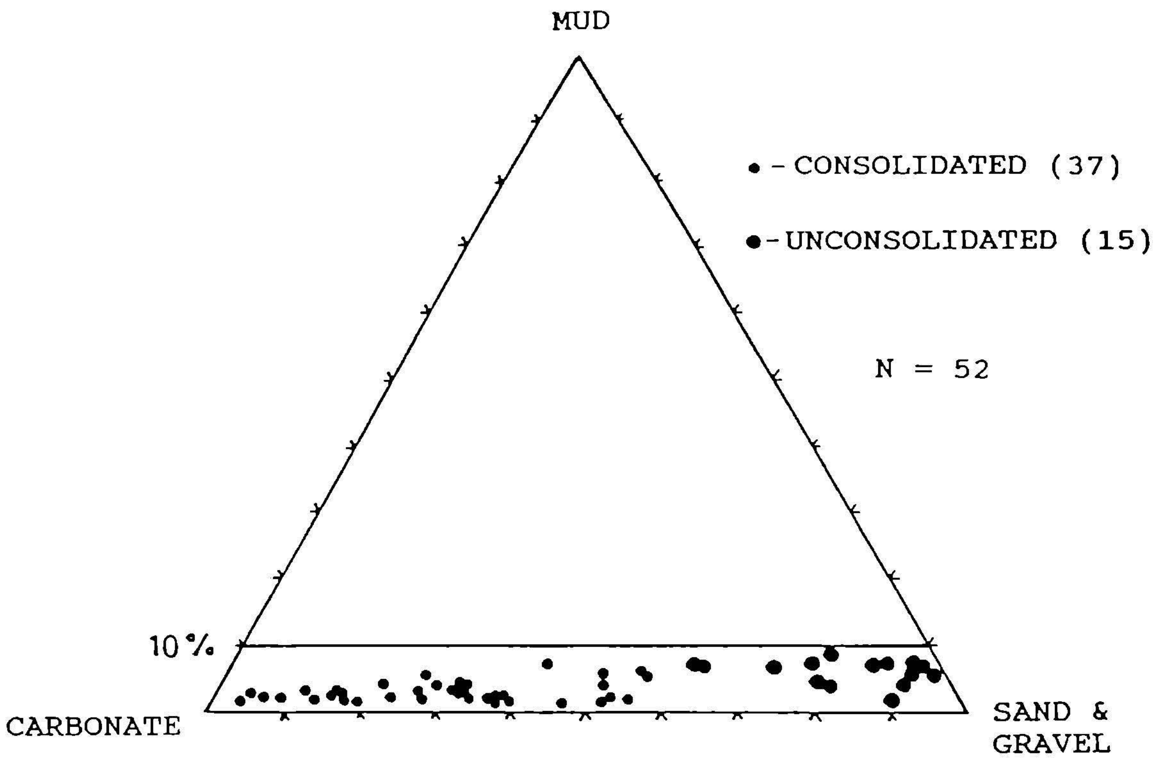


Fig. 4.1 Carbonate, mud, sand plus gravel percentages of samples from the terrigenous mixed carbonate sequence (Steyregg) are plotted on a ternary diagram in order to illustrate a general variation.

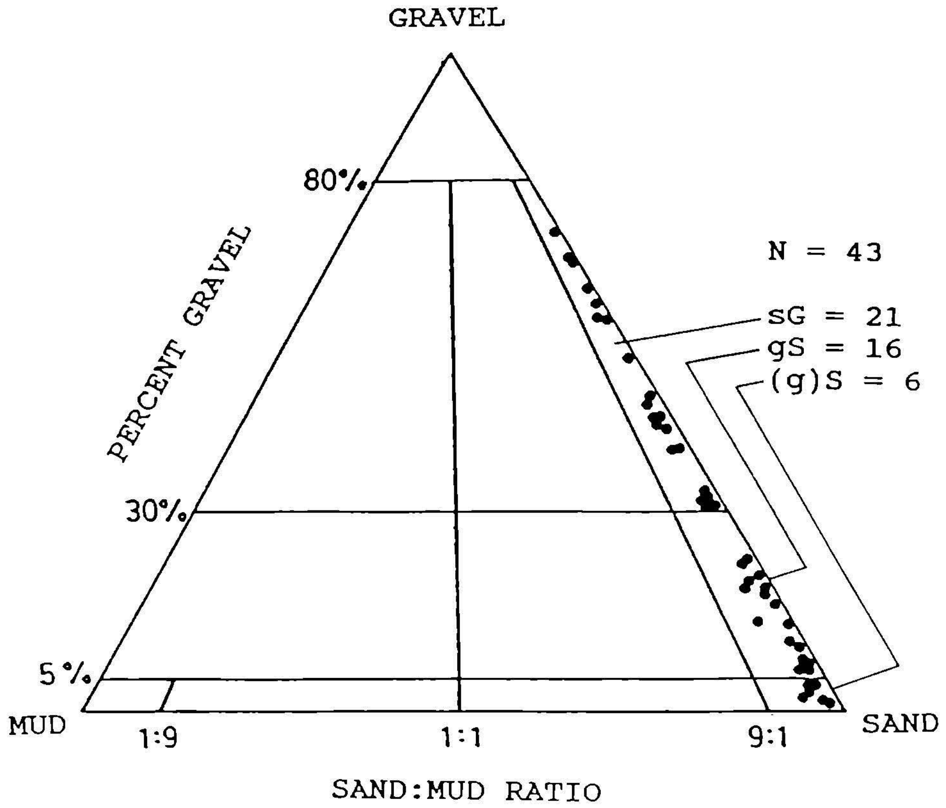


Fig. 4.2 Fourty-three samples of non-calcareous terrigenous sediments (Lithofacies A) of Steyregg are plotted on a gravel-bearing diagram for the terrigenous terminology by grain-size according to Lewis (1984 modified from Folk, 1980).

<u>Gravel and sand</u> - that portion (%) of a sample insoluble in 1:3 to 1:4 acetic acid and coarser than 0.063 mm (4 phi) in size or terrigenous gravel and sand. For purposes on the ternary plot of terrigenous mixed carbonates, gravel-size grains (coarser than 2 mm) and sand size grains (0.063 mm to 2 mm) are merged within this value.

<u>Mud</u> - that portion (%) of a sample insoluble in 1:3 to 1:4 acetic acid and finer than 0.063 mm in size or terrigenous muds. The mud fraction includes silt (0.004 mm to 0.063 mm) plus clay (finer than 0.004 mm or 8 phi).

In the carbonate, gravel plus sand and mud diagram (Fig. 4.1) is based on fifty-two analyses of representative samples from the consolidated calcarenites (Lithofacies C) and the calcarous terrigenous sediments (Lithofacies B) in the Steyregg area. It is clearly distinguished between those above lithofacies. The calcareous terrigenous sediments generally contain less than 35 % carbonate constituents, while the consolidated calcarenites contain the higher carbonate content. Variable values of terrigenous gravel and sand are generally more important than mud content, which is commonly less than 10 % mud in both lithofacies. It is also remarked, therefore, that the plot is defined partly on the basic of composition (carbonate content) and partly on the basic of texture (gravel, sand and mud content). An average of contents in these samples is summarized in the following manner:-

a. In the calcareous terrigenous sediments of fifteen samples: the contents are 12.4 % carbonate, 81.3 % gravel plus sand, and 6.3 % mud (5.9 % silt and 0.4 % clay).
b. In the consolidated calcarenites of thirty-seven samples: the contents are 66.7 % carbonate, 30.4 % gravel plus sand, and 3 % mud (2.6 % silt and 0.4 % clay).

4.2 <u>Terrigenous terminology by grain-size</u>.

Systematic terminology by grain-size of the terrigenous constituents is a part study of their variations (see data in

Appendix 3A). The terminology of the sediments can be represented on one of two standard diagrams of Lewis (1984; modified from Folk, 1980), for gravel-bearing sediments and for gravel-free sediments.

4.2.1 Terminology of the sediments in the terrigenous mixed carbonate sequence (Steyregg).

The ternary diagram for fourty-three samples of non-calcareous terrigenous sediments (Lithofacies A) of Steyregg clearly shows three grain-size classes (Fig. 4.2). The most abundant class is sandy gravel (sG), subdominated by gravelly sand (gS) and slightly gravelly sand ((g)S). The sand to mud ratio shows a preponderance of sand over mud with the ratio more than 9. The plots string along gravel-sand base of the triangle. Mud is relatively unimportant.

Fifteen insoluble residual samples from the calcareous terrigenous sediments (Lithofacies B) and thirty-seven samples from the consolidated calcarenites (Lithofacies C) plot into different fields in the diagram, Fig. 4.3. However, the samples from the consolidated calcarenites contain more mud than the calcareous terrigenous sediments. The major grain-size class in both sample-groups is gravelly sand (gS), subdominated by gravelly muddy sand (gmS) and slightly gravelly muddy sand ((g)mS). Sandy gravel (sG), slightly gravelly sand ((g)S) and muddy sandy gravel (msG) are less abundant.

4.2.2 Terminology of the sediments in the Linz sand sequence

The ternary diagram for 146 samples of the Linz sand sequence is shown in Fig. 4.4. This gravel-bearing diagram is used only for 139 samples in which the samples plot into four grain-size classes. They are dominated by slightly gravelly sand ((g)S), with subdominant gravelly sand (gS) and sandy gravel (sG), and rarely slightly gravelly mud ((g)M of Lewis, 1984 or (g)sM of Folk, 1974, 1980). The plots mostly strung along the gravel-sand base of the triangle with the

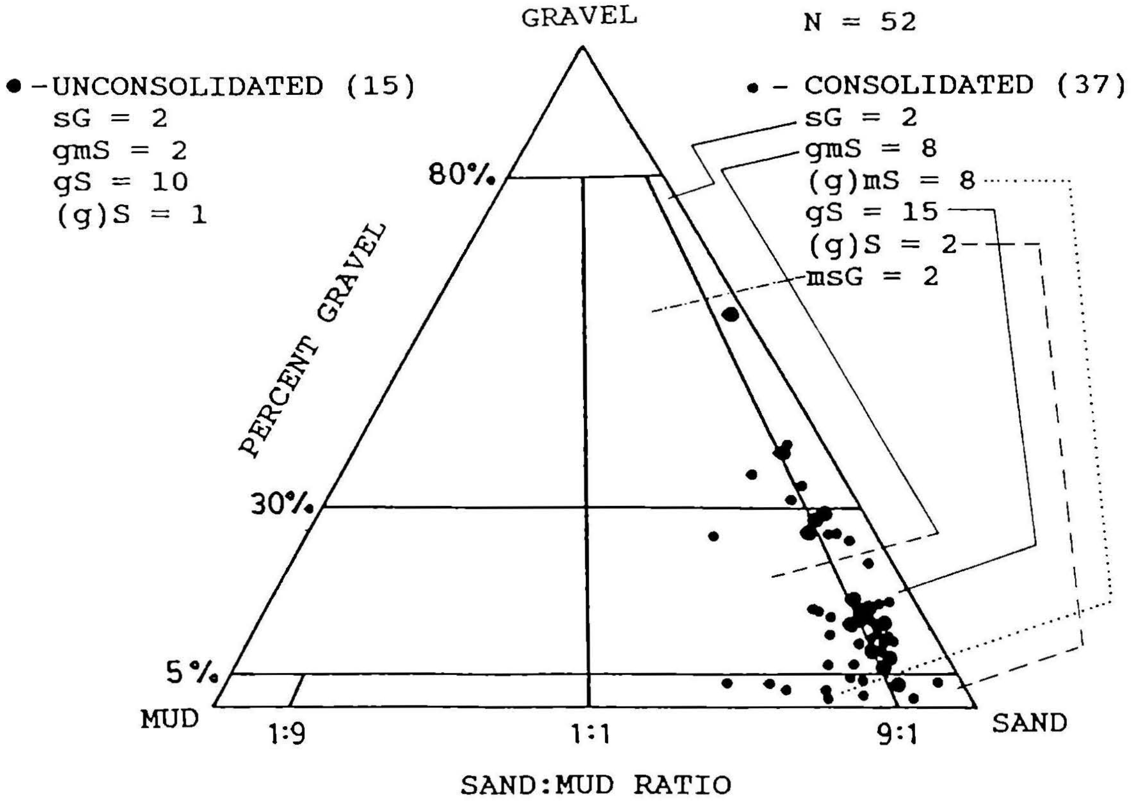


Fig. 4.3 Insoluble residual data after acid treatment of fifteen samples of calcareous terrigenous sediments (Lithofacies B) and thirty-seven samples of consolidated calcarenites (Lithofacies C) in the Steyregg area are plotted on a gravel-bearing diagram for the terrigenous terminology by grain-size according to Lewis (1984 modified from Folk, 1980).

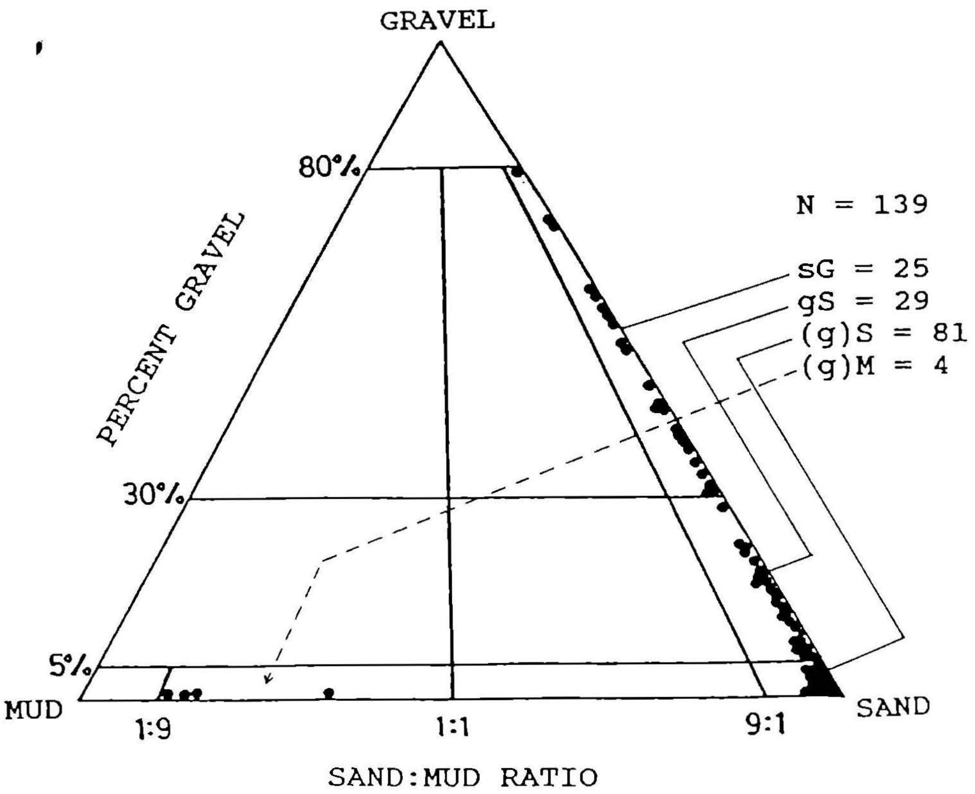


Fig. 4.4 139 samples from the non-calcareous Linz sand sequence are plotted on a gravel-bearing diagram for the terrigenous terminology by grain-size according to Lewis (1984 modified from Folk, 1980).

majority of samples having sand to mud ratio over 9. The mud content of these samples is very low (less than 5 %). Variations in gravel and sand content are important for the terrigenous terminology. Only four samples were plotted in the field of slightly gravelly mud ((g)M).

In addition, seven samples from the Linz sand sequence plot in the sand-field (S, over 90 % sand) of the gravel-free diagram of Lewis (1984) and/or Folk (1974, 1980).

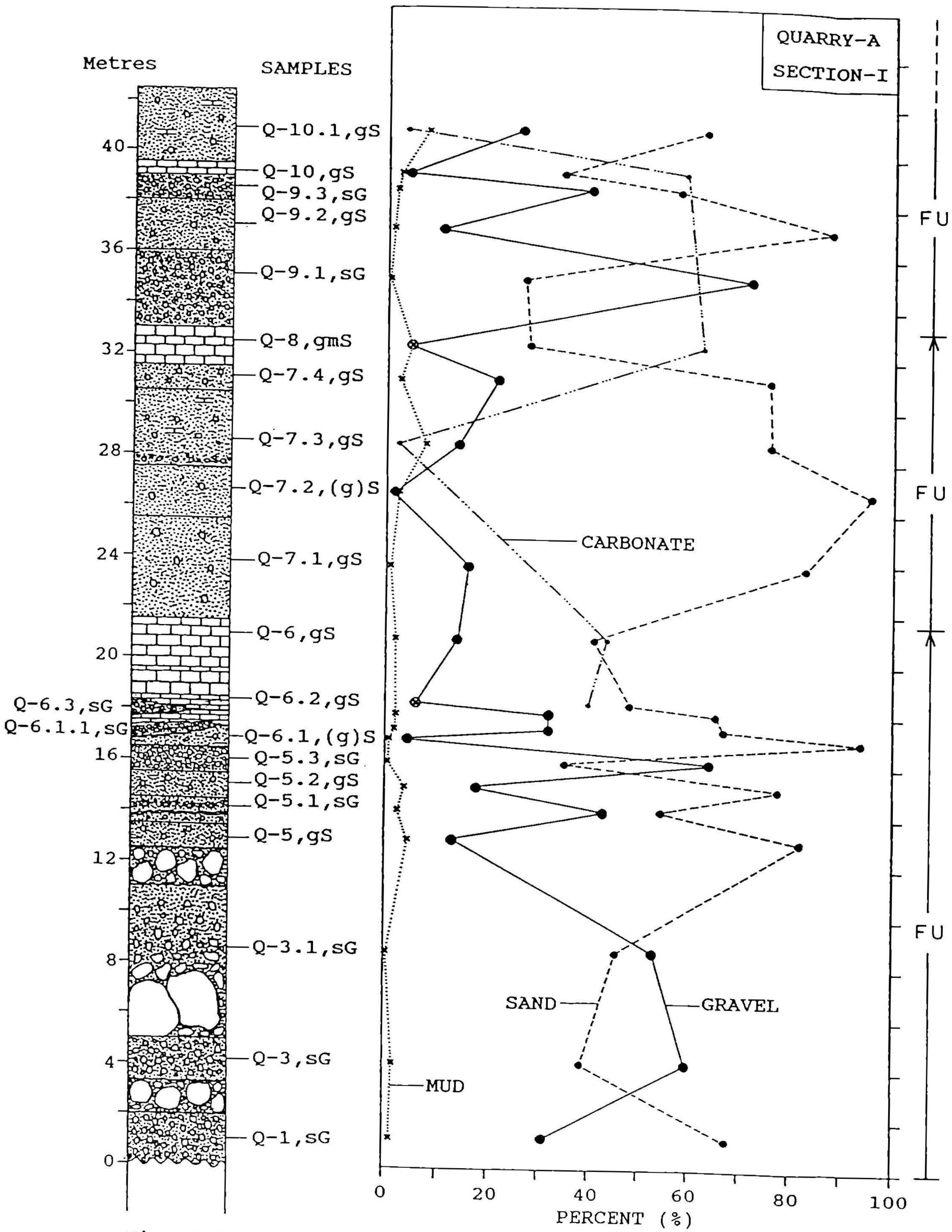
4.3 Vertical variations in the content of carbonate, gravel, sand and mud.

In order to gain some appreciation of the carbonate, gravel, sand and mud variations in the Steyregg area (see Appendix 3B) and to minimise repetition, the vertical variations are shown in Figs. 4.5, 4.6. The sample number and the terrigenous terminology (due to grain-size) are also presented beside each stratigraphic column. Symbols used in the columns are given in Fig 2.5. These vertical variations provide useful information for stratigraphic correlation. An attempt is then made to summarize in terms of energy levels for the gross sequences in section 4.3.3.

4.3.1 Vertical variations for the terrigenous mixed carbonate sequence (Steyregg).

The following conclusions are made from the variations of the contents (gravel, sand, mud and carbonate) in the representative stratigraphic section (Fig. 4.5) of the terrigenous mixed carbonate sequence (Steyregg).

1. Several fining upwards cycles are recognized by a high gravel content at their lower parts, for examples from the base to 21.5 m, from 21.5 m to 33 m and from 33 m to the top with several short cycles. Whilst, the sand content gradually increases upwards through the sequence.
2. The content of the terrigenous sand is generally dominant over the content of gravel and mud. The quantity of mud (less than 10 %) is far less than other components.



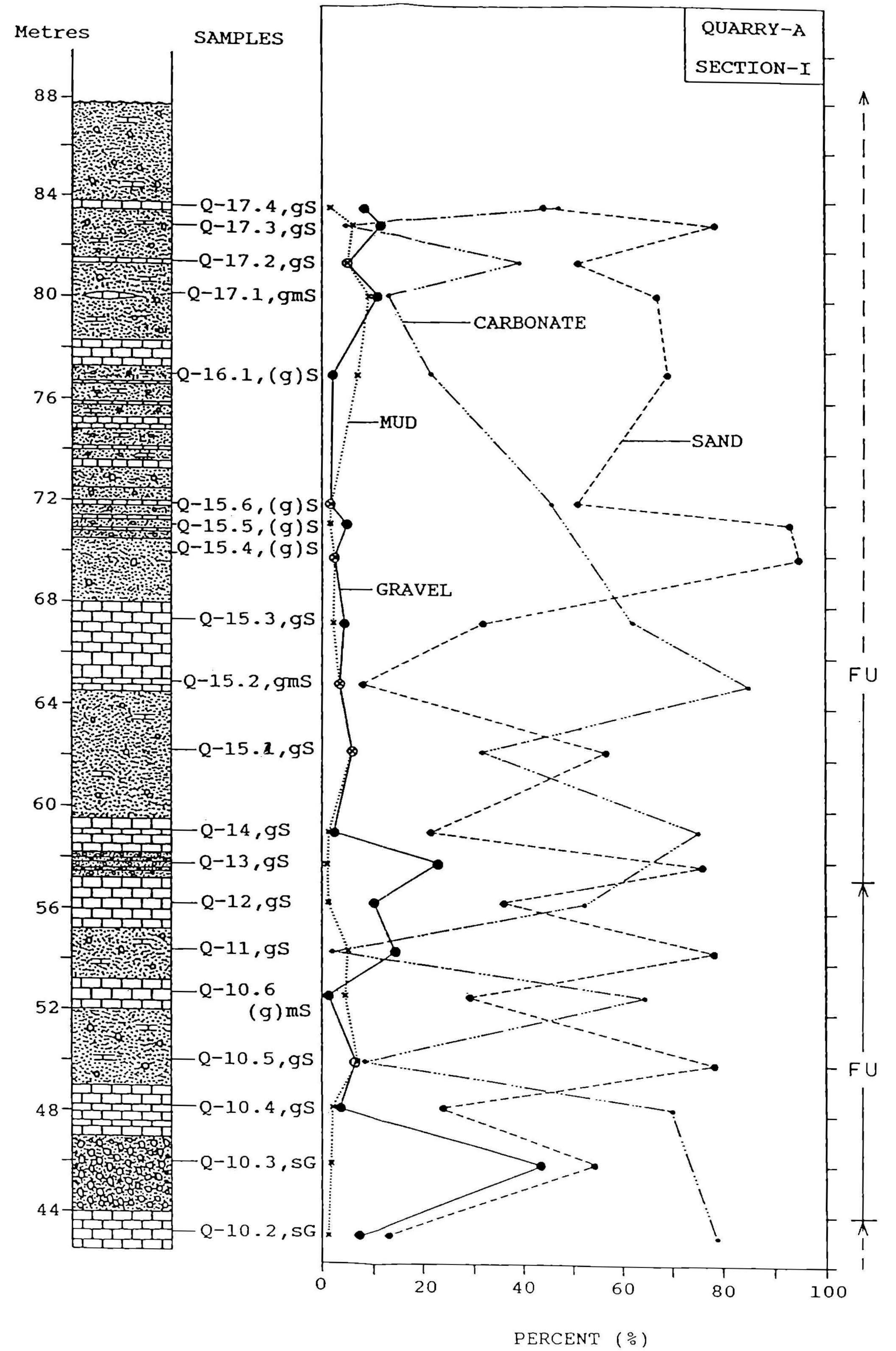


Fig. 4.5 A representative stratigraphical section of the terrigenous mixed carbonate sequence (section I of Quarry A, Steyregg) shows vertical variations of the contents of carbonate, gravel, sand and mud (data after acid treatment). The fining upwards trend is indicated by arrows.

3. The consolidated calcarenites are interbedded between the calcareous and non-calcareous terrigenous beds, and are generally marked the end of each cycle. They are dominated by high carbonate contents (more than 50 %) in the middle part of the sequence, between 32 m and 68 m.
4. From all stratigraphic sections and raw data of the terrigenous mixed carbonate sequence (Steyregg) in Appendices 3(A,B), it can be additionally summarized that:
   a. In fourty-three samples of the non-calcareous terrigenous sediments, an average of the contents is 29.1 % gravel, 69.2 % sand and 1.7 % mud (1.65 % silt and 0.03 % clay).
   b. In fifteen samples of the calcarous terrigenous sediments, an average of the contents is 17 % gravel, 64.3 % sand, 6.3 % mud (5.9 % silt and 0.4 % clay) and 12.4 % carbonate.
   c. In thirty-seven samples of the consolidated calcarenites, an average of the contents is 4.8 % gravel, 25.6 % sand, 3 % mud (2.6 % silt and 0.4 % clay) and 66.7 % carbonate.

4.3.2 Vertical variations for the Linz sand sequence.

Figure 4.6 shows the representative stratigraphic section with grain size variations (gravel, sand and mud) in the Linz sand sequence. The conclusions are as listed below:

1. In general, the fining upwards cycles are present such as from the base to 13 m, 13 m to 19 m, 19 m to 27 m and from 27 m to the top. The fining upwards beds are occasionally present.
2. The gravel content gradually decreases upwards from the base to about 19 m (near the middle part of the section in Fig. 4.6). Then, it irregularly increases upwards. This may be indicating that a major fining upwards cycle occurs in the lower part of the sequence between the base and 19 m. Whilst, the upper part is likely shown by a major coarsening upwards cycle.

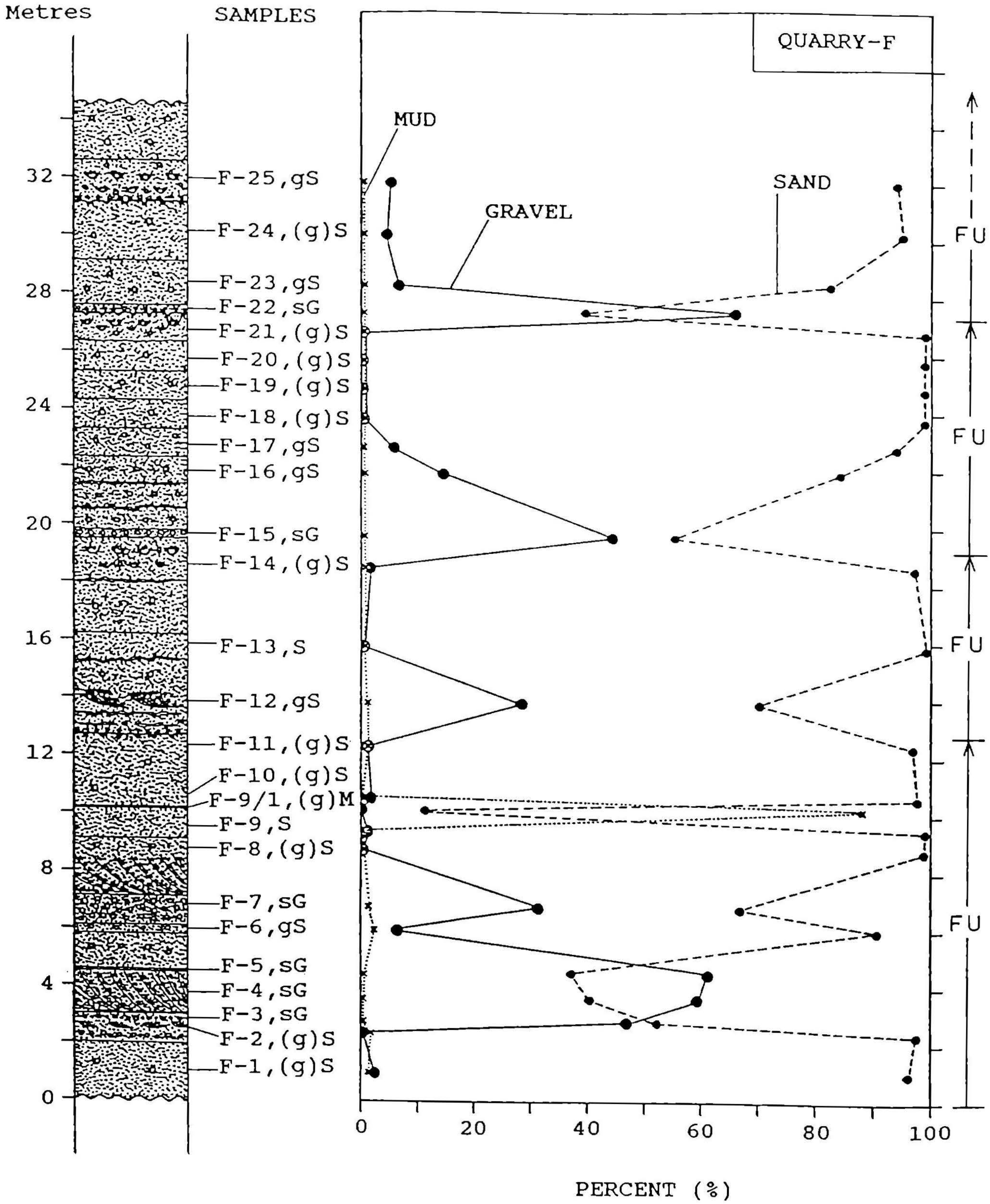


Fig. 4.6 A representative stratigraphical section of the Linz sand sequence (Quarry F) shows vertical variations of the contents of gravel, sand and mud. The fining upwards trend is indicated by arrows.

3. Terrigenous sand dominates over gravel in all stratigraphic sections (see Appendix 3B). In some cases, the quantity of mud-size materials is far greater than that typical of the Linz sand sediments, eg. sample F-9/1. This may suggest that the environment of deposition was suddenly dropped in an energy level.
4. From all stratigraphic sections and raw data (Appendices 3A,B) of the Linz sand sequence can be noted that an average of the content is 11.7 % gravel, 85.2 % sand and 3.1 % mud (2.5 % silt and 0.6 % clay).

4.3.3 Introduction to energy levels of the depositional environment.

In order to attempt to interpret the energy levels of the depositional environment of the terrigenous mixed carbonate (Steyregg) and the Linz sand sequence, the stratigraphic columns of the major compositional and textural variations between the different sediments were previously illustrated (Figs. 4.5, 4.6). The quantity of carbonate, gravel, sand, mud and sand to mud ratio (Figs. 4.2 to 4.4 and Appendices 3A,B) is possibly reflecting the degree of agitation of the water in which the sediments were deposited. According to the sand to mud ratio which is more than 1, the consolidated calcarenites of Steyregg were possibly deposited under a spectrum of environmental energy conditions ranging from moderately to strongly agitated waters. Whilst, the calcareous and non-calcareous terrigenous sediments were clearly deposited under high energy levels (sand to mud ratio is more than 9).

On the other hand, the non-calcareous Linz sand sediments were mostly deposited under strongly agitated water conditions. Only a few Linz sand sediments were clearly deposited under slightly quiet waters (sand to mud ratio is less than 1), eg. slightly gravelly mud ((g)M) lithofacies. The Linz sand sequence shows an overall trend from high energy environment at the lower part to lower energy environment to the top (see also Appendix 3B). These energy levels are supported by the presence of *Ophiomorpha*. The origin and significance of the environmental energy change is elaborated in section 6.4.

4.4 Detailed analysis of grain-size.

Grain-size characteristics for the "total" consolidated calcarenites can be determined only from thin-section analysis which is tedious, time-consuming, and of questionable validity (cf. Folk, 1966). Acid digestion frees the siliciclastic grains but destroys the bioclastic grains, the question arises, as to how well the siliciclastic grain size distribution in a mixed carbonate-terrigenous sediment characterizes the depositional environment. Fuller (1961) found little difference in the frequency distribution of grains from near-shore mixed carbonate-terrigenous sediments off the Cape of Good Hope, South Africa, before and after acid reaction. Additionally, Maiklem (1968) emphasized the large number of factors involved in the generation of a pure bioclastic carbonate grain-size distribution. However, he concluded that "raw grain-size distribution data for bioclastic carbonates are of little value". His interpretation is supported by "flume experiments" which emphasized that the hydraulic behaviour of bioclastic grains is as much a function of their shape and bulk density as it is of their size.

Terrigenous gravel, sand and mud were generally available from the Bohemian Massif basement rocks during sedimentation of the Molasse. The exceedingly slightly high sedimentation influxes are established for the sedimentary sequence suggesting that ample time was not available to widely disperse, transport and modify of the insoluble grains prior to final deposition. It is suggested that grain-size analyses of the insoluble residue from the consolidated calcarenites and calcareous terrigenous sediments (together with a knowledge of carbonate - gravel plus sand - mud ratios of samples) may provide useful information for assisting in the interpretation of sedimentary environments. It was well documented that different grain sizes are transported by quite different mechanisms (eg. Passega, 1957; Visher, 1969). They are likely to be more meaningful in providing information on the current energy available at the time when the sediment was introduced to the site of deposition.

Grain size analysis of the representative terrigenous Linz sand sequence, the non-calcareous terrigenous sediments of Steyregg and the insoluble residues after acid digestion were firstly done by wet sieving through a 63 microns sieve (4 phi; Wentworth, 1922). The mud fraction (finer than 63 microns sized) was determined by the Shimadzu Centrifugal Particle Size Analyzer (see Appendix 1). The fraction coarser than 63 microns sized was done by dry sieving through a column of Tyles Sieve at 1/2 phi intervals. A cumulative frequency curve was constructed by merging the sieve data with the Shimadzu data (see Appendix 2). Then, it was plotted on arithmetic-scale paper for each sample analysed. The percentiles were read in phi-units from the cumulative curve of the grain-size distribution. The statistical parameters, given in Folk (1974 or 1980; based on Folk and Ward, 1957) and also see Friedman (1967), were then calculated.

4.4.1 Results of grain-size analyses and environmental interpretations.

The central purpose of several following methods attempts to analyse samples, and determines their transportational and depositional histories. The methods developed up to now are chiefly empirical in character, utilizing statistical parameters based upon grain-size frequency distributions, and fall into three general following categories of analysis:-

1. Type-curve matching where distribution curves are categorized by their slope and form for specific environments.
2. Univariant devices, such as assigning particular ranges of size, sorting, or skewness to particular depositional environments.

3. Multivariant tests that combine two or more statistical parameters for separating sets of samples from two or more clearly defined depositional environments.

4.4.1.1 Cumulative weight percent curve shape and type-curve matching for specific environments.

The lithologic typical arithmetic cumulative weight percent curves, both for non-calcareous Linz sand sequence and terrigenous mixed carbonate sequence, are shown in Figs. 4.7, 4.8. In general, the curves commonly show more or less three straight line segments indicating the different patterns of transportation (eg. traction, saltation and suspension). Each transportational pattern is in the light of Sindowski's (1957) and Visher's (1969) works. The points of inflection between straight line segments in the most studied samples are commonly centred at about 3 phi and 0.5 phi (and/or -2 phi). These may be interpreted as corresponding to one or other mode of sediment transport (see section 4.4.1.4).

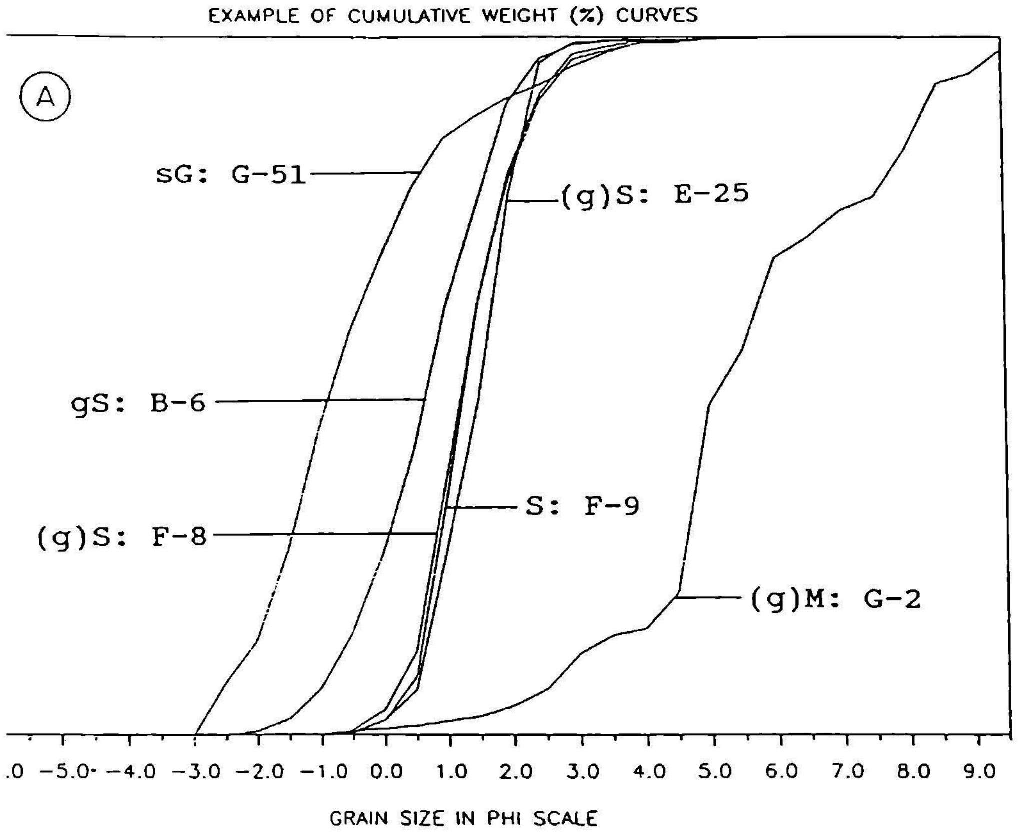
Amaral and Pryor (1977 based on Sindowski, 1957) defined three different cumulative curve types. These three types can be recognized in the non-calcareous Linz sand sediments (Fig. 4.7A), and can be defined in the following manner:-

Type 1: Slightly gravelly sand, (g)S eg. F-8, and sand, S eg. F-9, curves - extremely steep, early concave and then straight with a little convex middle part and again a steep straight with a transition to the flat convex end.

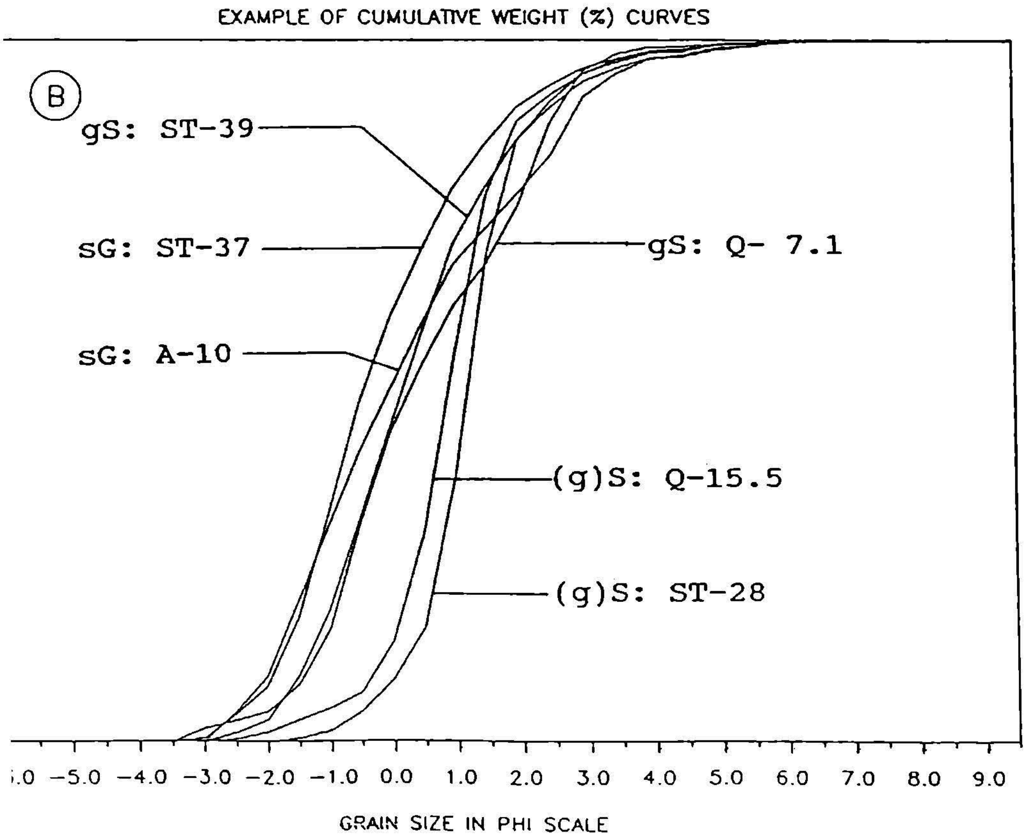
Type 2: Sandy gravel, sG eg. G-51, curves - steep, slightly straight curves with more than 60° slope and a transition to the flat wide convex form.

Type 3: Slightly gravelly mud, (g)M eg. G-2, curves - uncommon curves.

The curves of the siliciclastic sediment in the terrigenous mixed carbonate sequence generally relate to the curve Type 1 and Type 2 (Figs. 4.7B and 4.8A,B). According to Visher (1969), size frequency curve shapes can be used for



CONSOLIDATED NON-CALCAREOUS SEDIMENTS



7 Cumulative weight percent curves show the grain-size distribution of each different lithology.
A. Examples of the non-calcareous Linz sand sediments.
B. Examples of the non-calcareous terrigenous sediments, Steyregg.

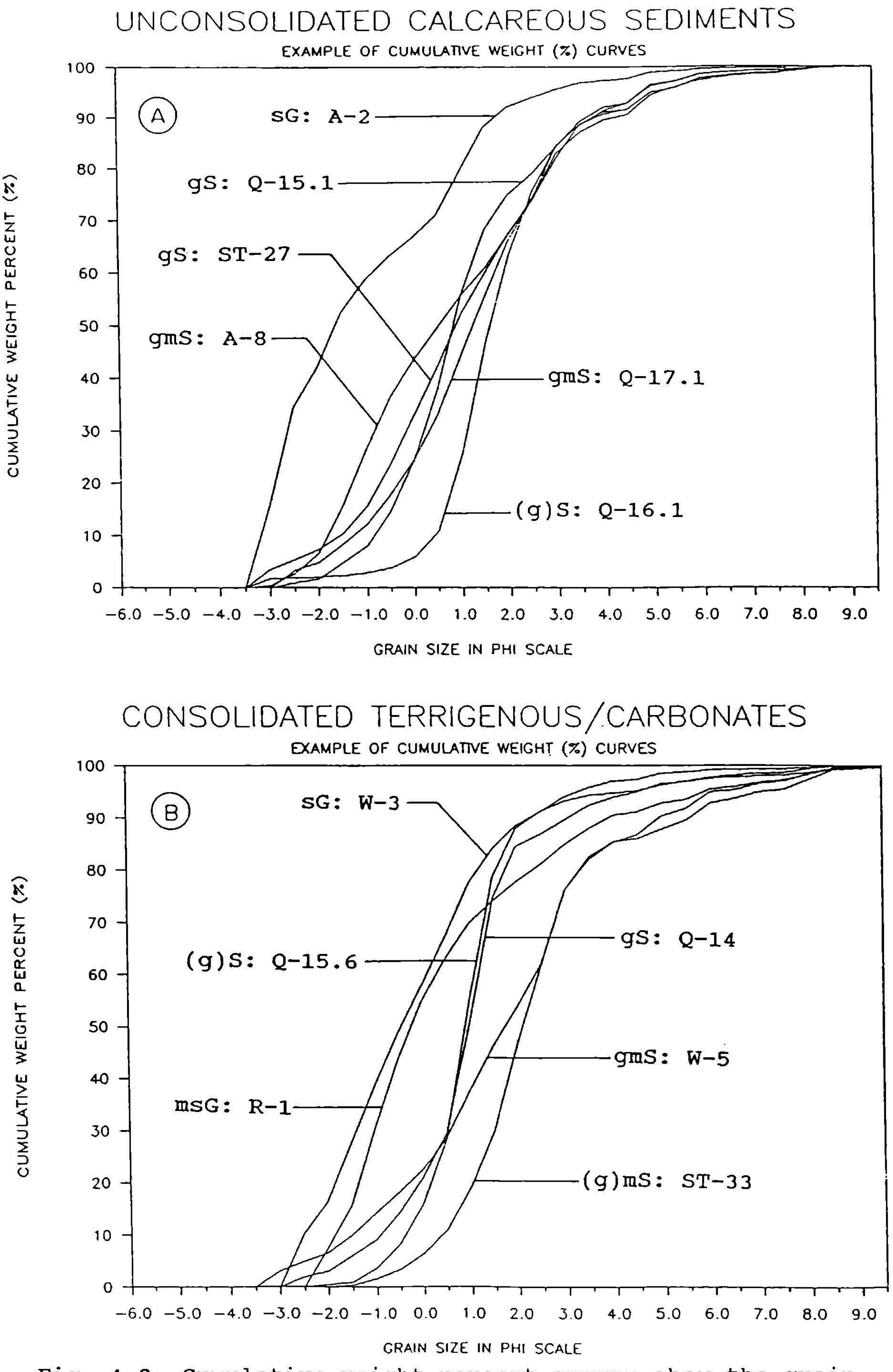


Fig. 4.8 Cumulative weight percent curves show the grain-size distribution of each different lithology, based on insoluble residual data after acid treatment of samples from the terrigenous mixed carbonate sequence, Steyregg.
A. Examples of the calcareous terrigenous sediments.
B. Examples of the consolidated calcarenites.

identifying sedimentary processes and predicting depositional environments. It can be noted that the cumulative grain size curves were plotted on arithmetic scale paper in this study. Several workers (Visher, 1969; Middleton, 1976; Sagoe and Visher, 1977) have plotted on log-probability paper for environmental interpretations. However, the cumulative grain size Type 1 curves may indicate either tidal sand flat or shallow marine sand bank environments according to Sindowski's analysis in Amaral and Pryor (1977). Some of the steeper (better sorted) Type 1 curves may also represent near shore deposits found in the beach foreshore environment. The sands from the berm and upper foreshore of modern beaches generally have steep slope (see Mason and Folk, 1958; Folk and Robles, 1964; Amaral and Pryor, 1977), similar to the Linz sand sediments (also see Nordstrom and Margolis, 1972; Lengauer et.al., 1987). Type 2 curves may characterize either submarine sand ridges, offshore bar, pass-sand or the tidal inlets of sand flats, including either fluvial or a low-gradient tidal channel environment. The uncommon Type 3 curves, found only in the Linz sand sequence, may possibly be interpreted as coastal muds (depositing in pond). The presence of glauconite in the terrigenous mixed carbonate sequence, and absence in the Linz sand sequence, corroborates the marine environment either to be a shoal sand or a shallow marine shelf environment, where wave actions were strong. Sediments of the Linz sand sequence can be interpreted to have been mainly deposited between the foreshore-beach or wave-reworked and swash zone of the upper foreshore environments. Horizontal bedforms and small to large scale cross-beds are locally present and support these interpretations for both sedimentary sequences. The size distribution curve shapes were therefore more or less considered useful in interpreting the depositional environment.

4.4.1.2 Statistic grain-size parameters.

The 5, 16, 50, 75, 84 and 95 percentiles are calculated for the grain size statistical parameters as used by Folk and

Ward (1957). Results of grain size analyses are given completely in Appendix 4A as numerical values. Histograms are constructed to show the overall contributions of the parameters, caused by the various lithofacies (Appendix 4B). A summary of an average parameter for sediments in the non-calcareous Linz sand and the terrigenous mixed carbonate sequence is shown on Table 4.1. The general conclusions for the studied samples are as follows:-

1. Graphic mean grain size (M_Z) - occurs predominantly in the coarse sand grade (and minor fine sand) for the Linz sand sediment, while it occurs in the coarse sand for sediments of the terrigenous mixed carbonate sequence.
2. Median grain size (M_D) - Figure 4.9 shows that there is only a small difference between mean and median grain size values of individual samples.
3. Inclusive graphic standard deviation (δ_I) - generally ranges between poor and moderately well sorted, with an average value in the moderately sorted range (but poorly sorted mode; see Appendix 4B) for the Linz sand sediments, and ranges between very poor and poor sorted for sediments of the terrigenous mixed carbonate sequence.
4. Inclusive graphic skewness (S_{KI}) - sediments of the terrigenous mixed carbonate sequence are generally of fine skewness, while in the Linz sand sediments occur both near-symmetrical and coarse skewness.
5. Graphic kurtosis (K_G) - the curves are platykurtic in both groups. In some case, they are in leptokurtic eg. the consolidated calcarenites.
6. The largest grain size (1^{st} percentile = C) - generally occurs in fine pebble size for sediments of the Linz sand sequence, and occurs in fine to medium pebble grades for that of the terrigenous mixed carbonate sequence.
7. Modal grain size - distinctly trimodal for the Linz sand and noncalcareous terrigenous sediments of Steyregg; fine sand, coarse sand and granule grades. Terrigenous materials in the consolidated calcarenites commonly show multi-modal size distributions. However, at least four

Table 4.1 Summary of average values of the grain-size statistical parameters, the samples are grouped on the basis of physical and chemical properties.

PARAMETERS ==> / SAMPLE PROPERTIES (GROUPING)	GRAPHIC MEAN SIZE	MEDIAN GRAIN SIZE	GRAPHIC S.D (sorting)	GRAPHIC SKEWNESS	GRAPHIC KURTOSIS	LARGEST GRAIN SIZE	MODE(S) 1st	MODE(S) 2nd	MODE(S) 3rd	MODE(S) 4th	MODAL TYPES
NON-CALCAREOUS LINZ SAND SEDIMENTS (146-SAMPLES)	coarse sand (0.14)	coarse sand (0.14)	moderately sorted (0.86)	coarse skewed to near symmetrical (-0.10)	platy-kurtic (0.89)	fine pebble (-2.31)	fine sand (2.43)	coarse sand (0.85)	granule (-1.86)		TRIMODAL
NON-CALCAREOUS TERRIGENOUS SEDIMENTS, STEYREGG. (43-SAMPLES)	coarse sand (0.09)	coarse sand (0.002)	poorly sorted (1.80)	fine skewed (0.15)	platy-kurtic (0.74)	medium pebble (-3.07)	fine sand (2.04)	coarse sand (0.42)	granule (-1.08)		TRIMODAL
CALCAREOUS TERRIGENOUS SEDIMENTS, STEYREGG. (15-SAMPLES)	coarse sand (0.80)	coarse sand (0.69)	poorly sorted (1.97)	fine skewed (0.12)	platy-kurtic (0.85)	medium pebble (-3.03)	coarse sand (0.58)	fine sand (2.71)	very fine silt (7.91)	medium silt (5.40)	MULTIMODAL
CONSOLIDATED CALCARENITES, STEYREGG. (37-SAMPLES)	coarse sand (0.31)	coarse sand (0.21)	very poorly sorted (2.07)	fine skewed (0.15)	lepto-kurtic (1.29)	fine pebble (-2.36)	fine sand (2.57)	coarse sand (0.37)	coarse silt (4.47)	very fine silt (7.15)	MULTIMODAL
AVERAGE FOR 95-STEYREGG'S SAMPLES	coarse sand (0.68)	coarse sand (0.58)	poorly sorted (1.93)	fine skewed (0.10)	platy-kurtic (0.96)	fine pebble (-2.82)	SEE APPENDIX-4B FOR ... HISTOGRAMS OF THE STATISTICAL PARAMETER PLOTS				

REMARKS: 1. Verbal scales for inclusive graphic standard deviation or sorting, inclusive graphic skewness and graphic skewness are followed Folk and Ward (1957).
2. Grain size classes are followed the Wentworth's (1922) scale.

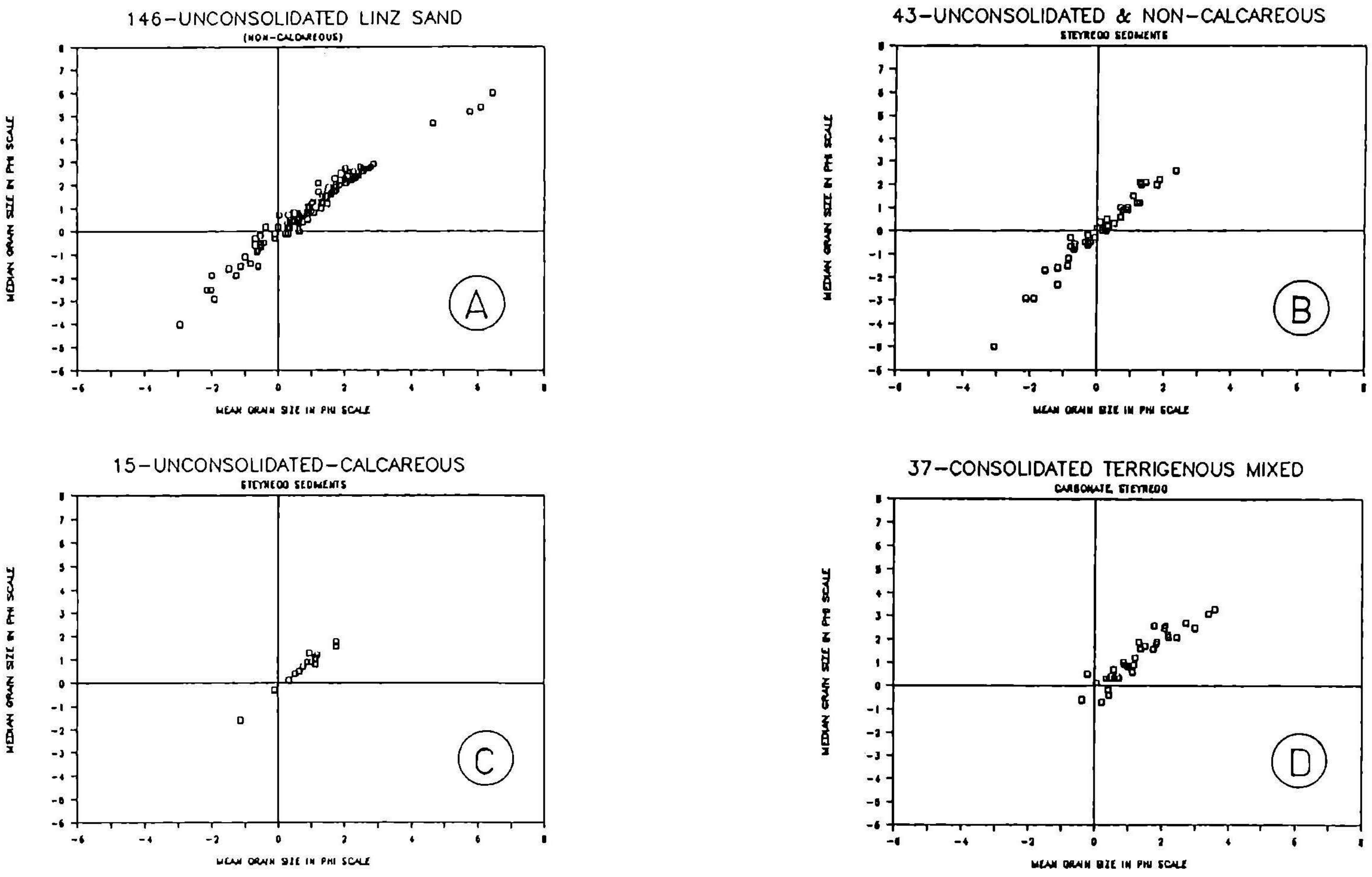


Fig. 4.9 Relationships between mean and median grain-sizes.
A. For non-calcareous Linz sand sediments.
B. For non-calcareous terrigenous sediments, Steyregg.
C. For calcareous terrigenous sediments, Steyregg.
D. For consolidated calcarenites, Steyregg.

principal modes lie in fine sand, coarse sand, medium and/or coarse silt and very fine silt classes.

4.4.1.3 Vertical variations in grain size statistical parameters.

Detailed variations in grain-size statistical parameters through the stratigraphic section are constructed (Appendix 4C). Variation in median grain size (M_D) of the terrigenous material in the terrigenous mixed carbonate sequence of Steyregg clearly shows at least three fining upward cycles; from the base to 21.5 m, 21.5 m to 33 m, and 33 m to the top (Fig. 4.10). The mean grain size (M_Z) curve also has a similar shape with more or less identical values. Assuming that the size range of the terrigenous material supplied by the Bohemian Massif basement rocks remained more or less similar throughout the sedimentation of the terrigenous mixed carbonate deposits, the mean and median grain size variation curves may be interpreted as reflecting variations in environmental energy conditions. However, it is not necessarily related to water depth.

Passega (1957, 1964) chose the first percentile (C) diameter, the largest grain size in this study, as representative of the competence of the agent of transport. The variation curve for the largest grain size in the terrigenous fraction of the terrigenous mixed carbonate (Steyregg) and the Linz sand sequence occurs in pebble to granule size classes for overall lithologies (Figs. 4.10, 4.11). The largest grain size tends to show fining upwards through both sequences.

Sorting in terrigenous materials of the terrigenous mixed carbonate sequence generally varies between very poor and poor sorted. This may reflect the variable local supply of the heterogenous mixture of grain size from the basement rocks together with unconstant energy levels and water depths.

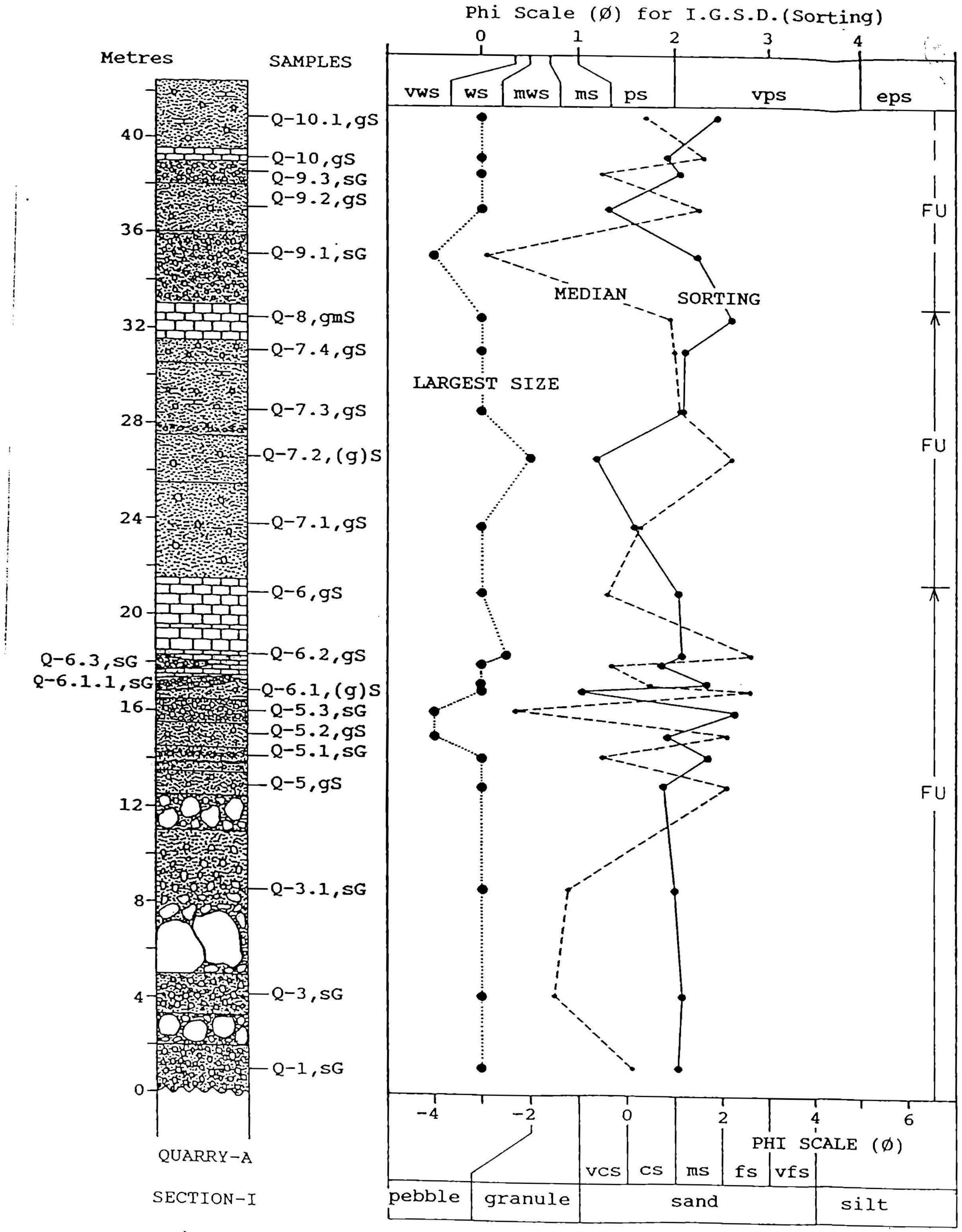
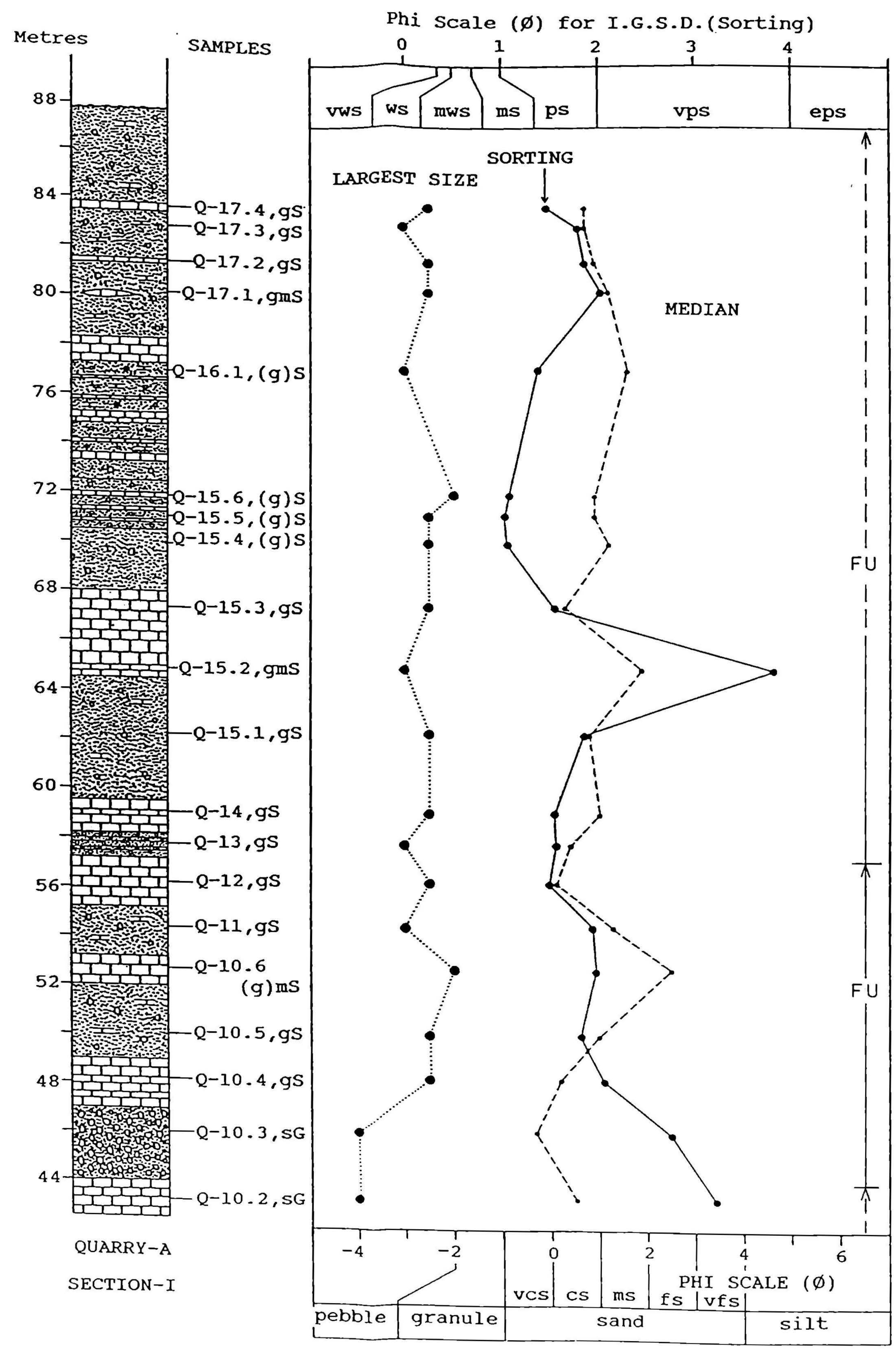


Fig. 4.10 Variations in the values of median, largest grain-size and inclusive graphic standard deviation (for insoluble residues of the terrigenous mixed carbonate sequence, Steyregg, Quarry A) through a representative stratigraphical section I.



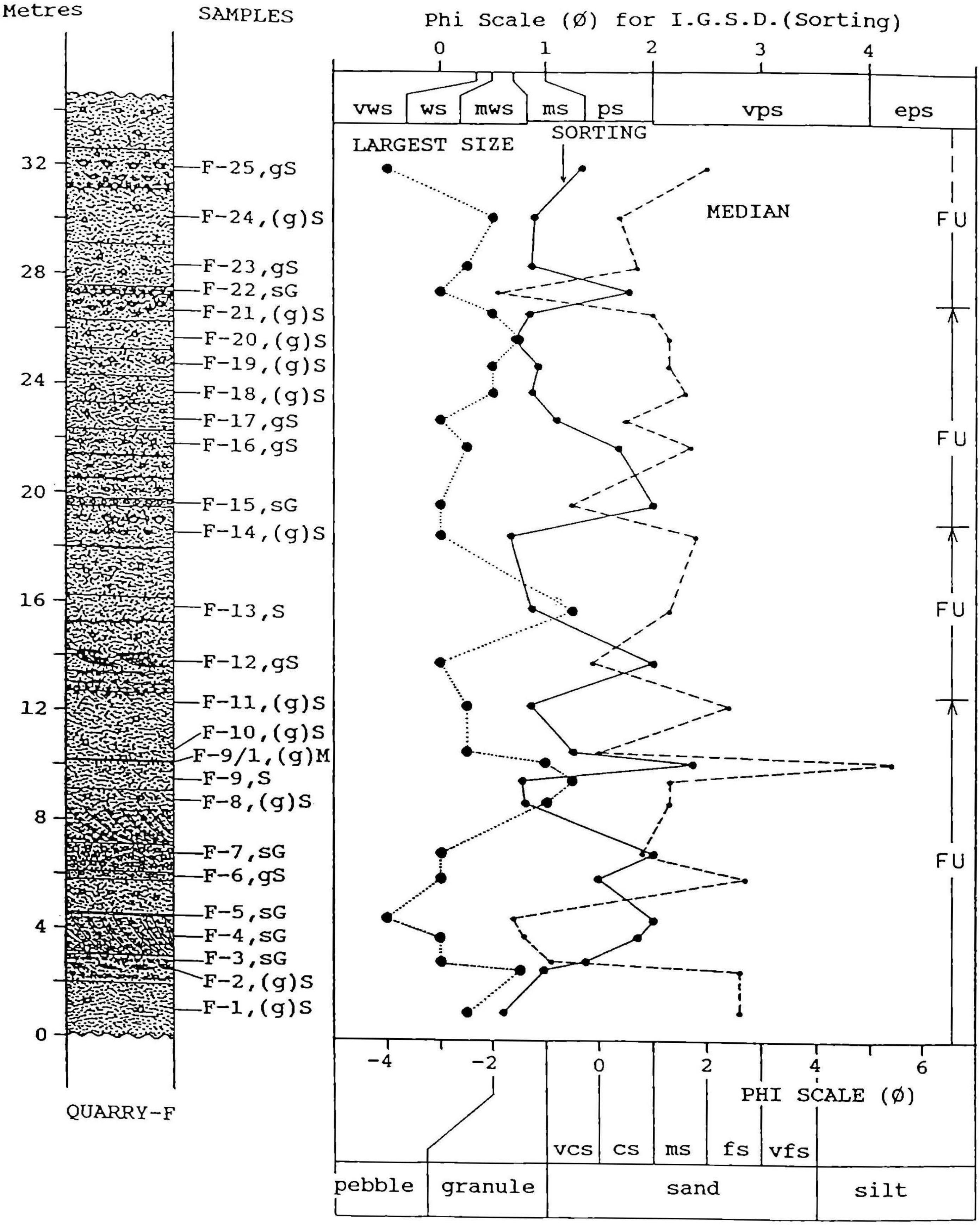


Fig. 4.11 Variations in the values of median, largest grain-size and inclusive graphic standard deviation through a representative stratigraphical section (Quarry F) of the non-calcareous Linz sand sequence.

4.4.1.4 Relationships between textural statistical paremeters and depositional environments.

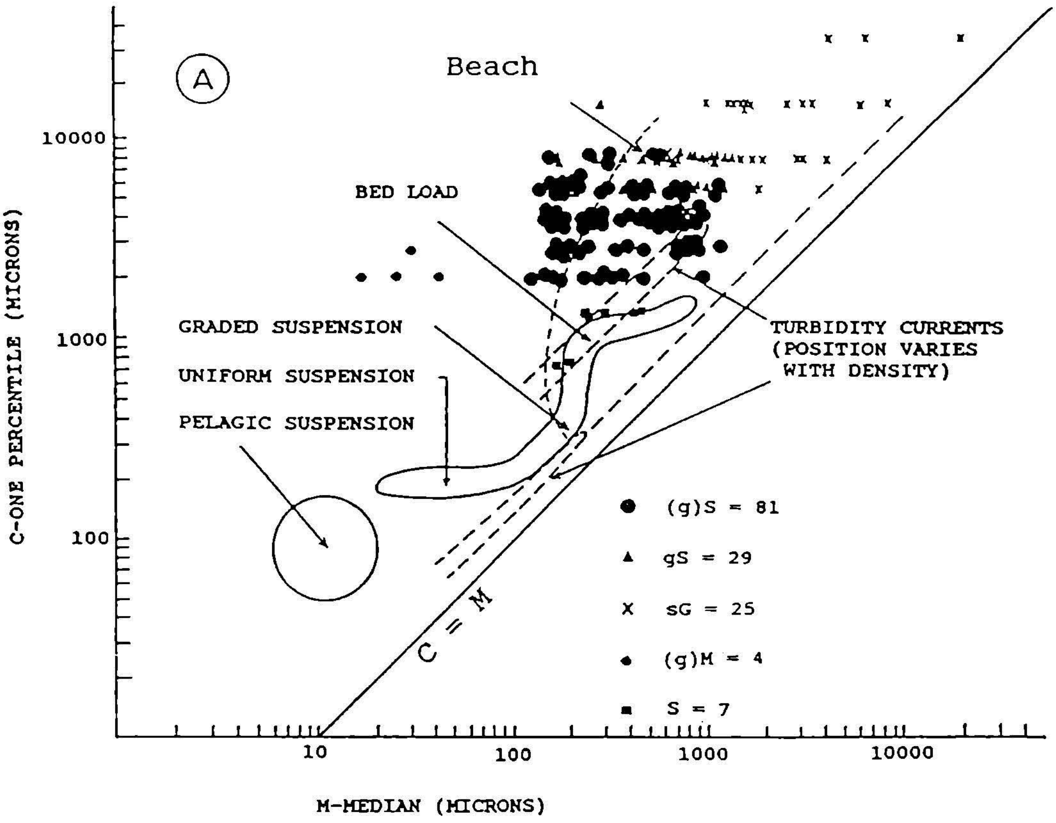
Passega (1957, 1964) presented plots of samples from known environments in which the largest grain size in the first percentile (C) of the size distribution was plotted as a function of the median grain size (M or M_D in this study) and requires only 20-30 data points. The value of C is representative of the (minimum) competence of the transporting agent, and M is a statistical characteristic of the total range of particle sizes undergoing transport by this agent. Basic types of CM-patterns of Passega are defined for material transported in pelagic, uniform, graded and turbid suspension. Later, Royse (1968) added a segment for wave-worked (beach) sediments (see Figs. 4.12, 4.13).

Samples from the Linz sand sequence with different lithologies plot in the field of wave-worked (beach) deposits (Fig. 4.12A). Depositional processes by turbidity and/or tractive currents seem unlikely, although few plots fall in these segments. The largest mud content of some samples, eg. slightly gravelly mud ((g)M), is reflected in their lower M-values (micron), and clearly suggests slow deposition from uniform suspension (quiet water).

Plots for noncalcareous terrigenous sediments (Fig. 4.12B) and calcareous terrigenous sediments of Steyregg (Fig. 4.13A) are similar to previous plots, and appear to represent mainly wave-worked (beach) deposits.

Siliciclastic materials in consolidated calcarenites of Steyregg fall also mainly within wave-worked (beach) deposits (Fig. 4.13B). Thus, total insoluble residues from this sediment plots in a similar position compared with the non-calcareous Linz sand sediments.

The samples both from the Linz sand and the terrigenous mixed carbonate sequence (Steyregg) can be interpreted as wave-worked (beach) deposits. However, the CM-field shows a



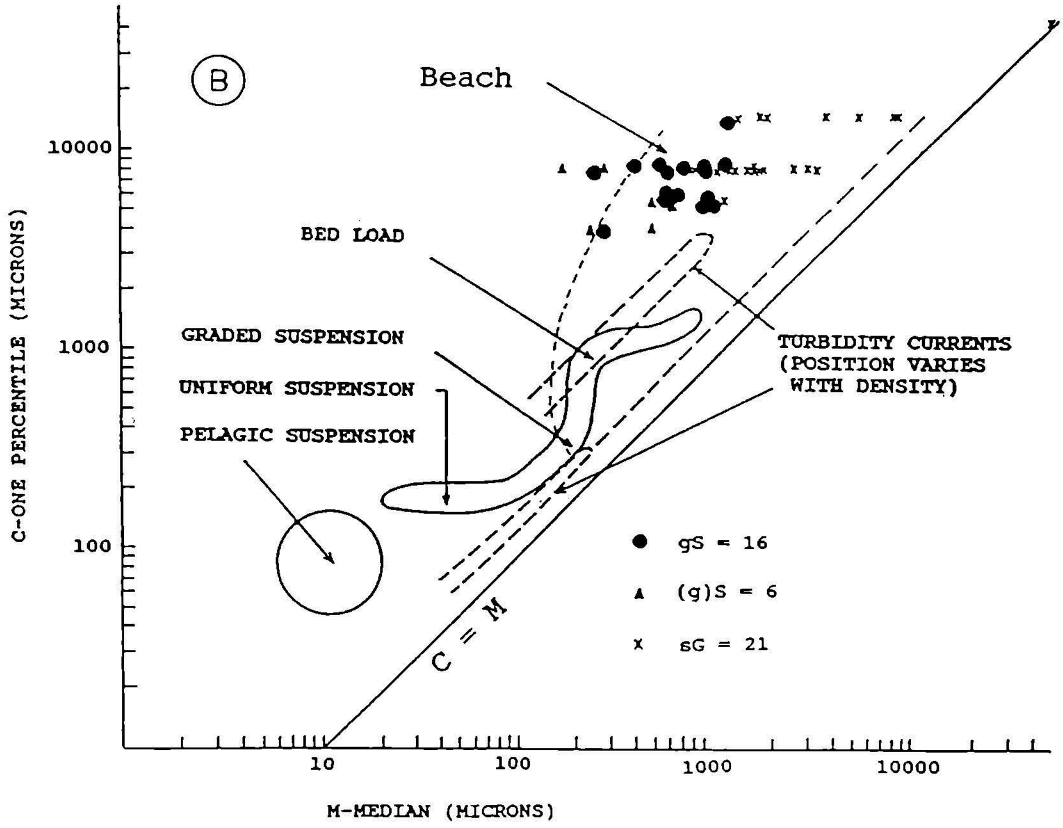


Fig. 4.12 CM-patterns as used by Passega (1957, 1964).
A. 146 samples from the non-calcareous Linz sand sequence plot in (wave-worked) beach deposits.
B. 43 samples from the non-calcareous terrigenous sediments of Steyregg plot also in beach.

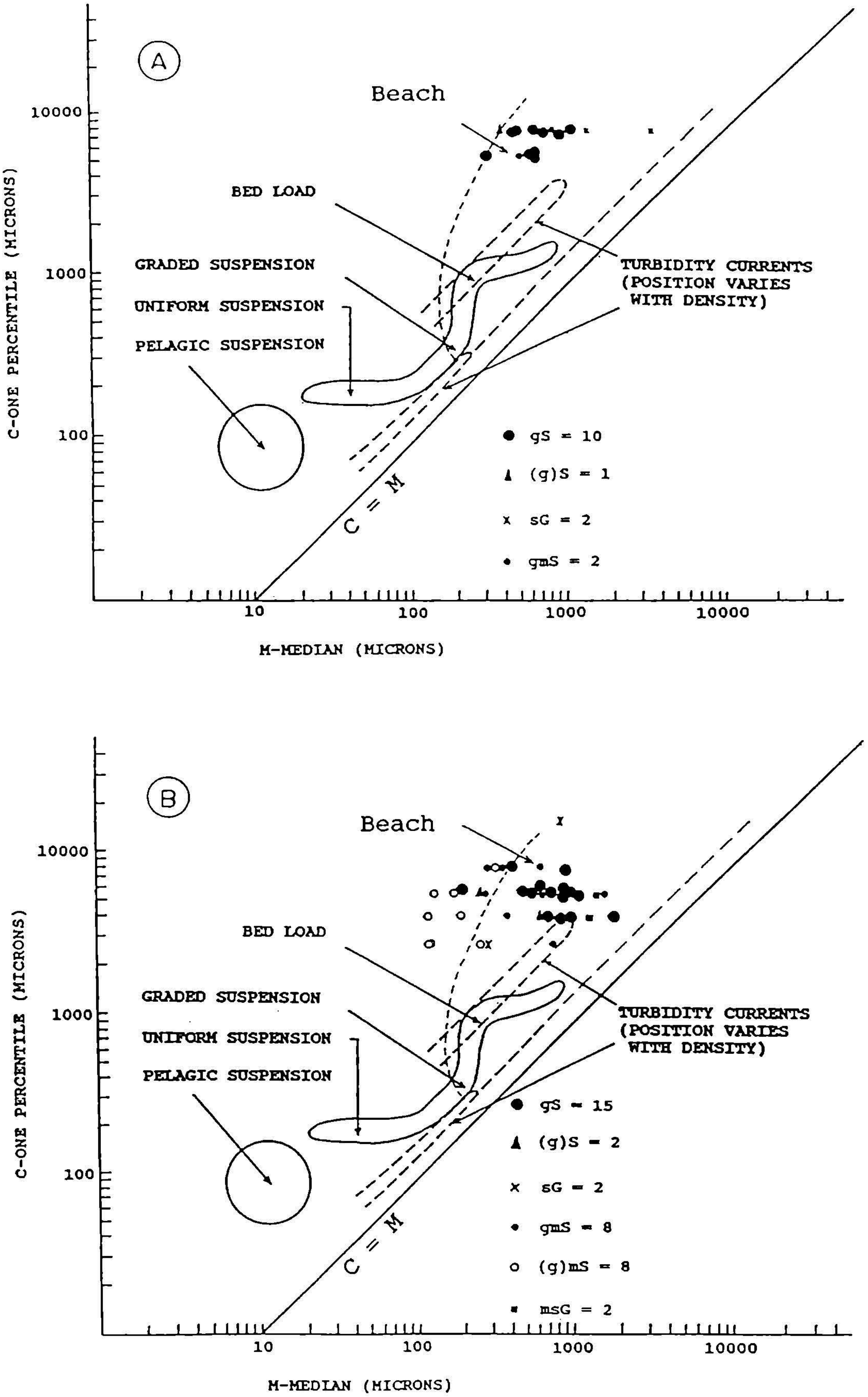


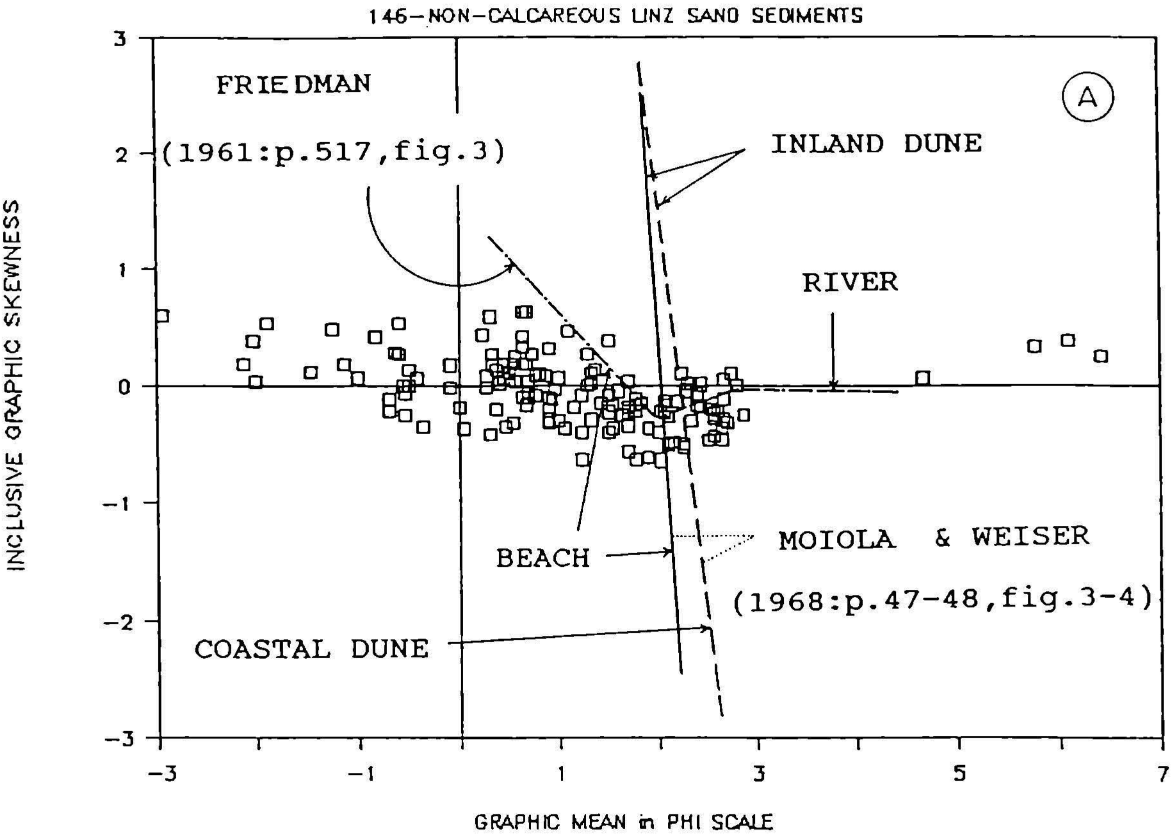
Fig. 4.13 CM-patterns as used by Passega (1957, 1964).
A. 15 samples from the calcareous terrigenous sediments of Steyregg plot in the field of beach.
B. 37 samples from the consolidated calcarenites of Steyregg plot also in (wave-worked) beach.

scatter of plots unparallel to the C = M line, and shows relatively poor to moderate sorting which differentiated them from many beach sands. A similar situation has been reported by Mason and Folk (1958), Friedman (1961), Amaral and Pryor (1977), Roetzel et.al. (1983), Lengauer et.al. (1987). Are they not yet in equilibrium with the depositional conditions of the beach? In general, higher C-values of the samples probably reflect either proximity to a source of coarse material (McLaren, 1981), ie. the Bohemian Massif basement rocks in this study, or higher energy levels and/or part of the main beach nearest the water (Mason and Folk, 1958).

Plots of graphic mean size (M_Z) versus inclusive graphic skewness (S_{KI}) have been used for differentiating between river and beach sands (ie. Friedman, 1961); and among beach, inland dune and coastal dune sands (ie. Moiola and Weiser, 1968). The plot shows that most negative skewness is in general associated with the Linz sand sediments (Fig. 4.14A), while higher positive skewness is related to the sediments of the terrigenous mixed carbonate sequence (Fig. 4.14B). The author suggests that negative skewness may be an indicator of higher energy conditions, whereas positive skewness mainly indicates lower energy levels. However, the nature and degree of the polymodality should be taken into account. This technique can distinguish beach deposits from other environments but there are no differences between the sediments of the Linz sand sequence and the terrigenous mixed carbonate sequence.

Friedman (1961, 1967) used a plot of inclusive graphic standard deviation (σ_I) versus inclusive graphic skewness (S_{KI}) to differentiate beach and river sands. The terrigenous detritus data of the Linz sand and the terrigenous mixed carbonate sequence were plotted on Friedman's (1967) diagrams for graphic grain-size parameters.

The plot of the Linz sand sediments (Fig. 4.15A) shows the points in a tight cluster, not pointing to a specific depositional environment. On the other hand, the plot of the



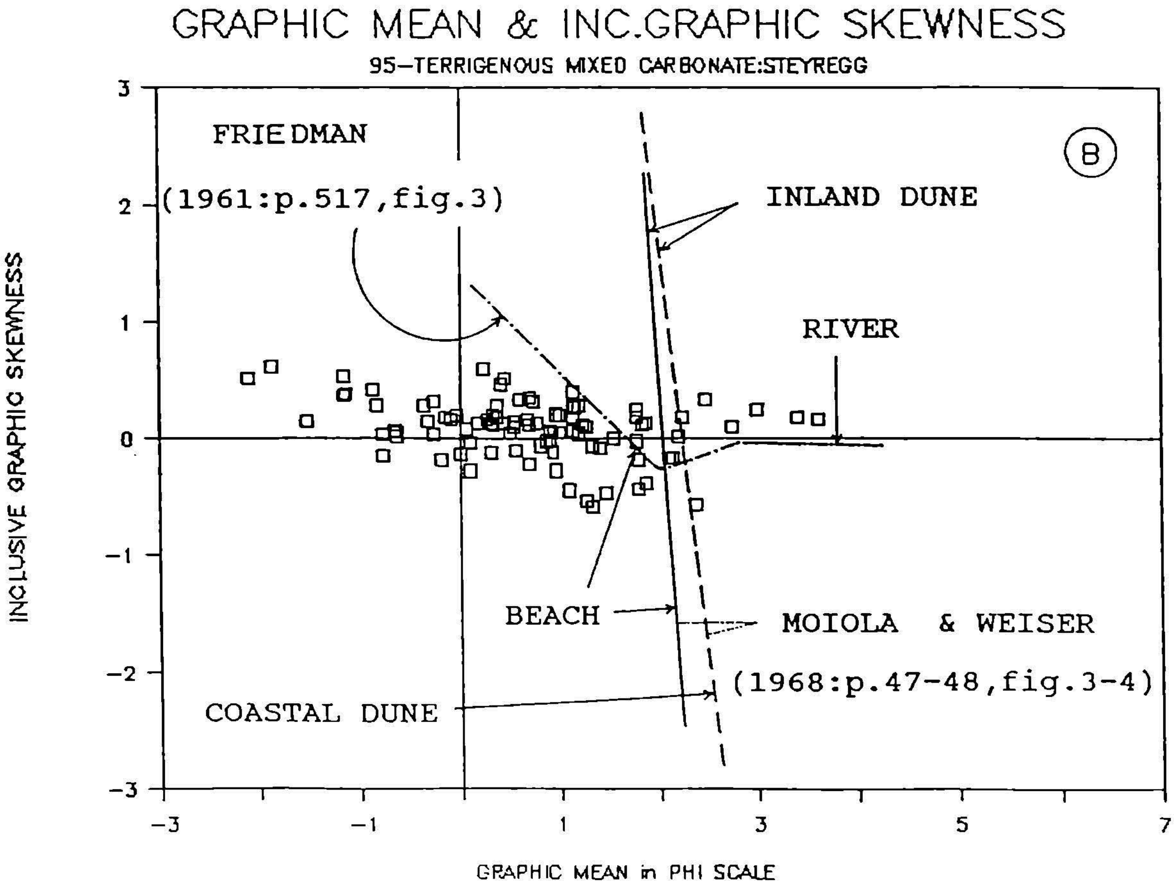
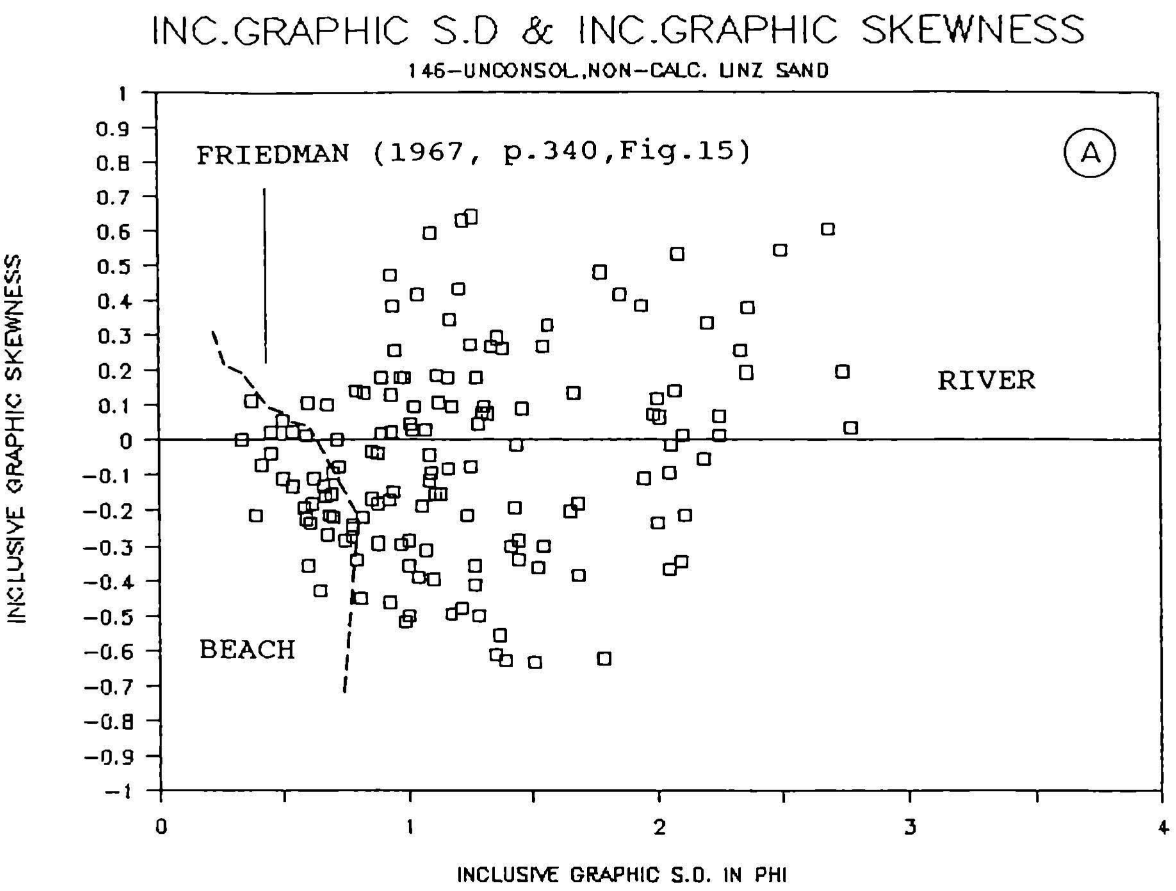


Fig. 4.14 Plots of graphic mean size versus inclusive graphic skewness.

A. For 146 samples from the non-calcareous Linz sand sequence.

B. For 95 samples from the calcareous terrigenous sediments and the consolidated calcarenites, Steyregg.



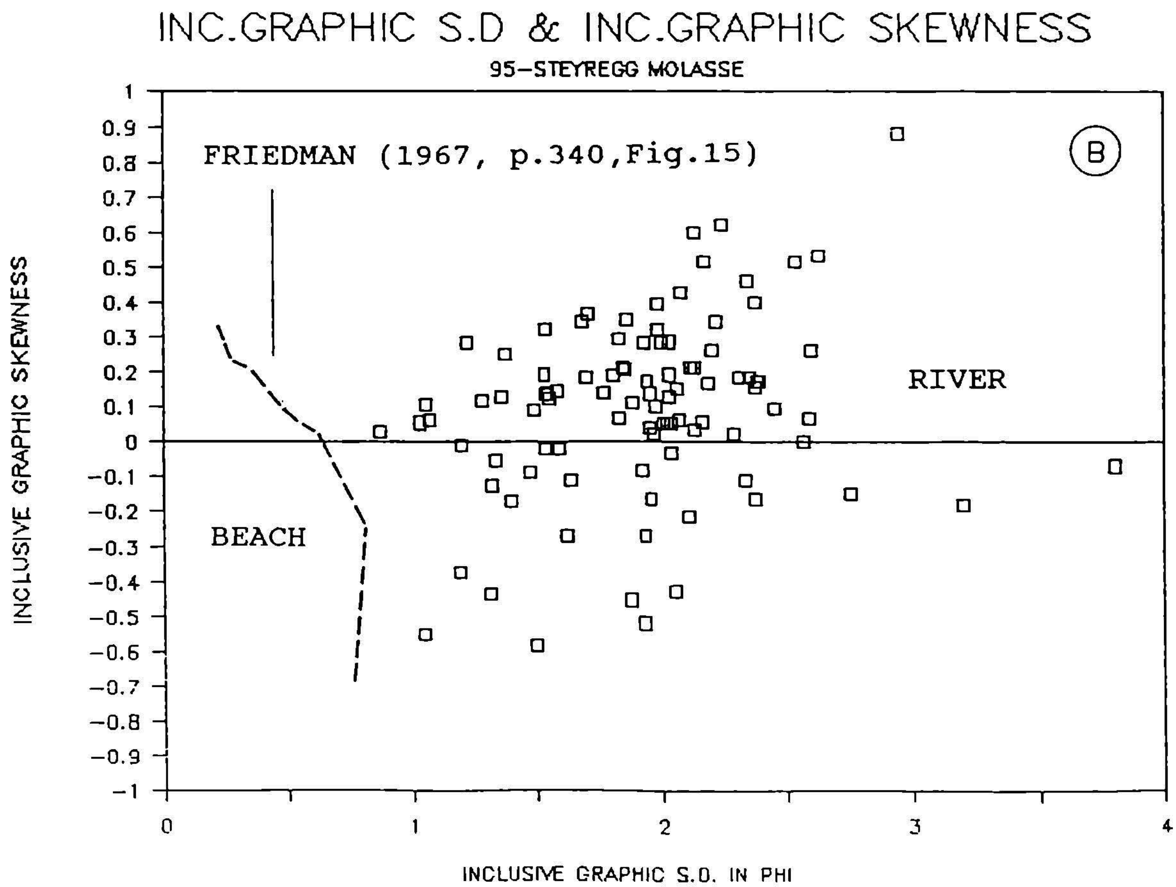


Fig. 4.15 Plots of inclusive graphic standard deviation versus inclusive graphic skewness.

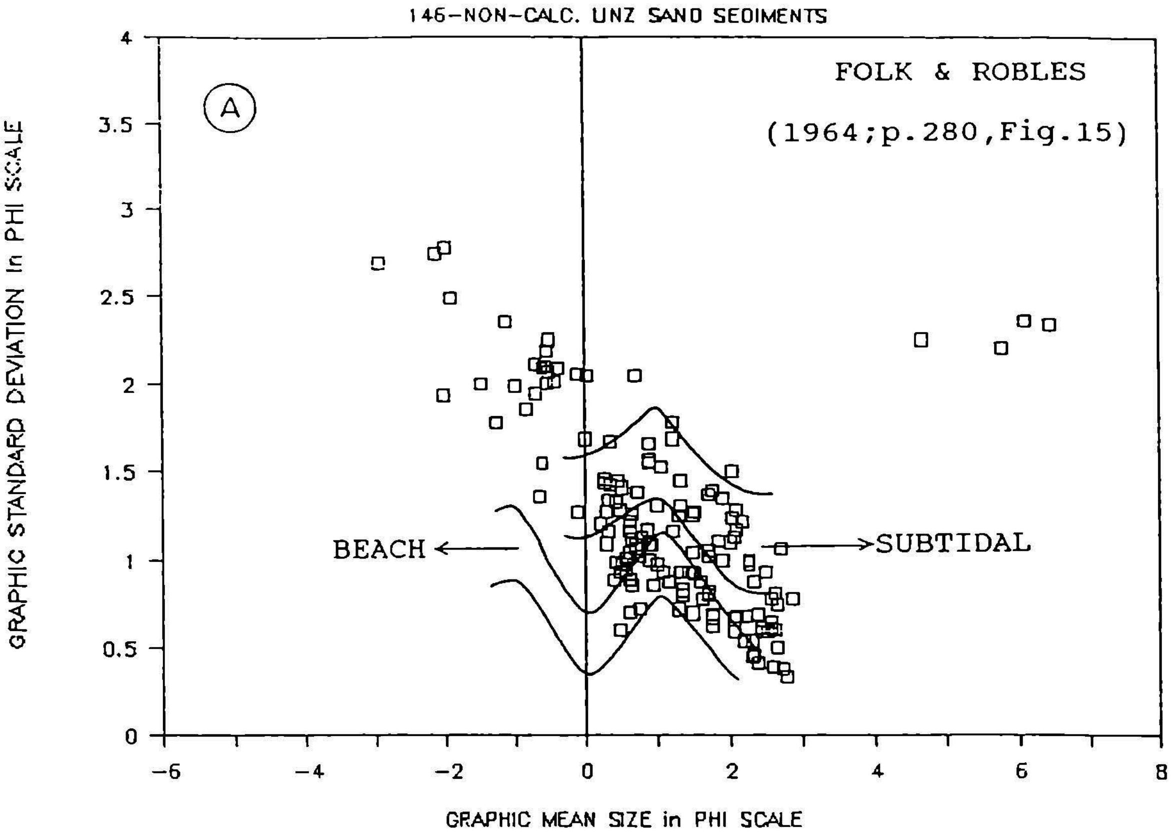
A. For 146 samples from the non-calcareous Linz sand sequence.

B. For 95 samples from the calcareous terrigenous sediments and the consolidated calcarenites, Steyregg.

samples of the terrigenous mixed carbonate sequence of Steyregg (Fig. 4.15B) shows that all data fall in the area designated as fluvial environment (river). The author suggests the presence of fluvial influenced environments during deposits of the sediments of the terrigenous mixed carbonate sequence. Therefore, this method is not useful for interpretation of the depositional environment.

Folk and Robles (1964) and Flügel (1982) used a plot of graphic mean size (M_Z) versus inclusive graphic standard deviation (δ_I) to distinguish carbonate beach and subtidal carbonate environments. Consequently, the textural data of the Linz sand and the terrigenous mixed carbonate sequence were plotted on their diagrams. The plot of the Linz sand sediments (Fig. 4.16A) shows a subequal mixture between beach and subtidal areas. Whilst, the plot of the data of the terrigenous mixed carbonate sequence (Fig. 4.16B) shows a dispersed plot and does not concentrate in a designated area. They are naturally more poorly sorted than that of the Linz sand sediments. Based only on these plots, therefore, subtidal environment seems to be related to the consolidated calcarenites and beach environment seems to be related to the non-calcareous terrigenous sediments.

Sahu (1964) proposed a plot involving the textural statistical parameters; graphic mean size (M_Z), inclusive graphic standard deviation (δ_I) and graphic kurtosis (K_G) for distinguishing between several depositional environments (Fig. 4.17). In this diagram, samples of the Linz sand sequence plot among shallow marine, deltaic (fluvial) and turbidites due to their differences in textural lithologies (see Table 4.2 for legends). On the other hand, samples from the terrigenous mixed carbonate sequence fall only in the area of deltaic (fluvial) environments, in which the fluidity and energy levels consistently decrease from non-calcareous terrigenous sediments (T) and calcareous terrigenous sediments (C-T) to slightly consolidated calcarenites (C). In general, therefore, no significant difference between the terrigenous materials from the Linz sand and the terrigenous



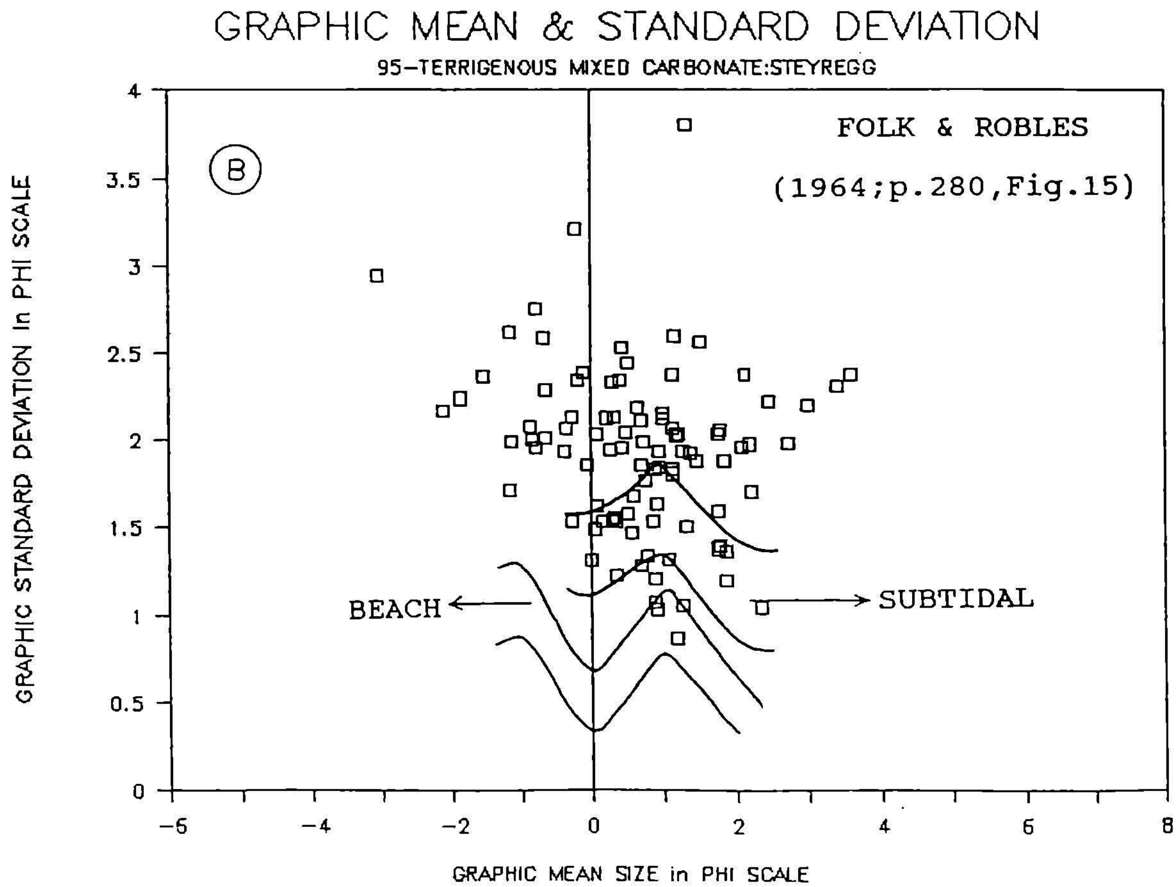


Fig. 4.16 Plots of graphic mean size versus inclusive graphic standard deviation.

A. For 146 samples from the non-calcareous Linz sand sequence.

B. For 95 samples from the calcareous terrigenous sediments and the consolidated calcarenites of Steyregg.

Table 4.2 Summary of the values of the grain-size statistical parameters for a diagram of Sahu (1964) with legends refer to Fig 4.17.

LITHOLOGIC GROUPS	LEGEND IN FIGURE	NUMBER OF SAMPLE	Data for SAHU,1964 plots	
			X-AXIS	Y-AXIS
* NON-CALCAREOUS LINZ SAND *		146		
SLIGHTLY GRAVELLY SAND	(g)S	81	0.21489	0.80914
GRAVELLY SAND	gS	29	0.74617	1.33991
SANDY GRAVEL	sG	25	0.32801	1.48712
SAND	S	7	0.10877	0.63181
SLIGHTLY GRAVELLY MUD	(g)M	4	0.07693	1.82801
* STEYREGG'S SAMPLES *		95		
TERRIGENOUS SEDIMENTS	T	43	0.60194	1.49540
CALC.TERRIGENOUS SEDIMENTS	C-T	15	0.83996	1.60960
CONSOLIDATED CALCARENITES	C	37	0.95862	1.76895

X-AXIS = square roots of arithmatic mean phi of inclusive graphic standard deviation (see formular in text).
Y-AXIS = ratio of arithmatic standard deviation of graphic kurtosis to graphic mean size times inclusive graphic standard deviation.

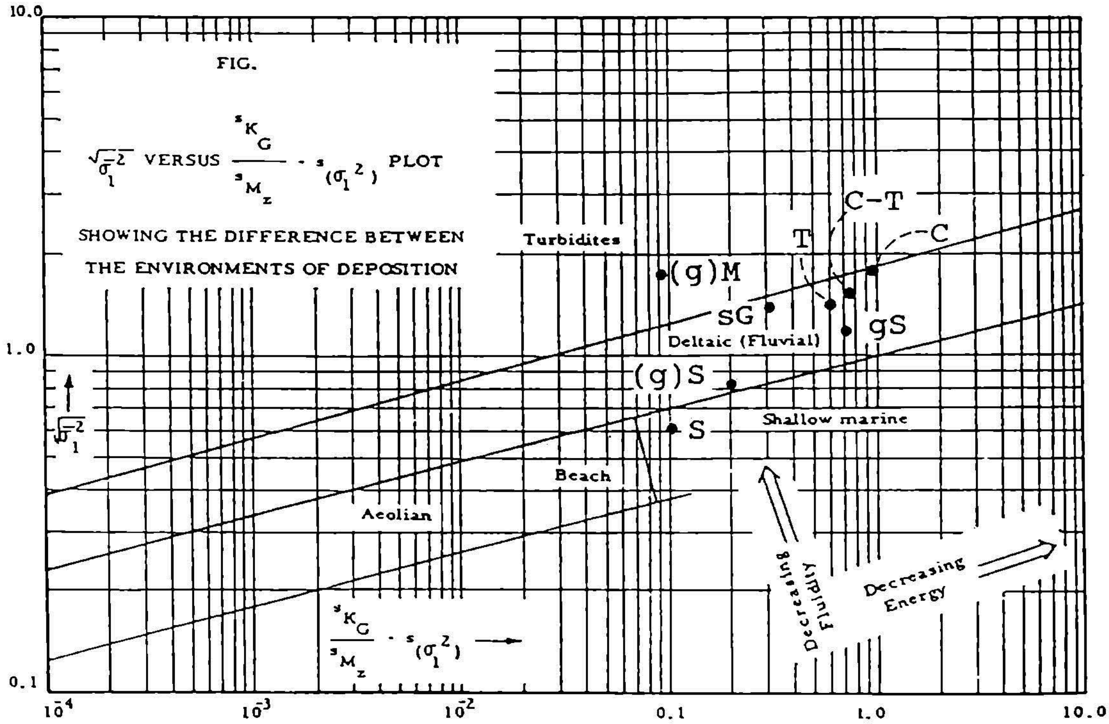


Fig. 4.17 Plots of statistical (textural) parameters of various Linz sand lithologies and insoluble residues of the terrigenous mixed carbonate sequence (Steyregg), which can be used for distinguishing between major depositional environments as proposed by Sahu (1964).

mixed carbonate sequence (Steyregg) could be found on the basic of this diagram.

In addition, why do these diagrams perform so miserably? In part, it is the basic a priori assumption of most of these discriminatory techniques that the samples to be tested are either derived from river bar, beach or dune environments. Amaral and Pryor (1977, pp. 45) pointed out that the stratigraphic world is not solely composed of beach, river bar or dune sands. Besides the limited number of environments considered, these devices also ignore the effects of regional variations in grain size, climate, sedimentation rate, tectonic stability and relative energy level within the environment.

4.5 Compositional characteristics.

The composition of mud (silt plus clay) fractions was investigated by the X-Ray Diffractometer (XRD), and was assisted by the Scanning Electron Microscope (SEM). Heavy minerals study, from the fraction coarser than 63 microns or 4 phi, was examined on grain-mounted slides under the petrographic microscope. However, several compositional characteristics of the sediments, both calcareous and non-calcareous nature, have already been mentioned in the petrographic Chapter 3.

4.5.1 Clay minerals.

The clay mineralogy of eighteen samples was investigated by using an oriented X-ray diffraction on ceramic plates (see Appendices 5,6). The minerals were identified mainly on the position and movement of the (001) reflections or X-ray diffractogram patterns according to the schemes by Swanson (1950), Smith (1964), Berry (1974), Bayliss et.al. (1980), Lindholm (1987: based on Carroll, 1970), Hardy and Tucker (1988: based on Carroll, 1970; Berry, 1974; Starkey et.al., 1984). Rough estimates were made of the relative abundance (abundant, common, moderately common and low) of the different clay mineral species in samples, using the area between the peak intensity and the background as suggested by Weaver (1958, 1967). The X-ray diffraction data are reported in Table 4.3, and described as follows:-

4.5.1.1 Clay minerals in the terrigenous mixed carbonate sequence (Steyregg).

A smectite group is the dominant clay minerals in nine samples from the terrigenous mixed carbonate sequence. It characterizes c-axis spacing between 14.5 A° (6.1° 2θ) and 15.5 A° (5.7° 2θ) suggesting the montmorillonite-15 A° species (Carroll, 1970). It contains two layers of water and probably Ca^{2+} and/or Mg^{2+} as exchangeable cations (Weaver, 1958). Cation exchange experiments demonstrate that Mg^{2+} is the major exchangeble cation. Variation in the (001) peak position (both before and after glycolation) indicated that the montmorillonite shows slightly different degrees of hydration and purity both within and between samples. The (001) reflection is generally fairly broad-based and most commonly forms a sharp peak variable from 13 A° (6.8° 2θ) to 15 A° (5.89° 2θ) which expands to about 17 A° (5.2° 2θ) or more after glycol treatment and collapse between 9 A° (9.8° 2θ) and 10 A° (8.8° 2θ) after heating treatment. Several samples generally show a 15 A° peak which, after glycolation, shifted to a maximum of about 17.7 A° (5.0° 2θ).

Small to moderate quantities of 10 A° (8.8° 2θ) illite (illite, sericite and/or muscovite) are present in all samples. The typical peaks are relatively broad and show low intensity. They are unchanged after glycolation. More intense peaks after heating suggest an illite-1Md (Carroll, 1970). However, integral series of a basal spacing at 5 A° (17.7° 2θ) are poorly identified.

A very small reflected peak at about 7.15 A° (12.4° 2θ) is only observed in the sample-CB of dark-green muds lying between granitic boulders of a recent colluvial sediment. The peak did not change after glycolation but this reflection

Table 4.3 Summary of the results of the clay mineralogy by using X-Ray Diffractometer (XRD), and see also Appendix 6.

CLAY MINERALS FROM TERRIGENOUS MIXED CARBONATES, STEYREGG.

SAMPLES	TYPE OF THE CLAY MINERALS		
CB	SMECTITE : Montmorillonite	ILLITE-1Md	KAOLINITE-1T
F-3	SMECTITE : Montmorillonite	ILLITE-1Md	
ST-1	SMECTITE : Montmorillonite	ILLITE-1Md	
ST-9	SMECTITE : Montmorillonite	ILLITE-1Md	
ST-14	SMECTITE : Montmorillonite	ILLITE-1Md	
ST-23	SMECTITE : Montmorillonite	ILLITE-1Md	
ST-24	SMECTITE : Montmorillonite	ILLITE-1Md	
R-1	SMECTITE : Montmorillonite	ILLITE-1Md	
R-3	SMECTITE : Montmorillonite	ILLITE-1Md	

SAMPLES	TYPES OF THE CLAY MINERAL IN LINZ SAND SEDIMENTS		
B-5		(ILLITE-1Md)	
D-9	(SMECTITE : Montmorillonite)		
E-8		ILLITE-1Md	
F-9/1		(ILLITE-1Md)	KAOLINITE-1T
F-25		ILLITE-1Md	KAOLINITE-1T
G-2		ILLITE-1Md	KAOLINITE-1T
G-3			KAOLINITE-1T
G-36		(ILLITE-1Md)	KAOLINITE-1T
G-46		ILLITE-1Md	KAOLINITE-1T

(......) = TRACE AMOUNTS OF CLAY

** CLAY NOMENCLATURES base on BERRY, 1974 (JCPDS-Publ.DMB-1-23) **

disappeared after heating, suggesting a kaolinite-1T (Berry, 1974). However, the latter higher order reflection (002) at 3.57 A° (24.94° 2θ) is not recorded.

The clays of the terrigenous mixed carbonate sequence of Steyregg are, therefore, characterized by the abundant presence of montmorillonite-15 A° (see Photo. 4/1), moderately common illite-1Md (Photo. 4/2) and perhaps low or small amounts of kaolinite-1T.

4.5.1.2 Clay minerals in the Linz sand sequence.

The clay mineralogy of eight samples of the Linz sand sediments appears to remain relatively constant over the sedimentary sequence. Kaolinite is the dominant clay mineral species in several samples. The pronounced (001) reflections at 7.15 A° (12.38° 2θ) and (002) peak at 3.57 A° (24.94° 2θ) are considered to represent kaolinite-1T on untreated samples. Small variations in peak position, broad and low intense basal reflections between samples suggest that disordered (poorly crystallized) kaolinite is present only in small amounts. Glycolation shows no changes in the reflections but the peak disappears after heated treatments, clearly suggesting a kaolinite-1T.

Small quantities of 10 A° (8.8° 2θ) illite-1Md are present in a few samples. However, relatively broad and low intensity peaks at 10 A° may also suggest the presence of mica-2M, ranging from fine-grained, poorly crystalline to disordered varieties. The mica peak is always noticeable enhanced following heating as illite-1Md.

Only one untreated sample D-9 shows a poor reflection at about 15 A° (5.89° 2θ) which shifts and becomes more intense after glycolation, and disappears after the heating treatment. This peak is recorded as a mineral species of the smectite group (montmorillonite-15A°).

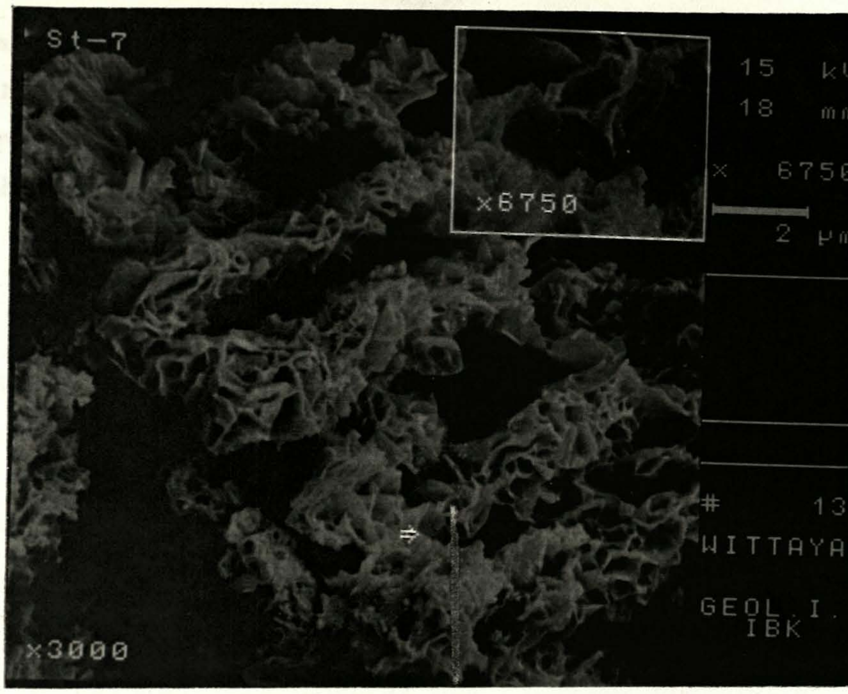


Photo 4/1 SEM photomicrograph showing boxwork structure, it is very delicate with cornflake-like particles, crenulations and numerous fibrous projections. This is the typical characteristic of smectite (ie. montmorillonite); Quarry A, Section III at 10.5 m., sample St-7 (the consolidated calcarenites of Steyregg).

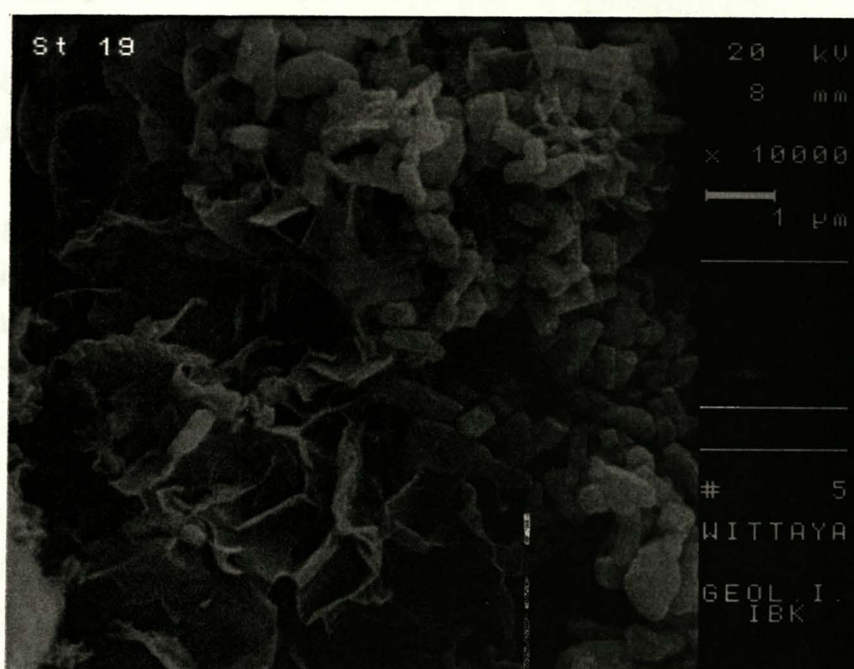


Photo 4/2 SEM photomicrograph showing that growth of illite has partially occluded the intergranular pore (half left), later micrite was developed on the top (half right); Quarry A, Section III at 24 m., sample St-19 (the consolidated calcarenites, Steyregg).

In general, the clay minerals in the Linz sand sediments are dominated mainly by kaolinite-1T (ie. Photo. 4/3), with small quantities of illite-1Md and trace amounts of montmorillonite-15 A° (Photo. 4/4).

4.5.1.3 <u>Origin of the clay minerals</u>.

The clay minerals identified in the Linz sand sediments include, in decreasing order of abundance, kaolinite, illite and very rarely montmorillonite. The relative abundance of the clay minerals from the terrigenous mixed carbonate sequence (Steyregg) is montmorillonite, illite and very rarely kaolinite. However, X-ray diffractogram patterns in this study are difficult to evaluate in terms of the mixed layered illite-montmorillonite or other mixed layered clay minerals.

One of the more lively controversies in the literature of clay geology concerns the relative importance of a detrital versus a diagenetic origin of clay minerals, ie. do the clay minerals simply reflect provenance? Are they constantly being modified or transformed by their environment into new, more stable and different clay mineral species? Most recent papers (eg. Keller, 1985; Chamley, 1989) accept both possibilities, and stress the polygenetic character of sedimentary clay minerals. In brief, the genesis of clay can be ascribed to three principal processes (Chamley, 1989 based on Millot, 1970):-

a. <u>Detrital inheritance</u> - whereby the clay minerals derived from the continents remain intact because of their stability.
b. <u>Transformation</u> - whereby the clay minerals are continually modified by the environment because of their instability; alteration may involve the substraction (degradation) or addition (aggradation) of elemental constituents.
c. <u>Neoformation</u> - whereby the clay minerals are to a large part or wholly chemically precipitated from the products dissolved in the hydrosphere.

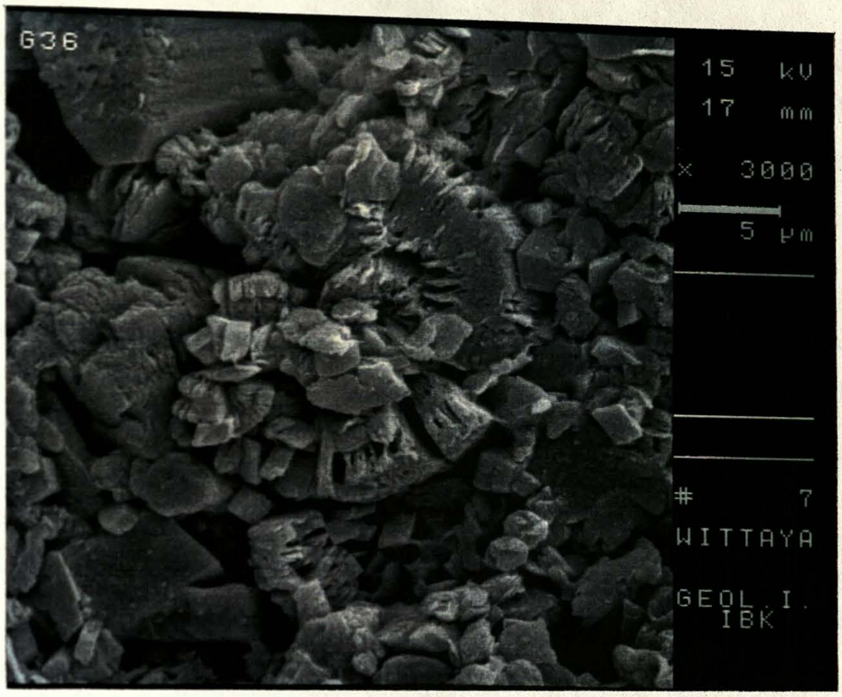


Photo 4/3 SEM photomicrograph showing pseudohexagonal outlines of kaolinite with closely packed platy or flaky appearence. Kaolinite crystals in this specimen are arranged in poorly distinct "booklets" structure of varying size with porosity. They are commonly associated with leaching of feldspar; Quarry G, Section II at 18.5 m., sample G-36 (slightly gravelly sand).

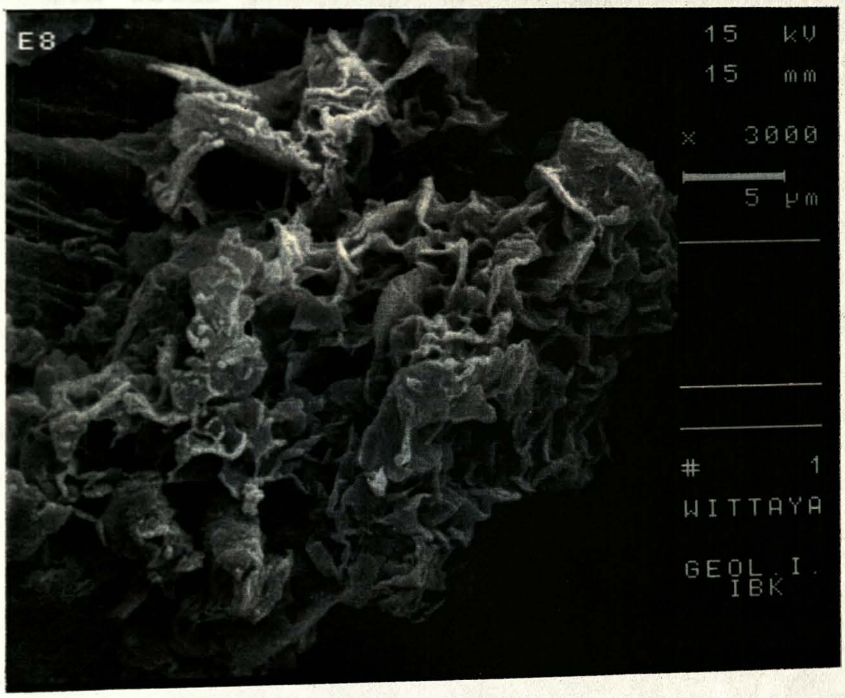
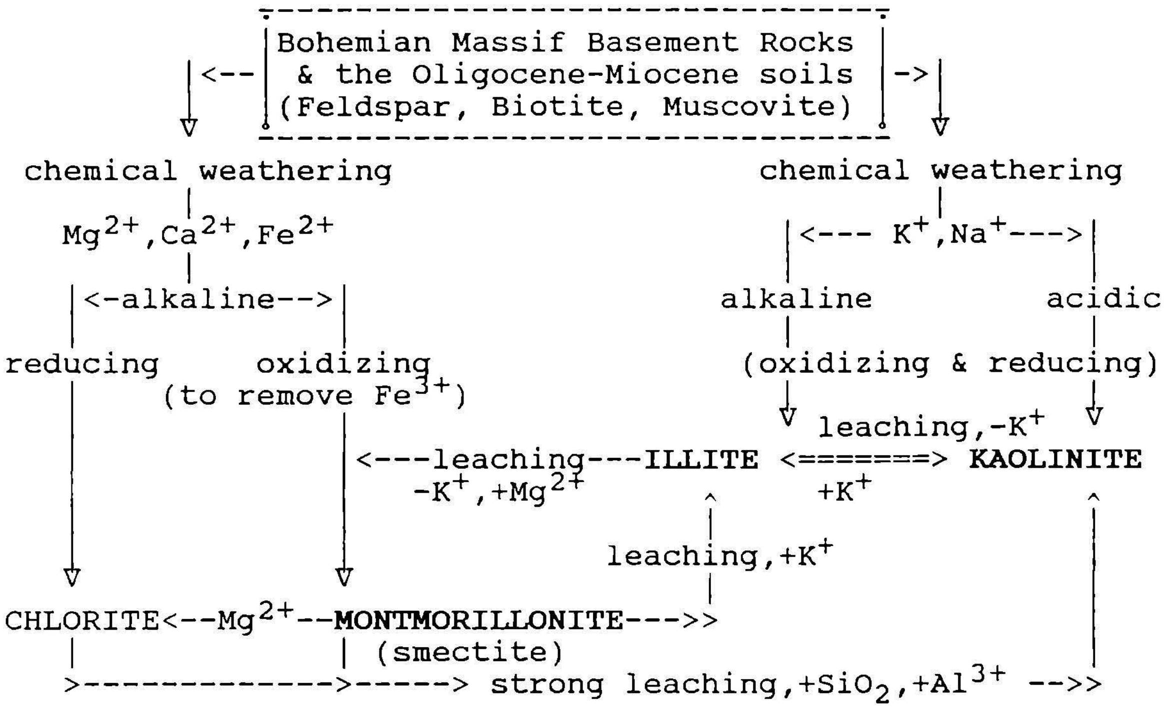


Photo 4/4 SEM photomicrograph of feldspathic grain-surface showing that smectite (montmorillonite) has been developed on top of pre-existing illite; Quarry E, Section I at 13 m., sample E-8 (slightly gravelly sand).

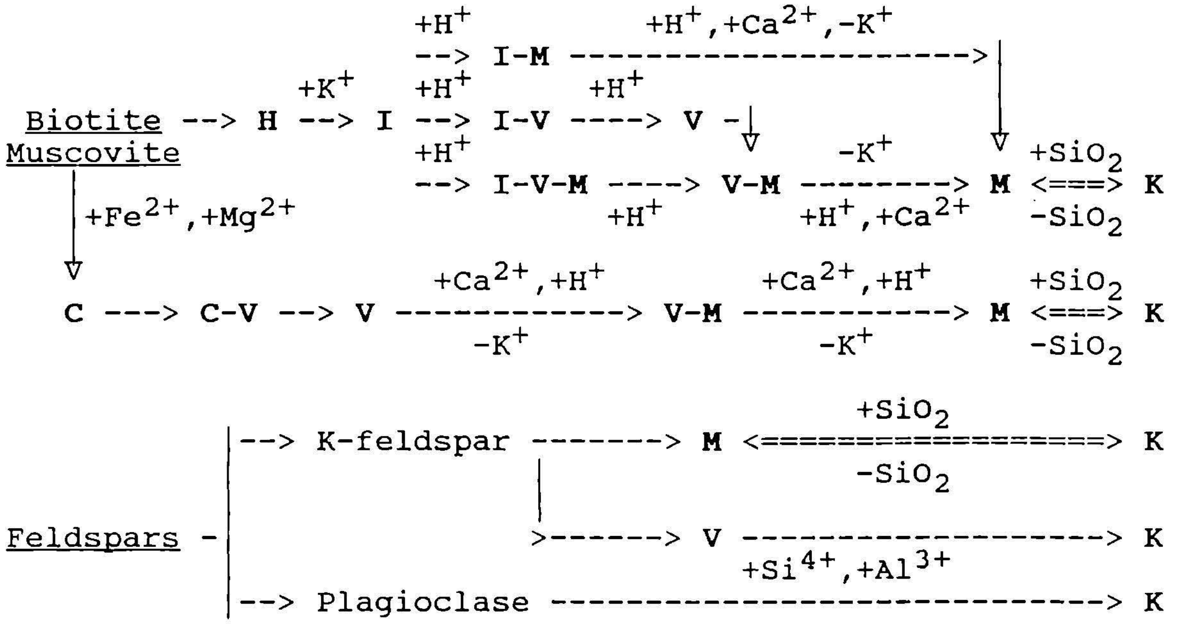
The rocks of the Bohemian Massif basement were the only source of terrigenous materials during the Molasse sedimentation (see section 4.5.2 and Fig. 3.5). Is the vast majority of the clay minerals in the terrigenous mixed carbonate (Steyregg) and the Linz sand sequence directly derived from the basement rock-source? In the terrigenous mixed carbonate sequence, montmorillonite is the most abundant. Whilst, in the Linz sand sediments, kaolinite is the dominant clay mineral. Montmorillonite is commonly an alteration product of glassy volcanic ash in the marine environment. However, there are no indications that the constituents in these studied sediments derived from volcanic rocks. Other questions will concentrate on the origin of illite and kaolinite.

Considering the generally low to moderate abundance of illite in the terrigenous mixed carbonate sequence of Steyregg (as well as in the Linz sand sediments), it is possible that montmorillonite has been derived via the transformation of illite. However, the relative stability of illite in sea water precludes any significant alteration to montmorillonite in the marine environment (Weaver and Pollard, 1973), and also the absence of mixed layer clay minerals, eg. illite-montmorillonite species. It is more resonable to suggest that any transformation of illite occured within the Oligocene-Miocene soils, developed on the Bohemian Massif basement rocks, adjacent to the marine sedimentary basin. To this end, it is pertinent to review briefly the general clay mineral characteristics of soils developed by the weathering, sequential transformation and/or neoformation. A general guideline for the genesis of clay minerals is presented on the next page.

It is assumed that the Bohemian Massif basement rocks (granite and gneissic granite) are parent materials for a number of zonal soil classes, forming under some ranges of climatic conditions. Micaceous minerals are the most readily weathered minerals in the basement rocks. Later, they are sequentially transformed with advancing weathering intensity



Flow charts showing possible routes followed during the weathering and sequential transformation of micas and feldspars in soils (after Lewis, 1984 for the upper flow chart;after Chamley, 1989 and Velde, 1985 for the lower flow chart).



LEGEND: **H** = hydromicas, **C** = chlorite, **I** = illite, **V** = vermiculite, **M** = montmorillonite (smectite group), **K** = kaolinite and hyphenated letter (-) couplets or triplets indicate a random mixed-layering of the clay minerals.

according to the simplified scheme outlined in both previous flow charts. The weathering of feldspar to sericite introduces additional micaceous clay minerals into the transformational sequence, including transformed alteration of chlorite (if present) as well.

The Oligocene-Miocene soils may have provided abundant montmorillonite, kaolinite and degraded illite to the marine sedimentary basin. Drainage basinal waters were undoubtedly relatively enriched in dissolved Si^{4+}, Ca^{2+}, Mg^{2+}, Fe^{2+}, Na^{+}, K^{+} from the chemical destruction of eg. micas, ferromagnesian minerals and feldspars of the basement rocks.

Several possible mechanisms may now be suggested for the origin of the clay mineral species in the terrigenous mixed carbonate (Steyregg) and the Linz sand sequence, as a whole, under the heading of detrital inheritance, transformation and neoformation.

1. **Detrital inheritance**: Large amounts of kaolinite in the Linz sand sediments may be of direct pedogenetic origin (ie. Photo. 4/3). Kaolinite remains stable in the more acid-environment (Hanson et.al., 1981). It would have been the dominant soil clays which now are apparently abundant in several samples of the Linz sand sequence and only in one sample of colluvial deposits of the basement boulders. The small to moderate quantities of illite in the terrigenous mixed carbonate sequence (ie. Photo. 4/2) and the Linz sand sediment (ie. Photo. 4/4) are not mainly detrital in origin. Although, considering the variety of micaceous species in the basement rocks, it is likely that some species are probably sufficiently well crystallized and ordered, or of sufficiently large size, to resist chemical alteration and major structural modification between source and sediment. The decreasing importance of illite in the sediments high in terrigenous sand and silt, such as in the Linz sand sediments and the terrigenous sediments of the terrigenous mixed carbonate sequence (Steyregg), do not support their detrital heritage. It is also unlikely that montmorillonite (ie.

Photo. 4/1) was inherited from the source rocks, substantial amounts may have been inherited from the contemporaneous soils (see the flow charts). Where given suitable environmental conditions, montmorillonites would have formed as a degradational alteration product of source rock clay minerals. Then, it was transported to marine sedimentary basins.

2. __Transformation__: It can be presumed that the majority of micaceous minerals and feldspars in the basement rocks have been weathered and then transformated within the contemporaneous soils, as previously discussed. Therefore, illite, the most stable clay mineral in the marine environment (Chamley, 1989 based on Millot, 1970), might be expected to be abundant in the terrigenous mixed carbonate sequence of Steyregg and/or the Linz sand sequence. The products of degradational alteration of illite were mainly degraded illite (another illite species), montmorillonite and kaolinite (also with a variety of mixed-layer assemblages and vermiculite, if present). The relative abundance of these minerals depends upon the effectiveness of eluviation, formed by rotting of rock inplace to greater or less depth, in the soil profile which cannot be positively established for the Oligocene-Miocene soils. Judging from the present-day situation it is most likely that kaolinite and some lesser illite may have been the dominant soil clays. However, both clay minerals are apparently less abundant than montmorillonite in the terrigenous mixed carbonate sequence, except in the Linz sand sequence, suggesting that the montmorillonite in these sediments may have originated by the aggradational transformation of several of the soil clays. Possible mechanisms include:-

a. The aggradational transformation of illite and degraded illite into montmorillonite in an alkaline marine environment (eg. Photo. 4/1) is possible during a late stage of syndiagenesis, where leaching is restricted and where pore-waters are rich in dissolved Mg^{2+}, lesser Ca^{2+} and Si^{4+}, and domimated by carbonate sedimentation.

b. The resilication of kaolinite in an alkaline environment rich in dissolved silica and alkaline earth elements.
c. In addition, the partial chemical reorganization of the degraded expandable illite, chlorite and various mixed-layer clays is not clearly evident to confirm such a transformation of some clay species in this study.

Major quantities of illite (Photo. 4/2) in the terrigenous mixed carbonate sequence (Steyregg) may have been formed by degradational alteration products of hydromicas and degradational transformed montmorillonite in an alkaline marine environment, since initial diagenesis and burial, where potassium ions are available. It may be supplied by the breakdown of K-feldspar during early diagenesis. While glauconite (see section 5.6.2), a clay mineral of the illite group, is only observed in thin-sections of the consolidated calcarenites. Glauconite is always a halmyrolitic or diagenetic product and formed where potassium and iron ions are available, under alkaline marine conditions. Illite in the sediments of the terrigenous mixed carbonate sequence may have largely been transformed into montmorillonite.

A minority of kaolinite in the Linz sand sediment may have been formed as a final product of feldspar retrodiagenesis, diagenetic alteration, in an acidic environment where strong leaching is available. While illite and montmorillonite are not stable in such conditions. Again, only trace amounts of kaolinite may have been modified from degradational alteration since burial of other clay minerals within the depositional environment such as from illite and/or montmorillonite (see the flow charts).

3. <u>Neoformation</u>: An assumption for the neoformation of montmorillonite is that if the relatively small amounts of dissolved silica were being released from the low-lying terrigenous mixed carbonate (Molasse) base and the pore-water was rich in Ca^{2+} and Mg^{2+}, small amounts of montmorillonite in this sediment may have been originated by neoformation. However, the evidence of silica precipitation among pores has

not been proved in the petrographic and Scanning Electron Microscopic study to support such a neoformational origin.

4.5.2 Heavy mineral analysis.

Ten samples of very fine to fine sand-size grains (2-4 phi) of the insoluble residues from the terrigenous mixed carbonate sequence (Steyregg) and eleven samples from the Linz sand sequence were used for heavy mineral study. Heavy minerals were concentrated by sedimentation through **"Sodium Polytungstate"** ($3Na_2WO_4.9WO_3.H_2O$, S.G. = 2.96) in steep-side separating funnels (see Appendix 1). Frequency analysis, ocular grid-counting, was applied for a quantitative heavy mineral analysis. All heavy minerals were counted, which were intersected by equally spaced lines lain upon the slide mounts. Table 4.4 and Fig. 4.18 summarize the results of the non-opaque heavy mineral study and include an absolute value in percent (%) of the abundance of the individual mineral species in samples.

The heavy minerals (non-opaque and opaque minerals) generally form less than 3 wt.% of the very fine and fine sand fractions of the samples, and are notably most abundant only in the very fine sand-size fraction. Volumetrically the most important non-opaque heavy minerals in the terrigenous mixed carbonate sequence are sphene, zircon, apatite and kyanite. Whilst, heavy minerals in the Linz sand sequence are ordered as zircon, sphene, kyanite and apatite.

a. Zircon: Colourless to very pale pink zircon is the most abundant transparent heavy mineral of the Linz sand sequence, and is the second most abundant heavy mineral in the terrigenous mixed carbonate sequence. It forms somewhat well-worn, euhedral, prismatic grains, about 0.15 to 0.25 mm long and 0.05 to 0.10 mm wide, that commonly show conspicuous pyramidal terminations at one or both ends. Zonning, strongly coloured varieties are pleochroism. Fluid and gas inclusions, large and rod-shaped, are common.

A

TERRIGENOUS MIXED CARBONATES	F-3	R-1	R-3	ST-1	ST-9	ST-14	ST-23	ST-24	ST-42	ST-48	AVERAGE (%)
	** SAMPLE NO. **										
ZIRCON	38.2	36.7	26.4	9.2	21.1	18.9	16.6	16.1	64.3	54.9	30.24
APATITE	19.8	25.8	28.3	19.0	23.1	30.1	20.7	28.5	8.1	8.5	21.19
RUTILE	0.3	0.7		0.6	0.3	0.7			0.4	0.7	0.37
SPHENE	21.6	21.3	30.9	59.2	46.9	42.7	56.2	46.8	23.2	22.5	37.15
TOURMALINE	0.6	0.7	1.1	0.6	0.3		0.3	0.9		0.7	0.54
ANATASE					0.7						0.07
SILLIMANITE	2.3	1.9	1.1	1.1	0.3	0.7	0.7		0.7	0.7	0.96
KYANITE	10.8	7.9	6.0	5.2	2.4	2.6	2.1	3.8	1.8	9.9	5.25
GARNET	2.0	3.4	4.5	4.6	3.7	3.6	2.1	2.5	1.1	0.7	2.83
SPINEL	0.6				0.3						0.09
ACTINOLITE	3.2	0.7	1.1	0.6	0.3	0.3	1.0	0.6	0.4	1.4	0.98
HORNBLENDE	0.6	0.7	0.4		0.3	0.3	0.3	0.6			0.34

B

LINZ SAND SEDIMENTS	B-5	C-2	C-5	D-4	D-11	E-3	E-13	F-6	F-14	G-7	G-44	AVERAGE (%)
	** SAMPLE NO. **											
ZIRCON	74.4	79.1	74.9	72.7	78.1	65.8	75.6	55.0	77.8	69.5	79.1	72.92
APATITE	5.0	4.0	1.8	11.0	1.0	10.5	6.4	4.0	0.6	9.6	1.7	5.04
RUTILE			0.3		1.0			1.0	0.6	0.4	0.4	0.34
SPHENE	9.2	9.3	11.6	6.6	3.8	9.3	7.1	14.5	3.8	5.0	3.4	7.60
TOURMALINE	0.8	0.7	1.8	2.5	2.9	0.8	0.6	1.0	3.2	0.4	1.7	1.49
ANATASE												
SILLIMANITE	2.7	1.3	1.8	0.9		2.0	3.2	1.5				1.22
KYANITE	4.2	3.0	6.3	4.1	7.6	8.8	5.1	14.0	7.6	11.7	12.0	7.66
GARNET	1.1	1.0	0.6	0.9	1.0	0.6			0.6	1.7	0.4	0.72
SPINEL	0.8	1.3		0.3	2.9	0.3		1.0		0.4	0.4	0.67
ACTINOLITE	1.9		0.9	0.6	1.9	1.4	1.9	8.0	3.8	1.3		1.97
HORNBLENDE		0.3		0.3		0.6			1.9		0.9	0.36

Table 4.4 Summary of the content (%) of the non-opaque heavy minerals.
A. Non-opaque heavy minerals from the terrigenous mixed carbonate sequence, Steyregg.
B. Non-opaque heavy minerals from the non-calcareous Linz sand sequence.

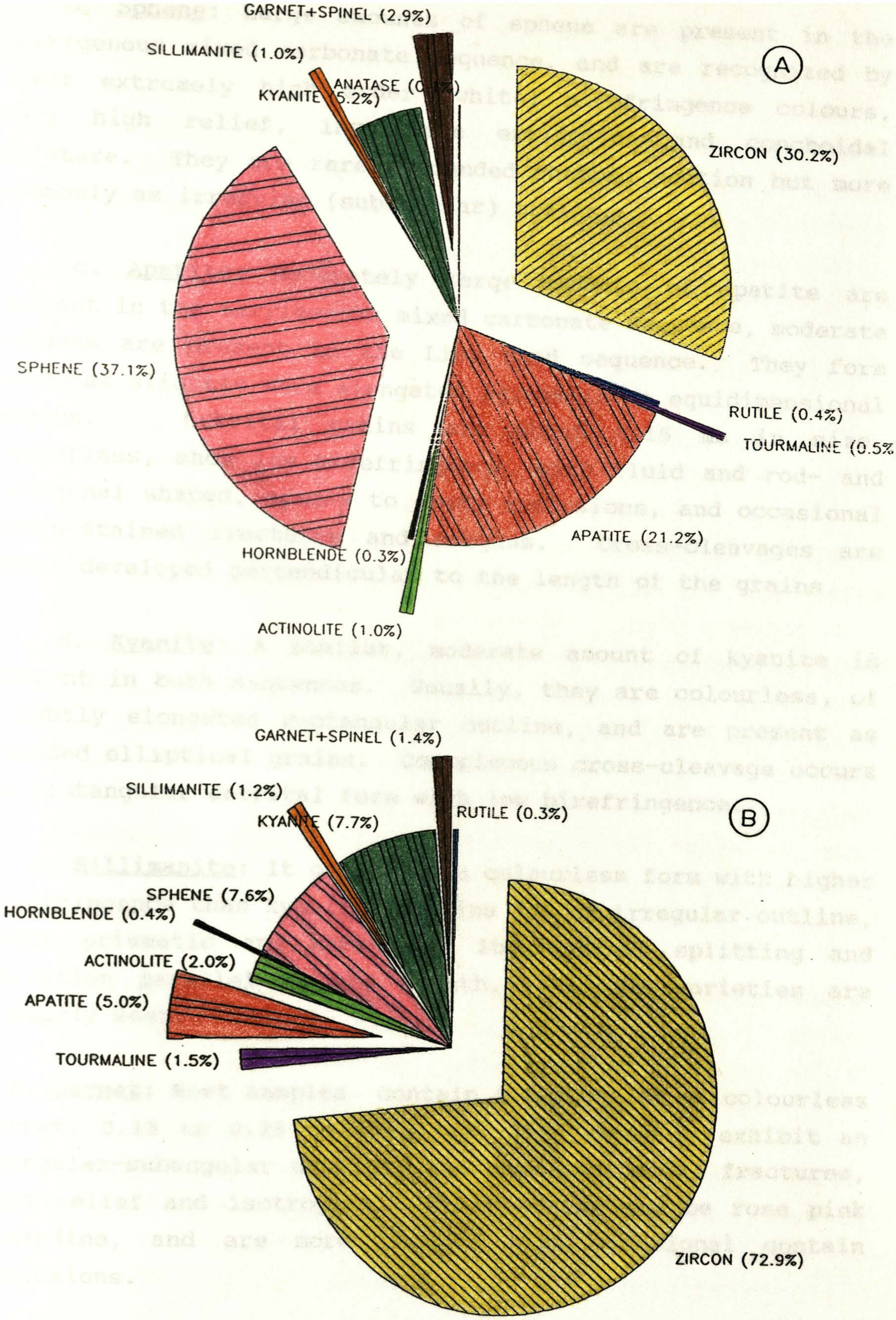


Fig. 4.18 Summary of non-opaque heavy minerals.
A. Ten samples from the terrigenous mixed carbonate sequence, Steyregg.
B. Eleven samples from the non-calcareous Linz sand sequence, St.Georgen an der Gusen.

b. <u>Sphene</u>: Large amounts of sphene are present in the terrigenous mixed carbonate sequence, and are recognized by their extremely high order (white) birefringence colours, very high relief, incomplete extinction and conchoidal fracture. They are rarely rounded rhombic section but more commonly as irregular (subangular) grains.

c. <u>Apatite</u>: Moderately large amounts of apatite are present in the terrigenous mixed carbonate sequence, moderate amounts are present in the Linz sand sequence. They form somewhat slightly worn elongated prismatic to equidimensional grains. Detrital grains are about 0.15 mm in size, colourless, show low birefringence, with fluid and rod- and hexagonal shaped, opaque to dusty inclusions, and occasional brown-stained fractures and margins. Cross-cleavages are often developed perpendicular to the length of the grains.

d. <u>Kyanite</u>: A similar, moderate amount of kyanite is present in both sequences. Usually, they are colourless, of slightly elongated rectangular outline, and are present as rounded elliptical grains. Conspicuous cross-cleavage occurs as rectangular detrital form with low birefringence.

e. <u>Sillimanite</u>: It occurs as a colourless form with higher birefringence than kyanite. Grains are of irregular outline, short prismatic and marked by longitudinal splitting and striation parallel to the length. Fibrous varieties are commonly seen.

f. <u>Garnet</u>: Most samples contain a few grains of colourless garnet, 0.15 to 0.25 mm in size. They commonly exhibit an irregular-subangular outline, and show conchoidal fractures, high relief and isotropism. Other grains may be rose pink almandine, and are more rounded with occasional contain inclusions.

g. <u>Rutile</u>: It is characterized by deep reddish brown (near opaque) to red colours, and occurs commonly as irregular grains, rarely with prismatic forms and rounded pyramidal ends. Rutile shows high relief and dark borders around the grains that are generally found in both sequences.

h. **Tourmaline**: Prismatic, variably rounded tourmaline grains with occasional fluid and opaque inclusions are present in small quantities in most samples. All grain shows strong pleochroism. Several varieties are distinguished by their colour: pale brown to pale green, pale yellow to blue green and deep blue to pale yellow.

i. **Actinolite**: Grains show a very pale colour, weak pleochroism, and are irregularly elongated with saw-toothed outline. They occur in minor quantities.

j. **Hornblende**: The hornblende content shows a slight variation among the studied samples. In the Linz sand sediments, hornblende is rare or absent. In the terrigenous mixed carbonate sequence (Steyregg), it is more concentrated in several samples. Hornblende occurs as elongated, prismatic forms with saw-toothed and ragged outlines. Three varieties of hornblende are recognized by their pleochroism: yellow green to blue green, light brown to dark brown and pale green to deep green. The first of these is most abundant, and is rarely choked with opaque mineral inclusions.

k. **Spinel**: Grains are typically subrounded in shape, larger than 0.15 mm, and show conchoidal fractures. They are isotropic and colourless to coffee-brown. The relief of spinels is generally lower than that of garnet.

l. **Anatase**: Grains showing blue colours, weakly pleochroism, rectangular outline with corners marked by striation and about 0.15 mm in size are identified as anatase. This mineral appears isotropic, indicated by well-centred uniaxial cross in convergent light parallel to the borders, as seen only in sample St-9 of the consolidated calcarenites.

4.5.2.1 Origin of the heavy minerals.

The majority of heavy minerals in the terrigenous mixed carbonate (Steyregg) and the Linz sand sequence are possibly derived from similar source rocks of the Bohemian Massif basement rocks. The heavy mineral assemblages are probably derived both from acid-intermediate igneous and, less important, medium to high-grade metamorphic rocks (see Fig. 3.4). The source area was situated in the north, where the sediments are likely adjoined the basement rocks. However, the heavy minerals of the Linz sand sequence may have been transported for much longer distances, due to their shape, than that of the terrigenous mixed carbonate sequence.

The assemblage of the heavy minerals in the rocks of the Bohemian Massif basement in the study area is unknown, although the heavy mineral data of Woletz (1963) and Roetzel et.al. (1983) proved that sediments of the Molasse can be derived mainly from the crystalline rocks of the Bohemian Massif rather than Alpine-crystalline source rocks (cf. Kurzweil, 1973). The detrital transparent heavy mineral data of Woletz (1963), Zimmerle (1964), Kurzweil (1973), Roetzel et.al. (1983) and Sauer et.al. (1992) may be taken as typical for the basement rocks as follows; zircon, apatite, rutile, tourmaline, garnet, staurolite, chloritoid, andalusite, monazite, xenotime, kyanite, sillimanite, epidote, titanite (sphene), hornblende, topaz, anatase, brookite and spinel. Of the heavy minerals in the terrigenous mixed carbonate (Steyregg) and the Linz sand sequence, only zircon, apatite, sphene, rutile, tourmaline, kyanite, sillimanite, garnet, spinel, actinolite, hornblende and anatase are accounted for that in the above list, except actinolite. In addition, biotite and collophane (authigenic and biogenic origins) are not included in Table 4.4.

Clearly, kyanite, sillimanite, spinel, garnet, bluish-green hornblende, actinolite and some varieties of tourmaline have been derived from metamorphic source rocks. Zircon, apatite, sphene and rutile have been derived from acid to intermediate plutonic rocks. However, sphene, rutile and garnet may come from both sources. Anatase has clearly been formed during diagenesis.

Volumetrically the most abundant non-opaque heavy minerals in both sequences have mainly been derived from plutonic rocks. Metamorphic source rocks are of lesser importance. Both source rock types are included within the Bohemian Massif basement rocks which are characterized by the strictly NW-SE striking of chiefly magmatitic gneisses cut by numerous granite bodies (Braumüller, 1959, 1961; Janoschek, 1961; Janoschek and Matura, 1980). Paragneisses, graphite-schists, calc-silicate rocks and amphibolites are a minor part of the basement which is partly overlain by Paleozoic and thick Mesozoic deposits (ie. Janoschek, 1961; Kollmann, 1977; Kollmann and Malzer, 1980; Malkovský, 1987; Nachtmann and Wagner, 1987; Wessely, 1987; Sauer et.al., 1992).

CHAPTER 5
DIAGENESIS

In this chapter an attempt is made to trace some of the major compositional, mineralogical and textural changes that the sediments of the terrigenous mixed carbonate (Steyregg) and the Linz sand sequence have undergone between the time of their deposition and the present-day. Although many of the diagenetic processes and fabrics discussed are related and overlap one another, it is convenient to initially describe them separately. At the end of the chapter, the various phenomena are integrated into a paragenetic sequence of diagenetic events.

5.1 Definition of diagenetic stages.

In this section diagenesis is taken to include all chemical and physical processes modifying sediments subsequent to deposition and prior to metamorphism. The process may be conveniently subdivided into the following three stages according to Fairbridge (1967, 1983):-

1. Syndiagenesis - Early diagenesis synchronous with deposition (or sedimentary phase); high porosity and large amounts of slowly circulating interstital waters.
   a. Initial stage - Oxidizing conditions, organic matter, burrowing organisms, aerobic bacteria, rising P_{CO2}, falling pH (to < 7), 0.0 to 0.5 m sediment depth.
   b. Early burial stage - reducing conditions, anaerobic bacteria, rising pH (to > 9), base of stage from 1 to 100 m sediment depth.
2. Anadiagenesis - Deep-burial phase of diagenesis (or compaction-maturation phase), pH 8-9, more neutral Eh, dewatering of sediment, lithification (if not already effected) is completed, from lower limit of anadiagenesis to about 10,000 m sediment depth.
3. Epidiagenesis - Late stage diagenesis following uplift (or emergent pre-erosional phase); oxidizing conditions, circulating meteoric waters, pH more neutral to somewhat acid.

However, detailed diagenetic studies of the consolidated calcarenites of Steyregg showed that the sediments do not follow the above diagenetic stages. Thus, three major regimes of carbonate diagenesis due to James and Choquette (1983) and Moore (1989) were also introduced:-

1. **The seafloor and shallow-marine subsurface regime** - It is characterized mainly by marine waters of normal salinity. Hypersaline water is present in evaporative environments. Mixed marine-meteoric waters may be present also near the strandline and in the shallow subsurface at the mixing interface between the marine realm and the meteoric realm, the seafloor and the very near-surface environment (or syndiagenesis).
2. **The meteoric regime** - It is characterized by the presence of fresh water and includes the unsaturated, vadose zone above the water-table and the phreatic zone, or saturated zone, below the water table, and a zone of mixed marine-meteoric realms (or syndiagenesis plus epidiagenesis).
3. **The deep subsurface** - It is referred to as the marine phreatic or deep phreatic zone. Sediment pores are filled with water that was either marine or meteoric water in the beginning (or anadiagenesis).

5.2 **Nature of the original sediment.**

Properties of the primary sediment that may be of significance in affecting, or even controlling, diagenetic modifications include:-

a. Mineralogical composition of siliciclastic grains, and especially clay minerals.
b. Mineralogical composition of calciclastic and/or bioclastic grains.
c. Texture of the sediment and, in particular, the quantity of mud-sized material and pore-space.
d. The quantity of organic matter and the bacterial population of the sediment.

Different combinations of these primary characteristics may undergo quite different reactions and follow diverse diagenetic paths in contrasting physicochemical environments. Each of the primary sediment characteristics is briefly discussed below.

5.2.1 Siliciclastic mineralogy in the original sediment.

Siliciclastic material in the terrigenous mixed carbonate (Steyregg) and the Linz sand sequence includes quartz, orthoclase, microcline, plagioclase, sedimentary and granitic (gneissic) rock fragments, clay minerals (montmorillonite, illite and kaolinite), glauconite, micaceous minerals and a variety of heavy minerals.

In the terrigenous mixed carbonate sequence (Steyregg): quartz, alkaline feldspar, granitic (gneissic) rock fragments, bioclastic fragments, montmorillonite and illite are commom (see Tables 3.1, 4.3 and Fig. 3.7). Whilst, quartz, alkaline feldspar, kaolinite and illite are abundant in the Linz sand sequence. Bioclastic materials and coarser siliciclastic grains are relatively unstable, and were altered during diagenesis. Some amounts of clay minerals (eg. montmorillonite and illite) may partly have formed during diagenesis.

5.2.2 Bioclastic mineralogy in the original sediment.

Bioclastic material in the consolidated calcarenites (see Table 3.1, Fig. 3.7) consists mainly of fragments of *Lithothamnium* and benthic foraminifers, with moderately common oyster skeletons, small amounts of echinoderms, bryozoans, gastropods, brachiopods, and rare planktic foraminifers and ostracods. The original mineralogical composition of these bioclastic grains is varied (see Table 5.1). It was dominated by the metastable carbonate species such as high-magnesium calcite and aragonite, destined to burial diagenetic alteration (Stehli and Hower, 1961). Aragonite in bioclastic grains transforms to calcite in time

TABLE 5.1: MINERALOGY OF MAJOR GROUPS OF CARBONATE-SECRETING ORGANISMS
(Data from SCHOLLE, 1978; TUCKER & WRIGHT, 1990)

TAXON	ARAGONITE	CALCITE <---- mole % Mg ----> 0 5 10 15 20 25 30 35	BOTH ARAGONITE & CALCITE
CALCAREOUS ALGAE			
Red algae	R	C------------C	
Green algae	C		
Coccoliths		C	
FORAMINIFERS			
Benthic	R	C-------C - - C	
Planktic		C--C	
SPONGES	R	C---C	
COELENTERATES			
Stromatoporoids **	C	C ?	
Milleporoids	C		
Rugose **		C ?	
Tabulate **		C ?	
Scleractinian	C		
Alcyonarian	R	C----C	
BRYOZOANS	R	C----C	R
BRACHIOPODS		C--C	
MOLLUSCS			
Chitons	C		
Pelecypods	C	C--C	C
Gastropods	C	C--C	C
Pteropods	C		
Cephalopods (most)	C		
Belemnoids **		C	
SERPULIDS	C	C-----C	C
ARTHROPODS			
Decapods		C--C	
Ostracods		C---C	
Barnacles		C--C	
Trilobites **		C	
ECHINODERMS		C--------C	

C = common R = rare ** = not based on modern forms and, as indicated, high-magnesium calcite may either lose Mg^{2+} and alter to low-magnesium calcite or gain Mg^{2+} to form dolomite.

5.2.3 Texture in the original sediment.

In the consolidated calcarenites of Steyregg and the Linz sand sediments, three different types of texture can be recognized:-

a. **Biocalcarenites** and **sandy biocalcarenites** (-rudites) contain relatively high amounts of bioclastic grains. They are very poorly to poorly sorted, consisting of mineralogically metastable skeletons dominated by *Lithothamnium*, oysters, benthic foraminifers, echinoderms. The framework grain-supported fabric, interparticle pore spaces are generally filled with calcisiltite, micrite and clay to silt-sized quartzose-feldspathic matrix. Lesser quantities of siliciclastic material are admixed within the bioclastic sediment.

b. **Bioclastic arenites** (-rudites) contain relatively high amounts of siliciclastic grains. They are poorly sorted, fine sand to medium pebble sized, and composed of quartz, feldspar and rock fragments with small to large quantities of admixed bioclastic sand sized grains consisting chiefly of benthic foraminifers. These sediments are grain-supported, and contain small amounts of micrite and clay to silt-sized quartzose-feldspathic matrix within the interparticle pore-spaces.

c. **Arkose** and **subarkose** are poorly to moderately sorted, rarely seen well sorted. Grains are very fine to very coarse sand-sized with some gravels. They consist of quartz admixed with metastable feldspars and rock fragments. Interparticle pore spaces are generally open, and rarely filled with quartzose-feldspathic silted matrix and clay-matrix. Organic burrowing activity is a local important feature.

5.2.4 Organic matter and bacterial population in the original sediment.

The mean organic content of carbonate rocks is commonly about 0.2 percent (Hunt, 1979; Bostick, 1979). However, the content of organic matter and the bacterial population of the primary terrigenous mixed carbonate sediments are impossible to assess, such as in the consolidated calcarenites of Steyregg. The huge numbers of benthos and plankton in the terrigenous mixed carbonate seas must have ensured, via decay of their soft tissues, an abundant supply of organic material in the sediments. The bacterial population would be directly related to the content of organic matter (Surdam et.al., 1989).

Thus, at the time of deposition, the consolidated calcarenites (Steyregg) consisted of a diverse assemblage of both metastable (eg. magnesium calcite, aragonite and certain clay minerals) and stable (eg. calcite, quartz and feldspar?) minerals whose grain-sizes varied from pebble to clay grades. The finer sediments were probably relatively enriched in organic matter, and probably supported a large bacterial population. Infaunal burrowing activity was important in muddier finer sand sediments. An initially high porosity of sediment favoured the slow unimpeded turnover of interstitial waters and provided a geochemically active environment conducive to diagenetic alteration (Ayalon and Longstaffe, 1988).

5.3 Biological and physical effects.

It is clear that siliciclastic sediments undergo sequential changes with some burial levels, that occur as a result of biogenic activity, eg. in the Linz sand sediments, and changed pore-water compositions. These diagenetic changes include (1) post-depositional mixing of sediments owing to bioturbation, (2) rearrangement of grain packing and loss of porosity as a result of compaction from sediment loading or loss of porosity through cementation, (3) destruction of some framework grains, cements, or matrices by dissolution, creating secondary porosity such as the sediments in the terrigenous mixed carbonate sequence, (4) replacement of some minerals by others, and (5) clay-mineral authigenesis. These processes are partly discussed in the following section.

5.3.1 Bioturbation effects.

Organisms reworked sediment from the depositional interface to depths of several tens of centimetres, resulting in churning or mixing sediments to various degrees. Their activities can destroy primary depositional features such as lamination. While it probably has little effect on the composition of siliciclastic sediments. Organisms in deep burrows may bring about an interchange of pore-waters with overlying sea-water. However, the effect of this process on the composition of the sediment is probably inconsequential (Tillman and Almon, 1979). Also bioturbation may act locally to alter the porosity and permeability of sediments. Whilst, subsequent changes in porosity, owing to compaction during burial, can be overshadow the effects of bioturbation. Except for destruction of sedimentary structures, which can be substantial, and minor changes in texture owing to mixing of sediments of different sizes or shapes. Bioturbation in the Linz sand sediments probably does not greatly modify the characteristics of sediments (Photos. 2/15, 2/27).

5.3.2 Compaction effects.

Pore space in the consolidated calcarenites was reduced or occluded by a combination of some degrees of compaction and cementation. The importance of pore-space reduction by compaction varies considerably among the pure terrigenous sediments, the calcareous terrigenous sediments and the consolidated calcarenites. Variations in sediment grain-size, grain-shape, grain-orientation, sorting, matrix content, cement, composition, and in the physicochemical nature of the depositional environment, account for these differences (Wolf and Chilingarian, 1976).

Ricken (1987) suggested a carbonate compaction law for terrigenous mixed carbonate rocks. This can be evaluated in terms of a percentage of compaction of the primary sediment volume (k) depending on porosity (expressed as a percentage of the rock or sediment volume = n), actual carbonate volume (expressed as a percentage of the volume of solids = c, which usually equals to weight percentage) and non-carbonate volume (expressed as a percentage of the decompacted sediment = NC_d, a constant factor during diagenesis). Therefore, the standardized non-carbonate fraction is given by the following formular:-

$$NC_d = \frac{(100-k)(100-n)(100-c)}{10000}$$

According to this law, the percentage of compaction for the consolidated calcarenites, as a whole (see Table 3.1 and Appendix 7), is about 4 %. The compactional degree for the Linz sand sediments, however, is near zero according to this formular and that of Smosna (1989).

On the other hand, qualitative petrographical evidence of compaction both in the terrigenous mixed carbonate (Steyregg) and the Linz sand sequence is provided by bent flexible grains of mica-flake deformation (Photo. 5/1) and, in addition, dislocated or crushed fabrics of benthic foraminifers (Photo. 5/2). Consequently, it can be assumed that the degree of compaction in the Linz sand sediments is more or less equivalent to the compaction in the terrigenous mixed carbonate sequence.

5.4 Alteration of metastable carbonate grains.

Fossil assemblages rarely represent their original life assemblages. The life assemblages are commonly selectively destroyed or altered by processes of (1) physical and biological destruction, (2) transportation in the depositional environment, (3) chemical and biochemical solution, and (4) decay both in the depositional and in the post-depositional environment. This section briefly asseses

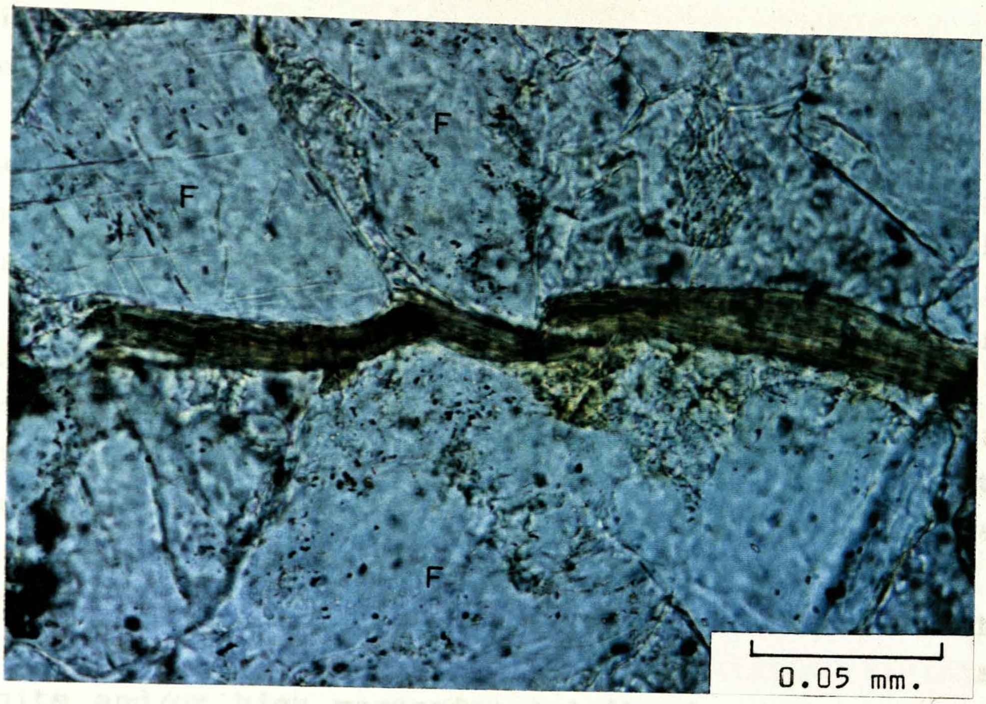


Photo 5/1 Compaction effects illustrated by deformation and dislocation of the mica flake among feldspathic grains (F) in subarkose of the Linz sand sediment; Quarry F, at 6 m., sample F-6, plane polarized light.

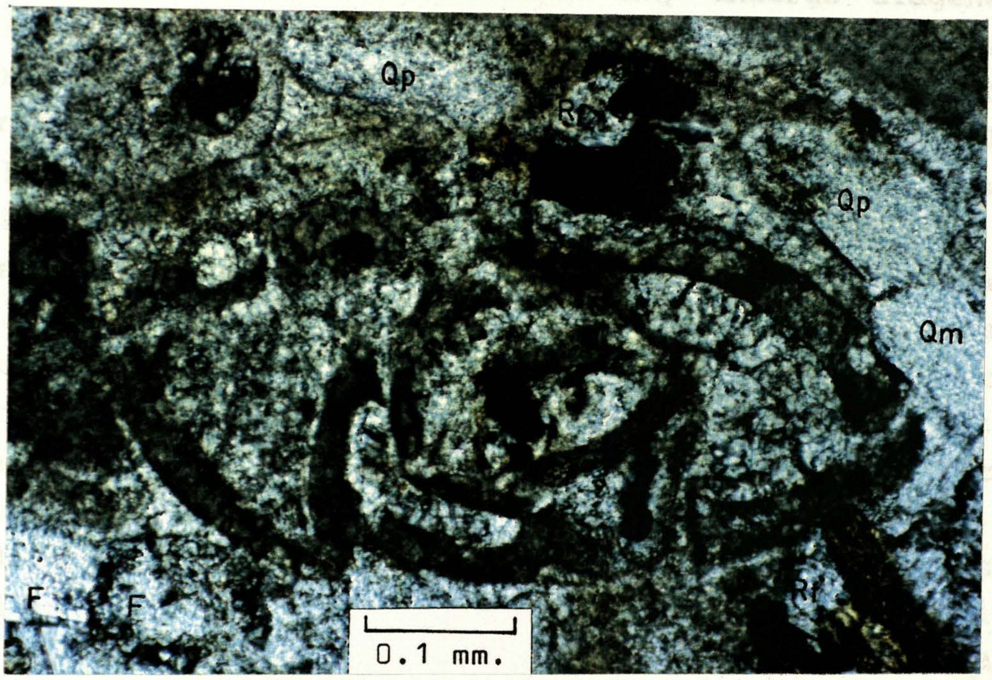


Photo 5/2 Foraminiferal shell (Rotaliina) in sandy biocalcarenite has been dislocated and crushed under superincumbent load of sediments. Test-chambers are filled with granular sparry calcite (Rock fragments = Rf, Polycrystalline quartz = Qp, Monocrystalline quartz = Qm, weathered feldspar = F); Steyregg, Grid-ref. 265505, sample W-4, plane polarized light.

the importance of skeletal mineralogy in affecting fossil preservation in the consolidated calcarenites of Steyregg.

The principal mineral species secreted by marine organisms are both low magnesium (less than 4 mole % $MgCO_3$) and high magnesium calcite (more than 4 mole % $MgCO_3$; see Table 5.1) with subdominate aragonite and rarely both mixed aragonite and calcite. High magnesium calcite and aragonite are metastable carbonate minerals, under natural near-surface conditions. The stability sequence, low magnesium calcite > aragonite > high magnesium calcite, is generally valid (Stehli and Hower, 1961); for high magnesium calcite the solubility increases with increasing Mg^{2+} content (Chave et.al., 1962). Most marine organisms precipitate metastable aragonite and/or high magnesium calcite in their skeletons. Fossil preservation of these forms may, then, be largely controlled by the timing and kind of diagenetic processes.

Metastable carbonate skeletons may undergo diagenetic reactions on the sea floor, during shallow burial and/or upon subaerial exposure (Tucker and Wright, 1990). Stabilization of aragonite skeletons most commonly involves a complete dissolution of the mineral and loss of textural details of the shells, depending on the degree of lithification of the enclosing sediment, may or may not leave a mould (Friedman, 1964). Stabilization of high magnesium calcite normally involves either incongruent solution (Land, 1967), whereby Mg^{2+} is lost to solution, yielding a replacement product of low magnesium calcite, or solution-deposition on a microscale (Friedman, 1964), in which high magnesium calcite is dissolved and low magnesium calcite is precipitated. These reactions are texturally non-destructive and the original shell outlines and microstructures are preserved faithfully (Photo. 5/3). Thus, although high magnesium phases are more metastable than aragonitic ones, the former ones are more likely to be preserved following diagenetic processes.

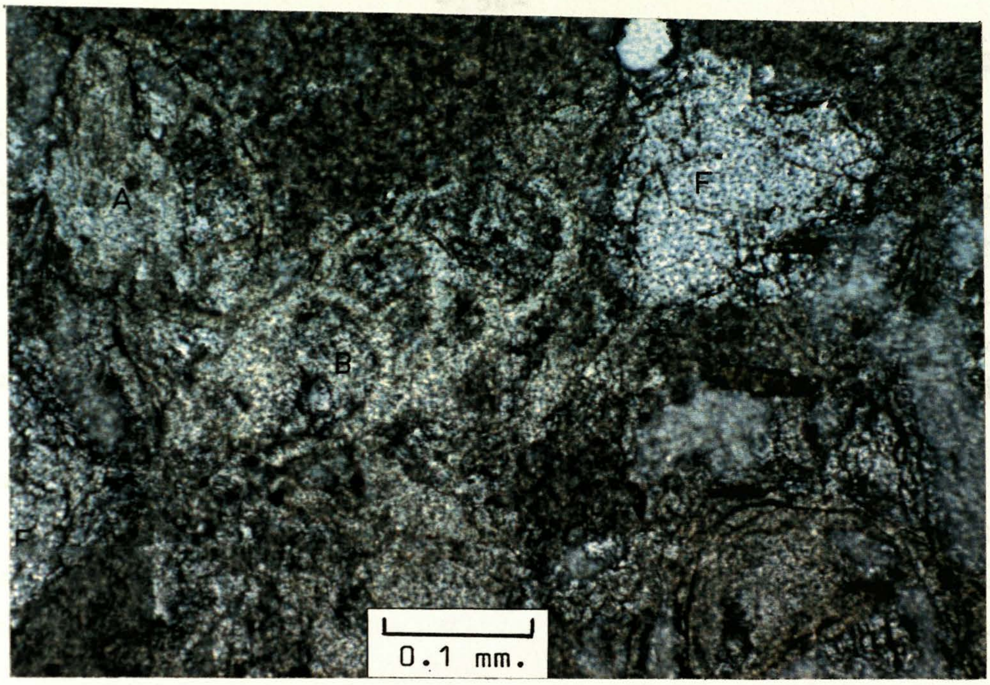


Photo 5/3 Microfauna in biocalcarenite may have been undergone diagenetic stabilization reactions on the sea floor (initial stage of syndiagenesis), involving a complete dissolution of high Mg-calcite and replaced by low Mg-calcite without destruction of the shell outline (Rotaliina: *Asterigina* = A, *Buliminidae* = B, Feldspar = F); Quarry A, unrecorded Section-levels, sample R-2, plane polarized light.

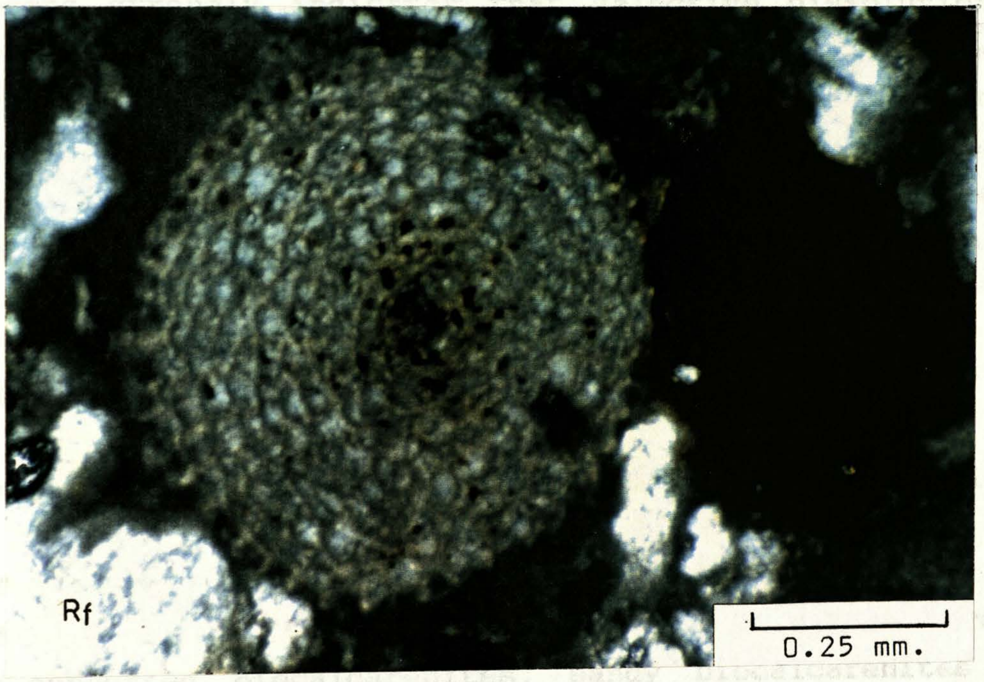


Photo 5/4 Well preserved "*Gypsina*" microstructures in *Lithothamnium* rich sandy biocalcarenite (rudite) with common rock fragments (lower left) and biotite (right) may have been involved with incongruent dissolution or solution-deposition reactions. Test-chambers are filled with granular sparry calcite and iron-oxide; Steyregg, Grid-ref. 260504, sample W-3, plane polarized light.

5.4.1 Skeletal mineralogy in the consolidated calcarenites.

The consolidated calcarenite's biota is dominated by calcareous red algae (*Lithothamnium*), bivalves (oysters), benthic foraminifers, echinoderms and others, all of which most commonly consist of metastable high magnesium calcite (Table 5.1). Petrographic thin-sections, stained with "Alizarin-Red" (eg. Photo. 5/5) and "Potassium Ferricyanide" (eg. Photo. 5/11), indicate that the skeletal tests are now constructed of stable calcite. Excellent preservation of shell microstructures in thin-sections indicates that high magnesium calcite was digenetically stabilized by incongruent dissolution or solution-deposition reactions (Photo. 5/4).

Moreover, evidence of an originally aragonitic fauna (eg. bivalve fragments) in thin-sections is relatively scarce. This is, sometimes, evidenced by diagenetic inversion or dissolution textures in which the shell is now replaced by calcite (Photo. 5/5). The scarcity of originally aragonitic skeletons strongly indicates that selective dissolution or alteration of metastable aragonitic skeletons has occurred in the consolidated calcarenites of Steyregg. Dissolution of aragonite in the sediments has occurred since early diagenesis (Bathurst, 1975, 1980), and has been regarded as largely a near surface meteoric diagenetic process (Palmer et.al., 1988; Tucker and Wright, 1990).

5.4.2 Calcisiltitic and micritic materials.

In the consolidated calcarenites (Steyregg), calcisiltite plus micrite is conveniently regarded as calciclastic mud-sized (or calcilutite) detritus in which large grains are embedded. However, calcilutite detritus is rather rare in grain-supported biocalcarenites, sandy biocalcarenites and bioclastic arenites (see Appendix 7A). It is only important in partially infilling pore spaces in these sediments (Photo. 5/6). In the coarseness of framework grains (eg. pebble sized bioclastic grains and/or particularly oyster and *Lithothamnium* fragments), calcilutite detritus is differently

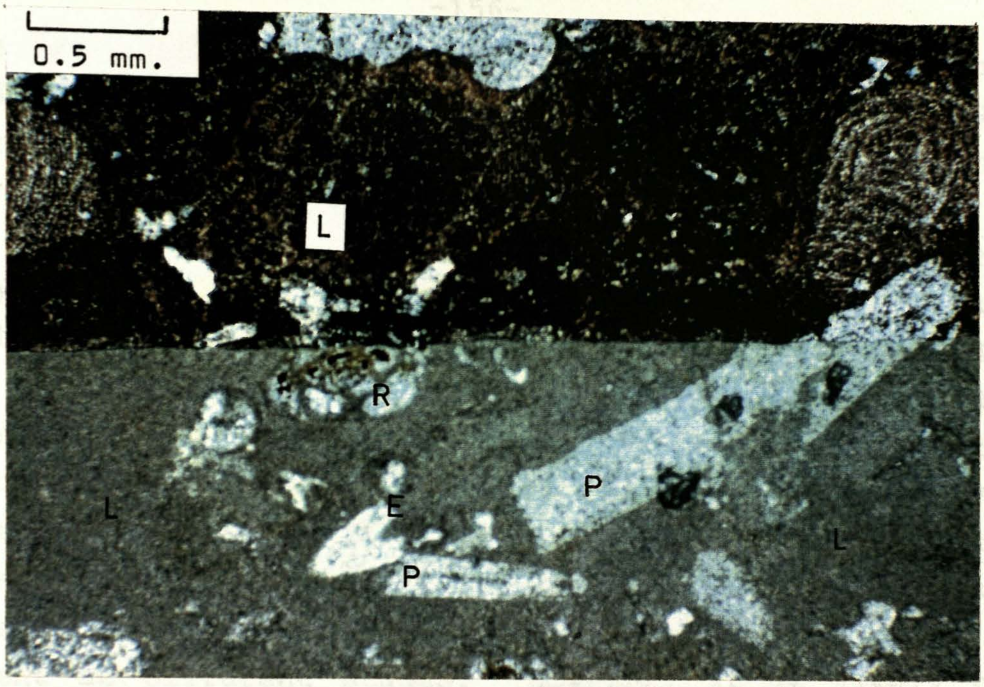


Photo 5/5 *Lithothamnium* (L) rich biocalcarenite showing that the diagenetic inversion of aragonitic shell fragments (P) now is replaced by calcite, and also shows the dislocated fabric (Rotaliina = R, Echinoderm skeleton = E); Quarry A,unrecorded Section-levels, Sample R-4, Alizarine-Red staining on the top half and unstaining on the lower part, plane polarized light.

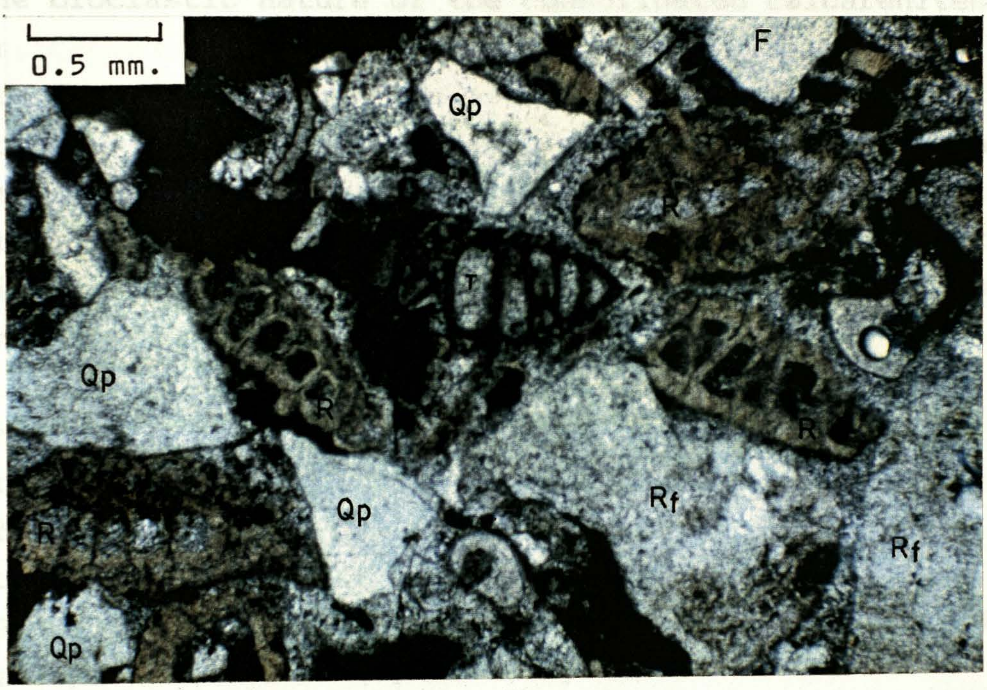


Photo 5/6 Bioclastic chambers and grain-boundaries in sandy biocalcarenite are partially occupied by micrites, terrigenous clays and granular sparry calcite (Textulariina = T, Rotaliina = R, Feldspar = F, Polycrystalline quartz = Qp, Rock fragments = Rf); Quarry A, Section III at 21 m., sample St-30, plane polarized light.

well seen. Under high magnified power, micrite consists of a tightly interlocking aphanocrystalline (Folk, 1959, 1962) mosaic of irregularly subequant particles (less than 4 microns in size). The micritic materials are generally of pale brownish colour at low magnification, and preserved mainly along skeletal boundaries (Photo. 5/7), called micritic envelopes (Friedman, 1964; Bathurst, 1966). They are uncommon features in the investigated samples. Calcisiltite includes recognisable foraminiferal, echinodermal, bryozoan, molluscan skeletons and a variety of indeterminable bioclasts. They are embedded in micrite. Calcisiltite and micrite are present in the same specimen, suggesting that they were probably introduced into the sediment at different stages. However, it is likely that calcilutite detritus in the consolidated calcarenites has originated mainly from the biological and mechanical erosion of skeleton tests and fragments. The following information is relevant:-

1. The bioclastic nature of the consolidated calcarenites, grain-fragmentation and -abrasion must have produced large quantities of mud-sized detritus as well as the more obvious sand-sized biofragments. Much of the fine calcisiltitic and micritic materials were ultimately transported into offshore deposits. Identifiable silt-sized bioclastic skeletons and micrites are now present in small amounts in the studied samples.

2. In general, grain-supported features are common framework particles in the consolidated calcarenites. If physicochemical conditions favoured for chemical precipitation of micrite from the sea water (Bathurst, 1975), then relatively widespread blanket deposits might be expected. Moreover, the complex and random distribution of micrite on a microscale makes an origin through chemical precipitation untenable in the studied samples.

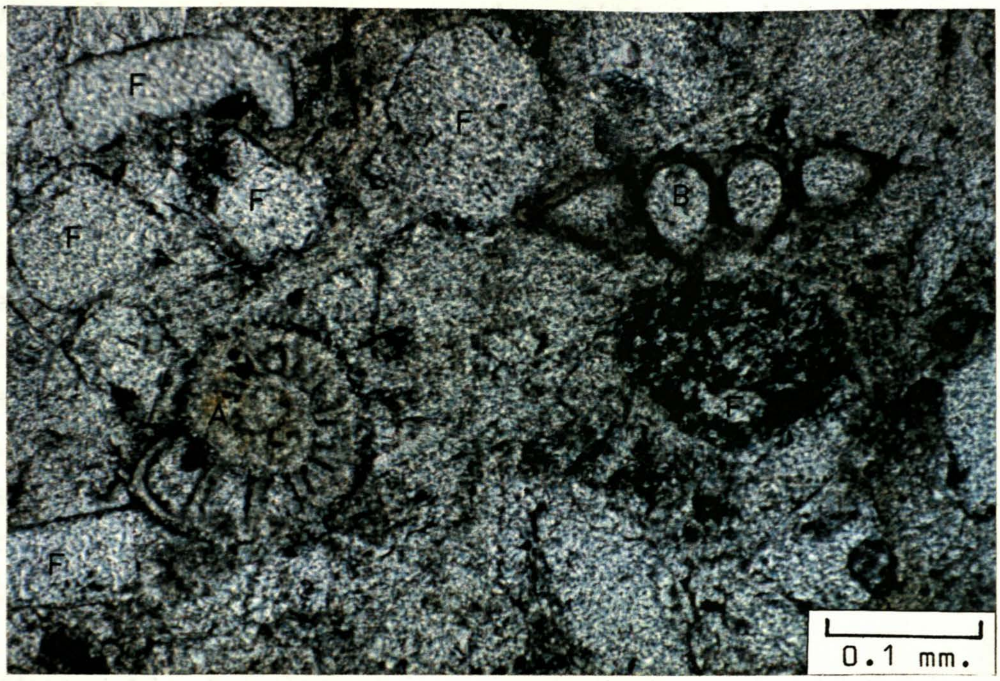


Photo 5/7 Micritic envelopes are poorly developed around foraminiferal tests (Rotaliina; *Ammonia* = A) in highly feldsparthic (F) bioclastic arenite. Note that test-chambers now are filled with very fine to fine crystalline (granular) sparry calcite (Bryozoa? = B); Quarry A, Section III at 6.5 m, sample F-3, plane polarized light.

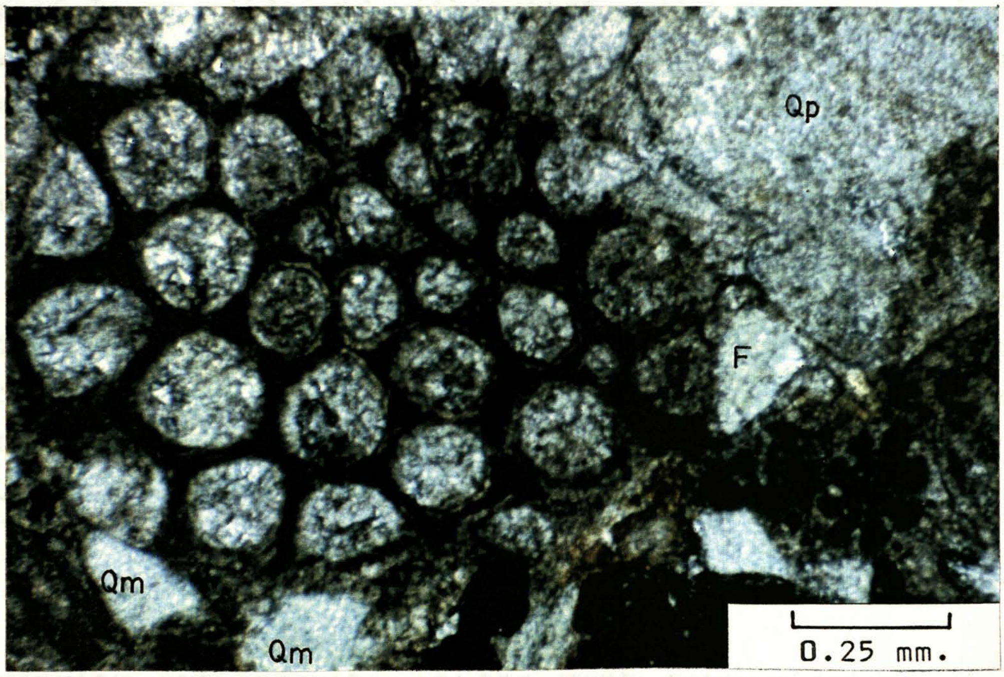


Photo 5/8 The zooecia of bryozoa are filled with granular sparry calcite in sandy biocalcarenite (Polycrystalline quartz = Qp, Monocrystalline quartz = Qm, Feldspar = F, Echinoderm in the lower right); Steyregg, Grid-ref. 265505, sample W-4, plane polarized light.

In a large bryozoan zooecium filled mainly by sparite (Photo. 5/8), indicate that physicochemical conditions were favourable for chemical precipitation of sparite rather than micrite.

In some additional cases, dark micritic concentric bands, cryptalgal fabrics (Monty, 1976), on the outer surface (Photo. 5/9) resemble certainly the sediment-binding and/or mineral-precipitating activities of blue-green algae (Monty, 1976). These fabrics may indicate that cryptalgal formation occurs at, or immediately below, the sea-floor in a very shallow marine environment in so far as most algae are light dependent.

5.5 Diagenetic fabrics.

The most important diagenetic processes in the consolidated calcarenites of Steyregg involved the precipitation of cementing minerals within pore-spaces of the original or modified sediment. Apart from rare ferroan calcite near the centre of large voids and within tests, the cementing mineral is now observed wholly as sparry calcite. In the Linz sand sediments, however, cementing minerals are never evidently observed in the petrographic thin-sections but they have been identified using the Scanning Electron Microscope

The sparry calcite crystal fabrics were described according to the scheme presented by Folk (1965). Cementational fabrics in the consolidated calcarenites are generally simple, and are described under the heading "granular or mosaic cements".

5.5.1 Granular or mosaic cements.

Granular orthosparite is the most common intrinsic and extrinsic cementing mineral. Crystal boundaries are straight (planar) or slightly curved. Granular orthosparite is generally formed as clear crystals but it is occasionally present slightly dusty. In large interparticle pore-spaces,

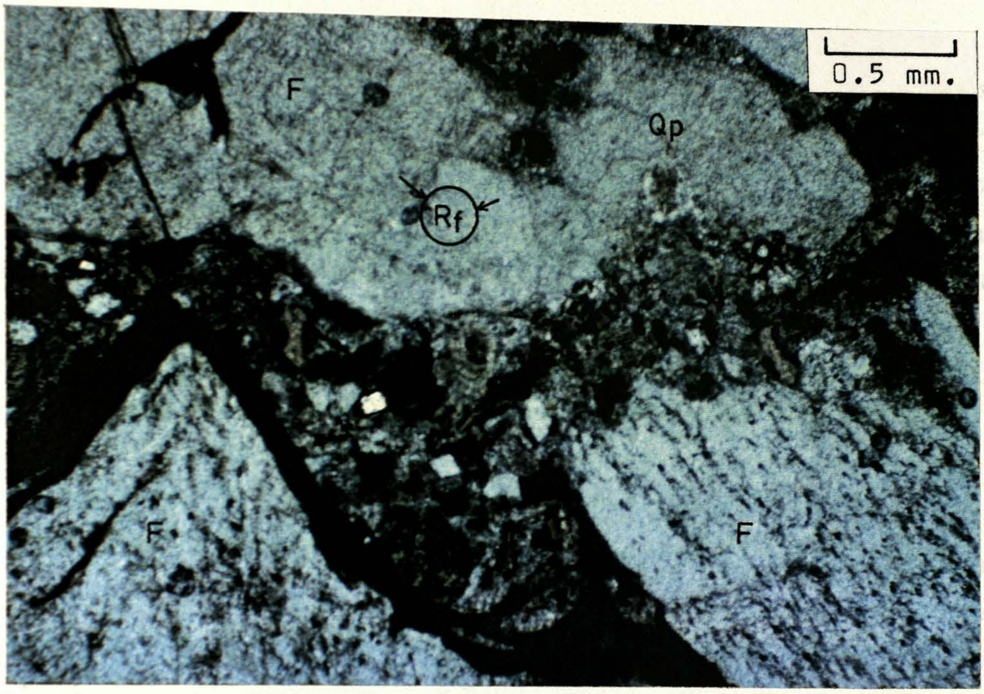


Photo 5/9 Laterally continuous laminated biosedimentary structures (cryptalgal fabrics) in bioclastic arenite (rudite) are encrushed feldspar (F) grain-surface. They may have been originated through the sediment binding and/or mineral precipitating activities of blue-green algae (Monty, 1976); Quarry A, Section IV at 30 m., plane polarized light (Polycrystalline quartz = Qp).

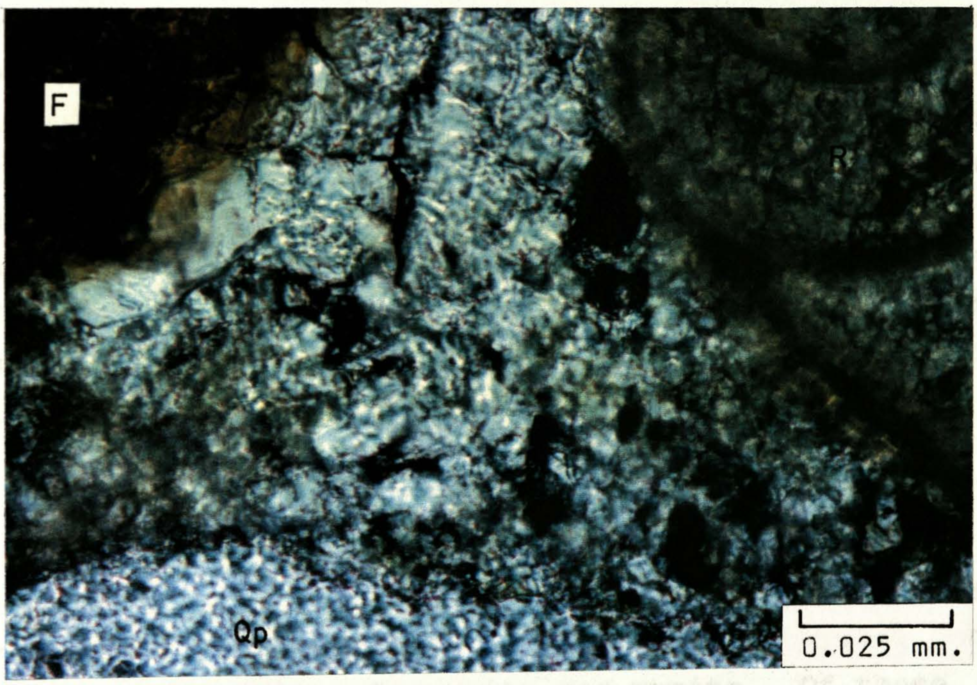


Photo 5/10 Pore-spaces in bioclastic arenite now are filled with mosaic sparry calcite, small crystals line at the margins of the pore and larger crystals tend to filled at the centre (Rotaliina = R, Polycrystalline quartz = Qp, highly weathered feldspar = F); Quarry A, Section I at 81.5, sample Q-17.2, plane polarized light.

an irregular increase in crystal size away from host boundaries forms a drusy texture. A portion of pores or cavities may be occupied by blocky, medium to coarsely crystalline sparite (Photo. 5/10). Increase in size occurs at a distance of about 0.1 mm or less from the host grains, and generally involves a rapid size increase rather than a gradual one. However, more uniform granular textures are common within smaller pores and either coarsely or finely crystalline sparite may grow in direct contact with the framework grains (Photo. 5/11). In a general way, there is a direct relationship between crystal-size and pore-size. In smaller, narrower and more elongated intrinsic pores, a distinct median junction line commonly separates crystals growing outwards from adjacent walls. Crystal growth occurs more or less simultaneously from the top, bottom and side of voids during early diagenesis on the sea-floor and shallow marine regime or early burial stage of syndiagenesis (Chilingar et.al., 1967, 1967a; Bathurst, 1975). Pressure solution between grains is generally absent.

In addition, the abrupt increase in the size of granular orthosparite crystals away from the margins of bioclastic and terrigenous grains in several thin-sections may be the result of a similar chemical "hiatus". Two different stages of cementation may have occured:-

a. A change in chemical characteristics of pore solutions.
b. The earlier formed sparite crystals substantially reduced sediment porosity and permeability and, then, the flow of interstitial pore-waters was obstructed.

5.6 Non-carbonate diagenetic minerals.

Recognizable non-carbonate authigenic and/or replacement minerals in the consolidated calcarenites of Steyregg include certain clay minerals, glauconite and pyrite. Of these, clay minerals and glauconite are by far the most important. Clay mineral characteristics and origin were discussed in section 4.5.1. The nature and occurrence of the remaining minerals are briefly mentioned below.

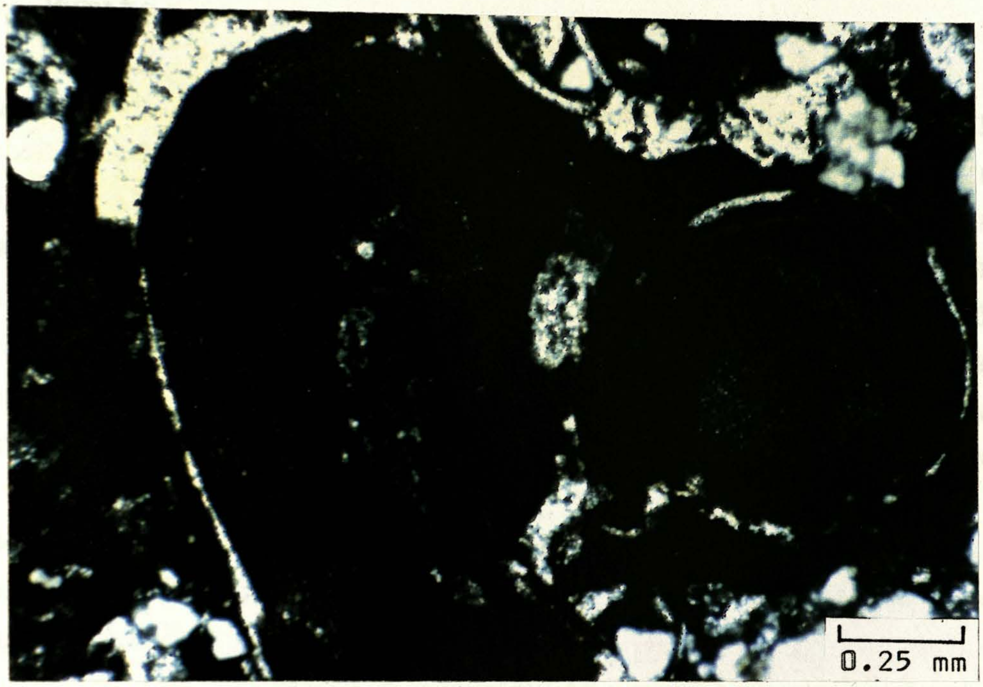


Photo 5/11 Fragments of coralline algae *(Lithothamnium)* with finely crystalline sparry calcite filled pore-spaces are common in sandy biocalcarenite. Note well developed layers of basal hypothallus (large cells) and perithallus (smaller cells); Quarry A, Section I at 48 m., sample Q-10.4, staining with Potassium Ferricyanide, plane polarized light.

Photo 5/12 Authigenic pyrite in a high terrigenous content of sandy biocalcarenite occurs mostly as rounded shape of microaggregates, forming as extrinsic materials rather than intrinsic ones; Steyregg, Grid-ref. 269503, sample W-2, plane polarized light.

5.6.1 Pyrite.

Pyrite is a more or less important authigenic mineral in the consolidated calcarenites (Steyregg), and occurs most commonly as rounded and irregularly shaped microaggregates and extrinsic shell-cavity fillings (Photo. 5/12). In most instances the surfaces of grains are intensely oxidized to iron-hydroxides. Disseminated grains of pyrite are the most common within both intrinsic and extrinsic granular sparry cement. The intrinsic and extrinsic pyrite probably results from the initially high content of organic material in sediments, ensuring a steady supply of H_2S in pore waters via the anerobic oxidation of organic carbon by sulphate-reducing bacteria (Morse and Mackenzie, 1990):-

$$2CH_2O + SO_4^{2-} \text{ ----------> } 2HCO_3^- + HS^- + H^+$$

The HS^- may then react with dissolved iron or iron-hydroxides to form metastable iron monosulphide (FeS) and/or additional sulphur to form stable iron sulphide (FeS_2) after the following formular:-

$$FeS + S^0 \text{ ----------> } FeS_2$$

These reactions lead to precipitation of pyrite and concentration of bicarbonate in pore waters. In the case of the consolidated calcarenites, the source of reactive irons was most probably supplied by dissolution/alteration of ferromagnesian minerals and/or a conversion of smectite to illite? (see section 4.5.1.3 and next section). Formation of pyrite (like glauconite) most commonly occurs in the pH range 7-8 and requires a somewhat negative Eh, between about -200 to -400 mv. These conditions are met during the early burial stage of syndiagenesis, closely below the sea-floor. Syndiagenetic pyrite grows at scattered centres in the sediments and, at times, within shell-chambers and probably coat bioclastic grains.

5.6.2 Glauconite.

Glauconite is an iron-potassium rich mica (illite) type of clay minerals (Burst, 1958; Van Houten and Purucker, 1984), and occurs in small amounts in thin-sections. Autochthonous glauconite is more common than detrital glauconite, and occurs only in the consolidated calcarenites (Steyregg). Autochthonous glauconite replaced bioclastic grains, infilled fossil chambers and occurs either as intrinsic or extrinsic disseminated grains in granular sparry cements.

The presence of glauconite generally indicates a relatively low sedimentation rate and/or locally reducing microenvironment (McRae, 1972), provided by decaying organic matter in the sediment and within fossil chambers. Alteration of a variety of iron-bearing minerals, eg. biotite, in the sediment provided major amounts of iron for glauconitization. The combination of low sedimentation rates, increased organic activity and iron supply possibly provided ideal micro-physicochemical conditions for glauconitization (Burst, 1958). Absorptional processes of potassium and iron from the early forming montmorillonitic clay mineral normally pass unaltered into fossil chamber cavities, reacting within the chamber and/or through the sediment-water interface. In other cases, glauconite may be formed by precipitation of dissolved ions in the fossil cavities and in the pores of a substrate, which is progressively altered and replaced (Odin and Matter, 1981). Evidence for extensive mobilization of iron in the sediment is seen in the thin-section where the glauconite incompletely replaced the test and infills shell chambers. Later, the glauconite is intensely altered to limonite.

Diagenetic alteration of the montmorillonite might have proceeded as follows:- Mg^{2+} (both from their interlamellar positions and sea water) and large quantities of Fe^{3+} ions (possible as ferric hydroxide) diffuse into octahedral layers of the montmorillonitic lattice where they replace Al^{3+}. A part or all of this Al^{3+} moves into the tetrahedral layer replacing Si^{4+}. Increasing total lattice changes resulting from substitution of Mg^{2+} and Fe^{2+} for Al^{3+} and of Al^{3+} for Si^{4+} allows continual absorption of K^{+} in interlamellar positions, occupying sites of original Mg^{2+}. Concurrent with this substitution, there is a gradual contraction of the structure with increasing numbers of non-expandable 10 Å layers. The occurrence of glauconitization processes may be exhibited mainly in montmorillonitic layers and only slightly modifying, or leaving unaffected, other interstratified clay minerals.

Thus, it can be concluded that a majority of glauconite in the consolidated calcarenites possibly originated from diagenetic alteration of the earlier forming montmorillonite clay under a similar condition of pyrite formation. The remaining glauconite probably originated from precipitation of dissolved materials and detrital origins.

5.7 Paragenesis of diagenetic features.

An outline summary of the paragenetic history of the sediments of the terrigenous mixed carbonate sequence of Steyregg is presented in Table 5.2. The indicated sequence of events, and especially those occurring during syndiagenesis, undoubtedly overlapped to a varying degree. Clearly, some events were not necessarily recorded in any one sediment.

The absolute sediment depth at which the various events took place cannot be accurately established. From evidence presented in preceding sections, it is likely that events 2 to 12 in Table 5.2 occurred within the first few metres of sediment burial, during syndiagenesis. Of event 13, the author believes that it was partially most active during and following uplift, epidiagenetic stage, active solution of calcium carbonate by meteoric water commenced locally at selective levels in the sedimentary column.

Table 5.2 Generalized paragenetic sequences of diagenetic events for the consolidated calcarenites, Steyregg.

EVENT	PROCESS	PRODUCT
1. Sediment deposition in very shallow marine, fluvial-influenced environment.	Slow, periodic accumulation of the sediments of bioclastic sand and gravel sized together with varying amounts of terrigenous materials (mud generally by passed as part of suspension load) BUT Calcisiltite, micrite, siliciclastic mud that had accumulated in shell cavities prior to and during transportation is protected and retained	Porous bioclastic sand and gravel sized sediments consisting mainly of metastable magnesium calcite with small amounts of metastable aragonite and siliciclastic grains. Intrinsic cavities open. BUT Extrinsic clay sized matrix and micrite relatively widespread, otherwise extrinsic void partly or fully open.
2. Physical modification of sediments.	Local reworking by benthic organisms and by current activity.	Bioturbation, sediment homogenization, coarser shell concentrates, lag deposits ?
3. Introduction of clay-matrix and micrite.	Infiltration of micrite and clay matrix.	Intrinsic and extrinsic voids partly infilled by internal sediments.
4. Destruction of organic materials.	Bacterial decomposition; process relatively retarded in sediments with intrinsic and extrinsic clay-sized micrite and matrix.	Changes in pore water chemistry (tendency for increased pressure of carbon dioxide (P_{CO2}) and decreased pH).
5. Stabilization of aragonite skeletons begins	Congruent dissolution	Total loss of much aragonite
6. Stabilization of magnesium calcite skeletons.	Incongruent dissolution	Calcite bioclastic grains preserving texture details of host.
7. Aggradational transformation of degraded and/or expandable clay minerals.	Cation exchange phenomena and lattice absorption, especially involving magnesium (Mg^{2+}) ions.	Dominance of magnesium-rich montmorillonite clay-minerals.
8. Transformation of expandable clay in restriced environment	Glauconitization	Intrinsic and extrinsic glauconite.
9. Authigenic growth of pyrite	Reaction of hydrogen sulfide, HS^- & iron, Fe^{2+} ions	Intrinsic and extrinsic pyrite.
10. Stabilization of aragonite skeletons continues.	Congruent dissolution	Total loss of aragonite.
11. Selective lithification begins.	Precipitation of cementing materials along grain margins.	Fibrous/blade/granular orthosparite crusts on free surfaces.
12. Lithification of bioclastic and siliciclastic grains under the influence of accumulating sediments.	Some degree of compaction by overburden sediments.	Grain to grain contacts, with magnitude varies, depending on mineralogy/property of each grain.
13. Uplift into zone affected by circulation of meteoric water	Selective dissolution of bioclastic grain and cement, partly or fully dissolution.	Partly or fully remaining aragonite/calcite skeleton and cement.

CHAPTER 6
PALEOENVIRONMENTS

In this chapter an attempt is made to determine depositional environments of major lithofacies and also sublithofacies (see Chapter 2) of the terrigenous mixed carbonate (Steyregg) and the Linz sand sequence on the basis of their physical and biological characteristics. According to the data about energy level conditions presented in the previous chapters and in order to relate more closely the energy level to water depth (and to estimate the temperature, salinity and turbidity of waters), it is relavant to consider the nature and paleoecologic implications of faunal elements in the sediments.

6.1 <u>Paleorelief of the lower Tertiary Landmass</u>.

On a regional scale, general unevenness of the lower Tertiary landscape has been noted by several writers (eg. Steininger et.al., 1986; Malkovsky', 1987; Nachtmann and Wagner, 1987; Wessely, 1987). Abrupt thickening and thinning, especially of the terrigenous mixed carbonate sequence (Steyregg) rather than the Linz sand sequence, and possible onlap of these sequences on to the Bohemian Massif basement rocks indicates that, more or less, the regional unconformity at or near the base of these sediments is that of a buried landscape of moderate relief. Smaller scale irregularities in the basement surface, with relief of up to a few metres, may be locally widespread (eg. in the Quarry A sections, Fig. 2.3). Also high angle contacts may be interpreted as faulted contacts, where the sediment infilled steep-sided basement depressions.

Basement paleotectonic features may be defined in terms of its present-day geographical position (Fig. 2.1). A broad morphological basement more or less high (Wagner, 1980; Malkovsky', 1987; Wesseley, 1987), in the north and at the middle part of the study area, is possibly a major positive element forming the eastern limit of sedimentation of the terrigenous mixed carbonate sequence. Whilst, it likely formed as the western limit of the Linz sand depositions. The depression filled by the terrigenous mixed carbonate sediments widened southwards to link, more or less, with the Linz sand sediments, although definitive evidence is lacking at present. The basins may not neccessarily correspond to original sedimentary basins but rather represent present-day structural depressions preserving significantly thick sedimentary sequences. On this basis, the sediments of the Linz sand sequence were deposited in a depression in the eastern part of the study area, while the sediments of the terrigenous mixed carbonate sequence were deposited in the western part.

In general, a present-day topographic feature may reflect a paleorelief of the lower Tertiary Landmass and areas of tectonic subsidence during deposition, and possibly indicate that large quantities of terrigenous sediments have been transported directly into the basins from the southern end of the Bohemian Massif High. Additionally, several stream systems possibly drained toward the south from the basement high.

6.2 Depositional characteristics of the large-sized gravels.

Gravels (cobble to boulder-sized) occur commonly near the base of the stratigraphic sections, such as Sublithofacies A-1 in the terrigenous mixed carbonate sequence (Steyregg) and Sublithofacies 1-A in the Linz sand sequence.

The lower boundary of the terrigenous mixed carbonate sequence and, as well as that, of the Linz sand sequence is the erosional surface of the Bohemian Massif. Basal lithologies commonly exhibit rapid lateral variations and pass vertically into the overlying sediment. General characteristics of this (near contact?) lithology, eg. in the terrigenous mixed carbonate sequence, are granitic cobbles and boulders (Photo. 2/3). They rest possibly with sharp lower contact in pockets and irregularities in the basement surface, and may show thickness variations from 1 m up to 3 m. Subrounded and rounded clasts of granite and quartz form the major gravel lithology, while gneiss and quartzite clasts are subprominent lithologies. They are generally poorly sorted and range up to 2 m in size, although more usually up to 30 cm with average pebble diameters in the range of 5-10 cm in the miscellaneous horizons near the base of the section. Pebble imbrication is absent. The matrix of the cobbles and boulders is composed of sands rich in quartz, feldspar and plutonic rock fragments. Fossils are absent.

It is clear that the sedimentation in the Steyregg area, eg. in Quarry A, was strongly affected by the proximity to the Bohemian Massif High, which formed an irregularly sharp northern boundary to the sedimentary basin. This area shows subsidence of the basement which resulted in deposition of a thick sedimentary sequence and transgression of the sea from south to north. As a consequence, composition and sedimentary structures show a marked lateral variation which may wedge out, bifurcate and form floating-pods over short distances in the area, making lithostratigraphic correlation difficult.

At the Quarry D section of the Linz sand sequence, a slightly consolidated cobble bed is conspicuous within the basal part of the stratigraphic profile (Photo. 2/12). This cobble derived from the erosion of stratigraphically lower beds caused by a regressive phase. The cobbles of this bed show the same composition as the Linz sands. The cobble bed shows normal grading. The cobbles are subrounded to rounded in shape (see Chapter 2). The irregularly sharp lower boundary of this bed, together with the dominance of cobble over matrix and the rounded shape of the clasts, suggest rapid submarine erosion, transportation and deposition. Rapid emplacement of cobbles is additionally supported by occasional strong cut (scour) and fill structures and a complete lack of cobble imbrication. The upper boundary of the cobble bed is generally sharp, in terms of grain-size variations and colour. Clearly, emplacement of this cobble bed was associated with a local change in the depositional environment.

6.3 Environmental interpretations of lithofacies and sublithofacies.

Depositional environments were interpreted from lithofacies and sublithofacies characteristics, both from the stratigraphic sections of the terrigenous mixed carbonate (Steyregg) and the Linz sand sequences (see section 2.2 and 2.4). The distribution of different lithofacies is presented in the lithostratigraphic cross-section (Fig. 2.3) and the fence diagram (Fig. 2.5). Interpretations in the following sections refer only to primary depositional conditions of the individual lithofacies and sublithofacies which are partly similar, eg. the terrigenous sediments, in both sequences.

6.3.1 Bedded and cross-bedded sandy gravel sublithofacies.

The bedded sandy gravel (Sublithofacies 1-B-1) appears to be a regressive gravel, lag deposits (cf. Miller, 1976). Gravel clasts are too large to be significantly engaged in transport, and are concentrated on the scoured surface. Then, if the transgression proceeds sufficiently, a water depth will be reached at each place such that sandy sediments will begin to accumulate on the lag gravel (Komar, 1976). At this depth either waves will no longer be able to modify the texture of the seafloor sediment or the shoreline is so far removed that only sandy sediments are available for deposition (Clifton, 1981). A high concentration (thick-bedded) of pebbles (eg. Sublithofacies A-2) indicates deposition from the largest and long-period breaking waves dominating the uppermost shoreface and foreshore (cf. Allen, 1970). The passage of the waves may throw many of the fine sediments into suspension which it would participate in an offshore bedload transport (Komar, 1976) together with rip currents. This is evident by deposition of the cross-bedded sandy gravel (Sublithofacies 1-B-2).

6.3.2 Bedded sand sublithofacies.

This bedded sand (Sublithofacies A-3-1 and 2-A) shows much evidence of reworking. The planar-bedded, medium to very coarse grained sands of these sublithofacies contain the features indicative mainly of beach deposit. Beds gently inclined in a seaward direction are a classic characteristic of the upper foreshore and high wave energy shorelines (Davidson-Arnott and Greenwood, 1976). Inverse sized grading within the individual bed, if present, is also characteristic feature of foreshore sands. In addition, the bimodal grain-size distribution in these bedded sand sublithofacies is a characteristic feature of the sediment depositing in the high wave energy shorelines (cf. Reading, 1989).

6.3.3 Cross-bedded sand sublithofacies.

This sublithofacies possibly originated in several different subenvironments within the foreshore of a high-energy coast. The dominantly seaward direction of foresets could be interpreted as resulting from rip current (Davidson-Arnott and Greenwood, 1976; Hunter et.al., 1979) and/or structures formed by the interaction of surf and swash (Clifton et.al., 1971). The common occurrence of seaward-dipping cross-bedding in coarse sands, gravelly sands and sandy gravels near the base of the terrigenous mixed carbonate sequence (Sublithofacies A-3-2) and the Linz sand sequence (Sublithofacies 2-B) is locally consistent with a rip current origin.

According to Hunter et.al. (1979), rip currents possibly migrate systematically along the shore, producing an erosional surface similar to that separating the cross-bedded coarse-grained sands from the underlying bedded fine-grained sands in this study. Hobday and Horne (1977) also suggested that migrating tidal inlets had possibly been involved to explain seaward-dipping foresets in ancient coastal deposits. However, the general absence of lagoonal deposits in the stratigraphical sections of the Linz sand sequence and the general absence of opposed tidal foresets in this cross-bedded coarse-grain sand argues against that interpretation of Hobday and Horne (1977).

Other paleocurrent directions of cross-bedding in these sublithofacies may indicate longshore currents, flowing both in northeast and southwest directions. These current directions implied that waves approached obliquely to the coast.

Moreover, the thin extensive pebble beds within these sublithofacies were probably formed during periods of particularly large waves. A high degree of segregation of pebbles into laterally persistent beds is characteristic of pebble and sand that have been reworked by waves (Clifton, 1973).

6.3.4 Channel fill sand sublithofacies.

Small channels and shallow cut and fill structures within the Sublithofacies A-3-3 and 2-A-2 possibly appear to be the result of small distributary channelized deposits after the regressional period. The rather poorly defined bedding in the shallow cut and fill deposits possibly dips down the paleoslope, the main dip to the southeast.

6.3.5 Bioturbated sand sublithofacies.

The original bedded slightly gravelly sand (Sublithofacies 2-A-1) possibly accumulated in water deep enough for bioturbation. However, a completely bioturbated sediment near the top of beds does not necessarily imply great water depth such as on the open coast of southern California (Clifton, 1981), where large long-period swell predominates, fine sand is completely bioturbated at depths as shallow as 10 m. The depth at which this occurs depends on (1) the composition of the fauna, (2) the depth in the sediments to which the organisms burrow, (3) the texture of the sediment, (4) the rate of deposition and (5) the characteristics of the surface waves (Clifton, 1976). The local thin irregular layers of pebbles in this sublithofacies appear to be lag deposits and indicate that the bottom was reworked at least intermittently by large waves.

The dominant presence of the trace fossil "*Ophiomorpha*", eg. in the Linz sand sediments, has been interpreted elsewhere as burrows of the marine decapod "*Callianassa*", a genus common in various high energy conditions of shallow marine environments (Weimer and Hoyt, 1964). According to Frey et.al (1978) and Curran (1985a), *Ophiomorpha* is well established as a nearshore indicator of 5-20 m water depth, and also extending between foreshore and shoreface environments. In some, a very low matrix content and slightly low distribution of bioturbation in the sediment possibly indicate moderate, high wave energy conditions. Highly burrowed sediments may reflect deposition in areas where wave and current stratification was overshadowed by biological reworking (Howard, 1972).

6.3.6 Bedded mud Lithofacies.

The slightly gravelly mud, Lithofacies 3 of the Linz sand sequence, may represent coastal (pond ?) deposits, developed locally on the underlying sands. A few granule to fine pebble quartz grains disseminated in the muddy groundmass, and may be introduced by storm washover events (see also section 2.6.7).

6.3.7 Consolidated calcarenite Lithofacies.

The consolidated calcarenites (Lithofacies C) have been divided into three sublithofacies (see section 2.2.3). The sediments typically contain medium to very coarse quartzo-feldspathic sand and granule disseminating in carbonate groundmasses. The skeletal composition is rather variable. As a whole, reworked-oyster fragments are important in the bioclastic arenite sublithofacies, while reworked-*Lithothamnium* fragments are the major faunal element in the sandy biocalcarenite and biocalcarenite sublithofacies. All sublithofacies commonly contain benthic foraminifers (especially *Quinqueloculina*, *Elphidium* and *Cibicides*), echinoderms, bivalve fragments; subordinate bryozoans, brachiopods and gastropod skeletons; and rarely ostracods. The general scarcity of pelagic foraminifers in all samples and the abundance of arenaceous forms suggest that the sediment has been deposited in very shallow waters (cf. Buxton and Pedley, 1989). Overall, the sediments in this lithofacies have been deposited adjacently or proximally to the terrigenous source, moderately to highly agitated waters, a very shallow marine between shoreface and foreshore of (inner) ramp setting (cf. Buxton and Pedley, 1989; Reading, 1989; Inden and Moore, 1983; Tucker et.al., 1993) and of normal salinity.

The consolidated calcarenite lithofacies is interpreted to represent deposition on a ramp setting as opposed to the clastic steep-margin shelf. This interpretation is suggested by the slope estimated from the stratigraphic profiles. Petrographic analyses and other lithofacies/sublithofacies associations have also revealed the following: (1) evidence of resedimentation (eg. *Lithothamnium* and oyster) related to wave generated currents (ie. Burchette and Wright, 1992) are present, (2) micrite is rare in all consolidated calcarenite samples and (3) there is no evidence of offshore reefal or grainstone belts. This suggests a high energy setting, which is more likely to occur on a low gradient slope, characteristic of a ramp, rather than shelf.

The ramp model with its associated terrigenous lithofacies proposed in this study for the consolidated calcarenites, compares favourably with the findings of Buxton and Pedley (1989), Sellwood, 1992, Tucker et.al. (1993) on other Tertiary ramps (see also Wright, 1986; Mresah, 1993), in which more or less a close similarity to the terrigenous mixed carbonate sequence (Steyregg) is evident.

Moreover, the lack of in-place fossils and paucity of whole macrofossils in the consolidated calcarenite lithofacies may partly reflect the mobility of sandy bottoms in wave-swept shoreface and foreshore environments. The abundance of comminuted shell fragments is commonly consistent with continual shifting of sediments. In the case of the terrigenous constituents in this lithofacies, C-M patterns and other textural statistical parameters are consistent with (wave-worked) beach deposition (see section 4.4.1.4).

6.3.7.1 Bioclastic arenite sublithofacies.

The bioclastic arenite (Sublithofacies C-1) contains a diverse open marine bioclastic faunal assemblage which includes oysters, bivalves, echinoderms, brachiopods, bryozoans, foraminifers and rare *Lithothamnium* skeletons. All bioclastic grains show a high degree of fragmentation. They are angular to subangular shape. These characteristics of the bioclastic grain, together with predominant immature to submature terrigenous sediments, suggest deposition in a slight high energy environment with moderately agitated waters and frequent reworking. The sedimentation rate was probably high. This is indicated by bioclastic grains which have not been strongly micritized. The high sedimentation rate also did not allow sufficient time for micritization to take place (cf. Gawthorpe, 1986). Large oyster fragments together with medium to very coarse quartzo-feldspathic sands and granules have possibly been transported by waves and also storms. This is characterized by a low terrigenous mud content, although the sediments are poorly sorted.

6.3.7.2 Sandy biocalcarenite sublithofacies.

The sandy biocalcarenite (Sublithofacies C-2) is marked by the textural and compositional transition between bioclastic arenite and biocalcarenite sublithofacies. The bioclastic grains are dominated by *Lithothamnium* fragments, bivalves, echinoderms, brachiopods, foraminifers and rare bryozoans, ostracods and oyster fragments. Allochems have generally not been micritized, although some of them have been partially micritized. The bioclastic grains are commonly disarticulated and fragmented with differing histories of reworking, and final deposition in a moderate to slight high energy environment. The sedimentation rates were generally high. The change in the nature from the bioclastic arenites to sandy biocalcarenites can be explained either as a slight decrease in energy level of the environment or to decreasing terrigenous supplies.

6.3.7.3 Biocalcarenite sublithofacies.

The biocalcarenite (Sublithofacies C-3) was possibly deposited in an environment characterized by weak, or only intermittently active, current activity. However, concentrations of fine pebble to granule and some detrital glauconites indicate increasing higher energy conditions in a shoaling water, activated by passing of mud across the sediment surface. The sediments in this sublithofacies are generally medium to very coarse grained biocalcarenites, and occasionally biocalcirudites in which they have been defined on the basis of grain-size and sorting. In some, the mud-supported fabric and the occurrence of whole bioclastic grains with minimal abrasion suggest deposition in a generally low energy environment. Other grain-supported fabrics with a high degree of fragmentation of the bioclastic grains, eg. *Lithothamnium* and/or oysters, indicate generally high energy conditions. These bioclastic grains may have been reworked elsewhere from the surrounding area.

Within these sublithofacies, therefore, there is a gradual decrease in environmental energy level through the formation from slightly high in bioclastic arenites, moderate in sandy biocalcarenites to lower values in biocalcarenites. This simple trend is interrupted by the development of higher energy wave of shoal waters and also possible storms. As noted by Tucker et.al,(1993), storm processes are generally important on ramps. The *Lithothamnium* fragments have clearly been reworked from low energy sediments in sheltered areas elsewhere. In some cases, however, very coarse and polymodal bioclastic grain sizes may also reflect local derivation of sediment rather than strong current action. This interpretation is supported by the very poor sorting and the broken, but little abraded, nature of framework grains. In addition, large reefal structures, tidal flats and lagoons are not evident in the study area, and are generally not well developed on a high energy type of ramp (Tucker et.al., 1993).

6.4 Depositional history; Tectonic and Sea-level episodes.

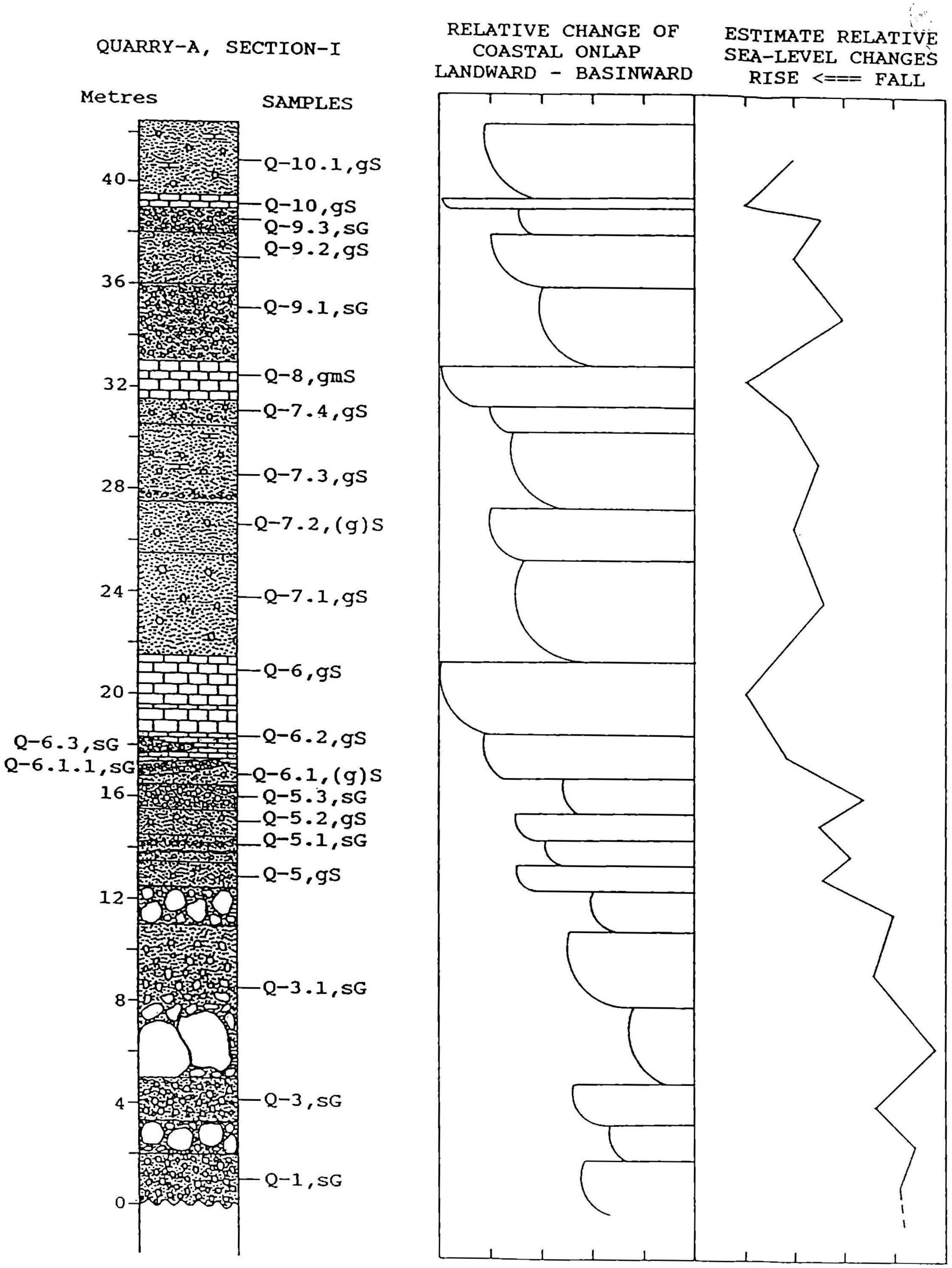
The Oligocene paleotopography seems to have had a pronounced effect on the subsequent deposition of the terrigenous mixed carbonate (Steyregg) and the Linz sand sequence. According to Braumüller (1961), at the end of the Eocene epoch, the Molasse area in Upper Austria and Salzburg was a broad epicontinental shallow sea. The Molasse sediments in the study area can be divided, more or less, into two main depositional settings: (1) the terrigenous mixed carbonate sequence was deposited between beach-foreshore and shoreface, together with conditions of a ramp setting (cf. Burchette and Wright, 1992) in the west, and (2) the non-calcareous Linz sand sequence was deposited in the area between beach-foreshore and upper shoreface in the east. In this study, several transgressive cycles are well developed in the terrigenous mixed carbonate sequence rather than in the Linz sand sequence. The base of the transgressive events is generally represented by erosional surface and lag deposits. They are common in ancient coastal deposits (Ryer, 1977). According to Swift (1968) during marine transgression, the nearshore part of the bathymetric profile (ie. the shoreface area) is subject to erosion as the profile shifts landward, resulting in a transgressional disconformity.

In the terrigenous mixed carbonate sequence, lithofacies transition from pure-terrigenous sediments to terrigenous mixed carbonate deposition (consolidated calcarenites) follows a pattern of transgression-regression at several different scales (Fig. 6.1). Following an initial early sea-level lowstand episode (marked by the pure-terrigenous lithofacies deposition) changes upward to the consolidated calcarenite deposition of more or less deeper water deposites. Each lithofacies and/or sublithofacies ranges in thickness from a few tens of centimetre to a metre. Within this transgressive sequence, small scale transgressive-regressive episodes occur in which the consolidated calcarenite lithofacies is prominent, alternated and also ended in each cycles (see Fig. 2.3). This alternation apparently records short-range fluctuations in the general position of the shoreline.

Moreover, an overall transgression of the terrigenous mixed carbonate sequence (Steyregg) possibly coincides with a part of global onlap cycles between cycle 2.1 and cycle 2.3 of supercycle TB2 (see Haq et.al., 1987), although the lower and upper contacts of the sequence cannot be dated precisely.

6.4.1 Terrigenous mixed carbonate sequence (Steyregg).

The terrigenous mixed carbonate sequence recorded shoreline sedimentation (see sections 4.4.1.4, 6.3), and evenly recorded relative sea-level rise that culminated in highstand conditions. The sediments were deposited in wave-dominated nearshore environments. The consolidated calcarenite lithofacies were probably deposited within the foreshore-shoreface environment of a ramp setting, overlain the terrigenous lithofacies which were clearly accumulated from beach-foreshore to upper shoreface environment (see also section 2.2). The terrigenous lithofacies must initially have been formed in a more nearshore environment than that of the consolidated calcarenite lithofacies, implying the reestablishment of net sea-level rise during the beach-foreshore progradation. The overall fining upwards trend throughout the sequence indicates that the balance between the regional subsidence and the rate of sediment supply was



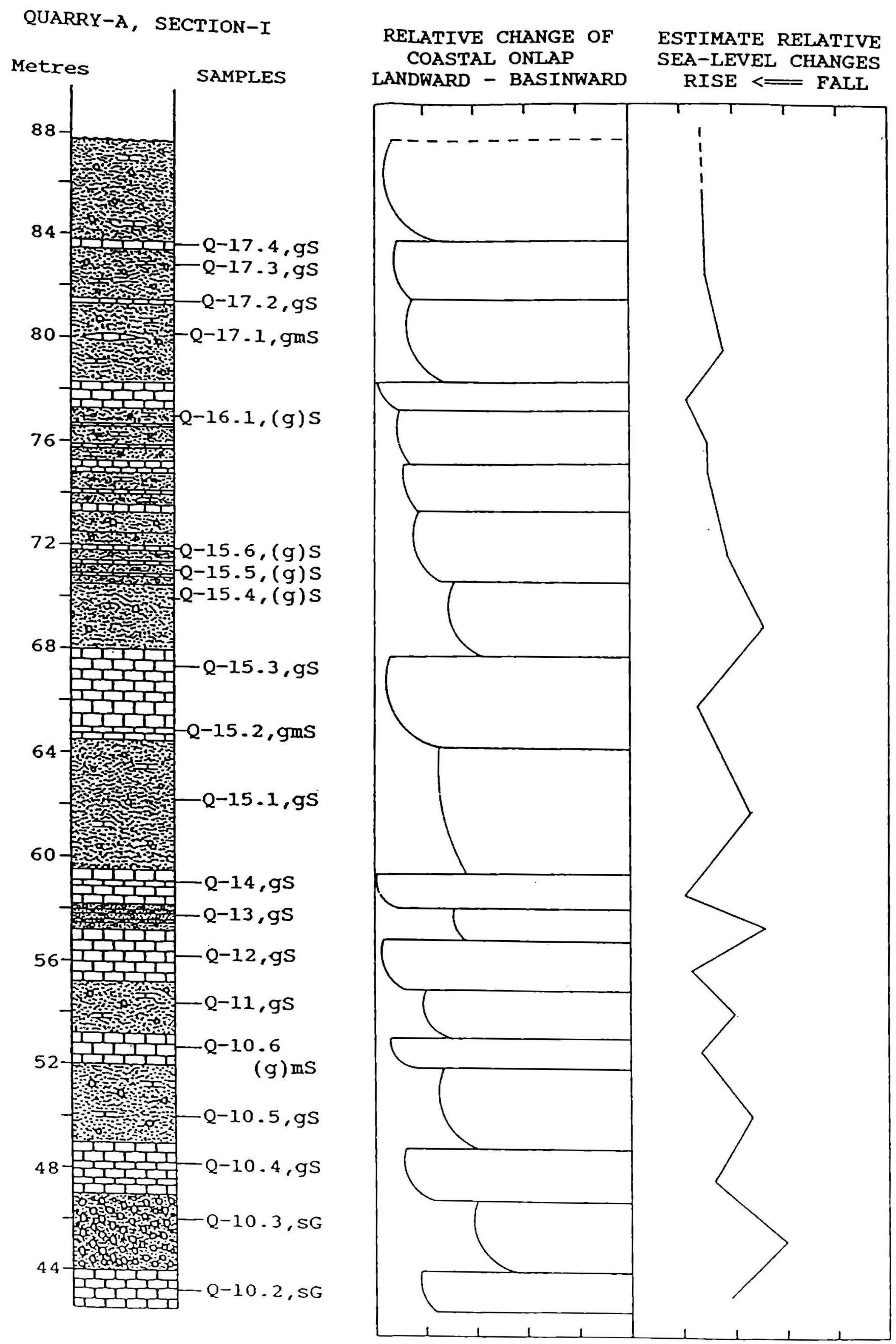


Fig. 6.1 A representative stratigraphical section shows relative changes of coastal onlap-offlap and (estimated) relative sea-level changes through the terrigenous mixed carbonate sequence, Steyregg.

strongly controlled by eustatic sea-level rise. However, the overall subsidence possibly exceeded the sedimentation rate alternating with shorter cycles of progradational episodes (subsidence rate lower than sedimentation rate). Moreover, textural and compositional data (eg. see section 3.4) suggest that the terrigenous detritus was derived from a relatively proximal Bohemian Massif terrain.

An early deposition of the terrigenous mixed carbonate sequence may have resulted directly from the basin subsidence and a superimposed second-order eustatic sea-level rise (of Vail et.al., 1977). This promoted the deposition of slightly thick beach-foreshore terrigenous lithofacies interbedded with very shallow marine (consolidated) calcarenite lithofacies. Depositional processes are generally considered to be important in the accumulation of these nearshore sediments. This includes transport of terrigenous materials onto the basin by storm-generated currents, rip currents and progradation of coastal depositional setting. All these played some roles in the deposition of the sequence.

The terrigenous lithofacies consists of beds typical of the beach-foreshore to upper shoreface environment. Deposition of this lithofacies began and signaled the beginning of sea-level rise and/or drowning of the Bohemian Massif basement, and probably ended as the standline migrated (landward) to the north. The absence of lagoonal and tidal deposits interstratified with the immature terrigenous mixed carbonate sequence (Steyregg) suggests that back-barrier lagoons were not developed or preserved. This is possibly caused by erosional processes in the breaker zone, they were displaced landward during sea-level rise and/or the tidal range was too small (Lindsey and Gaylord, 1992). Tucker et.al. (1993) also noted for the moderate to high energy types of ramp that (1) the shoreline will not be dominated by tidal flats and lagoons, (2) reefal structures are generally poorly developed on ramps and (3) storm processes are normally important on the middle part of ramps.

Within the consolidated calcarenite lithofacies, associations of thin-bedded biocalcarenites capping on sandy biocalcarenites and bioclastic arenites are typical of a very shallow marine carbonate, nearshore environment of inner ramp (cf. Tucker et.al., 1993). This is possibly interpreted to reflect minor fluctuations of the sea-level.

A rapid gradation from the high-energy (wave-dominated) terrigenous lithofacies into the lower-energy calcarenite lithofacies can be seen throughout the sequence, especially the northern part of Quarry A (Fig. 2.3). The advent of the calcarenite sedimentation was probably related to the geometry of the evolving shoreline. Different geometries are probably produced during sea-level transgression, depending on the relative rates of sea-level changes and paleotopography. However, the appearence of sheet-like bedding geometries is inferred to have been either primarily situated seawards or due to paleotopography. This is locally inferred to have been deposited by rip and/or storm relaxation currents.

Small scale facies variations seen in the terrigenous mixed carbonate sequence are reflected shifting of depositional styles. Such variations include (1) the beach-foreshore to shoreface (high energy, wave-dominated) deposits can be seen in the terrigenous lithofacies and (2) the foreshore to shoreface (wave-dominated, moderate to high energy ramps) deposits can be seen in the consolidated calcarenite lithofacies. These small scale fluctuated-deposits generally lack lateral continuity between outcrops. Thus, local factors seem to be more likely control on sedimentation. Such factors could include changing the detritus input as depositional environments shifted and local uplift and/or subsidence forcing localized shifts in depocentres. These factors are possibly consistent with the inferred depositional environments. Climatic effects on weathering, transportation and deposition may also have influence both local and regional depositional shift (see also section 3.4).

6.4.2 Non-calcareous Linz sand sequence.

The Linz sand sequence recorded the history of wave-dominated shoreline sedimentation after extensive pre-Tertiary drowning of the Bohemian Massif basement. This promoted the accumulation of thick coastal terrigenous sediments. Depositional processes are generally considered to be important in the accumulation of this siliciclastic sequence, including the transport of the terrigenous detritus into the deeper water by rip currents and long-shore currents.

In general, deposition of the Linz sand sequence is likely to be ended as the sea-level continued to rise and the standline migrated landward to the north. Minor fluctuations in the position of the standline occurred throughout deposition of the sequence, resulting in the formation of several tens of centimetres thick interbedded sequences of upper shoreface to beach-foreshore deposits. These interstratified deposits are extensively preserved (see section 2.4). These sediments are inferred to have been mainly deposited by wave-generated currents rather than storm relaxation currents (cf. Lindsey and Gaylord, 1992) because of the dominance of basin-directed paleocurrents. With increasing storm intensity, however, relaxation currents are also interpreted to have scoured these sediments producing lag surfaces and transporting winnowed sand seawards as rip currents. Rip currents generally transported sand seawards producing cross-bedding and normal grading. Thicker sand beds are structureless, while thin beds are normally graded and cross-bedded. The presence of thin muddy beds within the Linz sand sequence strongly suggests the occurrence of sea-level fluctuations throughout the deposition of the sequence.

The general rise in sea-level as recorded in the Linz sand sequence (Fig. 6.2) and the fluctuations of sea-level are reflected by local variations in depositional environments which occur throughout the sequence. Such fluctuations include those between beach-foreshore deposits seen mostly in

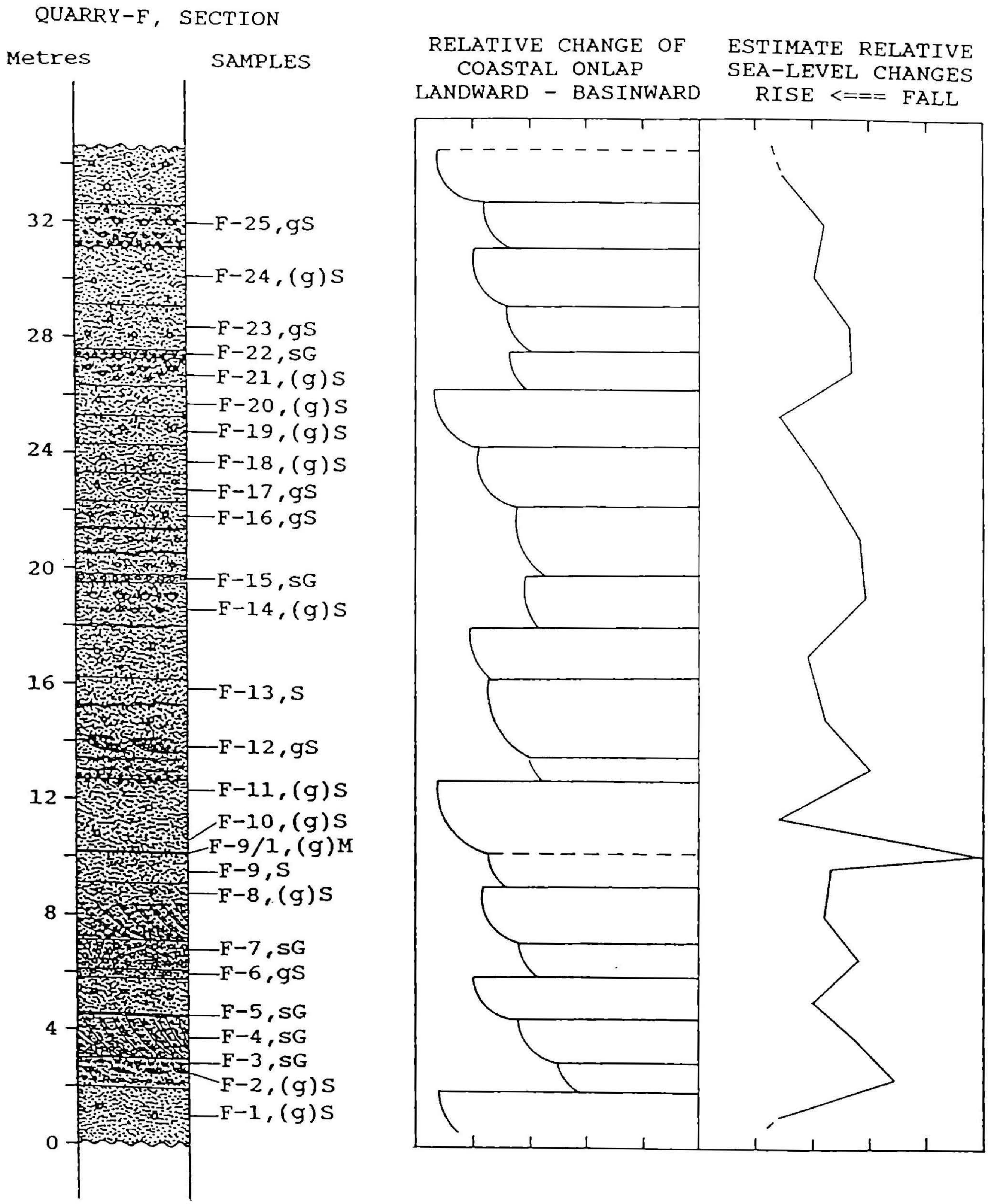


Fig. 6.2 A representative stratigraphical section shows relative changes of coastal onlap-offlap and (estimated) relative sea-level changes through the Linz sand sequence.

the lower sequence and shoreface deposits seen in the upper sequence (Fig. 2.5). The sediments are inferred to have been derived from a relatively distal source, and were re-worked. Distally derived detritus could have been transported into the region by littoral currents. The lack of fresh large clasts (eg. granitic rock-fragments) derived from the basement rocks suggests that the Bohemian Massif Terrain underwent relatively little uplift but intense chemical weathering under the humid and warm climatic condition (see section 3.4.3) during periods of the Linz sand sedimentation.

In addition, an overall transgression of the Linz sand sequence probably coincides with a part of global onlap cycles between cycle 1.1 and cycle 1.3 of supercycle TB1 (see Haq et.al., 1987), although the lower and upper contacts of the sequence may not be dated precisely.

6.5 Bedforms and sedimentary cycles.

Based on the terrigenous mixed carbonate sequence in Fig. 2.3 and cycles discussed in section 2.3, the development is partly inferred to represent the initial upbuilding of the bedform during a phase when sedimentation rate was keeping-up with relative sea-level rise (cf. Wright, 1986). The overall onset of the transgressive sequence reflects a change of vertical growth. As an example, the consolidated calcarenite bedforms seem to have been prograding seaward with minimal vertical accretion. Dipping directions of bedforms and small scale cross-beds indicate both slightly oblique landward and basinward sediment transport. However, the predominant basinward transport of sediments together with the larger scale bedform may suggest that prevailing offshore-wave and storm driven currents may also have been important along the shore (Gawthorpe and Gutteridge, 1990).

However, the overall bedform may have been partly controlled by an initially rapid relative transgression followed by stillstand and the others were of paleotopographic control, including the balance between subsidence and rate of sediment supply, rate of carbonate production, wave energy, composition of the water mass, cementation and time (see Gawthorpe, 1986). The terrigenous mixed carbonate sequence (Steyregg) produces a wedge-shaped terrigenous shore succession, thinning away from the shoreline towards the basin, alternating with the consolidated calcarenite lithofacies reflecting a gradual deepening.

Such a repetitive pattern may be "autocyclic" (produced by shifting patterns of sedimentation in a continuously subsidence basin) or "allocyclic" resulting from external events (see Clifton, 1981 based on Beerbower, 1964). Autocyclic models include such phenomena as the shifting of the site of primary accumulation on a delta front or the alternating progradation and retreat of barrier islands in response to a variation of the sediment-trapping capability of the associated lagoons. On the other hand, allocyclic models involve changes in relative sea-level, fluctuations in the rate of sediment input into the basin or some combination of these processes. Changes in relative sea-level may result from tectonism, compaction of underlying sediment, eustatic sea-level changes, or any combination of these processes. Fluctuations in sediment supply may arise from tectonic uplift, climatic changes, or from a combination of these processes.

There is little evidence that the transgressive-regressive cycles in the terrigenous mixed carbonate (Steyregg) and the Linz sand sequence result from an autocyclic mechanism. Such evidence including lagoonal sediments that are absent in both sequences, suggesting that lagoons were not possibly developed.

The pattern of the transgressive-regressive cycle changing with time in the terrigenous mixed carbonate sequence occurs in groups (see Fig. 2.3). Individual cycles are traceable for considerate distances, mostly in the north rather than the south of the Steyregg Quarry A. This difference could have resulted from various factors, eg. shifting in tectonic, eustatic or climatic patterns. An average duration of these cycles can be estimated by dividing the number of identifiable progradational-retrogradational associations into the time represented by the entire shoreline succession. Thus, the duration and pattern of the cycles may provide a basis for speculating about the climatic and tectonic controls on their development. However, little is known about the periodicity of tectonic events. Such a periodicity is possibly quite consistent with that postulated for climatic fluctuations.

Small-scale sedimentary cycles, involving vertical repetition of similar lithofacies, are common in the terrigenous mixed carbonate (Steyregg) and the Linz sand sequence. These cycles record short-term rhythmic variations in the energy level of the depositional environment at a particular site, and may be related to changes in water depth or water circulation. The ultimate controlling mechanism of these minor cycles, be it eustatic sea-level fluctuations or some other cause, is unknown at this stage. But clearly the cycle-generating process is complex, especially in the terrigenous mixed carbonate sequence. Any hypothesis attempting to explain cyclic sedimentary processes in this sequence must account for both the small and large scale sedimentary cycles.

6.6 Terrigenous mixed carbonate sequence (Steyregg) versus carbonate ramp depositional environments.

Over the past decade, the origin of carbonate ramps, and of the processes and products that serve to profoundly modify their sediment, has become increasingly well understood as a result of detailed investigations in both ancient and modern carbonate ramp environments (see Sellwood, 1992) together with carbonate shelves (see Nelson, 1988). The carbonate ramp depositional environments share, to a varying degree, some, or all, of the following characteristics:-

1. They are essentially tropical and subtropical in aspect, lying at the latitude between 30° N and S. In some, they occur between latitudes 35°-60° N and S, from cool to warm temperate climatic zone.
2. Levels of $CaCO_3$ saturation in sea-waters of several regions are saturated to supersaturated in aspect.
3. They receive little terrigenous materials.
4. They contain a very high carbonate material (> 90 %), and carbonate muds are also abundant.
5. Reef structures (eg. atolls and fringing, barrier, patch or table reefs) are important.
6. The biota is dominated by corals, calcareous algae (green algae > red algae), benthic foraminifers, molluscs, subdominated by bryozoans, echinoderms and brachiopods.
7. Primary mineralogy of the skeletons is mostly aragonite rather than magnesium calcite.
8. Non-skeletal carbonate grains (eg. oolites, pisolites, pellets and carbonate intraclasts) are abundant.
9. Evaporitic minerals (including dolomite) are commonly important, especially in supratidal locations.

By the way of comparison, the terrigenous mixed carbonate sequence (Steyregg) formed nearly at the latitude 48°N (a present-day position) under the influence of moderate to high terrigenous sediment influx, and do not contain reefs, only present reworked-calcareous red algae, and few or no carbonate intraclasts. The environmental setting during the terrigenous mixed carbonate (sequence) sedimentation was apparently significantly different from that suggested by the majority of published literature on carbonate ramp deposits (see Buxton and Pedley, 1989; Obrador et.al., 1992; Follows, 1992; Gawthorpe, 1986; Gawthorpe and Gutteridge, 1990; Pedley, 1992; Pedley et.al., 1992; Somerville and Strogen, 1992; Wright, 1986). Recognition only of the importance of consolidated calcarenite sedimentation in the terrigenous mixed carbonate sequence (Steyregg) away from carbonate ramps is:-

1. The consolidated calcarenite lithofacies of Steyregg generally contain about 50-70 % carbonate materials, and form in an area of slightly high latitude with warm climatic condition (see also section 3.4.3).
2. Reef structures, lagoons and tidal flats are generally absent.
3. Reworked calcareous organisms in very shallow waters (within inner ramp setting) calcify rapidly. They chiefly consist of calcareous red algae (eg. *Lithothamnium*), molluscs (mainly oysters), benthic foraminifers, bryozoans, echinoderms and brachiopods; of these, *Lithothamnium* skeletons and oyster fragments appear especially important.
4. The sediments contain moderate to high amounts of terrigenous grains, and small amounts of terrigenous mud.
5. The distribution of consolidated calcarenite lithofacies is primarily governed by the rate of terrigenous supply, dispersal patterns and relative sea-level changes.

This above mentioned observation is partly relevant to the carbonate ramp depositional systems (ie. Burchette and Wright, 1992). The differences in texture and composition of the terrigenous mixed carbonate (Steyregg) and other carbonate ramp sediments may well cause the studied sediment to follow significantly different paths of diagenesis. Contrary conclusions may have been drawn from many studies of the very shallow marine carbonate ramp deposits. According to petrographical data of the consolidated calcarenites (see Chapters 3 and 5) is indicated that magnesium calcite, with small amounts of aragonite, is the dominant skeletal minerals. It was, therefore, possible for magnesium calcite (and aragonite) to be selectively alterated or dissolved during early (syn-) diagenesis by sea waters whose level of carbonate saturation is low (cf. Nelson, 1988). And that calcite may be inorganically precipitated as a cement from such waters. Time, perhaps, is a key criterior due to the above processes which are undoubtedly slow (?).

CHAPTER 7
CONCLUSIONS

A geological map (scale 1:10000) of the Steyregg area has been compiled (see map pocket). Two sedimentary sequences are distinguished in the Tertiary Molasse sediments in the study area, terrigenous mixed carbonate (Steyregg) and non-calcareous Linz sand. They are characterized by low dips (5-30°) to the south-southeast. Two major directions of faults occurring in the sedimentary sequences lie parallel to the major strike of the Bohemian Massif basement faults, striking between N 10°W to N 50°W and N 20°E to N 70°E. Rocks of the Bohemian Massif in the study area are mainly granites, and locally gneissic granites.

Four stratigraphic columns are produced on the basis of a detailed stratigraphical-sedimentological study of sediments of the terrigenous mixed carbonate sequence (Fig. 2.3), five transgressive cycles are identified. Whilst eight stratigraphic columns are produced for the Linz sand sequence (Fig. 2.5) which is divided into two parts due to a massive sand bed. Rapid lateral and vertical lithologic variations in the sequences is accommodated by recognition of lithofacies and sublithofacies (see Chapter 2). These variations partly reflect paleorelief, differential tectonic movements in the source and depositional areas, location of source areas and dispersal paths of terrigenous sand and mud, and distance from shore. A strong lithologic relationship exists in both sedimentary sequences which, therefore, proves invaluable in lithostratigraphic mapping of the sequences.

Sediments of the terrigenous mixed carbonate sequence include all lithologies lying near an unconformity developed on the Bohemian Massif basement rocks and below the Pleistocene sands (Fig. 2.2). Sediments are texturally immature. A maximum exposed thickness of the sequence is 90 m and thinning to a minimum of about 35 m to the south-southeast. Lithologies are classified into three commonly occurring types:

A. Non-calcareous terrigenous sediments include mainly sandy gravel, gravelly sand and large-sized gravel. They are mostly horizontally bedded, and locally cross-bedded with channel fill structures.

B. Calcareous terrigenous sediments (as transitional sediments between A and C) include mainly gravelly sand.

C. Slightly consolidated calcarenites include bioclastic arenite, sandy biocalcarenite and biocalcarenite. In this calcarenite sediments, fragments of macrofossils are dominated by large oysters, coralline algae (*Lithothamnium* skeletons), bivalves and brachiopods. Microfossils are mainly benthonic foraminifers. Infaunal burrowing activity is locally prominent.

On the other hand, lithologies in the Linz sand sequence consist only of non-calcareous terrigenous sediments (Fig. 2.4). Slightly gravelly sand, gravelly sand and sandy gravel are the most abundant lithologies with locally bedded mud, pebble and cobble-sized of sand clasts. Sedimentary structures are commonly horizontal bedded with channels and cut-and-fill structures. They are associated with cross-bedding in a lower part of the sequence, and associated with bioturbation *of Ophiomorpha* in upper part. The sequence shows a maximum exposed thickness of about 40 m, lying near granitic rocks of the Bohemian Massive basement and below Pliocene sediments.

Primary sedimentary structures are seldom clearly defined in both studied sequences as a result of lithologic uniformity and/or post-depositional modification, eg. bioturbation and diagenetic processes. True horizontal stratification occurs only in medium to thick beds (eg. Photos. 2/17, 2/20). Locally, mud deposits alternating with sand are characteristically thinly bedded (3-10 cm thick) in subhorizontal wavy stratified (Photo. 2/22) which formed from an unequal reaction to loading. Lenticular beds (Photo. 2/8) and lenticular-like structures (Photo. 2/11) resulted from an unequal reaction to loading of fine-grained sediments, eg. biocalcarenite. Differences in subaerial weathering characteristics are also responsible for developing conspicuous lenticular-like stratification. Internal stratification in these beds is generally absent. The base level of deposition controlled the upper limit of permanent accumulation of beds and selective transportation and by-passing of sediment was thereafter important. Large scale, low angle (avg. 10° dip), tabular cross-stratified units (up to 3 m thick, eg. Photos. 2/7, 2/24) mainly originated by the spreading and interfering of sand sheets across extensive flat areas of a shallow sea floor. At a smaller scale, laterally discontinuous cross-bedded units (up to a few tens of centimetres thick, eg. Photos. 2/6, 2/18) possibly indicated movement and deposition of wave-generated rip currents. Channels and scour-and-fill structures (Photos. 2/13, 2/16, 2/23) are indicators of regressive gravel lag deposits.

Several standard sedimentary petrographic terms are briefly defined in Chapter 3. Association of terrigenous sand and gravel in slightly consolidated calcarenites of the terrigenous mixed carbonate sequence (Steyregg) emphasized the necessity for establishing sediment's terminology by petrographical compositions. Sediments are named according to their percentual abundance of bioclastic grains, siliciclastic grains and micrite. Data are readily summarized on a fundamental classification of Folk (1968, 1980) in Fig. 3.1 and Lewis (1984) in Fig. 3.2.

The petrography of consolidated calcarenites of Steyregg and Linz sand sediments is described and illustrated in some detail (Tables 3.1, 3.2 and Appendix 7). Textural and compositional data for the consolidated calcarenites are summarized on pie diagrams (Figs. 3.7A, 3.8), and those of the Linz sand sediments are presented in Fig 3.7B.

The content of biofragments in the consolidated calcarenites varies from 12 % to 83 % (average 51 %). They are mainly coralline algae (27 % of *Lithothamnium* skeletons), benthic foraminifers (19 %), molluscs (4 %), and small amounts (1 %) of brachiopods, echinoderms and bryozoans. Bioclastic grains, ranging from silt to gravel-size, are very poorly sorted. They are moderately abraded. Siliciclastic sand plus gravel-size grains are mainly quartz (12 %), granitic rock fragments (10%) and feldspar (6 %), and rarely glauconite and clay minerals. They are poorly sorted. Sand and gravel grains are generally angular to subangular. Interparticle pore-space in this sediment is largely filled with granular orthosparitic cement (Photos. 3/5, 3/6), or by a variety of matrix including micritic materials. Intrinsic matrix plus cement forms about 10-15 %, and exceptionally up to 28 %. Solution alteration of bioclastic grains ranges from mild to advanced (eg. Photos. 5/3, 5/5).

On the other hand, petrographic characteristics of the Linz sand sediments are only dominated by siliciclastic sand and gravel-size grains with very small amounts of matrix (Fig. 3.7B, Table 3.1). Grains generally range from sand to gravel-size, and are subangular to subrounded. Sorting is poor to moderate, and occasionally well. Terrigenous sediments consist mainly of quartz (56 %), feldspar (27 %) and minor granitic rock fragments (5 %). Sediment pores are infilled with matrix, and rare calcite. Matrix forms about 1-2 % with very small amounts of clay minerals. The observed porosity is about 10 %, ranging from 5 % to 17 %.

The quantity of sand-sized quartz, feldspar and rock fragments in both sedimentary sequences are plotted on a primary triangle of Mcbride (1963) for sandstone (and sand) classification. These terrigenous samples can be named as arkose to subarkose (Fig. 3.3). Samples plotting on diagrams of Dickinson et.al. (1983) mainly indicate the transitional continental tectonic provenance (Fig. 3.5), and on diagrams of Suttner et.al. (1981) show plutonic source rocks under the humid climatic condition (Fig. 3.6). Variations in the content of sand-sized quartz in the sediments support a progressive increase in intensity of weathering of soils during the Oligocene-Miocene time (eg. Fig. 3.4).

Stratigraphic cross-sections in Fig. 2.3 also display the vertical variation in petrographic properties of the consolidated calcarenites through the terrigenous mixed carbonate sequence of Steyregg. Significant conclusions include the following:

A. Individual cycle shows the lithologic upwards change from bioclastic arenite (rudite) to sandy biocalcarenite (rudite) and biocalcarenite. Cyclic alternations of lithofacies and petrolithofacies are evident.
B. Bioclastic and siliciclastic grains are inversely correlated. There is a progressive reduction in grain-size of siliciclastic constituents on passing up the section.
C. Oyster fragments are the major bioclastic constituents in bioclastic arenite (rudite), and are of only low to moderate abundance in sandy biocalcarenite (rudite) in the lower and upper part of the section. Whilst *Lithothamnium* skeletons are the most bioclastic grains in biocalcarenite and sandy biocalcarenite in the middle part of the section. Benthic foraminifers are moderately abundant in these consolidated calcarenites.
D. In addition, mean and maximum grain-sizes of bioclastic grains increase to a maximum in *Lithothamnium*-poor (Oyster-rich) petrolithofacies, and gradually decrease in *Lithothamnium*-bearing (Oyster-poor) petrolithofacies. Polymodal grain-size distributions commonly occur in these consolidated calcarenites.

Compositional and textural variations through all stratigraphic sections of both sedimentary sequences are summarized in Appendices 3B (gravel, sand, mud and carbonate variations) and 4C (variations of textural parameters). Average limits for lithofacies in the terrigenous mixed carbonate sequence (Steyregg) and the Linz sand are as follows:

- Non-calcareous terrigenous lithofacies consists of 29.1 % gravel, 69.2 % sand and 1.7 % mud (1.65 % silt and 0.03 % clay).

- Calcareous terrigenous lithofacies consists of 17 % gravel, 64.3 % sand, 6.3 % mud (5.9 % silt and 0.4 % clay) and 12.4 % carbonate.
- Consolidated calcarenite lithofacies consists of 4.8 % gravel, 25.6 % sand, 3 % mud (2.6 % silt and 0.4 % clay) and 66.7 % carbonate.
- Non-calcareous Linz sand sediments consist of 11.7 % gravel, 85.2 % sand and 3.1 % mud (2.5 % silt and 0.6 % clay).

It is suggested that depositional mechanisms in mixed bioclastic-siliciclastic sediments are best reflected by grain-size characteristics of the siliciclastic fraction. Moreover, the grain-size distribution of the gravel, sand and mud-sized material is considered most useful in providing information on the current energy available at the time when sediment was introduced to the depositional site.

Average grain-size parameters for siliciclastic fractions from different lithofacies in both sedimentary sequences are presented in Table 4.1. Fining upward trends and variations in grain-sizes through the representative stratigraphic column of each sequence (Figs. 4.5, 4.6, 4.10, 4.11) can be explained in terms of proximity to source, degree and persistency of water turbulence in the depositional environment. The data used for interpreting conditions of the depositional environment of individual lithofacies are presented in Figs. 4.12 to 4.17. The sediments of the terrigenous mixed carbonate sequence (Steyregg) accumulated in wave-worked beach environments, under a spectrum of environmental energy conditions ranging from moderate to strongly agitated waters. Also, the sediments of the Linz sand sequence deposited in wave-worked beach environmants.

Clay minerals in sediments of the terrigenous mixed carbonate sequence include montmorillonite and illite. Whilst kaolinitic and illitic clay minerals occur in the Linz sand (see Table 4.3 and Appendix 6). The kind, origin and relative abundance of these clay minerals are broadly predictable. Some amounts of illitic clay minerals in both sequences may have been detritally inherited from basement rocks and from Oligocene-Miocene soils on the basement. Some quantities of montmorillonite may have had its origin in the marine diagenetic transformation of degraded illite (and also vermiculite, if present) derived from Oligocene-Miocene soils on basement rocks. In general, however, reactions of the aggradational transformation towards montmorillonitic clay minerals are favoured by slow deposition in an alkaline marine environment (rich in dissolved calcium, magnesium and silica), dominated by carbonate sedimentation. A variety of transformational paths are also suggested (Section 4.5.1.3). The possibility is considered that a part of the montmorillonitic clay in sediments of the terrigenous mixed carbonate sequence is neoformed. Kaolinitic clay minerals in the Linz sand sediments may partly be of direct pedogenetic origin. Some amounts of kaolinite have formed by degradational transformation of a variety of phyllosilicates in an acid environment, following uplift.

A variety of heavy minerals occur in sediments of the terrigenous mixed carbonate sequence (Steyregg) and the Linz sand (see Table 4.4, Fig. 4.18). The principal non-opaque heavy minerals in the terrigenous mixed carbonate sequence (Fig. 4.18A) are mainly sphene (37 %), zircon (30 %), apatite (21 %) and kyanite (5 %). On the other hand, heavy minerals in the Linz sand sequence (Fig. 4.18B) are mostly zircon (73 %), sphene (8 %), kyanite (8 %) and apatite (5 %). The heavy minerals in both sedimentary sequences have been derived from rocks of the Bohemian Massif basement.

Bioclastic grains in primary calcarenite sediments of the terrigenous mixed carbonate sequence constructed shells of metastable magnesium calcite and, to a lesser extent, of aragonite. However, stable calcitic shells were also common, eg. oyster fragments (Photo. 3/8). Metastable skeletons have undergone diagenetic stabilization reactions, in practically all cases. In the case of magnesium calcitic skeletons stabilization involved the texturally non-destructive process of incongruent dissolution during syndiagenesis, biofragments can be replaced by calcite without loss of detail in grain-outline or internal structure (eg. Photo. 5/3). Dissolved magnesium ions were possibly absorbed by degraded clay minerals during their aggradational transformation. For aragonite, however, dissolution caused total destruction of shell textures and total loss of aragonitic fauna. A variety of evidence (see Sections 5.2.2 and 5.4) indicates that large quantities of skeletal aragonite were dissolved before lithification of the calcarenite sediment. Evidence of an original aragonitic fauna is scarce but it possibly occurs in the form of sparite moulds enclosed with slight micritic envelopes (eg. Photo. 5/7). In general, aragonitic shells preserved their primary metastable mineralogy under anaerobic conditions in the sediment. This condition prevented oxidation of the organic matter of shells, eg. in sediments notably rich in glauconite and pyrite. The nature and occurrence of the glauconite and pyrite in this calcarenite sediment is also outlined in Section 5.6.

Micritic materials in the consolidated calcarenites originated mainly from the biological and mechanical erosion of skeletal tests and fragments (see Section 5.4.2). Cementing materials are wholly orthosparry calcite. Granular orthosparite cementational fabric is most common (Photos. 3/5, 5/10), and often shows a drusy mosaic habit. Sources of calcium carbonate for cementation are possibly from pre- and syn-cementational solution of aragonitic skeletons close below the sea-floor, during syndiagenesis. In a case of stabilization of metastable carbonate species occurred in the shallow marine environment, it can be suggested that removal of magnesium ions from sea water was accomplished by cation exchange on degraded montmorillonitic clay minerals. A generalized paragenetic sequence of diagenetic events is established for the consolidated calcarenites of Steyregg in Table 5.2.

The gross depositional environment during sediments of the terrigenous mixed carbonate sequence (Steyregg) was a very shallow sea, in the ramp setting conditions between beach-foreshore and shoreface, in which sedimentation occurred along a NNE-SSW trending shoreline. On the other hand, the sedimentary environment during deposition of the Linz sand sediments was beach-foreshore to upper shoreface. The depositional history of both sedimentary sequences began when the sea entered the Steyregg area from the south, flooding northwards across a low-lying landmass of the Bohemian Massif. Several indirect lines of evidence suggest that wave-generated currents may have been the foremost agents in transportation and deposition of the sediments.

In the terrigenous mixed carbonate sequence (Steyregg), relative sea-level changes and subsequent changes in the position of the shoreline (Figs. 4.5, 4.10, 6.1) indicate an overall transgression. In general, small and large scale transgressive cycles formed the sequence of sediments from non-calcareous terrigenous sediments at the base grading up into calcareous terrigenous sediments and then slightly consolidated calcarenites (see also Fig. 2.3). However, sedimentary cycles and lithofacies may not be coincidental. The cycle-generating mechanism in this sequence is complex.

On the other hand, in the Linz sand sequence, small and large scale sedimentary cycles (Figs. 4.6, 4.11, 6.2) suggest an overall transgression. The sequence of sediments formed from cross-bedded sand and gravel lithofacies in the lower part of the sequence grading up into massive sand and then bioturbated sand lithofacies of the upper part (Fig. 2.5).

Finally, attention is drawn to some fundamental differences in the character of mixed terrigenous-allochemical sediments of ancient and modern carbonate ramp environments together with carbonate shelves (see Section 6.6). The consolidated calcarenite of the terrigenous mixed carbonate sequence (Steyregg) formed in a non-tropical environment. Diagenetic processes and products in other environmental settings may be significantly different from the consolidated calcarenites of Steyregg.

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Arch. f. Lagerst. forsch. Geol. = Archiv für Lagerstättenforschung der Geologischen Bundesanstalt, Wien, Austria.
Eclogae Geol. Helvetiae = Eclogae Geologicae Helvetiae, Switzerland.
Erdoel Zeitschrift usw = Erdoel Zeitschrift für Bohr-und Fördertechnic, Wien-Hamburg.
Erdöl-Erdgas Zeitschrift, Wien-Hamburg.
Geol. Jahrbuch = Geologisches Jahrbuch, Hannover, Germany.
Geol. Rundschau = Geologische Rundschau, Stuttgart, Germany
Giornale di Geologia, Bologna, Italy.
Jb. Geol. B.-A = Jahrbuch der Geologische Bundesanstalt, Wien, Austria.
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Mitt. Geol. Ges. = Mitteilungen der Geologischen Gesellschaft in Wien, Austria.
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APPENDIX 1

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Sample preparations and methods for grain-size analyses in the study

1. Acid digestion.
2. Wet sieving.
3. SHIMADZU Centrifugal Particle Size Analyzer.
4. Dry sieving.
5. Heavy mineral seperation.

APPENDIX 1

SAMPLE PREPARATIONS AND METHODS FOR GRAIN SIZE ANALYSES

1. Acid digestion.

Representative terrigenous mixed carbonate samples, both calcareous terrigenous sediments and consolidated calcarenites, were thoroughly cleaned and dried in an oven at 60°C for 24 hours. Hydraulic pressure was applied for consolidated samples which were reduced in dimension to a smaller size (average 1 cm). The dry sample, about 150 grams, was placed in 1 litre beakers or jars. In order to avoid any alteration of clay minerals, 1:3 to 1:4 of 60 % acetic acid (CH_3COOH) was used instead of hydrochloric acid (HCl) for dissolving the calcium carbonate (Ray et.al., 1957). Up to a litre of dilute acetic acid was added, and the mixture was periodically stirred for 2 to 3 days until reaction ceased. In some cases, it was necessary to decant and add additional fresh acid to ensure a complete reaction. Consequently, the insoluble residue was washed 2 to 3 times with distilled water, and prepared for wet sieving.

2. Wet sieving.

The insoluble residues and the representative samples, both non-calcareous and calcareous terrigenous sediments, were wet-sieved through a 230-mesh screen (0.063 mm or 4 phi) to separate gravels and sands from muds (silts plus clays). The coarse fractions were dried at 100°C, then, weighed separately by dry sieving at 1/2 phi intervals (see 4. for dry sieving). The mud fractions were collected in a 3 litre jar, prepared for the "SHIMADZU" Centrifugal Particle Size Analyzer (see 3. for Shimadzu) and X-Ray Diffraction (XRD) for clay mineralogy (see Appendix 5). Then, the suspended mud was dried and weighed.

3. <u>SHIMADZU Centrifugal Particle Size Analyzer</u> (Type SA-CP2)

The Shimadzu is a special type of hydrophotometer that relates to changes in intensity of a beam of light passed through a column of suspended sediment to particle settling velocities and thus to particle size (Jordan et.al., 1971).

The muds in 3 litre jar were stirred throughly. A pipette was inserted, 20 seconds after stirring, at the bottom of the container. The suspension of about 20 ml was withdrawn, and placed in a small beaker. Mechanical stirring of the suspended samples was necessary for 5 to 10 minutes before working on the Shimadzu machine. Then, a few eye-drops of the mud-suspension were withdrawn at the bottom of the samll beaker, and placed in the Shimadzu cell. It was necessary to fill the cell with distilled water, to diluted mud-concentrations, up to the height level of the cell's scale which needed to work on. The suspended sample, now in the cell, was manually shaken for a few seconds before running on the Shimadzu machine.

4. **<u>Dry sieving</u>.**

The dry sieving method is a technique for measuring the grain size of unconsolidated sediments (see standard methods in Ingram, 1971; Folk, 1980). Unconsolidated samples; non-calcareous terrigenous sediments, insoluble residual sand plus granule fractions after acid digestion of terrigenous sediments and consolidated calcarenites, were cleaned, dried at 60˚C, quartered, weighed to two decimal about 150 grams, and then dry sieved at 1/2 phi intervals on a mechanical shaker for 20 minutes. The different sizes were grouped and reweighed. Some different size fractions were examined under the stereozoom microscope to determine the presence of aggregates. Any aggregated materials were gently disaggregated with finger and manually re-sieved. Then, carbonate, gravel, sand and mud percentages were calculated.

The modal grain-class of each sample was also examined for trends of changing roundness, sphericity and mineralogy. The grain size grades between 2 to 4 phi of the selective samples were prepared for the heavy mineral study (see 5. below).

5. <u>Heavy mineral separation</u>.

Representative sand-size, 2-4 phi, samples were microsplitted into subsamples of 2 grams. Heavy minerals were concentrated from the fine to very fine sand sizes (see Lewis, 1984 for a standard method) by sedimentation through "Sodium Polytungstate" ($3Na_2WO_4.9WO_3.H_2O$) solution for 15-20 minutes. Its specific gravity can be prepared with varying densities up to 3.1 g/cm^3 (Gregory and Johnston, 1987). The heavy liquid, specific gravity (S.G.) = 2.96, was used in steep-sided separating funnels. In general, the heavy liquid (S.G. = 2.96) can float quartz, feldspar, calcite, glauconite and also muscovite. The heavy and light minerals were then separated, washed and dried. A detailed study of the heavy minerals was carried out by using a "Frantz Isodynamic Magnetic Separator" with side-tilt 15˘, forward-tilt 25˘ , 0.5 Amperes and vibration between 3 and 5. These settings will remove ferromagnetic grains from non-ferromagnetic heavy minerals, making mineral identification easier, on the slide mounting, under transmitted light microscope. In some cases, it was necessary to remove ferromagnetic grains with a hand magnet before running on the electromagnetic separator.

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APPENDIX 2

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An example of merged data

between

SHIMADZU Centrifugal Particle Size Analyzer

and sieving

A. Raw SHIMADZU data.

B. Merged table for cumulative weight percentages.

2A

Datum : 20.09.1993
Probe : St-28
(2.5 g/cm3)
Dispersionsmittel : H2O Bi-dest.
(.99823 g/cm3, 1.009 mPa s)
Drehzahl : 1000 1/min

Wertetabelle fuer Teilchengroessenverteilung
Modellunabhaengig

Klasse bis um	Durchgang in %	Rueckstand in %	Anteil pro Klasse in %
0.60	0.1	99.9	0.1
0.80	0.2	99.8	0.1
1.00	0.3	99.7	0.1
2.00	0.9	99.1	0.5
3.00	1.6	98.4	0.7
4.00	2.2	97.8	0.6
5.00	3.3	96.7	1.0
6.00	3.9	96.1	0.7
8.00	5.3	94.7	1.4
10.00	7.8	92.2	2.4
15.00	14.3	85.7	6.6
20.00	22.5	77.5	8.2
25.00	35.0	65.0	12.5
30.00	50.7	49.3	15.7
35.00	62.5	37.5	11.9
40.00	84.1	15.9	21.6
45.00	100.0	0.0	15.9

Weitere Summenwerte

Durchmesser in um	Summenwert in %
1.00	0.3

D(50.0 / 50.0 %) = 29.7 um

2B

SAMPLE NO: ST-28 (STEYREGG QUARRY)

GRAIN SIZE CLASS (WENTWORTH)	SIZE IN mm. SCALE	SIZE IN PHI SCALE (WENTWORTH)	WEIGHT IN % SHIMADZU (DATA)	WEIGHT IN GRAMS (SIEVING & SHIMADZU)	INDIVIDUAL WEIGHT PERCENTS (%)	CUMULATIVE WEIGHT PERCENTS (%)
MEDIUM PEBBLE						
....	8.0000	-3.0		0.00	0.0000	0.000
FINE PEBBLE	5.6570	-2.5		0.00	0.0000	0.000
....	4.0000	-2.0		0.18	0.1200	0.120
GRANULE	2.8280	-1.5		0.56	0.3733	0.493
....	2.0000	-1.0		1.67	1.1133	1.607
VERY COARSE SAND	1.4140	-0.5		4.09	2.7265	4.333
....	1.0000	0.0		6.92	4.6130	8.946
COARSE SAND	0.7070	0.5		11.14	7.4262	16.372
....	0.5000	1.0		32.45	21.6319	38.004
MEDIUM SAND	0.3540	1.5		47.17	31.4446	69.449
....	0.2500	2.0		24.56	16.3722	85.821
FINE SAND	0.1770	2.5		8.18	5.4530	91.274
....	0.1250	3.0		5.97	3.9797	95.254
VERY FINE SAND	0.0880	3.5		2.88	1.9199	97.174
....	0.0625	4.0		1.98	1.3199	98.493
	0.0450	4.5	15.9	0.34026	0.2268	98.720
COARSE SILT	0.0400		21.6	0.46224	0.3081	99.028
	0.0350		11.9	0.25466	0.1698	99.198
....	0.0300	5.0	15.7	0.33598	0.2240	99.422
	0.0250	5.5	12.5	0.26750	0.1783	99.600
MEDIUM SILT	0.0200		8.2	0.17548	0.1170	99.717
....	0.0150	6.0	6.6	0.14124	0.0942	99.812
FINE SILT	0.0100	6.5	2.4	0.05136	0.0342	99.846
....	0.0080	7.0	1.4	0.02996	0.0200	99.866
	0.0060	7.5	0.7	0.01498	0.0100	99.876
VERY FINE SILT	0.0050		1.0	0.02140	0.0143	99.890
....	0.0040	8.0	0.6	0.01284	0.0086	99.899
	0.0030		0.7	0.01498	0.0100	99.909
	0.0020	9.0	0.5	0.01070	0.0071	99.916
CLAY	0.0010	10.0	0.1	0.00214	0.0014	99.917
	0.0008		0.1	0.00214	0.0014	99.919
	0.0006		0.1	0.00214	0.0014	99.920

REMARKS:

1. FORMULAR FOR WEIGHT IN GRAMS OF SHIMADZU DATA

$$\frac{\text{(weight in \% from shimadzu data) X (total weight in grams of mud)}}{100}$$

2. FORMULAR FOR INDIVIDUAL WEIGHT PERCENTS (%)

$$\frac{\text{(weight in grams of individual fraction) X 100}}{\text{(total weight in grams of gravel-sand-mud)}}$$

3. TOTAL WEIGHT OF SAMPLE NO. ST-28 = 150.01 GRAMS
   WEIGHT OF MUD = 2.14 GRAMS

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APPENDIX 3A

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Raw terrigenous terminology

by grain-size for

unconsolidated sediments

from

the terrigenous mixed carbonate sequence,

of Steyregg

	SAMPLE NO.	GRAVEL %	SAND %	SILT %	CLAY %	100% MUD %	TEXTURAL TERMINOLOGY FOR UNCONSOLIDATED SEDMENTS	LEGEND
		TOTAL = 100%						
UNCONSOLIDATED	A-10	30.82	66.63	2.46	0.09	2.54	SANDY GRAVEL	sG
NON-CALCAREOUS	A-11	9.54	89.92	0.53	0.01	0.54	GRAVELLY SAND	gS
STEYREGG	A-12	12.71	85.39	1.87	0.03	1.90	GRAVELLY SAND	gS
MOLASSE	A-13	45.79	51.72	2.40	0.10	2.50	SANDY GRAVEL	sG
SEDIMENTS	Q-1	30.92	67.71	1.36	0.02	1.37	SANDY GRAVEL	sG
(43-SAMPLES)	Q-3	59.65	38.67	1.63	0.05	1.68	SANDY GRAVEL	sG
	Q-3.1	53.30	45.72	0.96	0.03	0.99	SANDY GRAVEL	sG
	Q-5	13.24	82.30	4.41	0.05	4.46	GRAVELLY SAND	gS
	Q-5.1	43.06	54.63	2.27	0.04	2.30	SANDY GRAVEL	sG
	Q-5.2	17.91	78.43	3.63	0.03	3.66	GRAVELLY SAND	gS
	Q-5.3	64.12	35.20	0.67	0.01	0.68	SANDY GRAVEL	sG
	Q-6.1	4.60	94.35	1.03	0.02	1.05	SLIGHTLY GRAVELLY SAND	(g)S
	Q-6.1.1	31.62	66.68	1.67	0.03	1.70	SANDY GRAVEL	sG
	Q-6.3	32.32	65.60	2.06	0.03	2.08	SANDY GRAVEL	sG
	Q-7.1	16.07	83.11	0.81	0.01	0.82	GRAVELLY SAND	gS
	Q-7.2	1.51	96.43	2.03	0.04	2.07	SLIGHTLY GRAVELLY SAND	(g)S
	Q-7.4	21.59	76.04	2.30	0.07	2.37	GRAVELLY SAND	gS
	Q-9.1	72.25	27.21	0.52	0.02	0.54	SANDY GRAVEL	sG
	Q-9.2	10.65	88.25	1.07	0.04	1.11	GRAVELLY SAND	gS
	Q-9.3	39.87	58.18	1.90	0.06	1.96	SANDY GRAVEL	sG
	Q-10.3	43.63	54.39	1.93	0.06	1.98	SANDY GRAVEL	sG
	Q-13	22.92	76.16	0.89	0.03	0.91	GRAVELLY SAND	gS
	Q-15.4	2.80	94.70	2.44	0.05	2.49	SLIGHTLY GRAVELLY SAND	(g)S
	Q-15.5	4.84	93.42	1.71	0.03	1.74	SLIGHTLY GRAVELLY SAND	(g)S
	ST-25	39.54	58.26	2.15	0.06	2.21	SANDY GRAVEL	sG
	ST-26	58.78	40.70	0.50	0.02	0.52	SANDY GRAVEL	sG
	ST-28	1.61	96.96	1.41	0.02	1.43	SLIGHTLY GRAVELLY SAND	(g)S
	ST-29	61.15	38.10	0.74	0.02	0.75	SANDY GRAVEL	sG
	ST-32	6.77	91.62	1.56	0.05	1.61	GRAVELLY SAND	gS
	ST-36	46.65	52.31	1.03	0.02	1.05	SANDY GRAVEL	sG
	ST-37	32.76	65.80	1.42	0.02	1.44	SANDY GRAVEL	sG
	ST-38	42.45	55.87	1.63	0.05	1.68	SANDY GRAVEL	sG
	ST-39	18.92	78.74	2.31	0.04	2.34	GRAVELLY SAND	gS
	ST-40	44.04	54.45	1.47	0.04	1.51	SANDY GRAVEL	sG
	ST-41	18.73	80.11	1.14	0.02	1.16	GRAVELLY SAND	gS
	ST-42	68.03	31.26	0.70	0.02	0.71	SANDY GRAVEL	sG
	ST-43	6.07	92.11	1.78	0.03	1.82	GRAVELLY SAND	gS
	ST-44	17.33	80.88	1.76	0.03	1.79	GRAVELLY SAND	gS
	ST-45	6.44	91.78	1.75	0.03	1.78	GRAVELLY SAND	gS
	ST-46	2.50	93.35	4.09	0.06	4.15	SLIGHTLY GRAVELLY SAND	(g)S
	ST-47	7.30	91.07	1.61	0.03	1.64	GRAVELLY SAND	gS
	ST-48	20.24	79.11	0.63	0.01	0.65	GRAVELLY SAND	gS
	ST-49	67.81	31.79	0.38	0.01	0.39	SANDY GRAVEL	sG

	SAMPLE NO.	INSOLUBLE RESIDUES GRAVEL %	SAND %	SILT %	CLAY %	(MUD) %	SUBTOTAL INSOLUBLE RESIDUE(%)	SUBTOTAL CARBONATE CONTENT(%)	TOTAL= 100 % GRAVEL %	SAND %	MUD %	TOTAL= 100 % % SAND+ GRAVEL	MUD %	CaCO3 %	TEXTURAL TERMINOLOGY FOR TERRIGENOUS COMPONENTS	LEGEND
UNCONSOLIDATED	A-2	53.98	35.60	2.27	0.10	2.37	91.94	8.06	58.71	38.72	2.58	89.57	2.37	8.06	SANDY GRAVEL	sG
CALCAREOUS	A-5	24.63	55.67	4.09	0.37	4.46	84.76	15.24	29.06	65.68	5.26	80.30	4.46	15.24	GRAVELLY SAND	gS
STEYREGG	A-7	31.52	46.90	4.63	0.26	4.89	83.31	16.69	37.84	56.29	5.87	78.42	4.89	16.69	SANDY GRAVEL	sG
MOLASSE	A-8	24.83	61.14	6.97	0.35	7.32	93.29	6.71	26.61	65.54	7.85	85.97	7.32	6.71	GRAVELLY MUDDY SAND	gmS
SEDIMENTS	Q-7.3	14.13	76.02	6.93	0.53	7.45	97.60	2.40	14.47	77.89	7.64	90.15	7.45	2.40	GRAVELLY SAND	gS
(15-SAMPLES)	Q-10.1	25.87	63.02	7.06	0.41	7.47	96.37	3.63	26.85	65.40	7.75	88.89	7.47	3.63	GRAVELLY SAND	gS
	Q-10.5	6.42	78.31	6.65	0.37	7.01	91.74	8.26	7.00	85.36	7.64	84.73	7.01	8.26	GRAVELLY SAND	gS
	Q-11	14.47	78.23	4.90	0.34	5.24	97.94	2.06	14.78	79.87	5.35	92.70	5.24	2.06	GRAVELLY SAND	gS
	Q-15.1	5.48	56.55	5.72	0.61	6.33	68.36	31.64	8.02	82.72	9.26	62.03	6.33	31.64	GRAVELLY SAND	gS
	Q-16.1	2.24	69.10	6.42	0.45	6.87	78.22	21.78	2.86	88.35	8.79	71.34	6.87	21.78	SLIGHTLY GRAVELLY SAND	(g)S
	Q-17.1	10.62	67.35	8.39	0.58	8.97	86.95	13.05	12.21	77.47	10.32	77.97	8.97	13.05	GRAVELLY MUDDY SAND	gmS
	Q-17.3	11.43	78.19	5.28	0.35	5.63	95.26	4.74	12.00	82.09	5.91	89.63	5.63	4.74	GRAVELLY SAND	gS
	ST-27	13.10	63.50	6.77	0.35	7.12	83.72	16.28	15.65	75.85	8.50	76.60	7.12	16.28	GRAVELLY SAND	gS
	ST-31	12.30	76.38	6.24	0.27	6.51	95.19	4.81	12.92	80.24	6.84	88.68	6.51	4.81	GRAVELLY SAND	gS
	ST-34	3.81	59.02	6.05	0.60	6.65	69.48	30.52	5.49	84.95	9.56	62.83	6.65	30.52	GRAVELLY SAND	gS
CONSOLIDATED	A-1	1.75	26.04	4.01	0.27	4.28	32.07	67.93	5.47	81.18	13.35	27.79	4.28	67.93	GRAVELLY MUDDY SAND	gmS
CARBONATE	A-3	0.32	6.24	2.01	0.21	2.22	8.78	91.22	3.64	71.06	25.31	6.56	2.22	91.22	SLIGHTLY GRAVELLY MUDDY SAND	(g)mS
MIXED	A-4	2.61	23.70	3.20	0.10	3.30	29.61	70.39	8.80	80.06	11.14	26.31	3.30	70.39	GRAVELLY MUDDY SAND	gmS
TERRIGENOUS	A-6	2.19	15.61	1.07	0.25	1.31	19.12	80.88	11.47	81.67	6.87	17.81	1.31	80.88	GRAVELLY SAND	gS
STEYREGG	A-9	10.07	26.87	1.38	0.39	1.77	38.71	61.29	26.02	69.41	4.57	36.94	1.77	61.29	GRAVELLY SAND	gS
MOLASSE	F-3	10.69	28.22	2.08	0.16	2.24	41.15	58.85	25.98	68.58	5.44	38.92	2.24	58.85	GRAVELLY SAND	gS
(37-SAMPLES)	Q-6	13.81	40.62	1.87	0.07	1.94	56.37	43.63	24.50	72.06	3.44	54.43	1.94	43.63	GRAVELLY SAND	gS
	Q-6.2	6.34	48.19	5.16	0.50	5.66	60.20	39.80	10.54	80.06	9.40	54.54	5.66	39.80	GRAVELLY SAND	gS
	Q-8	4.94	27.61	3.58	1.35	4.93	37.48	62.52	13.17	73.67	13.16	32.55	4.93	62.52	GRAVELLY MUDDY SAND	gmS
	Q-10	3.98	34.27	2.18	0.48	2.66	40.91	59.09	9.72	83.77	6.51	38.25	2.66	59.09	GRAVELLY SAND	gS
	Q-10.2	7.03	12.69	1.12	0.19	1.31	21.04	78.96	33.42	60.34	6.24	19.72	1.31	78.96	SANDY GRAVEL	sG
consolidated calcarenites	Q-10.4	3.49	24.09	1.76	0.49	2.25	29.83	70.17	11.69	80.77	7.54	27.58	2.25	70.17	GRAVELLY SAND	gS
	Q-10.6	1.52	29.42	3.85	0.61	4.46	35.40	64.60	4.30	83.11	12.59	30.94	4.46	64.60	SLIGHTLY GRAVELLY MUDDY SAND	(g)mS
	Q-12	10.29	35.89	1.00	0.32	1.32	47.50	52.50	21.66	75.57	2.77	46.18	1.32	52.50	GRAVELLY SAND	gS
	Q-14	2.31	21.53	1.19	0.33	1.52	25.36	74.64	9.13	84.88	5.99	23.84	1.52	74.64	GRAVELLY SAND	gS
	Q-15.2	3.75	7.93	2.43	0.65	3.08	14.75	85.25	25.41	53.72	20.86	11.67	3.08	85.25	GRAVELLY MUDDY SAND	gmS
	Q-15.3	4.06	31.63	2.05	0.11	2.17	37.85	62.15	10.72	83.55	5.72	35.69	2.17	62.15	GRAVELLY SAND	gS
	Q-15.6	2.01	50.67	1.40	0.19	1.59	54.27	45.73	3.71	93.37	2.92	52.68	1.59	45.73	SLIGHTLY GRAVELLY SAND	(g)S
	Q-17.2	4.42	51.25	4.32	0.72	5.04	60.71	39.29	7.28	84.41	8.31	55.67	5.04	39.29	GRAVELLY SAND	gS
	Q-17.4	8.27	43.61	1.20	0.27	1.47	53.35	46.65	15.50	81.73	2.76	51.88	1.47	46.65	GRAVELLY SAND	gS
	R-1	10.59	20.73	2.69	0.47	3.16	34.48	65.52	30.72	60.12	9.16	31.32	3.16	65.52	MUDDY SANDY GRAVEL	msG
	R-3	4.52	32.96	1.96	0.09	2.06	39.53	60.47	11.42	83.37	5.20	37.47	2.06	60.47	GRAVELLY SAND	gS
	ST-1	7.53	42.94	4.13	0.23	4.36	54.83	45.17	13.73	78.32	7.94	50.47	4.36	45.17	GRAVELLY SAND	gS
	ST-9	0.13	4.29	1.18	0.23	1.41	5.83	94.17	2.28	73.57	24.16	4.42	1.41	94.17	SLIGHTLY GRAVELLY MUDDY SAND	(g)mS
	ST-14	0.20	4.29	1.75	0.27	2.02	6.51	93.49	3.04	65.94	31.01	4.49	2.02	93.49	SLIGHTLY GRAVELLY MUDDY SAND	(g)mS
	ST-23	2.16	11.00	1.93	0.23	2.16	15.32	84.68	14.11	71.82	14.07	13.17	2.16	84.68	GRAVELLY MUDDY SAND	gmS
	ST-24	0.20	8.69	1.83	0.22	2.05	10.94	89.06	1.82	79.44	18.74	8.89	2.05	89.06	SLIGHTLY GRAVELLY MUDDY SAND	(g)mS
	ST-30	5.20	27.78	2.03	0.27	2.30	35.28	64.72	14.75	78.73	6.52	32.98	2.30	64.72	GRAVELLY SAND	gS
	ST-33	0.30	15.02	2.31	0.31	2.62	17.94	82.06	1.68	83.72	14.60	15.32	2.62	82.06	SLIGHTLY GRAVELLY MUDDY SAND	(g)mS
	ST-35	19.23	29.54	5.27	1.22	6.49	55.25	44.75	34.80	53.46	11.75	48.76	6.49	44.75	MUDDY SANDY GRAVEL	msG
	W-1	2.33	38.90	5.84	0.88	6.72	47.95	52.05	4.86	81.12	14.01	41.23	6.72	52.05	SLIGHTLY GRAVELLY MUDDY SAND	(g)mS
	W-2	0.50	25.54	4.82	1.10	5.92	31.97	68.03	1.57	79.91	18.52	26.05	5.92	68.03	SLIGHTLY GRAVELLY MUDDY SAND	(g)mS
	W-3	13.85	20.06	1.62	0.22	1.84	35.74	64.26	38.74	56.12	5.15	33.90	1.84	64.26	SANDY GRAVEL	sG
	W-4	0.41	31.08	2.30	0.39	2.68	34.18	65.82	1.21	90.95	7.85	31.50	2.68	65.82	SLIGHTLY GRAVELLY SAND	(g)S
	W-5	3.60	17.93	2.96	0.68	3.65	25.18	74.82	14.29	71.22	14.49	21.53	3.65	74.82	GRAVELLY MUDDY SAND	gmS
	W-6	1.81	13.54	2.18	0.46	2.63	17.98	82.02	10.08	75.28	14.65	15.35	2.63	82.02	GRAVELLY MUDDY SAND	gmS
					[illegible]	[illegible]	18.99	81.01	5.83	78.00	16.17	15.92	3.07	81.01	GRAVELLY MUDDY SAND	gmS

APPENDIX 3A

Raw terrigenous terminology

by grain-size for

unconsolidated sediments

from

the Linz sand sequence

TOTAL 146 SAMPLES	SAMPLE NO.	TOTAL = 100% GRAVEL %	SAND %	SILT %	CLAY %	MUD %	TEXTURAL TERMINOLOGY FOR UNCONSOLIDATED SEDMENTS	LEGEND
LINZ SAND QUARRY-B (11-SAMPLES)	B-1	20.55	79.33	0.12	0.00	0.12	GRAVELLY SAND	gS
	B-2	30.98	68.87	0.14	0.01	0.15	SANDY GRAVEL	sG
	B-3	12.15	87.64	0.21	0.00	0.21	GRAVELLY SAND	gS
	B-4	35.27	64.36	0.37	0.00	0.37	SANDY GRAVEL	sG
	B-5	4.63	95.09	0.27	0.01	0.28	SLIGHTLY GRAVELLY SAND	(g)S
	B-6	6.76	92.95	0.28	0.01	0.29	GRAVELLY SAND	gS
	B-7	2.25	97.63	0.12	0.00	0.13	SLIGHTLY GRAVELLY SAND	(g)S
	B-8	7.33	91.26	1.38	0.03	1.41	GRAVELLY SAND	gS
	B-9	1.71	98.02	0.27	0.00	0.27	SLIGHTLY GRAVELLY SAND	(g)S
	B-10	22.66	76.66	0.67	0.01	0.68	GRAVELLY SAND	gS
	B-11	1.84	97.85	0.30	0.00	0.31	SLIGHTLY GRAVELLY SAND	(g)S
LINZ SAND QUARRY-C (6-SAMPLES)	C-1	0.22	99.33	0.45	0.00	0.45	SLIGHTLY GRAVELLY SAND	(g)S
	C-2	0.00	99.30	0.69	0.02	0.70	SAND	S
	C-3	1.63	98.21	0.16	0.00	0.16	SLIGHTLY GRAVELLY SAND	(g)S
	C-4	33.66	65.82	0.52	0.00	0.52	SANDY GRAVEL	sG
	C-5	3.69	95.95	0.36	0.00	0.36	SLIGHTLY GRAVELLY SAND	(g)S
	C-6	0.65	98.96	0.39	0.00	0.39	SLIGHTLY GRAVELLY SAND	(g)S
LINZ SAND QUARRY-D (14-SAMPLES)	D-1	0.41	97.56	1.98	0.04	2.03	SLIGHTLY GRAVELLY SAND	(g)S
	D-2	3.51	95.91	0.57	0.01	0.58	SLIGHTLY GRAVELLY SAND	(g)S
	D-3	0.98	98.30	0.71	0.02	0.72	SLIGHTLY GRAVELLY SAND	(g)S
	D-4	0.00	98.87	1.11	0.02	1.13	SAND	S
	D-5	37.84	61.91	0.25	0.00	0.25	SANDY GRAVEL	sG
	D-6	0.10	99.58	0.31	0.01	0.32	SLIGHTLY GRAVELLY SAND	(g)S
	D-7	2.25	97.56	0.18	0.01	0.19	SLIGHTLY GRAVELLY SAND	(g)S
	D-8	2.62	96.76	0.61	0.01	0.62	SLIGHTLY GRAVELLY SAND	(g)S
	D-9	0.92	97.70	1.36	0.02	1.38	SLIGHTLY GRAVELLY SAND	(g)S
	D-10	0.19	99.35	0.46	0.01	0.47	SLIGHTLY GRAVELLY SAND	(g)S
	D-11	0.34	99.25	0.40	0.01	0.41	SLIGHTLY GRAVELLY SAND	(g)S
	D-12	1.87	96.81	1.29	0.02	1.32	SLIGHTLY GRAVELLY SAND	(g)S
	D-13	2.49	95.87	1.58	0.06	1.64	SLIGHTLY GRAVELLY SAND	(g)S
	D-14	0.34	97.61	2.02	0.03	2.05	SLIGHTLY GRAVELLY SAND	(g)S
LINZ SAND QUARRY-E (34-SAMPLES)	E-1	0.15	99.32	0.51	0.01	0.53	SLIGHTLY GRAVELLY SAND	(g)S
	E-2	0.16	99.37	0.46	0.01	0.47	SLIGHTLY GRAVELLY SAND	(g)S
	E-3	58.28	41.51	0.21	0.01	0.21	SANDY GRAVEL	sG
	E-4	2.06	97.21	0.72	0.02	0.74	SLIGHTLY GRAVELLY SAND	(g)S
	E-5	13.29	86.26	0.44	0.01	0.45	GRAVELLY SAND	gS
	E-6	0.55	96.85	2.55	0.04	2.59	SLIGHTLY GRAVELLY SAND	(g)S
	E-7	13.25	85.90	0.83	0.02	0.85	GRAVELLY SAND	gS
	E-8	1.36	95.97	2.61	0.06	2.67	SLIGHTLY GRAVELLY SAND	(g)S
	E-9	0.19	96.63	3.11	0.06	3.17	SLIGHTLY GRAVELLY SAND	(g)S
	E-10	5.11	93.37	1.50	0.02	1.52	GRAVELLY SAND	gS
	E-11	3.03	96.25	0.68	0.03	0.71	SLIGHTLY GRAVELLY SAND	(g)S
	E-11/1	0.55	98.30	1.12	0.03	1.15	SLIGHTLY GRAVELLY SAND	(g)S
	E-12	0.43	97.90	1.62	0.05	1.67	SLIGHTLY GRAVELLY SAND	(g)S
	E-13	1.24	97.21	1.51	0.04	1.55	SLIGHTLY GRAVELLY SAND	(g)S
	E-14	1.53	97.49	0.95	0.02	0.98	SLIGHTLY GRAVELLY SAND	(g)S
	E-15	3.54	95.50	0.95	0.02	0.96	SLIGHTLY GRAVELLY SAND	(g)S
	E-16	0.96	98.50	0.52	0.02	0.54	SLIGHTLY GRAVELLY SAND	(g)S
	E-17	0.65	97.77	1.54	0.04	1.58	SLIGHTLY GRAVELLY SAND	(g)S
	E-18	1.89	97.59	0.52	0.01	0.52	SLIGHTLY GRAVELLY SAND	(g)S
	E-19	0.26	98.84	0.88	0.02	0.90	SLIGHTLY GRAVELLY SAND	(g)S
	E-20	18.36	81.41	0.23	0.01	0.23	GRAVELLY SAND	gS

	SAMPLE NO.	GRAVEL %	TOTAL = 100% SAND %	SILT %	CLAY %	MUD %	TEXTURAL TERMINOLOGY FOR UNCONSOLIDATED SEDMENTS	LEGEND
	E-21	0.25	98.60	1.13	0.02	1.14	SLIGHTLY GRAVELLY SAND	(g)S
	E-22	9.08	90.63	0.29	0.00	0.29	GRAVELLY SAND	gS
	E-23	0.17	98.23	1.57	0.03	1.60	SLIGHTLY GRAVELLY SAND	(g)S
	E-24	60.27	39.45	0.26	0.02	0.28	SANDY GRAVEL	sG
	E-25	0.06	99.82	0.11	0.01	0.12	SLIGHTLY GRAVELLY SAND	(g)S
	E-26	0.05	99.49	0.44	0.01	0.45	SLIGHTLY GRAVELLY SAND	(g)S
	E-27	40.83	59.04	0.13	0.00	0.13	SANDY GRAVEL	sG
	E-28	2.47	96.72	0.78	0.02	0.80	SLIGHTLY GRAVELLY SAND	(g)S
	E-29	0.26	98.82	0.91	0.02	0.92	SLIGHTLY GRAVELLY SAND	(g)S
	E-30	2.33	97.09	0.56	0.01	0.57	SLIGHTLY GRAVELLY SAND	(g)S
	E-31	11.19	87.99	0.81	0.01	0.82	GRAVELLY SAND	gS
	E-32	0.08	98.25	1.64	0.03	1.67	SLIGHTLY GRAVELLY SAND	(g)S
	E-33	0.55	96.75	2.66	0.04	2.70	SLIGHTLY GRAVELLY SAND	(g)S
LINZ SAND	F-1	2.16	96.18	1.63	0.03	1.66	SLIGHTLY GRAVELLY SAND	(g)S
QUARRY-F	F-2	0.37	97.75	1.83	0.05	1.88	SLIGHTLY GRAVELLY SAND	(g)S
(26-SAMPLES)	F-3	47.17	52.33	0.49	0.01	0.50	SANDY GRAVEL	sG
	F-4	59.04	40.66	0.29	0.01	0.30	SANDY GRAVEL	sG
	F-5	61.62	37.73	0.63	0.02	0.65	SANDY GRAVEL	sG
	F-6	6.94	90.96	2.06	0.05	2.10	GRAVELLY SAND	gS
	F-7	31.47	67.21	1.29	0.03	1.32	SANDY GRAVEL	sG
	F-8	0.05	98.97	0.95	0.03	0.98	SLIGHTLY GRAVELLY SAND	(g)S
	F-9	0.00	99.57	0.42	0.02	0.43	SAND	S
	F-9/1	0.16	11.72	63.45	24.67	88.12	SLIGHTLY GRAVELLY MUD	(g)M
	F-10	1.86	97.83	0.30	0.02	0.31	SLIGHTLY GRAVELLY SAND	(g)S
	F-11	1.48	96.97	1.50	0.06	1.55	SLIGHTLY GRAVELLY SAND	(g)S
	F-12	28.59	70.25	1.13	0.02	1.15	GRAVELLY SAND	gS
	F-13	0.00	99.65	0.34	0.02	0.35	SAND	S
	F-14	1.93	97.12	0.91	0.03	0.94	SLIGHTLY GRAVELLY SAND	(g)S
	F-15	44.24	55.47	0.27	0.01	0.29	SANDY GRAVEL	sG
	F-16	14.18	84.93	0.88	0.01	0.89	GRAVELLY SAND	gS
	F-17	5.74	94.00	0.26	0.01	0.27	GRAVELLY SAND	gS
	F-18	0.47	99.14	0.39	0.01	0.39	SLIGHTLY GRAVELLY SAND	(g)S
	F-19	0.75	98.91	0.33	0.01	0.34	SLIGHTLY GRAVELLY SAND	(g)S
	F-20	0.17	99.55	0.27	0.01	0.28	SLIGHTLY GRAVELLY SAND	(g)S
	F-21	0.35	99.33	0.32	0.01	0.33	SLIGHTLY GRAVELLY SAND	(g)S
	F-22	60.62	39.19	0.19	0.01	0.19	SANDY GRAVEL	sG
	F-23	6.89	92.95	0.15	0.01	0.16	GRAVELLY SAND	gS
	F-24	4.90	95.00	0.09	0.01	0.10	SLIGHTLY GRAVELLY SAND	(g)S
	F-25	5.04	94.46	0.50	0.01	0.51	GRAVELLY SAND	gS
LINZ SAND	G-1	0.49	97.17	2.19	0.16	2.35	SLIGHTLY GRAVELLY SAND	(g)S
QUARRY-G	G-2	0.19	14.90	68.44	16.47	84.91	SLIGHTLY GRAVELLY MUD	(g)M
(55-SAMPLES)	G-3	79.85	19.28	0.81	0.05	0.86	SANDY GRAVEL	sG
	G-4	0.65	98.85	0.47	0.03	0.50	SLIGHTLY GRAVELLY SAND	(g)S
	G-5	0.75	95.41	3.72	0.12	3.85	SLIGHTLY GRAVELLY SAND	(g)S
	G-6	44.28	55.28	0.42	0.02	0.44	SANDY GRAVEL	sG
	G-7	3.34	96.11	0.53	0.02	0.55	SLIGHTLY GRAVELLY SAND	(g)S
	G-8	2.56	96.27	1.14	0.03	1.17	SLIGHTLY GRAVELLY SAND	(g)S
	G-9	44.10	55.59	0.30	0.02	0.31	SANDY GRAVEL	sG
	G-10	15.26	84.25	0.46	0.03	0.49	GRAVELLY SAND	gS
	G-11	4.60	94.97	0.41	0.02	0.43	SLIGHTLY GRAVELLY SAND	(g)S
	G-12	53.44	46.13	0.42	0.02	0.43	SANDY GRAVEL	sG
	G-13	0.94	97.21	1.80	0.05	1.85	SLIGHTLY GRAVELLY SAND	(g)S

SAMPLE NO.	GRAVEL %	SAND %	SILT %	CLAY %	MUD %	TEXTURAL TERMINOLOGY FOR UNCONSOLIDATED SEDMENTS	LEGEND
	TOTAL = 100%						
G-14	1.80	96.31	1.85	0.05	1.90	SLIGHTLY GRAVELLY SAND	(g)S
G-15	61.33	38.39	0.27	0.01	0.28	SANDY GRAVEL	sG
G-16	7.22	90.94	1.79	0.05	1.84	GRAVELLY SAND	gS
G-17	0.29	96.59	3.00	0.12	3.12	SLIGHTLY GRAVELLY SAND	(g)S
G-18	15.91	83.03	1.02	0.04	1.06	GRAVELLY SAND	gS
G-19	0.75	98.57	0.66	0.03	0.69	SLIGHTLY GRAVELLY SAND	(g)S
G-20	0.19	98.58	1.19	0.05	1.23	SLIGHTLY GRAVELLY SAND	(g)S
G-21	17.41	81.57	1.00	0.02	1.02	GRAVELLY SAND	gS
G-22	0.00	97.55	2.36	0.09	2.45	SAND	S
G-23	1.65	97.90	0.44	0.02	0.46	SLIGHTLY GRAVELLY SAND	(g)S
G-24	0.10	98.41	1.45	0.04	1.49	SLIGHTLY GRAVELLY SAND	(g)S
G-25	1.53	97.99	0.46	0.02	0.47	SLIGHTLY GRAVELLY SAND	(g)S
G-26	0.13	99.21	0.64	0.02	0.66	SLIGHTLY GRAVELLY SAND	(g)S
G-27	3.11	96.24	0.61	0.04	0.65	SLIGHTLY GRAVELLY SAND	(g)S
G-28	11.21	88.05	0.71	0.03	0.74	GRAVELLY SAND	gS
G-29	0.84	98.59	0.55	0.02	0.57	SLIGHTLY GRAVELLY SAND	(g)S
G-30	0.38	97.46	2.11	0.05	2.15	SLIGHTLY GRAVELLY SAND	(g)S
G-31	3.03	96.06	0.88	0.03	0.91	SLIGHTLY GRAVELLY SAND	(g)S
G-32	17.76	81.81	0.42	0.02	0.43	GRAVELLY SAND	gS
G-33	0.00	99.36	0.62	0.02	0.64	SAND	S
G-34	0.03	33.43	56.33	10.22	66.54	SLIGHTLY GRAVELLY MUD	(g)M
G-35	3.98	95.42	0.55	0.05	0.60	SLIGHTLY GRAVELLY SAND	(g)S
G-36	0.68	97.56	1.72	0.03	1.75	SLIGHTLY GRAVELLY SAND	(g)S
G-37	71.98	27.76	0.25	0.01	0.26	SANDY GRAVEL	sG
G-38	7.07	92.35	0.56	0.02	0.58	GRAVELLY SAND	gS
G-39	12.87	86.81	0.30	0.01	0.31	GRAVELLY SAND	gS
G-40	8.28	91.24	0.46	0.02	0.47	GRAVELLY SAND	gS
G-41	0.30	98.95	0.73	0.02	0.75	SLIGHTLY GRAVELLY SAND	(g)S
G-42	3.10	95.66	1.19	0.05	1.24	SLIGHTLY GRAVELLY SAND	(g)S
G-43	39.40	60.14	0.43	0.02	0.45	SANDY GRAVEL	sG
G-44	71.31	28.50	0.17	0.01	0.19	SANDY GRAVEL	sG
G-45	5.59	93.10	1.28	0.03	1.30	GRAVELLY SAND	gS
G-46	0.04	13.68	56.73	29.55	86.28	SLIGHTLY GRAVELLY MUD	(g)M
G-47	0.00	99.09	0.89	0.02	0.91	SAND	S
G-48	14.22	84.90	0.85	0.02	0.87	GRAVELLY SAND	gS
G-49	16.70	81.22	2.05	0.04	2.08	GRAVELLY SAND	gS
G-50	4.23	94.69	1.05	0.03	1.08	SLIGHTLY GRAVELLY SAND	(g)S
G-51	43.61	55.54	0.81	0.03	0.84	SANDY GRAVEL	sG
G-52	56.08	43.46	0.43	0.02	0.45	SANDY GRAVEL	sG
G-53	1.65	96.69	1.60	0.06	1.66	SLIGHTLY GRAVELLY SAND	(g)S
G-54	37.73	61.70	0.55	0.02	0.57	SANDY GRAVEL	sG
G-55	40.46	59.08	0.44	0.02	0.46	SANDY GRAVEL	sG

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APPENDIX 3B

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Vertical variations of gravel, sand,

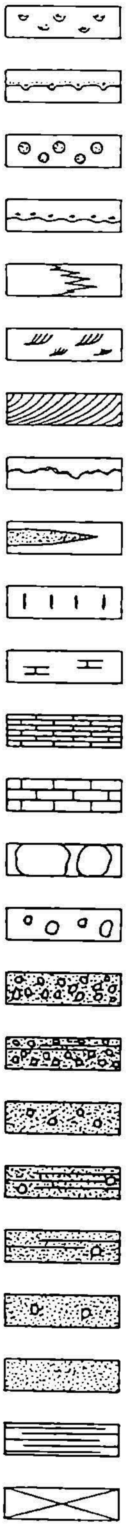
mud and carbonate contents plot

for the sections of

the terrigenous mixed carbonate sequence

of Steyregg

LEGEND	DESCRIPTION



SMALL CHANNELS, CUT AND FILL STRUCTURES

SHALLOW CHANNELS, CUT (SCOURED) AND FILL STRUCTURES

BIOTURBATED, BURROWED TUNNELS

UNCONFORMITY

INTERFINGERING CONTACT

SMALL-, MEDIUM-SCALE CROSS-BEDDING

LARGE-SCALE CROSS-BEDDING

IRREGULAR, THIN-BEDDING

CLASTIC OR CARBONATE LENSES

BIOTURBATED, BURROWED SHAFTS WITH IRON-OXIDE

CALCAREOUS NATURE OF SEDIMENTS

THIN BEDDED, SLIGHTLY CONSOLIDATED CALCARENITES

MEDIUM BEDDED, SLIGHTLY CONSOLIDATED CALCARENITES

COBBLE-BOULDER SIZED

PEBBLE SIZED

SANDY GRAVELS

MUDDY SANDY GRAVELS

GRAVELLY SANDS

GRAVELLY MUDDY SANDS

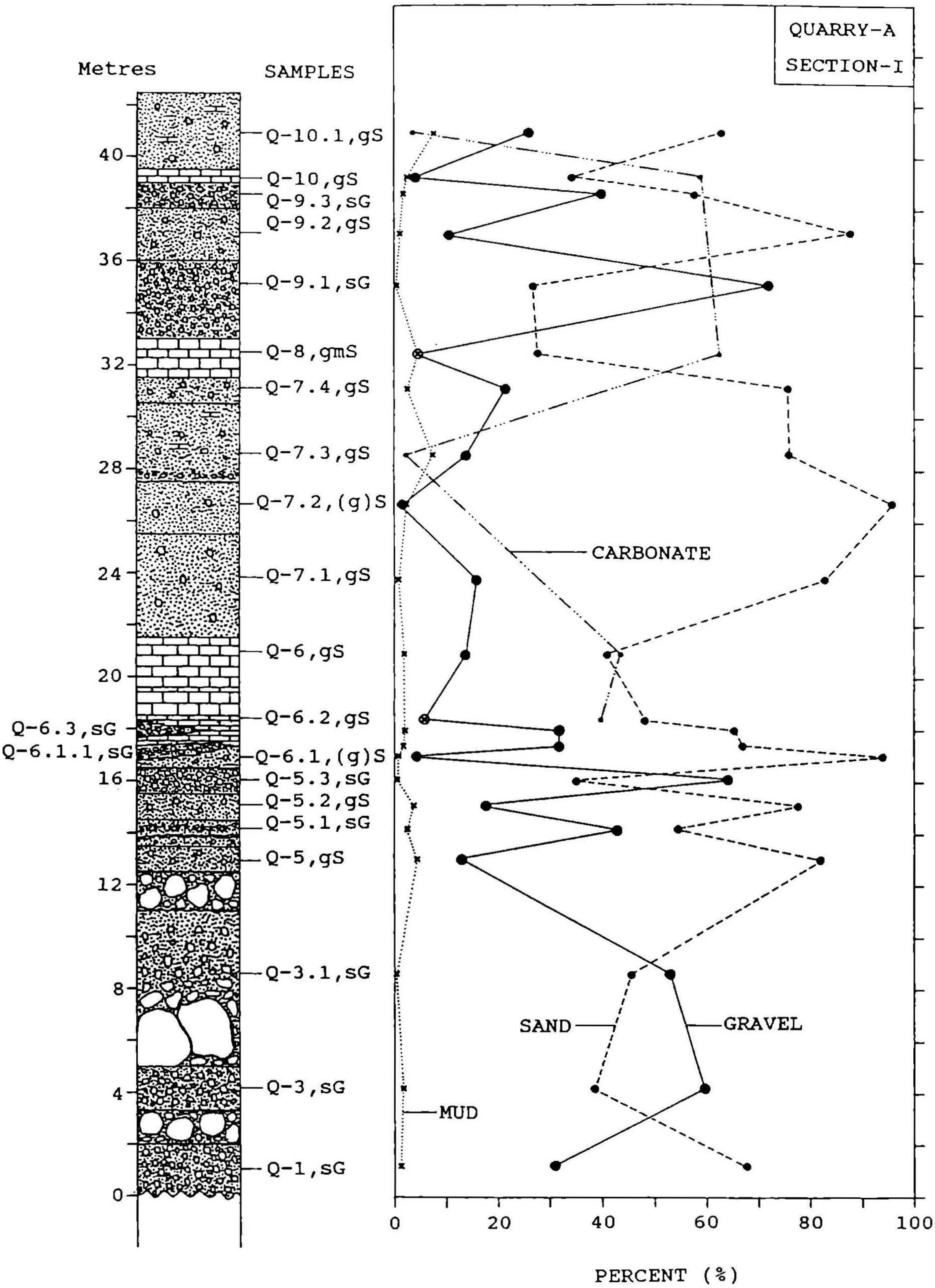
SLIGHTLY GRAVELLY MUDDY SANDS

SLIGHTLY GRAVELLY SANDS

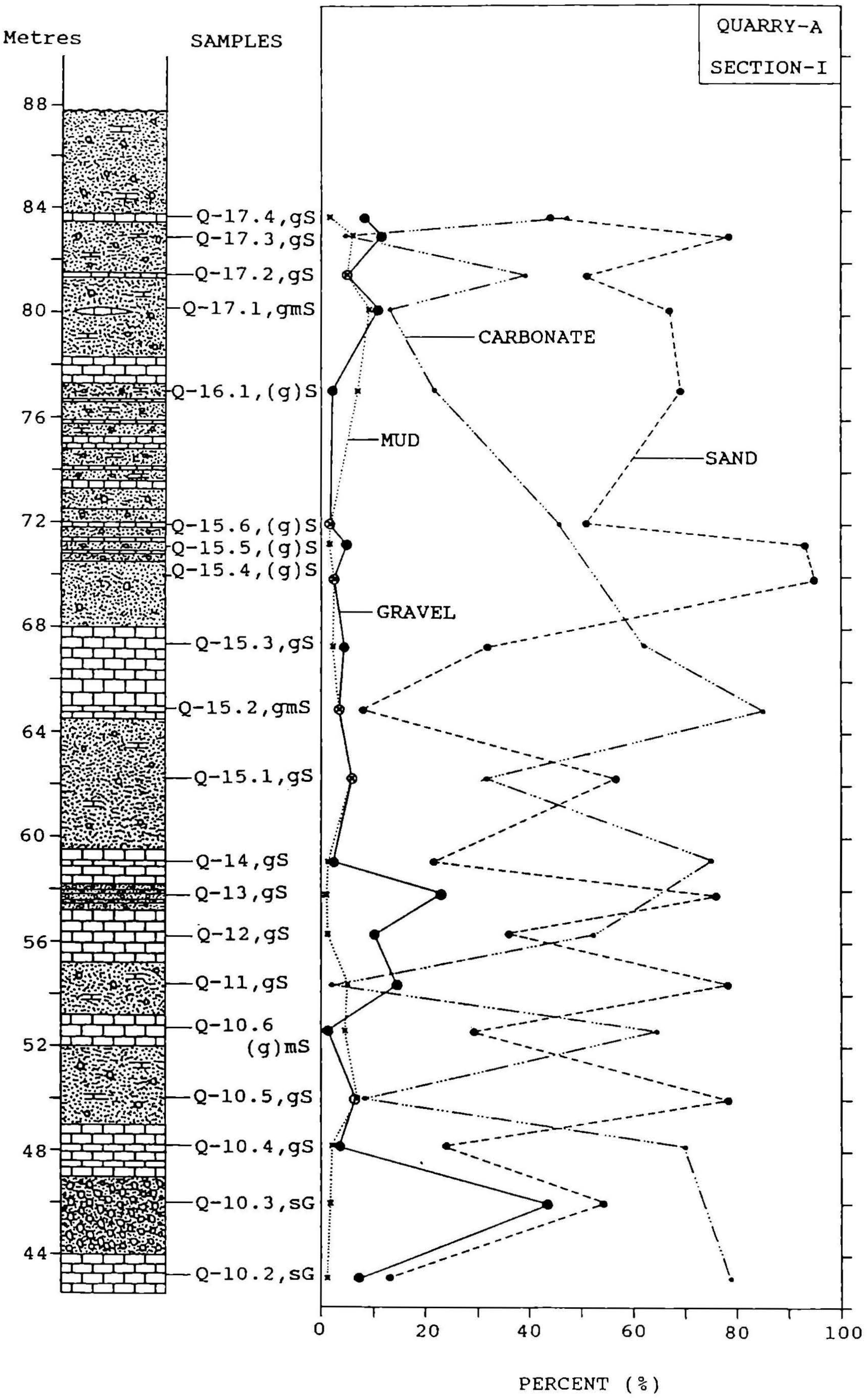
SANDS

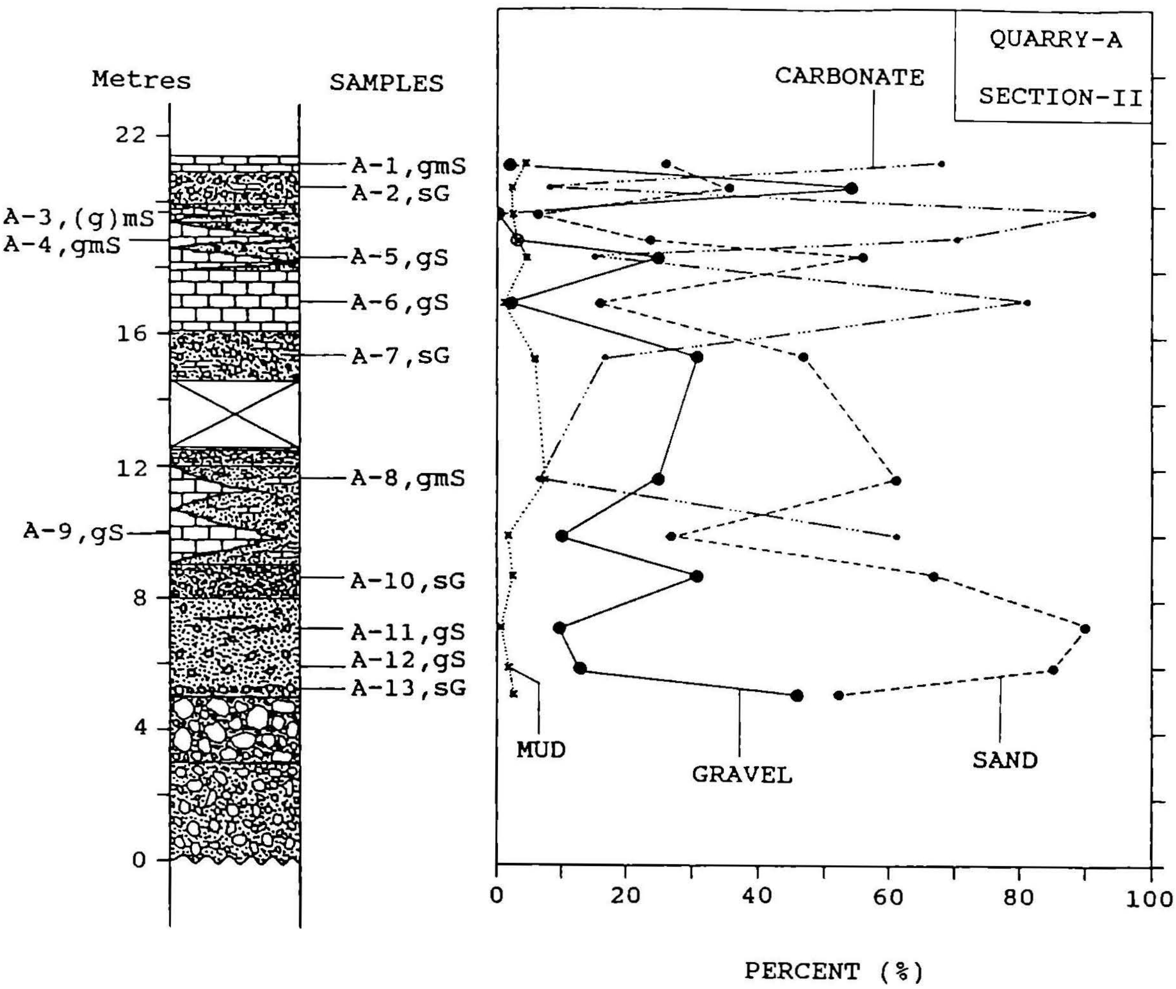
MUDS

COVERED

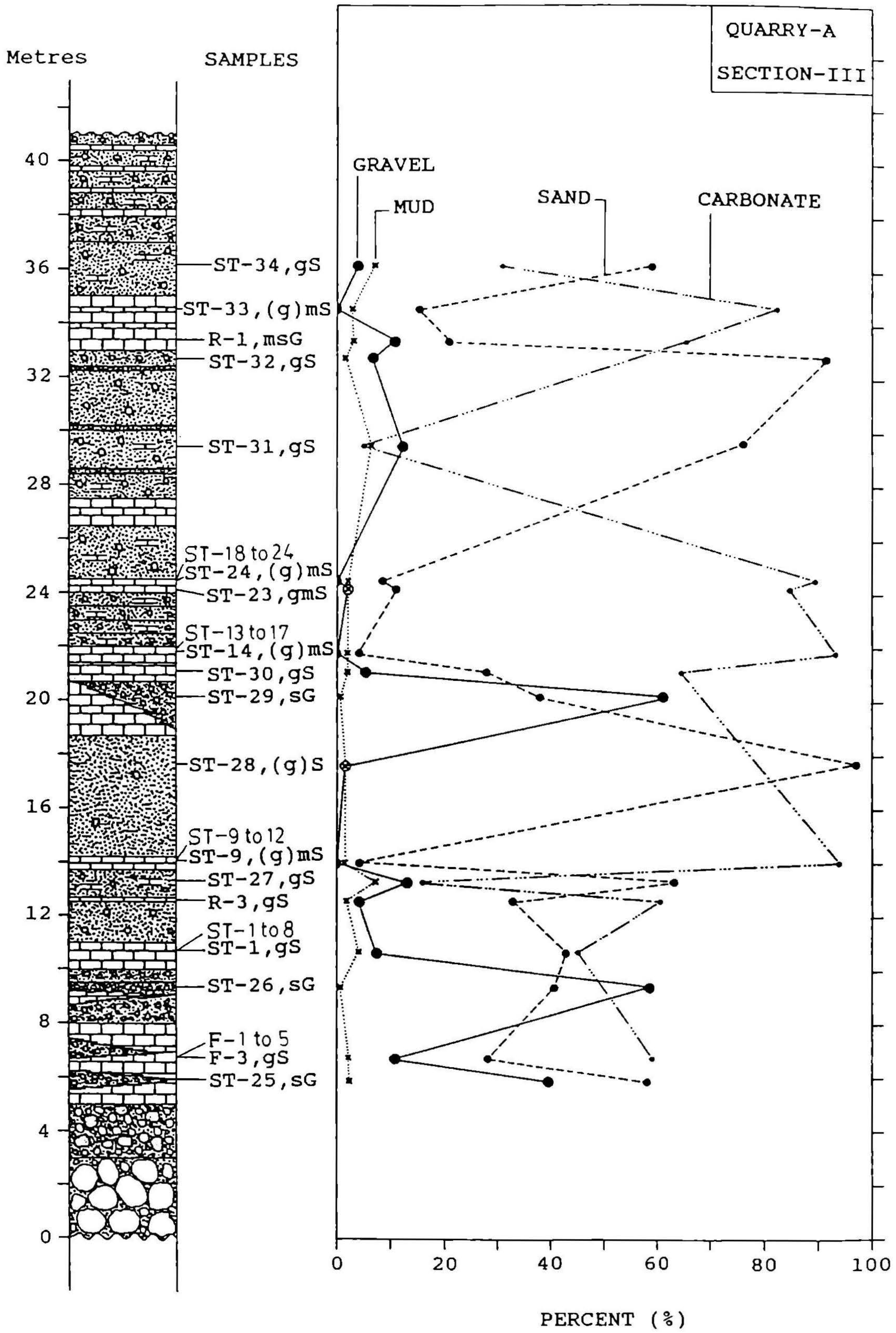


QUARRY-A
SECTION-I
Metres
SAMPLES
Q-10.1,gS
Q-10,gS
Q-9.3,sG
Q-9.2,gS
Q-9.1,sG
Q-8,gmS
Q-7.4,gS
Q-7.3,gS
Q-7.2,(g)S
Q-7.1,gS
Q-6,gS
Q-6.2,gS
Q-6.3,sG
Q-6.1.1,sG
Q-6.1,(g)S
Q-5.3,sG
Q-5.2,gS
Q-5.1,sG
Q-5,gS
Q-3.1,sG
Q-3,sG
Q-1,sG
0
4
8
12
16
20
24
28
32
36
40
CARBONATE
SAND
GRAVEL
MUD
0
20
40
60
80
100
PERCENT (%)

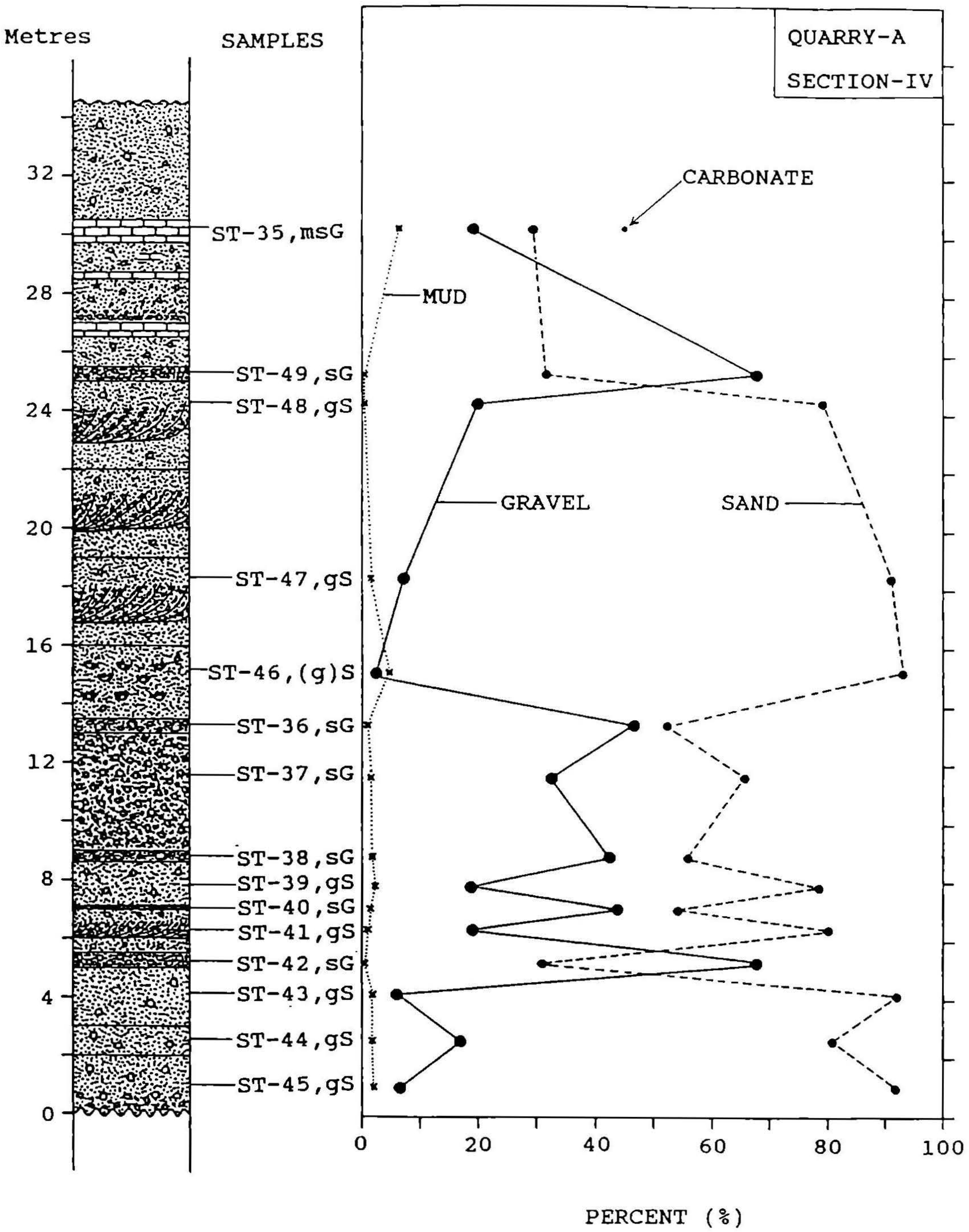

Metres
SAMPLES
QUARRY-A
SECTION-I
88
84
80
76
72
68
64
60
56
52
48
44
Q-17.4,gS
Q-17.3,gS
Q-17.2,gS
Q-17.1,gmS
Q-16.1,(g)S
Q-15.6,(g)S
Q-15.5,(g)S
Q-15.4,(g)S
Q-15.3,gS
Q-15.2,gmS
Q-15.1,gS
Q-14,gS
Q-13,gS
Q-12,gS
Q-11,gS
Q-10.6
(g)mS
Q-10.5,gS
Q-10.4,gS
Q-10.3,sG
Q-10.2,sG
CARBONATE
MUD
SAND
GRAVEL
0
20
40
60
80
100
PERCENT (%)



Metres
SAMPLES
QUARRY-A
SECTION-II
CARBONATE
22
16
12
8
4
0
A-1,gmS
A-2,sG
A-3,(g)mS
A-4,gmS
A-5,gS
A-6,gS
A-7,sG
A-8,gmS
A-9,gS
A-10,sG
A-11,gS
A-12,gS
A-13,sG
MUD
GRAVEL
SAND
0
20
40
60
80
100
PERCENT (%)



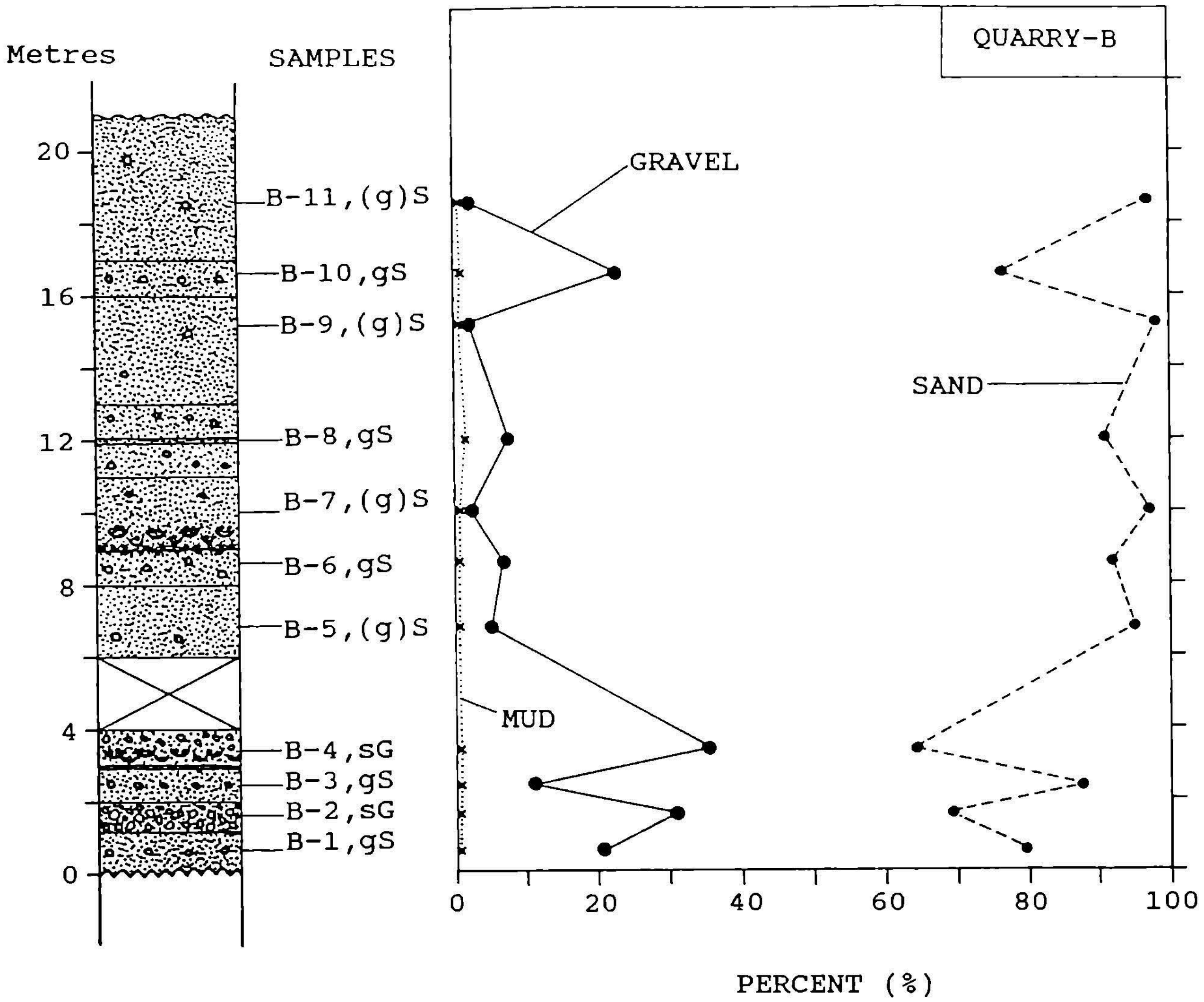
QUARRY-A
SECTION-III
Metres
SAMPLES
GRAVEL
MUD
SAND
CARBONATE
ST-34, gS
ST-33, (g)mS
R-1, msG
ST-32, gS
ST-31, gS
ST-18 to 24
ST-24, (g)mS
ST-23, gmS
ST-13 to 17
ST-14, (g)mS
ST-30, gS
ST-29, sG
ST-28, (g)S
ST-9 to 12
ST-9, (g)mS
ST-27, gS
R-3, gS
ST-1 to 8
ST-1, gS
ST-26, sG
F-1 to 5
F-3, gS
ST-25, sG
40
36
32
28
24
20
16
12
8
4
0
0
20
40
60
80
100
PERCENT (%)



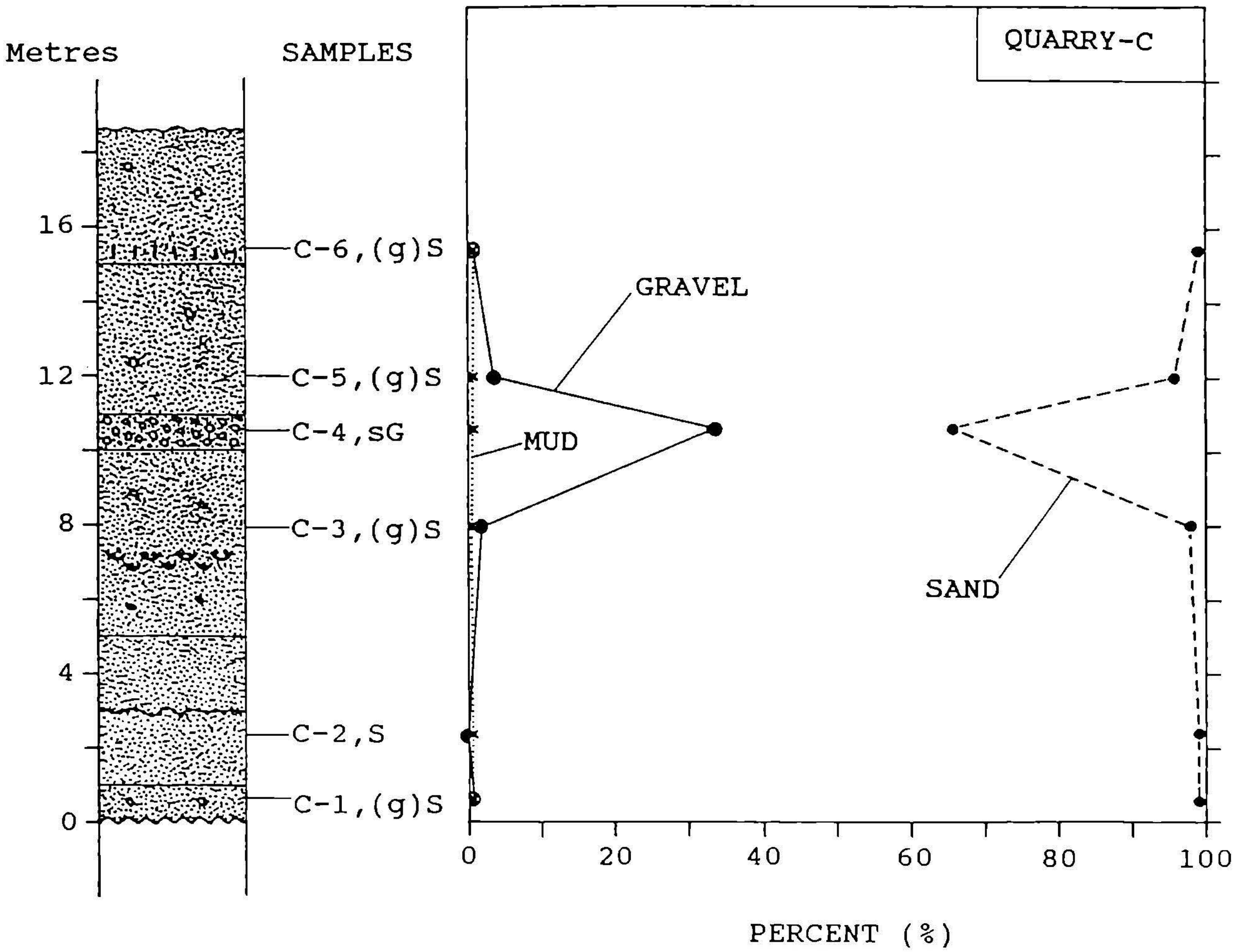
Metres
SAMPLES
QUARRY-A
SECTION-IV
CARBONATE
ST-35,msG
MUD
ST-49,sG
ST-48,gS
GRAVEL
SAND
ST-47,gS
ST-46,(g)S
ST-36,sG
ST-37,sG
ST-38,sG
ST-39,gS
ST-40,sG
ST-41,gS
ST-42,sG
ST-43,gS
ST-44,gS
ST-45,gS
32
28
24
20
16
12
8
4
0
0
20
40
60
80
100
PERCENT (%)

APPENDIX 3B

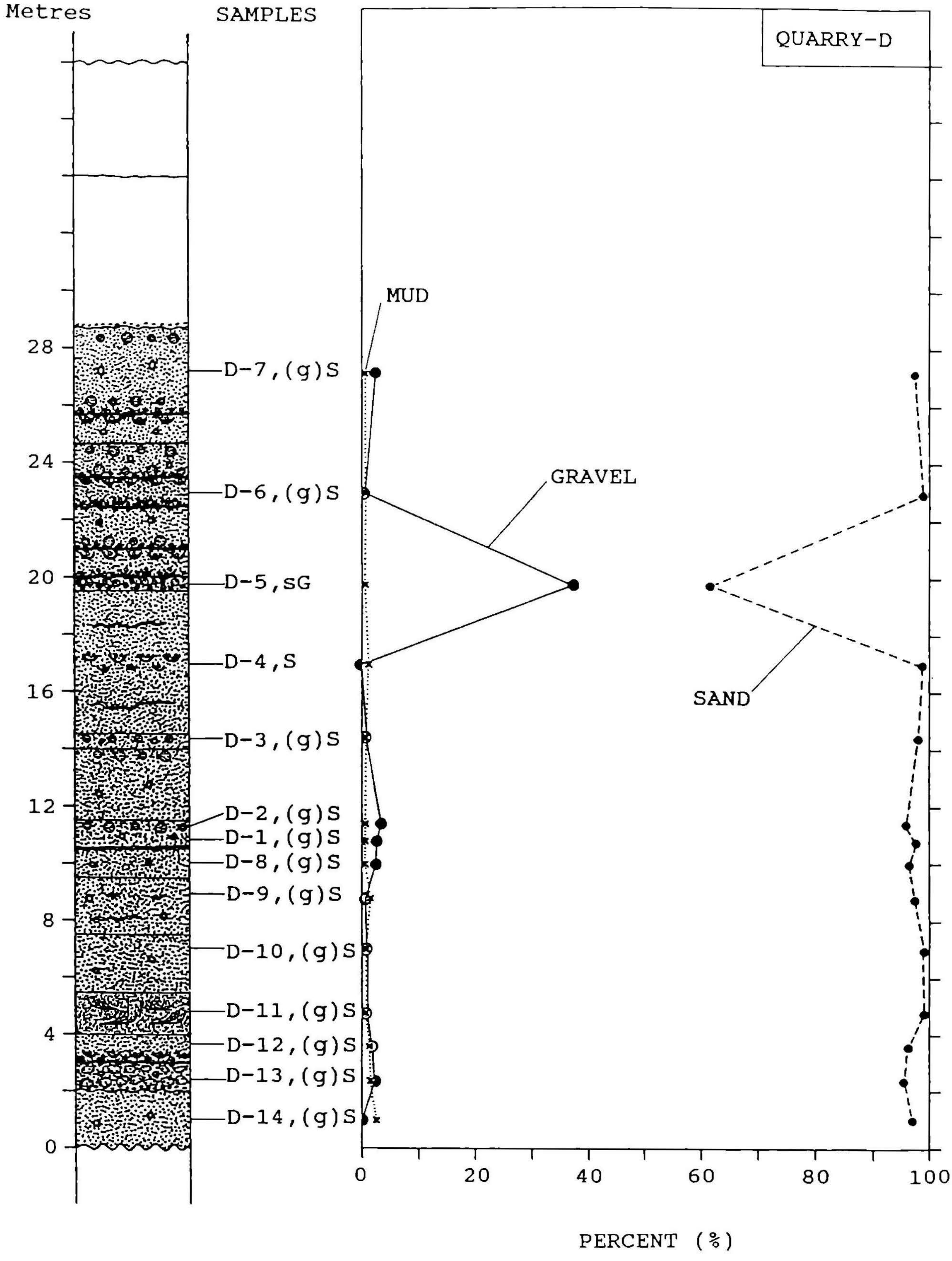
Vertical variations of gravel, sand, mud and carbonate contents plot for the sections of the Linz sand sequence



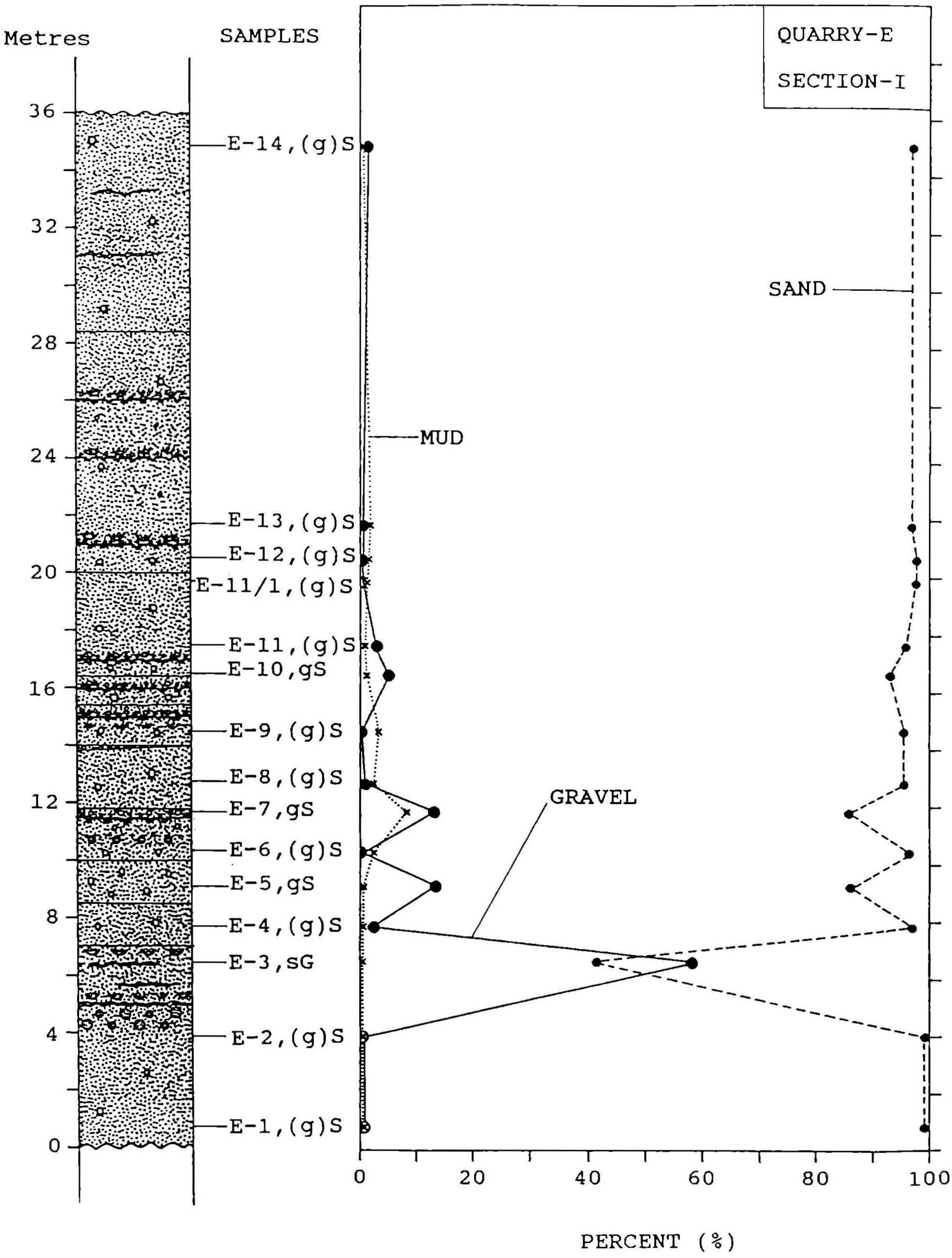
Metres
SAMPLES
QUARRY-B
GRAVEL
SAND
MUD
B-11,(g)S
B-10,gS
B-9,(g)S
B-8,gS
B-7,(g)S
B-6,gS
B-5,(g)S
B-4,sG
B-3,gS
B-2,sG
B-1,gS
0
4
8
12
16
20
0
20
40
60
80
100
PERCENT (%)



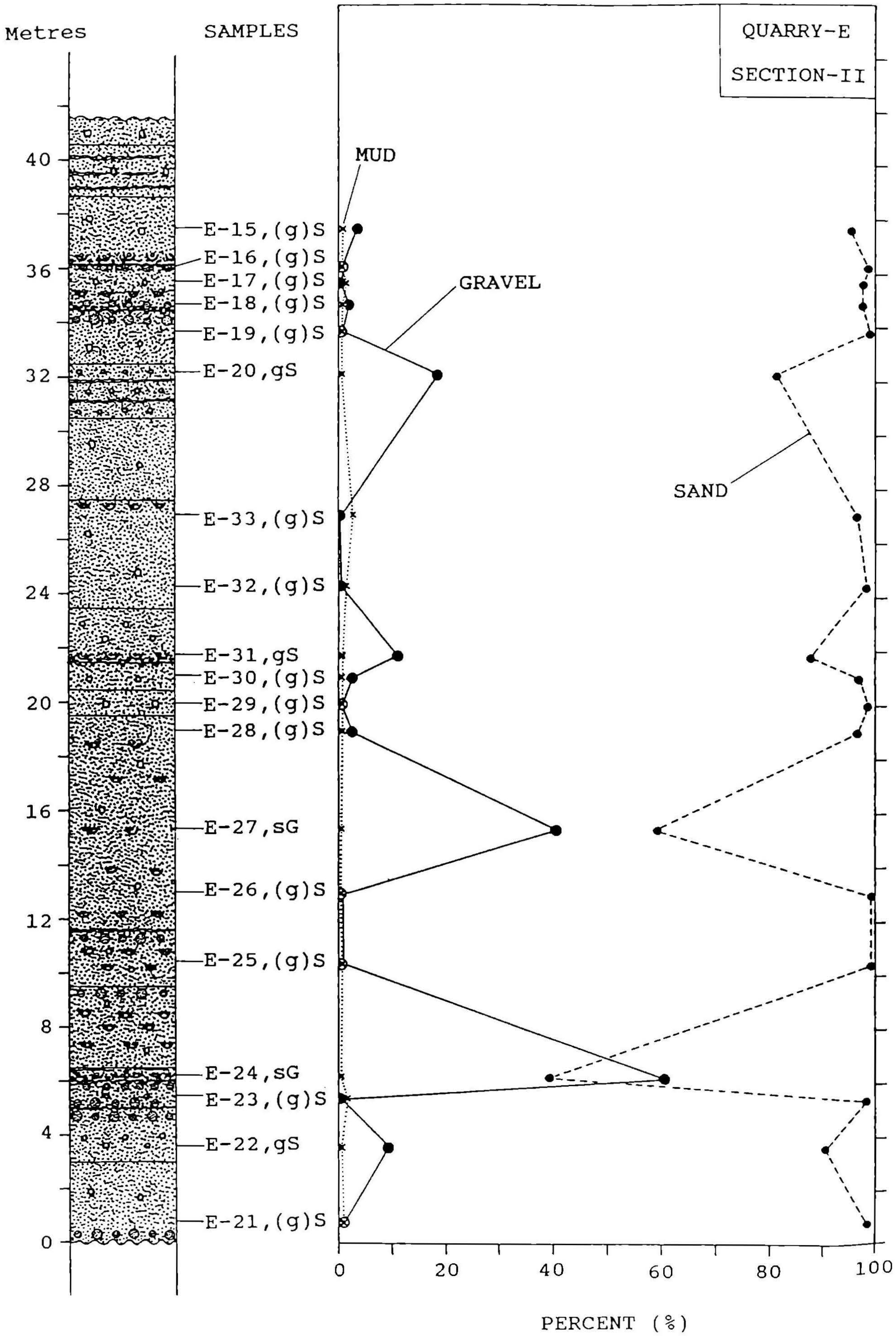
Metres
SAMPLES
QUARRY-C
GRAVEL
MUD
SAND
C-6,(g)S
C-5,(g)S
C-4,sG
C-3,(g)S
C-2,S
C-1,(g)S
0
4
8
12
16
0
20
40
60
80
100
PERCENT (%)

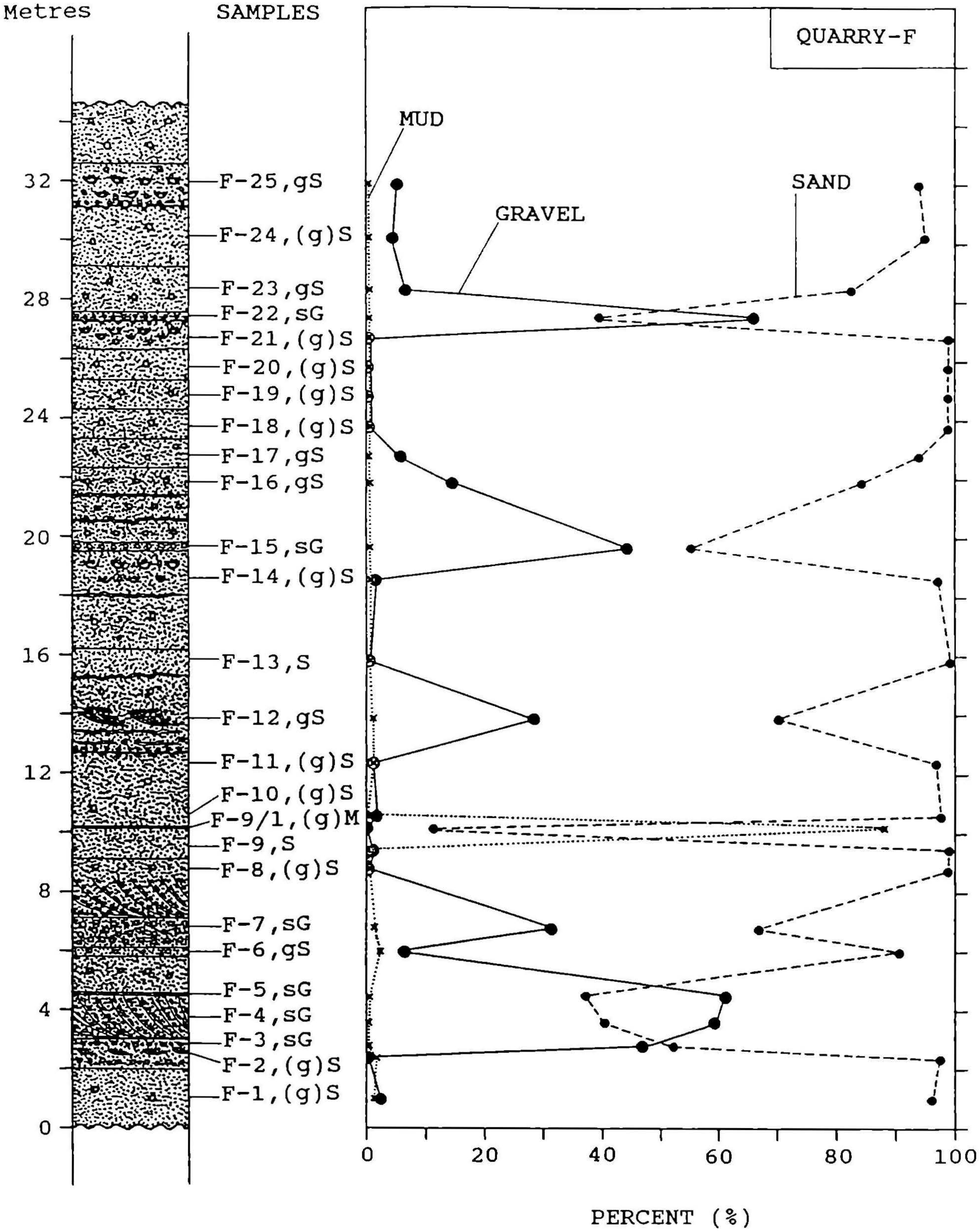


Metres
SAMPLES
QUARRY-D
MUD
GRAVEL
SAND
D-7,(g)S
D-6,(g)S
D-5,sG
D-4,S
D-3,(g)S
D-2,(g)S
D-1,(g)S
D-8,(g)S
D-9,(g)S
D-10,(g)S
D-11,(g)S
D-12,(g)S
D-13,(g)S
D-14,(g)S
28
24
20
16
12
8
4
0
0
20
40
60
80
100
PERCENT (%)

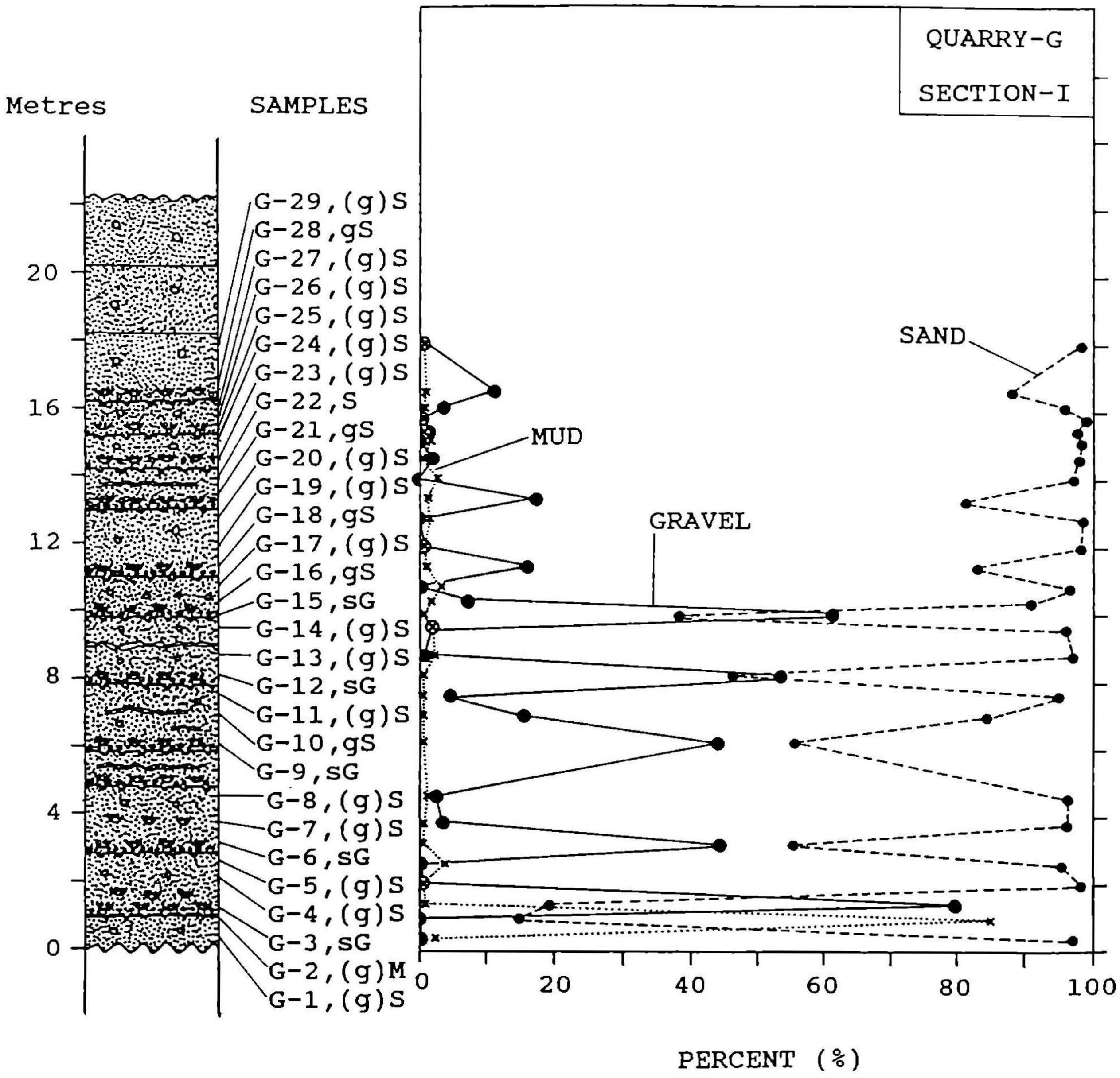


Metres
SAMPLES
QUARRY-E
SECTION-I
36
32
28
24
20
16
12
8
4
0
E-14,(g)S
E-13,(g)S
E-12,(g)S
E-11/1,(g)S
E-11,(g)S
E-10,gS
E-9,(g)S
E-8,(g)S
E-7,gS
E-6,(g)S
E-5,gS
E-4,(g)S
E-3,sG
E-2,(g)S
E-1,(g)S
SAND
MUD
GRAVEL
0
20
40
60
80
100
PERCENT (%)


Metres
SAMPLES
QUARRY-E
SECTION-II
MUD
GRAVEL
SAND
E-15,(g)S
E-16,(g)S
E-17,(g)S
E-18,(g)S
E-19,(g)S
E-20,gS
E-33,(g)S
E-32,(g)S
E-31,gS
E-30,(g)S
E-29,(g)S
E-28,(g)S
E-27,sG
E-26,(g)S
E-25,(g)S
E-24,sG
E-23,(g)S
E-22,gS
E-21,(g)S
0 4 8 12 16 20 24 28 32 36 40
0 20 40 60 80 100
PERCENT (%)



Metres
SAMPLES
QUARRY-F
MUD
SAND
GRAVEL
F-25,gS
F-24,(g)S
F-23,gS
F-22,sG
F-21,(g)S
F-20,(g)S
F-19,(g)S
F-18,(g)S
F-17,gS
F-16,gS
F-15,sG
F-14,(g)S
F-13,S
F-12,gS
F-11,(g)S
F-10,(g)S
F-9/1,(g)M
F-9,S
F-8,(g)S
F-7,sG
F-6,gS
F-5,sG
F-4,sG
F-3,sG
F-2,(g)S
F-1,(g)S
32
28
24
20
16
12
8
4
0
0
20
40
60
80
100
PERCENT (%)



QUARRY-G
SECTION-I
Metres
SAMPLES
G-29,(g)S
G-28,gS
G-27,(g)S
G-26,(g)S
G-25,(g)S
G-24,(g)S
G-23,(g)S
G-22,S
G-21,gS
G-20,(g)S
G-19,(g)S
G-18,gS
G-17,(g)S
G-16,gS
G-15,sG
G-14,(g)S
G-13,(g)S
G-12,sG
G-11,(g)S
G-10,gS
G-9,sG
G-8,(g)S
G-7,(g)S
G-6,sG
G-5,(g)S
G-4,(g)S
G-3,sG
G-2,(g)M
G-1,(g)S
0
4
8
12
16
20
SAND
MUD
GRAVEL
0
20
40
60
80
100
PERCENT (%)

APPENDIX 4A

Raw statistical parameters.

for samples of

the terrigenous mixed carbonate sequence

of Steyregg

	SAMPLE NO.	TEXTURAL TERMINOLOGY (LEGEND)	LARGEST GRAIN-SIZE	LARGEST in Microns	MEDIAN phi at 50th %	MEDIAN in Microns	GRAPHIC MEAN (phi)	GRAPHIC S.D (phi)	SKEWNESS (FOLK)	KURTOSIS (FOLK)	1st MODE (phi)	2nd MODE (phi)	3rd MODE (phi)	4th MODE (phi)	MODE TYPE(S)
UNCONSOLIDATED	A-10	sG	-2.5	5657	0.0	1000	0.267	1.944	0.172	0.806	-1.3	3.0	5.0	6.0	MULTI-
NON-CALCAREOUS	A-11	gS	-2.0	4000	2.0	250	1.333	1.502	-0.585	0.678	2.5	-0.5	1.0		TRI-
STEYREGG	A-12	gS	-3.0	8000	1.0	500	0.933	1.638	-0.106	0.820	2.5	1.0			BI-
MOLASSE	A-13	sG	-4.0	16000	-0.8	1741	-0.667	2.586	0.068	0.854	-2.5	3.0			BI-
SEDIMENTS	Q-1	sG	-3.0	8000	0.1	930	0.100	2.039	-0.032	0.820	-0.5	1.0	2.5	-3.0	MULTI-
(43-SAMPLES)	Q-3	sG	-3.0	8000	-1.5	2828	-0.867	2.080	0.425	0.922	-1.5	-2.5	2.5		TRI-
	Q-3.1	sG	-3.0	8000	-1.2	2297	-0.833	1.999	0.284	0.781	-2.5	-1.5	1.0		TRI-
	Q-5	gS	-3.0	8000	2.1	235	1.467	1.880	-0.455	1.359	2.8	-1.8			BI-
	Q-5.1	sG	-3.0	8000	-0.5	1414	-0.167	2.350	0.184	0.615	3.0	-2.5	-1.0		TRI-
	Q-5.2	gS	-4.0	16000	2.1	235	1.267	1.934	-0.522	0.768	3.0	0.5			BI-
	Q-5.3	sG	-4.0	16000	-2.3	4924	-1.167	2.626	0.535	0.766	-3.0	3.0			BI-
	Q-6.1	(g)S	-3.0	8000	2.6	165	2.367	1.042	-0.552	2.576	3.0				UNI-
	Q-6.1.1	sG	-3.0	8000	0.5	710	0.300	2.335	-0.109	0.634	3.0	-2.5	-0.5		TRI-
	Q-6.3	sG	-3.0	8000	-0.3	1231	-0.033	1.859	0.205	1.118	-0.3	-2.5	3.0		TRI-
	Q-7.1	gS	-3.0	8000	0.3	810	0.533	1.583	0.146	0.788	0.5	2.5			BI-
	Q-7.2	(g)S	-2.0	4000	2.2	220	1.867	1.191	-0.375	0.888	3.0	1.0			BI-
	Q-7.4	gS	-3.0	8000	1.0	500	0.700	2.110	-0.215	0.807	3.0	1.0	-2.5		TRI-
	Q-9.1	sG	-4.0	16000	-2.9	7464	-1.867	2.240	0.622	0.915	-3.0	2.0			BI-
	Q-9.2	gS	-3.0	8000	1.5	355	1.100	1.317	-0.435	1.503	2.0	-1.0			BI-
	Q-9.3	sG	-3.0	8000	-0.5	1414	-0.333	2.064	0.152	0.907	-2.5	-1.0	1.0	3.0	MULTI-
	Q-10.3	sG	-4.0	16000	-0.3	1231	-0.767	2.752	-0.149	0.537	2.0	-2.5	2.5		TRI-
	Q-13	gS	-3.0	8000	0.4	760	0.100	1.623	-0.270	1.148	1.0	-3.0			BI-
	Q-15.4	(g)S	-2.5	5657	1.2	435	1.267	1.056	0.106	1.490	1.5				UNI-
	Q-15.5	(g)S	-2.5	5657	0.9	540	0.933	1.031	0.054	1.490	1.0				UNI-
	ST-25	sG	-3.0	8000	-0.2	1149	-0.267	2.135	0.032	0.859	-2.5	1.0	-1.5		TRI-
	ST-26	sG	-4.0	16000	-1.7	3249	-1.533	2.370	0.156	0.690	-2.5	1.0			BI-
	ST-28	(g)S	-2.0	4000	1.2	435	1.200	0.865	0.029	1.393	1.5				UNI-
	ST-29	sG	-3.0	8000	-1.6	3031	-1.167	1.713	0.368	0.820	-2.5	-1.5	1.0		TRI-
	ST-32	gS	-2.5	5657	0.9	540	0.900	1.202	-0.012	1.469	1.0				UNI-
	ST-36	sG	-4.0	16000	-0.7	1624	-0.633	2.291	0.021	0.798	-2.5	1.0			BI-
	ST-37	sG	-3.0	8000	-0.6	1516	-0.267	1.538	0.321	1.015	-0.8				UNI-
	ST-38	sG	-3.0	8000	-0.6	1516	-0.633	2.014	0.053	0.820	-2.5	1.0	0.0	5.0	MULTI-
	ST-39	gS	-2.5	5657	0.2	880	0.300	1.548	0.137	1.045	0.0	5.0			BI-
	ST-40	sG	-3.0	8000	-0.7	1624	-0.767	1.959	0.043	0.820	-3.0	-0.5	5.0		TRI-
	ST-41	gS	-2.5	5657	0.2	880	0.333	1.558	0.123	0.976	0.3	3.0	5.0		TRI-
	ST-42	sG	-5.0	31500	-5.0	31500	-3.033	2.948	0.881	0.675	-5.0	3.0	0.0	-3.0	MULTI-
	ST-43	gS	-2.5	5657	0.2	880	0.367	1.227	0.283	1.259	0.0	3.0			BI-
	ST-44	gS	-3.0	8000	0.0	1000	0.167	1.539	0.136	1.374	0.0	3.0	-2.5		TRI-
	ST-45	gS	-3.0	8000	0.6	660	0.700	1.287	0.118	1.284	0.8				UNI-
	ST-46	(g)S	-3.0	8000	2.0	250	1.800	1.397	-0.172	0.992	3.0	1.0			BI-
	ST-47	gS	-2.5	5657	0.9	540	0.800	1.342	-0.056	0.949	1.8	0.0			BI-
	ST-48	gS	-3.0	8000	0.1	930	-0.000	1.322	-0.125	1.178	1.0	-2.5			BI-
	ST-49	sG	-4.0	16000	-2.9	7464	-2.100	2.170	0.516	0.771	-3.0	1.0	-1.0		TRI-

	SAMPLE NO.	TEXTURAL TERMINOLOGY (LEGEND)	LARGEST GRAIN-SIZE	LARGEST in Microns	MEDIAN phi at 50th %	MEDIAN in Microns	GRAPHIC MEAN (phi)	GRAPHIC S.D (phi)	SKEWNESS (FOLK)	KURTOSIS (FOLK)	1st MODE (phi)	2nd MODE (phi)	3rd MODE (phi)	4th MODE (phi)	MODE TYPE(S)
UNCONSOLIDATED	A-2	sG	-3.0	8000	-1.6	3031	-1.133	1.989	0.392	0.747	-2.5	-1.5	1.3		TRI-
CALCAREOUS	A-5	gS	-3.0	8000	0.1	930	0.333	2.136	0.210	0.956	-0.8	3.0	5.0		TRI-
STEYREGG	A-7	sG	-3.0	8000	-0.3	1231	-0.100	2.386	0.173	0.878	-0.5	-1.5	-2.5	3.0	MULTI-
MOLASSE	A-8	gmS	-3.0	8000	0.5	710	0.667	2.186	0.170	0.797	-1.0	3.0	5.0		TRI-
SEDIMENTS	Q-7.3	gS	-3.0	8000	1.1	435	1.133	2.070	0.063	0.912	3.0	0.0	5.0	6.0	MULTI-
(15-SAMPLES)	Q-10.1	gS	-3.0	8000	0.4	760	0.533	2.447	0.097	0.899	0.0	3.0	-3.0	6.0	MULTI-
	Q-10.5	gS	-2.5	5657	1.0	500	1.133	1.809	0.189	0.878	0.5	3.0	5.0	6.0	MULTI-
	Q-11	gS	-3.0	8000	1.3	405	0.967	1.936	-0.270	2.364	1.5				UNI-
	Q-15.1	gS	-2.5	5657	0.8	570	1.133	1.835	0.293	2.664	1.0	3.0	5.0		TRI-
	Q-16.1	(g)S	-3.0	8000	1.6	330	1.767	1.378	0.250	1.448	1.5	5.0	6.0		TRI-
	Q-17.1	gmS	-2.5	5657	1.2	435	1.200	2.026	0.049	1.164	1.0	3.0	5.0	6.0	MULTI-
	Q-17.3	gS	-3.0	8000	0.7	620	0.767	1.770	0.141	1.249	1.0	5.0	6.0		TRI-
	ST-27	gS	-3.0	8000	0.9	540	1.000	2.161	0.057	1.025	1.0	3.0	5.0		TRI-
	ST-31	gS	-2.5	5657	0.9	540	0.900	1.835	0.069	1.158	1.0	5.0	6.0		TRI-
	ST-34	gS	-2.5	5657	1.8	285	1.767	1.595	-0.020	1.639	2.0	5.0	6.0		TRI-
CONSOLIDATED	A-1	gmS	-2.0	4000	1.6	330	1.767	2.036	0.193	1.103	1.5	3.0	5.5	8.0	MULTI-
CARBONATE	A-3	(g)mS	-2.5	5657	2.5	180	3.000	2.207	0.260	1.453	3.0	1.0	5.5	8.0	MULTI-
MIXED	A-4	gmS	-2.5	5657	0.9	540	1.200	2.036	0.287	0.989	1.0	3.0	5.5	7.5	MULTI-
TERRIGENOUS	A-6	gS	-2.0	4000	0.4	760	0.700	1.860	0.352	1.110	-0.5	3.0	6.0	8.5	MULTI-
STEYREGG	A-9	gS	-2.5	5657	0.3	810	0.433	1.955	0.137	0.890	-0.8	2.0	5.5	8.0	MULTI-
MOLASSE	F-3	gS	-2.0	4000	-0.7	1624	0.233	2.130	0.598	0.774	3.0	-1.0	1.0	5.0	MULTI-
(37-SAMPLES)	Q-6	gS	-3.0	8000	0.4	760	0.500	2.045	0.051	0.846	0.0	1.0	3.0	-2.5	MULTI-
	Q-6.2	gS	-2.5	5657	2.6	165	1.800	2.061	-0.429	0.989	3.0	0.0			BI-
	Q-8	gmS	-3.0	8000	0.9	540	1.167	2.595	0.262	1.548	1.0	-2.8	6.0	9.0	MULTI-
	Q-10	gS	-3.0	8000	1.6	330	1.400	1.924	-0.083	0.833	3.0	-0.3	1.0	5.5	MULTI-
consolidated calcarenites	Q-10.2	sG	-4.0	16000	0.5	710	-0.200	3.204	-0.182	0.565	3.0	1.0			BI-
	Q-10.4	gS	-2.5	5657	1.2	435	1.233	2.036	0.127	0.956	3.0	1.0	0.0	5.0	MULTI-
	Q-10.6	(g)mS	-2.0	4000	2.5	180	2.100	1.961	-0.167	1.148	3.0	1.0	5.5	9.0	MULTI-
	Q-12	gS	-2.5	5657	0.1	930	0.067	1.493	0.093	1.165	1.0	-0.3	3.5		TRI-
	Q-14	gS	-2.5	5657	1.0	500	0.867	1.539	-0.019	1.955	1.5	3.0	5.0	9.0	MULTI-
	Q-15.2	gmS	-3.0	8000	1.9	265	1.333	3.802	-0.067	1.016	3.0	1.0	6.0	9.0	MULTI-
	Q-15.3	gS	-2.5	5657	0.3	810	0.367	1.535	0.192	2.220	0.5	3.0			BI-
	Q-15.6	(g)S	-2.0	4000	0.9	540	0.900	1.071	0.061	1.528	1.0				UNI-
	Q-17.2	gS	-2.5	5657	0.9	540	0.967	1.845	0.212	1.347	1.0	0.0	5.0	6.0	MULTI-
	Q-17.4	gS	-2.5	5657	0.7	620	0.567	1.477	-0.087	0.855	2.0	-0.3	0.5		TRI-
	R-1	msG	-2.0	4000	-0.2	1149	0.400	2.342	0.461	1.200	-1.0	3.0	6.0	5.0	MULTI-
	R-3	gS	-2.0	4000	0.3	820	0.600	1.684	0.345	1.230	0.0	6.0	5.0		TRI-
	St-1	gS	-2.0	4000	0.8	570	1.000	2.121	0.210	1.166	1.0	3.0	6.0		TRI-
	St-9	(g)mS	-1.5	2828	3.1	118	3.400	2.313	0.186	2.177	3.3	6.0	7.0	8.5	MULTI-
	St-14	(g)mS	-2.0	4000	3.3	102	3.600	2.378	0.174	1.356	3.5	6.0	0.5	9.0	MULTI-
	St-23	gmS	-1.5	2828	0.6	660	1.133	2.377	0.402	1.145	0.0	1.0	3.0	6.0	MULTI-
	St-24	(g)mS	-1.5	2828	2.7	155	2.733	1.981	0.103	1.760	3.0	6.0	8.5	7.0	MULTI-
	ST-30	gS	-2.5	5657	0.3	810	0.733	1.990	0.323	1.056	0.0	3.0	5.0		TRI-
	ST-33	(g)mS	-1.5	2828	2.1	235	2.233	1.705	0.186	1.614	2.0	5.0	6.0	8.5	MULTI-
	ST-35	msG	-2.5	5657	-0.4	1320	0.433	2.533	0.516	0.850	-1.0	3.5	6.0	5.0	MULTI-
	W-1	(g)mS	-3.0	8000	1.8	285	1.833	1.886	0.115	1.366	2.0	5.0	6.0	8.5	MULTI-
	W-2	(g)mS	-2.5	5657	2.1	235	2.467	2.222	0.343	1.704	2.5	5.0	6.0	8.0	MULTI-
	W-3	sG	-2.5	5657	-0.6	1516	-0.367	1.936	0.286	1.148	-1.3	1.0	5.0	8.0	MULTI-
	W-4	(g)S	-1.5	2828	1.9	265	1.867	1.358	0.131	1.734	2.0				UNI-
	W-5	gmS	-3.0	8000	1.7	310	1.533	2.564	0.002	1.442	3.0	1.0	6.0	8.5	MULTI-
	W-6	gmS	-2.5	5657	2.6	165	2.133	2.374	-0.163	1.926	3.0	5.0	6.0	8.0	MULTI-
	W-7	gmS	-2.5	5657	2.2	220	2.200	1.976	0.021	1.455	3.0	5.0	6.0	8.0	MULTI-

APPENDIX 4A

Raw statistical parameters.

for samples of

the Linz sand sequence

LINZ SAND TOTAL 146-SAMPLES	SAMPLE NO.	TEXTURAL TERMINOLOGY (LEGEND)	LARGEST GRAIN-SIZE	LARGEST in Microns	MEDIAN phi at 50th %	MEDIAN in Microns	GRAPHIC MEAN (phi)	GRAPHIC S.D (phi)	SKEWNESS (FOLK)	KURTOSIS (FOLK)	1st MODE (phi)	2nd MODE (phi)	3rd MODE (phi)	4th MODE (phi)	MODE TYPE(S)
UNCONSOLIDATED	B-1	gS	-3.0	8000	0.8	570	0.467	1.447	-0.341	0.820	2.0	-1.0	-3.0		TRI-
LINZ SAND	B-2	sG	-3.0	8000	0.2	880	0.000	1.688	-0.179	0.789	2.0	-1.0			BI-
QUARRY-B	B-3	gS	-3.0	8000	1.3	405	1.067	1.523	-0.362	1.639	2.0	-3.0			BI-
(11-SAMPLES)	B-4	sG	-3.0	8000	0.7	620	0.033	2.048	-0.369	0.604	2.0	-2.5			BI-
	B-5	(g)S	-2.0	4000	1.0	500	0.933	1.080	-0.117	0.897	2.0	1.0			BI-
	B-6	gS	-2.0	4000	0.7	620	0.700	1.080	-0.043	0.897	1.0				UNI-
	B-7	(g)S	-2.0	4000	1.2	435	1.000	0.970	-0.295	0.977	2.0				UNI-
	B-8	gS	-2.5	5657	-0.1	1072	0.233	1.206	0.433	1.093	0.0				UNI-
	B-9	(g)S	-1.5	2828	0.4	760	0.533	0.970	0.181	0.794	0.0				UNI-
	B-10	gS	-3.0	8000	0.3	810	0.267	1.442	-0.016	0.784	2.0	0.0	-1.0		TRI-
	B-11	(g)S	-2.0	4000	0.7	620	0.633	0.698	-0.093	1.047	1.0				UNI-
UNCONSOLIDATED	C-1	(g)S	-1.5	2828	0.5	710	0.500	0.598	0.109	1.347	0.5				UNI-
LINZ SAND	C-2	S	0.5	710	2.4	190	2.400	0.412	-0.071	0.956	2.5				UNI-
QUARRY-C	C-3	(g)S	-1.5	2828	0.7	620	0.700	1.065	0.029	0.820	0.0	1.5			BI-
(6-SAMPLES)	C-4	sG	-4.0	16000	-0.2	1149	-0.533	2.005	-0.238	0.890	0.0	1.0	-2.5	-4.0	MULTI-
	C-5	(g)S	-2.0	4000	0.6	660	0.567	1.005	0.045	1.103	1.0	3.0			BI-
	C-6	(g)S	-2.0	4000	0.8	570	0.767	0.719	-0.077	1.184	1.0				UNI-
UNCONSOLIDATED	D-1	(g)S	-1.0	2000	2.7	155	2.667	0.745	-0.287	3.176	3.0	1.0			BI-
LINZ SAND	D-2	(g)S	-1.5	2828	0.4	760	0.433	0.986	0.178	1.516	0.5	3.0			BI-
QUARRY-D	D-3	(g)S	-1.5	2828	-0.1	1072	0.300	1.091	0.595	1.453	0.0	3.0			BI-
(14-SAMPLES)	D-4	S	0.5	710	2.7	155	2.733	0.372	0.110	1.776	3.0				UNI-
	D-5	sG	-4.0	16000	-0.3	1231	-0.700	2.111	-0.214	0.989	0.8	-4.0	-2.5	3.0	MULTI-
	D-6	(g)S	-1.0	2000	1.9	265	1.700	0.794	-0.341	0.888	2.5	1.0			BI-
	D-7	(g)S	-1.5	2828	0.7	620	0.800	1.125	0.105	0.751	0.5	2.5			BI-
	D-8	(g)S	-3.0	8000	1.8	285	1.500	1.040	-0.391	0.995	2.0	0.0	-3.0		TRI-
	D-9	(g)S	-3.0	8000	2.7	155	2.600	0.387	-0.214	1.148	3.0				UNI-
	D-10	(g)S	-1.0	2000	1.7	310	1.633	0.774	-0.250	1.639	2.0	0.5			BI-
	D-11	(g)S	-1.0	2000	0.3	810	0.633	1.035	0.415	0.729	0.0	2.0			BI-
	D-12	(g)S	-2.0	4000	2.3	205	1.700	1.371	-0.556	1.400	2.8	0.0			BI-
	D-13	(g)S	-2.5	5657	1.8	285	1.700	1.051	-0.184	1.416	2.0	0.0			BI-
	D-14	(g)S	-1.0	2000	2.6	165	2.533	0.583	-0.191	1.288	3.0				UNI-
UNCONSOLIDATED	E-1	(g)S	-1.5	2828	2.3	205	2.300	0.447	-0.038	1.066	2.5				UNI-
LINZ SAND	E-2	(g)S	-1.5	2828	2.3	205	2.333	0.452	0.022	1.230	2.5				UNI-
QUARRY-E	E-3	sG	-3.0	8000	-1.5	2828	-0.600	2.089	0.530	0.570	-1.5	-2.5	2.5		TRI-
(34-SAMPLES)	E-4	(g)S	-2.5	5657	1.2	435	1.333	1.306	0.096	0.713	3.0	1.0			BI-
	E-5	gS	-2.5	5657	0.4	760	0.433	1.327	0.077	1.037	1.0	3.0			BI-
	E-6	(g)S	-1.5	2828	2.6	165	2.267	0.995	-0.500	2.108	3.0	1.0			BI-
	E-7	gS	-3.0	8000	0.5	710	0.367	1.429	-0.194	1.828	1.0	-3.0	3.0		TRI-
	E-8	(g)S	-2.0	4000	2.6	165	2.100	1.281	-0.503	0.820	3.0	1.0	5.0		TRI-
	E-9	(g)S	-1.0	2000	2.8	145	2.500	0.925	-0.462	2.705	3.0	1.5			BI-
	E-10	gS	-2.0	4000	0.5	710	0.900	1.567	0.326	0.564	3.0	-0.5			BI-
	E-11	(g)S	-2.5	5657	0.6	660	0.633	0.890	0.180	1.548	0.8	3.0			BI-
	E-11/1	(g)S	-1.5	2828	0.5	710	0.567	0.945	0.257	1.475	1.0	3.0			BI-
	E-12	(g)S	-2.0	4000	2.3	205	2.000	1.101	-0.398	0.973	3.0	1.5			BI-
	E-13	(g)S	-2.0	4000	0.4	760	0.633	1.166	0.344	1.066	0.0	3.0			BI-
	E-14	(g)S	-2.0	4000	0.5	710	0.500	0.930	0.129	1.304	1.0				UNI-
	E-15	(g)S	-2.0	4000	2.7	155	2.633	0.806	-0.450	3.279	3.0				UNI-
	E-16	(g)S	-2.0	4000	2.2	220	2.033	1.236	-0.214	0.722	3.5	1.8			BI-
	E-17	(g)S	-2.0	4000	2.8	145	2.800	0.332	0.000	1.639	3.0				UNI-
	E-18	(g)S	-2.5	5657	1.9	265	1.533	1.270	-0.356	0.671	3.0	0.0			BI-
	E-19	(g)S	-2.0	4000	1.2	435	1.500	0.934	0.381	0.738	1.0	3.0			BI-
	E-20	gS	-3.0	8000	0.7	620	0.300	1.271	-0.414	0.934	1.0				UNI-

	SAMPLE NO.	TEXTURAL TERMINOLOGY (LEGEND)	LARGEST GRAIN-SIZE	LARGEST in Microns	MEDIAN phi at 50th %	MEDIAN in Microns	GRAPHIC MEAN (phi)	GRAPHIC S.D (phi)	SKEWNESS (FOLK)	KURTOSIS (FOLK)	1st MODE (phi)	2nd MODE (phi)	3rd MODE (phi)	4th MODE (phi)	MODE TYPE(S)
	E-21	(g)S	-2.0	4000	2.7	155	2.633	0.594	-0.356	2.664	3.0	1.0			BI-
	E-22	gS	-2.5	5657	0.2	880	0.333	1.161	0.178	0.892	0.0				UNI-
	E-23	(g)S	-2.0	4000	2.7	155	2.567	0.644	-0.431	2.664	3.0	1.5			BI-
	E-24	sG	-5.0	31500	-2.5	5657	-2.133	2.746	0.193	0.632	-2.5	-5.0	1.5		TRI-
	E-25	(g)S	-1.0	2000	1.6	330	1.500	0.693	-0.219	0.861	2.0				UNI-
	E-26	(g)S	-1.0	2000	2.2	220	2.200	0.538	-0.132	1.557	2.5				UNI-
	E-27	sG	-4.0	16000	0.2	880	-0.367	2.095	-0.345	0.709	1.0	-2.5	2.5	-4.0	MULTI-
	E-28	(g)S	-2.0	4000	1.0	500	1.300	1.251	0.272	0.708	1.0	3.0			BI-
	E-29	(g)S	-2.0	4000	0.8	570	1.100	0.930	0.470	1.366	1.0	3.0			BI-
	E-30	(g)S	-2.5	5657	0.8	570	0.867	1.176	0.094	1.198	1.0	3.0			BI-
	E-31	gS	-3.0	8000	0.1	930	0.333	1.342	0.266	1.202	0.0	3.0			BI-
	E-32	(g)S	-1.0	2000	2.7	155	2.667	0.498	-0.111	1.844	3.0	1.0			BI-
	E-33	(g)S	-2.0	4000	2.0	250	1.833	1.105	-0.152	0.717	3.0	1.0			BI-
UNCONSOLIDATED	F-1	(g)S	-2.5	5657	2.6	165	2.567	0.604	-0.236	1.464	3.0				UNI-
LINZ SAND	F-2	(g)S	-1.5	2828	2.6	165	2.267	0.980	-0.521	1.793	3.0	1.0			BI-
QUARRY-F	F-3	sG	-3.0	8000	-0.9	1866	-0.633	1.362	0.292	1.133	-1.0	1.0			BI-
(26-SAMPLES)	F-4	sG	-3.0	8000	-1.4	2639	-0.833	1.858	0.416	0.867	-2.5	2.5			BI-
	F-5	sG	-4.0	16000	-1.6	3031	-1.467	2.005	0.119	0.890	-1.5	-4.0	1.0	3.5	MULTI-
	F-6	gS	-3.0	8000	2.7	155	2.033	1.508	-0.633	1.138	3.0	1.0	-0.5		TRI-
	F-7	sG	-3.0	8000	0.8	570	0.700	2.049	-0.091	0.641	3.0	-1.0	2.0	1.0	MULTI-
	F-8	(g)S	-1.0	2000	1.3	405	1.367	0.824	0.134	1.043	1.3				UNI-
	F-9	S	-0.5	1414	1.3	405	1.367	0.794	0.139	1.066	1.5				UNI-
	F-9/1	(g)M	-1.0	2000	5.4	24	6.100	2.363	0.379	1.056	5.0	9.0	3.0		TRI-
	F-10	(g)S	-2.5	5657	0.0	1000	0.667	1.261	0.641	0.632	0.0	2.5			BI-
	F-11	(g)S	-2.5	5657	2.4	190	2.333	0.876	-0.294	2.225	3.0	0.0			BI-
	F-12	gS	-3.0	8000	-0.1	1072	-0.100	2.059	-0.017	0.768	0.0	2.5	-3.0	5.5	MULTI-
	F-13	S	-0.5	1414	1.3	405	1.167	0.874	-0.183	0.956	2.0	0.5			BI-
	F-14	(g)S	-3.0	8000	1.8	285	1.767	0.669	-0.161	1.522	2.0				UNI-
	F-15	sG	-3.0	8000	-0.5	1414	-0.433	2.014	0.066	0.615	-2.5	2.0	-1.5	0.8	MULTI-
	F-16	gS	-2.5	5657	1.7	310	1.233	1.688	-0.387	0.969	3.0	1.0	-1.5		TRI-
	F-17	gS	-3.0	8000	0.5	710	0.667	1.116	0.183	1.142	0.5				UNI-
	F-18	(g)S	-2.0	4000	1.6	330	1.600	0.874	-0.036	0.820	2.5	1.5			BI-
	F-19	(g)S	-2.0	4000	1.3	405	1.333	0.930	0.026	0.946	1.0				UNI-
	F-20	(g)S	-1.5	2828	1.3	405	1.300	0.714	-0.000	0.984	1.5				UNI-
	F-21	(g)S	-2.0	4000	1.0	500	0.967	0.849	-0.029	1.043	1.3				UNI-
	F-22	sG	-3.0	8000	-1.9	3732	-1.267	1.778	0.479	0.658	-2.5	-1.0			BI-
	F-23	gS	-2.5	5657	0.7	620	0.667	0.855	-0.167	2.049	1.0				UNI-
	F-24	(g)S	-2.0	4000	0.4	760	0.400	0.889	0.017	0.849	0.0	1.0			BI-
	F-25	gS	-4.0	16000	2.0	250	1.767	1.390	-0.629	3.432	2.5	1.0			BI-
UNCONSOLIDATED	G-1	(g)S	-1.5	2828	1.7	310	1.700	1.015	0.029	1.161	2.0				UNI-
LINZ SAND	G-2	(g)M	-1.5	2828	5.2	28	5.767	2.202	0.335	1.383	5.0	6.0	9.0	3.0	MULTI-
QUARRY-G	G-3	sG	-5.0	31500	-4.0	16000	-2.933	2.692	0.605	0.988	-3.0				UNI-
(55-SAMPLES)	G-4	(g)S	-2.0	4000	1.5	355	1.433	0.935	-0.149	1.192	2.0				UNI-
	G-5	(g)S	-2.5	5657	2.9	135	2.867	0.775	-0.242	1.691	3.0				UNI-
	G-6	sG	-3.0	8000	-0.7	1624	-0.500	2.074	0.139	0.833	-1.0	-3.0	1.0	3.0	MULTI-
	G-7	(g)S	-2.5	5657	1.5	355	1.500	1.256	-0.075	0.863	1.0	3.0			BI-
	G-8	(g)S	-2.5	5657	2.4	190	2.400	0.689	-0.155	1.698	2.5				UNI-
	G-9	sG	-4.0	16000	-0.6	1516	-0.700	1.949	-0.110	0.833	1.0	-2.5	-1.0		TRI-
	G-10	gS	-3.0	8000	0.8	570	0.533	1.412	-0.302	0.917	1.0	-2.5			BI-
	G-11	(g)S	-3.0	8000	1.1	465	0.900	1.000	-0.286	1.040	1.5	0.5	-2.5		TRI-
	G-12	sG	-4.0	16000	-1.1	2144	-1.000	1.990	0.076	0.947	-2.5	-1.0	1.0		TRI-
	G-13	(g)S	-2.0	4000	2.2	220	2.067	1.130	-0.155	0.755	3.0	1.5			BI-

SAMPLE NO.	TEXTURAL TERMINOLOGY (LEGEND)	LARGEST GRAIN-SIZE	LARGEST in Microns	MEDIAN phi at 50th %	MEDIAN in Microns	GRAPHIC MEAN (phi)	GRAPHIC S.D (phi)	SKEWNESS (FOLK)	KURTOSIS (FOLK)	1st MODE (phi)	2nd MODE (phi)	3rd MODE (phi)	4th MODE (phi)	MODE TYPE(S)
G-14	(g)S	-2.5	5657	2.6	165	2.167	1.216	-0.478	0.841	3.0	1.0			BI-
G-15	sG	-5.0	31500	-1.9	3732	-2.000	2.772	0.033	0.600	-2.5	1.0			BI-
G-16	gS	-3.0	8000	2.7	155	2.700	1.068	-0.315	4.426	3.0				UNI-
G-17	(g)S	-1.5	2828	2.7	155	2.667	0.498	0.056	1.475	3.0				UNI-
G-18	gS	-2.5	5657	1.1	465	0.900	1.658	-0.203	0.683	2.5	-0.5			BI-
G-19	(g)S	-1.5	2828	1.6	330	1.533	0.920	-0.168	0.977	2.0				UNI-
G-20	(g)S	-2.0	4000	2.1	235	2.067	0.658	-0.129	1.002	2.5				UNI-
G-21	gS	-3.0	8000	0.1	930	0.367	1.668	0.136	1.107	0.0	2.5	-2.5		TRI-
G-22	S	-0.5	1414	2.2	220	2.233	0.673	0.104	1.047	2.5				UNI-
G-23	(g)S	-2.5	5657	0.0	1000	0.633	1.220	0.630	0.820	0.0	2.5			BI-
G-24	(g)S	-1.5	2828	2.5	180	2.433	0.614	-0.183	1.405	2.8				UNI-
G-25	(g)S	-2.5	5657	0.7	620	0.767	1.020	0.094	0.794	0.0	2.0			BI-
G-26	(g)S	-1.0	2000	1.8	285	1.700	0.814	-0.221	1.189	2.0				UNI-
G-27	(g)S	-3.0	8000	1.0	500	0.900	1.090	-0.095	0.774	2.0	0.0			BI-
G-28	gS	-3.0	8000	1.1	465	0.900	1.548	-0.304	1.043	2.0	0.0	3.0		TRI-
G-29	(g)S	-2.0	4000	1.8	285	1.767	0.684	-0.212	1.581	2.0				UNI-
G-30	(g)S	-2.0	4000	2.6	165	2.567	0.770	-0.278	2.108	3.0	0.0			BI-
G-31	(g)S	-2.5	5657	0.9	540	1.000	1.301	0.078	0.649	0.0	2.5			BI-
G-32	gS	-3.0	8000	-0.3	1213	-0.100	1.277	0.178	1.639	0.0	2.0	-3.0		TRI-
G-33	S	-0.5	1414	1.8	285	1.767	0.623	-0.111	1.347	2.0				UNI-
G-34	(g)M	-1.0	2000	4.7	39	4.667	2.251	0.067	0.970	5.0	2.5	6.0	9.0	MULTI-
G-35	(g)S	-3.0	8000	2.1	235	2.067	0.589	-0.222	1.405	2.5				UNI-
G-36	(g)S	-2.0	4000	2.3	205	2.300	0.538	0.026	1.298	2.5				UNI-
G-37	sG	-4.0	16000	-2.9	7464	-1.900	2.495	0.541	0.707	-4.0	-2.5	2.5		TRI-
G-38	gS	-3.0	8000	1.6	330	1.333	1.447	-0.286	0.857	2.5	0.5			BI-
G-39	gS	-2.0	4000	0.5	710	0.500	1.286	0.048	1.148	1.0	-1.0	2.5		TRI-
G-40	gS	-2.5	5657	0.4	760	0.733	1.386	0.262	1.076	0.5	3.0			BI-
G-41	(g)S	-2.0	4000	2.2	220	1.900	0.995	-0.359	0.747	3.0	1.0			BI-
G-42	(g)S	-2.5	5657	1.3	405	1.233	1.161	-0.082	0.798	2.5	0.8			BI-
G-43	sG	-4.0	16000	-0.6	1516	-0.567	2.105	0.012	1.161	0.0	-3.0	3.0		TRI-
G-44	sG	-4.0	16000	-2.5	5657	-2.033	1.939	0.385	0.941	-3.0	-1.5			BI-
G-45	gS	-2.5	5657	2.4	190	2.100	1.172	-0.498	1.714	3.0	-1.0			BI-
G-46	(g)M	-1.0	2000	6.0	16	6.433	2.333	0.254	0.945	5.0	9.0	6.0	3.0	MULTI-
G-47	S	-0.5	1414	2.2	220	2.100	0.673	-0.268	1.178	2.5				UNI-
G-48	gS	-3.0	8000	0.1	930	0.267	1.458	0.091	1.734	0.0				UNI-
G-49	gS	-3.0	8000	2.1	235	1.233	1.783	-0.624	0.867	2.5	-1.0	-2.5		TRI-
G-50	(g)S	-2.5	5657	2.5	180	1.900	1.352	-0.612	1.037	3.0	0.5			BI-
G-51	sG	-2.5	5657	-0.8	1741	-0.600	1.548	0.268	1.148	-1.0	3.0			BI-
G-52	sG	-4.0	16000	-1.5	2828	-1.133	2.355	0.192	0.753	-2.5	2.0			BI-
G-53	(g)S	-2.5	5657	2.4	190	2.433	0.589	0.014	1.405	2.8				UNI-
G-54	sG	-4.0	16000	-0.5	1414	-0.533	2.186	-0.054	1.063	-0.5				UNI-
G-55	sG	-4.0	16000	-0.6	1516	-0.500	2.251	0.011	0.970	-0.8	1.0	3.0	-2.5	MULTI-

APPENDIX 4B

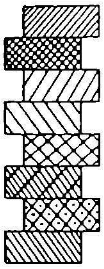
Histogram summarized the results

of

the grain size statistical parameters

LEGEND AND MAP VIEW FOR HISTOGRAM IN APPENDIX-4B

"TEXTURAL-TERMINOLOGY OF UNCONSOLIDATED SEDIMENTS"
(base on Folk, 1954 & 1980)



=	sandy gravel	sG
=	muddy sandy gravel	msG
=	gravelly sand	gS
=	slightly gravelly sand	(g)S
=	sand	S
=	gravelly muddy sand	gmS
=	slightly gravelly muddy sand	(g)mS
=	slightly gravelly mud	(g)M

VERBAL SCALES OF FOLK AND WARD (1975)

"INCLUSIVE GRAPHIC <u>STANDARD DEVIATION</u> (SORTING)"

VWS =	very well sorted	(<0.35 phi)
WS =	well sorted	(0.35 to 0.50 phi)
MWS =	moderately well sorted	(0.50 to 0.71 phi)
MS =	moderately sorted	(0.71 to 1.00 phi)
PS =	poorly sorted	(1.00 to 2.00 phi)
VPS =	very poorly sorted	(2.00 to 4.00 phi)
EPS =	extremely poorly sorted	(>4.00 phi)

"INCLUSIVE GRAPHIC <u>SKEWNESS</u>"

VCSK =	very coarse-skewed	(-1.0 to -0.3)
CSK =	coarse-skewed	(-0.3 to -0.1)
NSK =	near-symmetrical	(-0.1 to +0.1)
FSK =	fine-skewed	(+0.1 to +0.3)
VFSK =	very fine-skewed	(+0.3 to +1.0)

"GRAPHIC <u>KURTOSIS</u>"

VPK =	very platykurtic	(less than 0.67)
PK =	platykurtic	(0.67 to 0.90)
MK =	mesokurtic	(0.90 to 1.11)
LK =	leptokurtic	(1.11 to 1.50)
VLK =	very leptokurtic	(1.50 to 3.00)
ELK =	extremely leptokurtic	(more than 3.00)

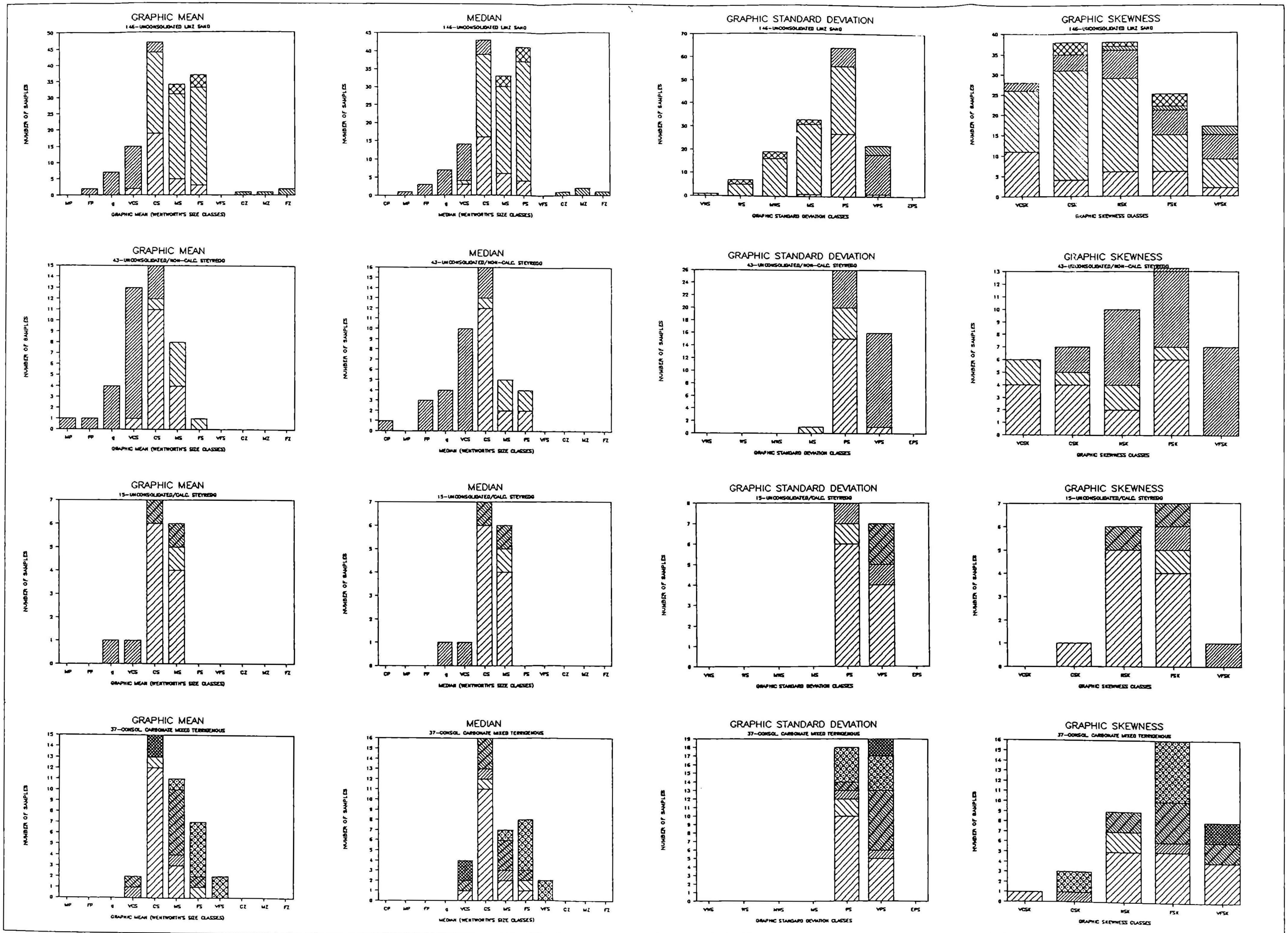
"WENTWORTH'S (1922) <u>GRAIN-SIZE</u> CLASSES"

VCP =	very coarse pebble	(-6.0 to -5.0 phi)
CP =	coarse pebble	(-5.0 to -4.0 phi)
MP =	medium pebble	(-4.0 to -3.0 phi)
FP =	fine pebble	(-3.0 to -2.0 phi)
g =	granule	(-2.0 to -1.0 phi)
VCS =	very coarse sand	(-1.0 to 0.0 phi)
CS =	coarse sand	(0.0 to +1.0 phi)
MS =	medium sand	(+1.0 to +2.0 phi)
FS =	fine sand	(+2.0 to +3.0 phi)
VFS =	very fine sand	(+3.0 to +4.0 phi)
CZ =	coarse silt	(+4.0 to +5.0 phi)
MZ =	medium silt	(+5.0 to +6.0 phi)
FZ =	fine silt	(+6.0 to +7.0 phi)
VFZ =	very fine silt	(+7.0 to +8.0 phi)
cly =	clay	(finer than +8.0 phi)

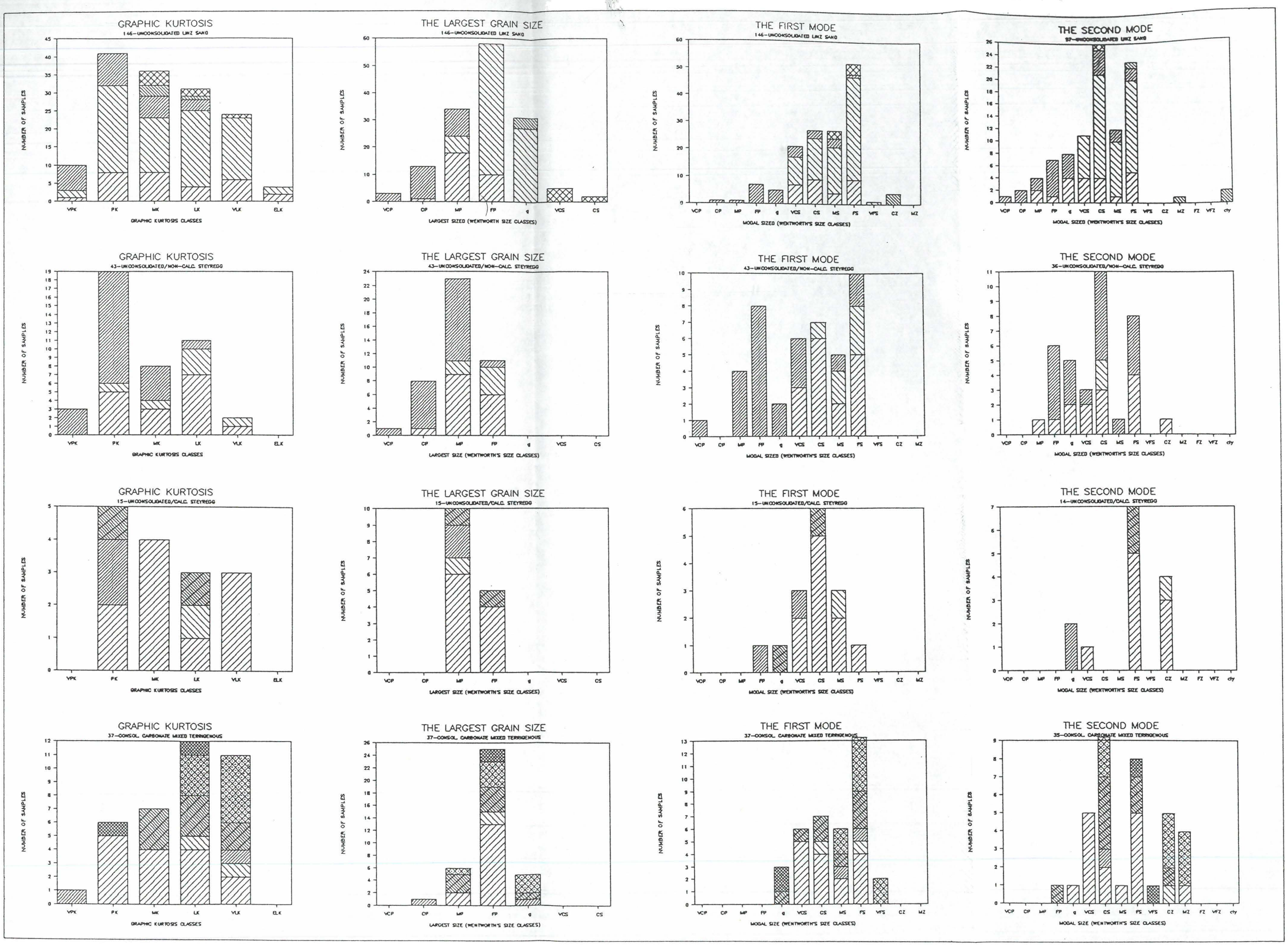
GROUPING OF SAMPLES	FREQUENCY HISTOGRAM OF ALL STATISTICAL PARAMETERS			
NON-CALCAREOUS LINZ SAND SEDIMENTS (146 SAMPLES)	ALL THE UPPER ROW	FROM (LEFT)	========>	TO (RIGHT)
NON-CALCAREOUS TERRIGENOUS SEDIMENTS, STEYREGG (43 SAMPLES)	ALL THE SECOND ROW	FROM (LEFT)	========>	TO (RIGHT)
CALCAREOUS-TERRIGENOUS SEDIMEMTS, STEYREGG (15 SAMPLES)	ALL THE THIRD ROW	FROM (LEFT)	========>	TO (RIGHT)
CONSOLIDATED CALCARENITES, STEYREGG (37 SAMPLES)	ALL THE FOURTH ROW	FROM (LEFT)	========>	TO (RIGHT)

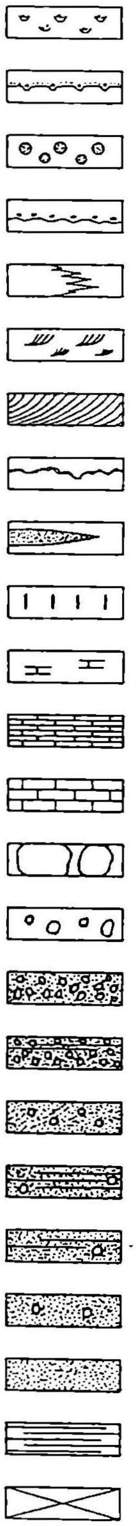
APPENDIX 4C

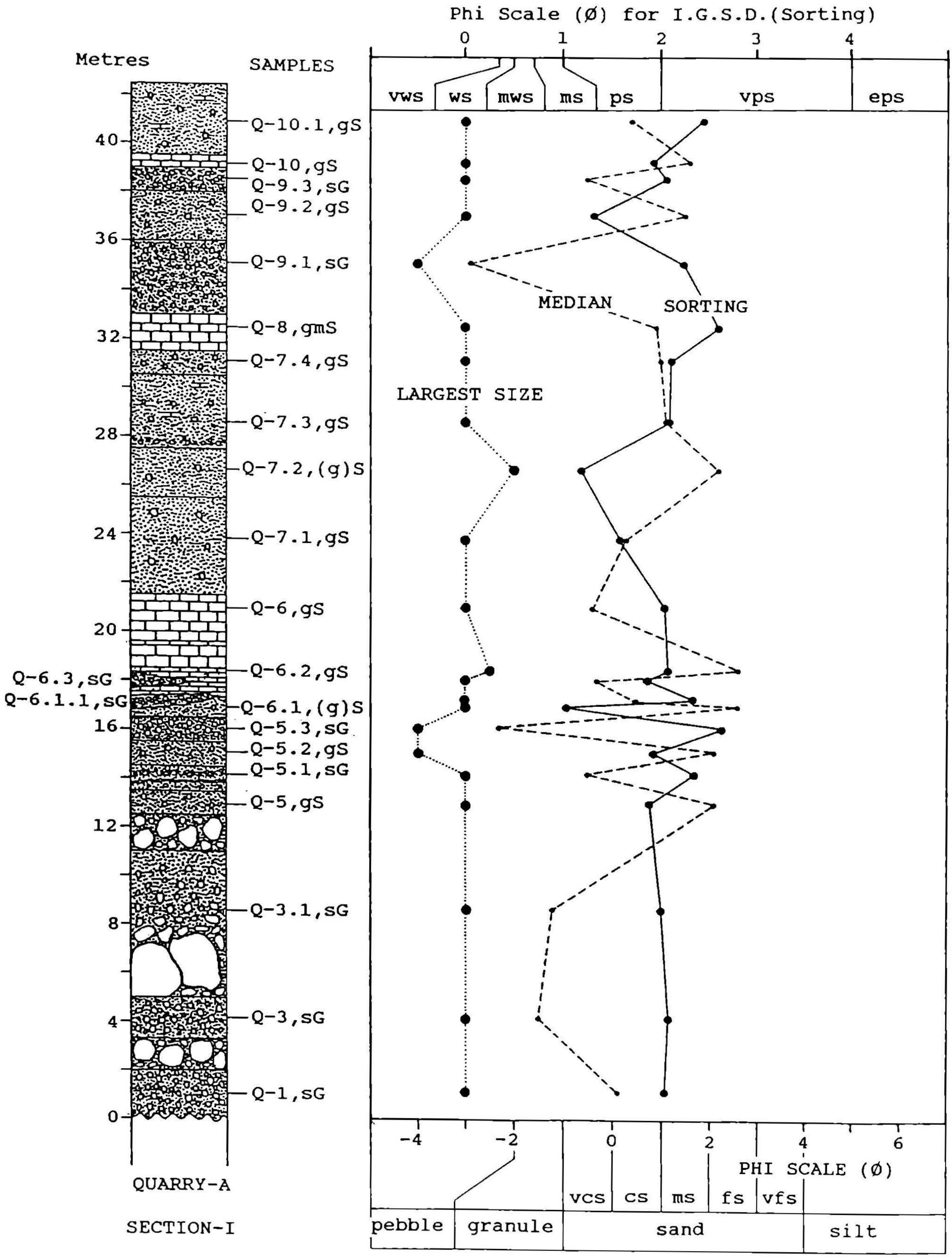
Vertical variations of the
statistical parameter plot
for the sections of
the terrigenous mixed carbonate sequence
of Steyregg

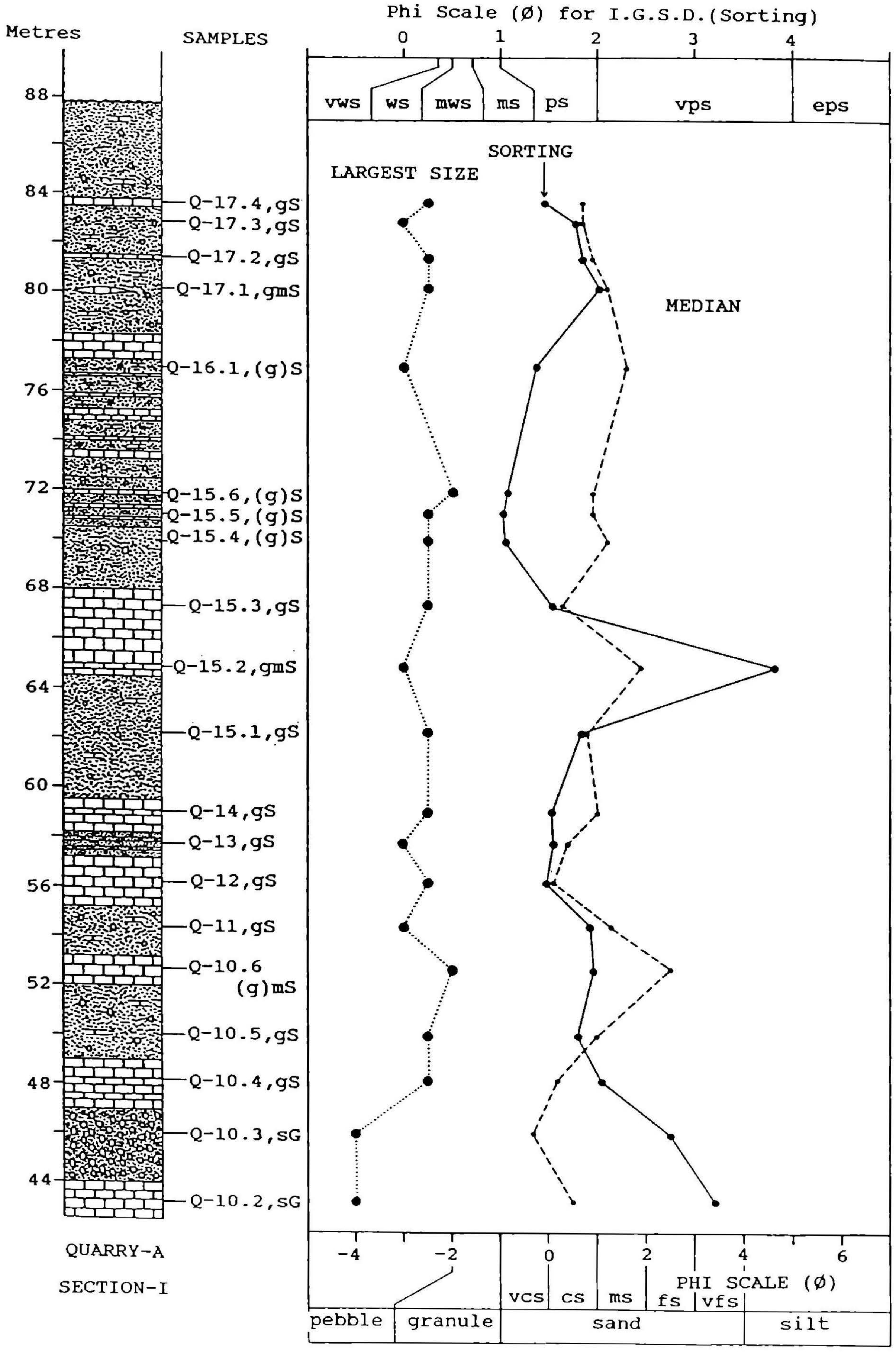


GRAPHIC MEAN
MEDIAN
GRAPHIC STANDARD DEVIATION
GRAPHIC SKEWNESS
GRAPHIC MEAN
MEDIAN
GRAPHIC STANDARD DEVIATION
GRAPHIC SKEWNESS
GRAPHIC MEAN
MEDIAN
GRAPHIC STANDARD DEVIATION
GRAPHIC SKEWNESS
37-CONSOL. CARBONATE MIXED TERRIGENOUS
GRAPHIC MEAN
MEDIAN
GRAPHIC STANDARD DEVIATION
GRAPHIC SKEWNESS
NUMBER OF SAMPLES
MP FP g VCS CS MS FS VFS CZ MZ FZ
GRAPHIC MEAN (WENTWORTH'S SIZE CLASSES)
MEDIAN (WENTWORTH'S SIZE CLASSES)
VWS WS MWS MS PS VPS EPS
GRAPHIC STANDARD DEVIATION CLASSES
VCSK CSK NSK FSK VFSK
GRAPHIC SKEWNESS CLASSES

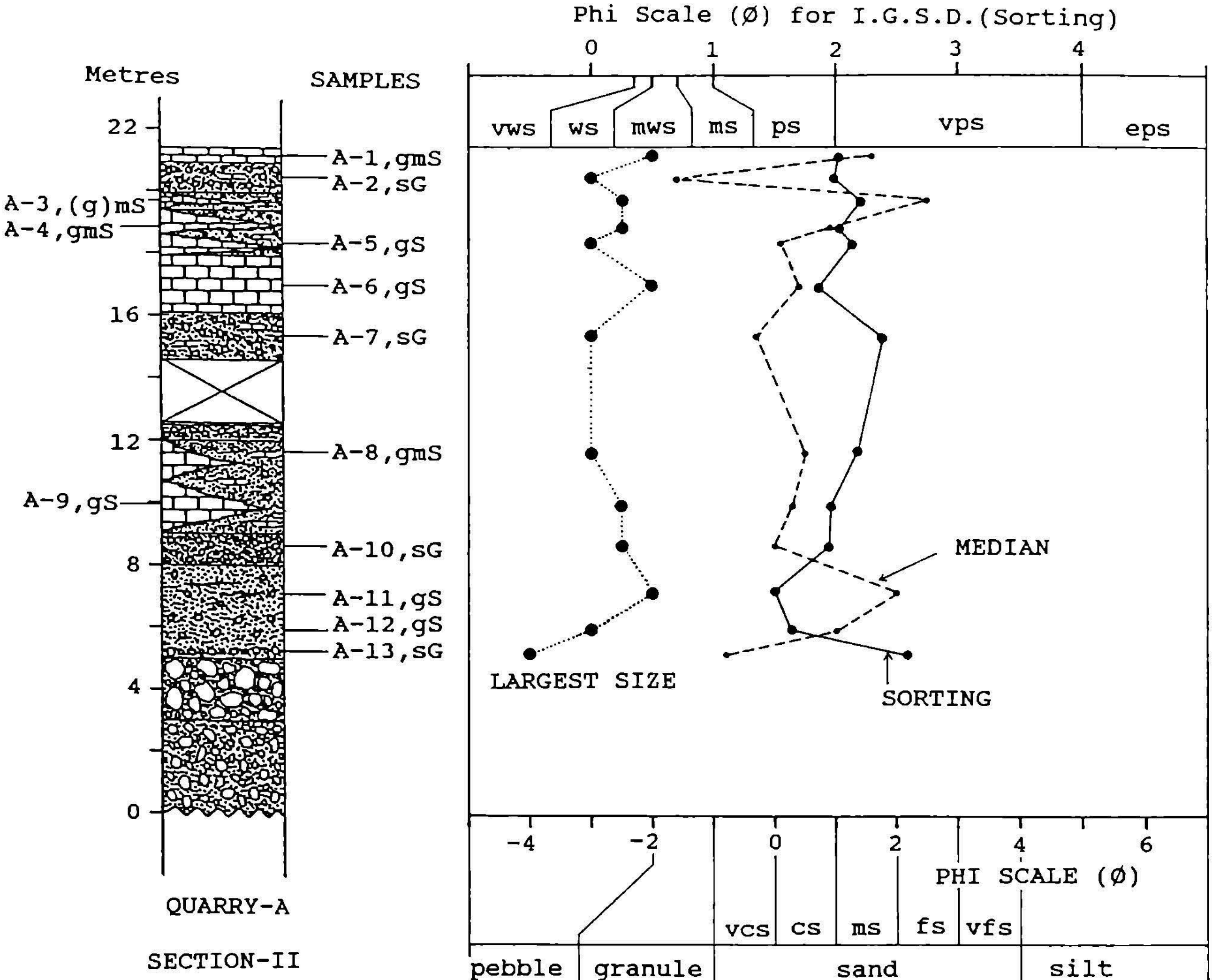

GRAPHIC KURTOSIS
146-UNCONSOLIDATED LINZ SAND
THE LARGEST GRAIN SIZE
146-UNCONSOLIDATED LINZ SAND
THE FIRST MODE
146-UNCONSOLIDATED LINZ SAND
THE SECOND MODE
GRAPHIC KURTOSIS
43-UNCONSOLIDATED/NON-CALC. STEYREGG
THE LARGEST GRAIN SIZE
43-UNCONSOLIDATED/NON-CALC. STEYREGG
THE FIRST MODE
43-UNCONSOLIDATED/NON-CALC. STEYREGG
THE SECOND MODE
36-UNCONSOLIDATED/NON-CALC. STEYREGG
GRAPHIC KURTOSIS
15-UNCONSOLIDATED/CALC. STEYREGG
THE LARGEST GRAIN SIZE
15-UNCONSOLIDATED/CALC. STEYREGG
THE FIRST MODE
15-UNCONSOLIDATED/CALC. STEYREGG
THE SECOND MODE
14-UNCONSOLIDATED/CALC. STEYREGG
GRAPHIC KURTOSIS
37-CONSOL. CARBONATE MIXED TERRIGENOUS
THE LARGEST GRAIN SIZE
37-CONSOL. CARBONATE MIXED TERRIGENOUS
THE FIRST MODE
37-CONSOL. CARBONATE MIXED TERRIGENOUS
THE SECOND MODE
35-CONSOL. CARBONATE MIXED TERRIGENOUS
NUMBER OF SAMPLES
GRAPHIC KURTOSIS CLASSES
LARGEST SIZE (WENTWORTH'S SIZE CLASSES)
MODAL SIZE (WENTWORTH'S SIZE CLASSES)
VPK
PK
MK
LK
VLK
ELK
VCP
CP
MP
FP
g
VCS
CS
MS
FS
VFS
CZ
MZ
FZ
VFZ
cly

LEGEND	DESCRIPTION
	SMALL CHANNELS, CUT AND FILL STRUCTURES
	SHALLOW CHANNELS, CUT (SCOURED) AND FILL STRUCTURES
	BIOTURBATED, BURROWED TUNNELS
	UNCONFORMITY
	INTERFINGERING CONTACT
	SMALL-, MEDIUM-SCALE CROSS-BEDDING
	LARGE-SCALE CROSS-BEDDING
	IRREGULAR, THIN-BEDDING
	CLASTIC OR CARBONATE LENSES
	BIOTURBATED, BURROWED SHAFTS WITH IRON-OXIDE
	CALCAREOUS NATURE OF SEDIMENTS
	THIN BEDDED, SLIGHTLY CONSOLIDATED CALCARENITES
	MEDIUM BEDDED, SLIGHTLY CONSOLIDATED CALCARENITES
	COBBLE-BOULDER SIZED
	PEBBLE SIZED
	SANDY GRAVELS
	MUDDY SANDY GRAVELS
	GRAVELLY SANDS
	GRAVELLY MUDDY SANDS
	SLIGHTLY GRAVELLY MUDDY SANDS
	SLIGHTLY GRAVELLY SANDS
	SANDS
	MUDS
	COVERED

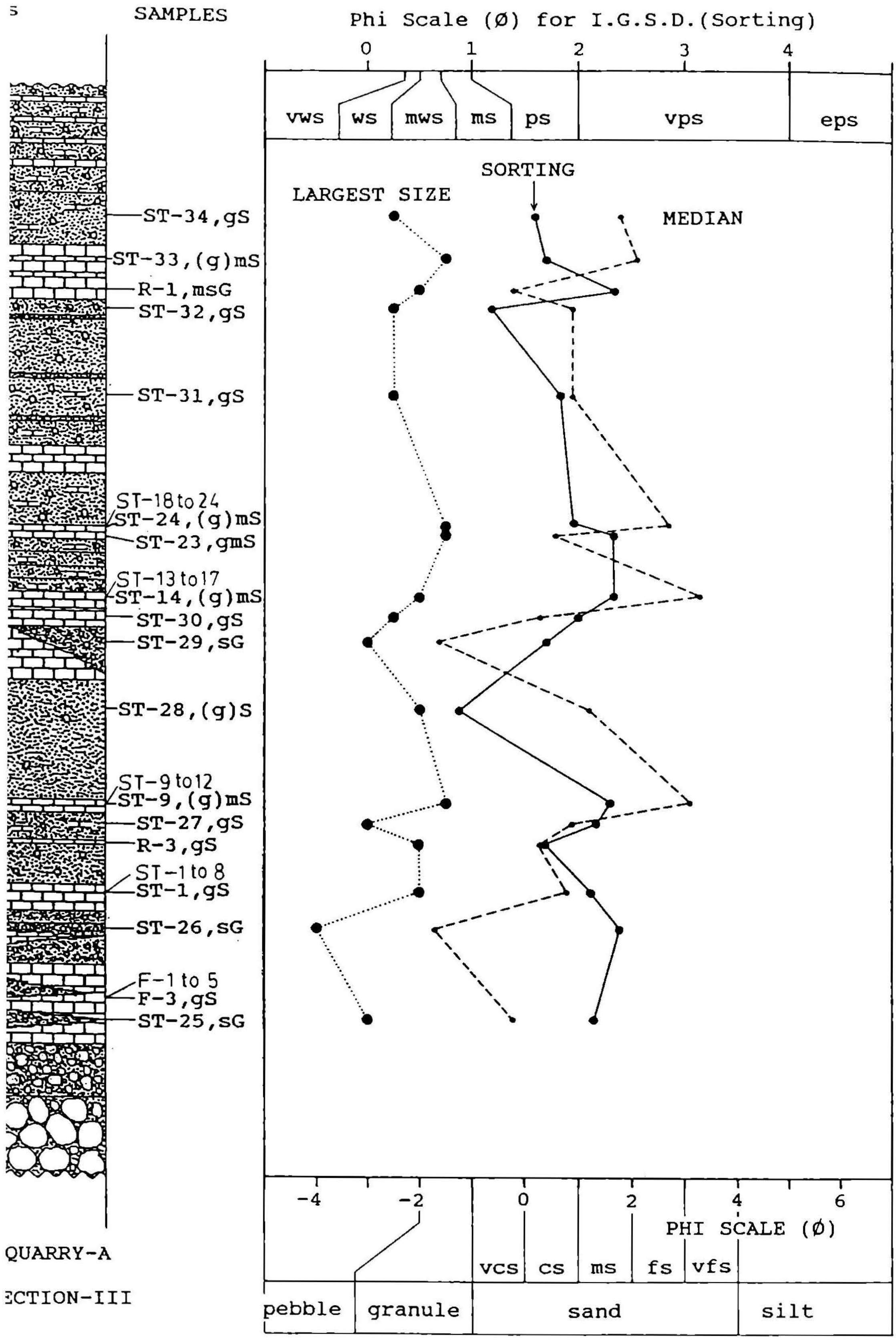

Phi Scale (Ø) for I.G.S.D.(Sorting)
0
1
2
3
4
vws
ws
mws
ms
ps
vps
eps
Metres
SAMPLES
40
36
32
28
24
20
16
12
8
4
0
Q-10.1,gS
Q-10,gS
Q-9.3,sG
Q-9.2,gS
Q-9.1,sG
Q-8,gmS
Q-7.4,gS
Q-7.3,gS
Q-7.2,(g)S
Q-7.1,gS
Q-6,gS
Q-6.2,gS
Q-6.3,sG
Q-6.1.1,sG
Q-6.1,(g)S
Q-5.3,sG
Q-5.2,gS
Q-5.1,sG
Q-5,gS
Q-3.1,sG
Q-3,sG
Q-1,sG
MEDIAN
SORTING
LARGEST SIZE
-4
-2
0
2
4
6
PHI SCALE (Ø)
vcs
cs
ms
fs
vfs
pebble
granule
sand
silt
QUARRY-A
SECTION-I

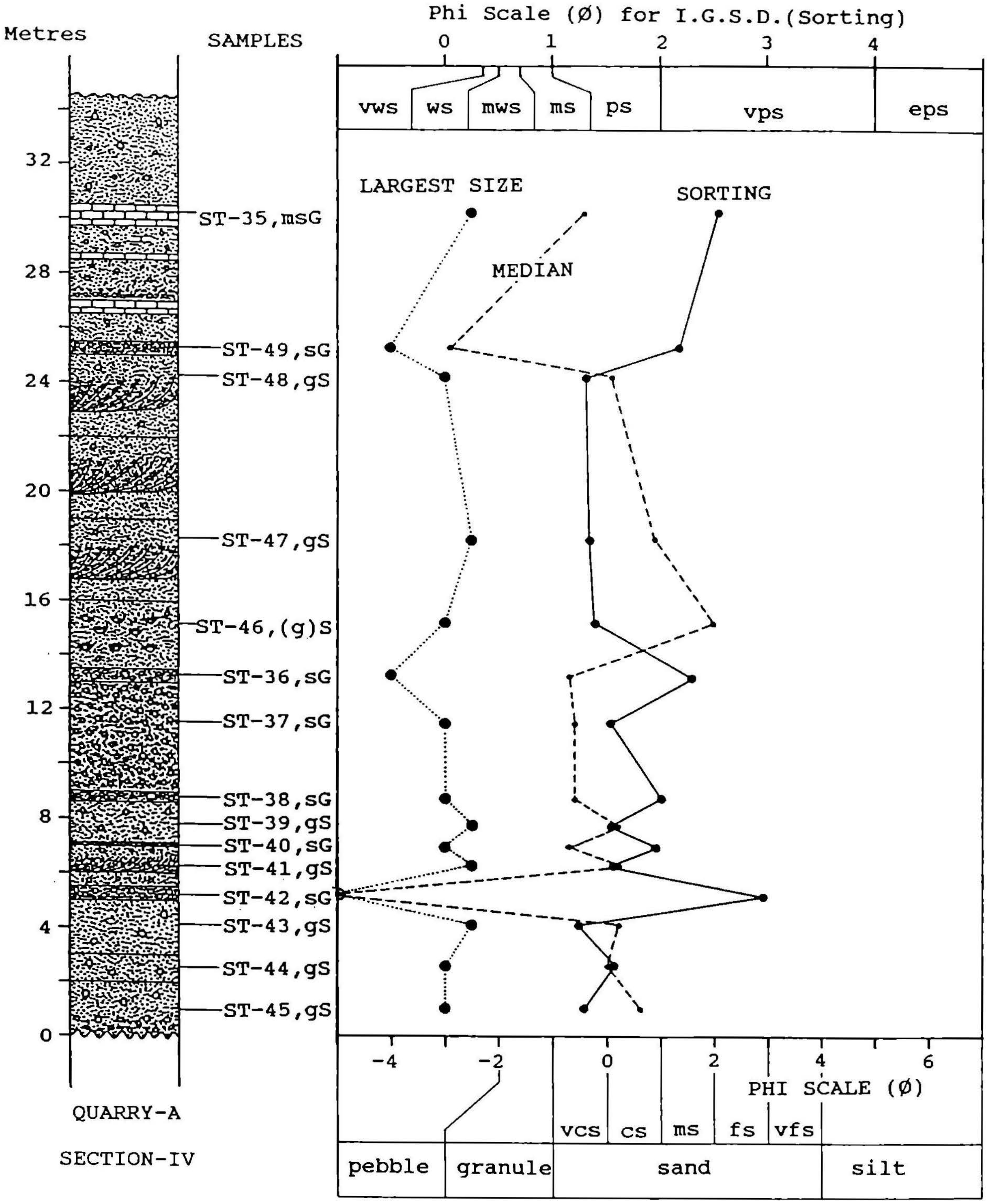


Phi Scale (Ø) for I.G.S.D.(Sorting)
0
1
2
3
4
vws
ws
mws
ms
ps
vps
eps
Metres
SAMPLES
88
84
80
76
72
68
64
60
56
52
48
44
Q-17.4,gS
Q-17.3,gS
Q-17.2,gS
Q-17.1,gmS
Q-16.1,(g)S
Q-15.6,(g)S
Q-15.5,(g)S
Q-15.4,(g)S
Q-15.3,gS
Q-15.2,gmS
Q-15.1,gS
Q-14,gS
Q-13,gS
Q-12,gS
Q-11,gS
Q-10.6
(g)mS
Q-10.5,gS
Q-10.4,gS
Q-10.3,sG
Q-10.2,sG
LARGEST SIZE
SORTING
MEDIAN
-4
-2
0
2
4
6
PHI SCALE (Ø)
vcs
cs
ms
fs
vfs
pebble
granule
sand
silt
QUARRY-A
SECTION-I



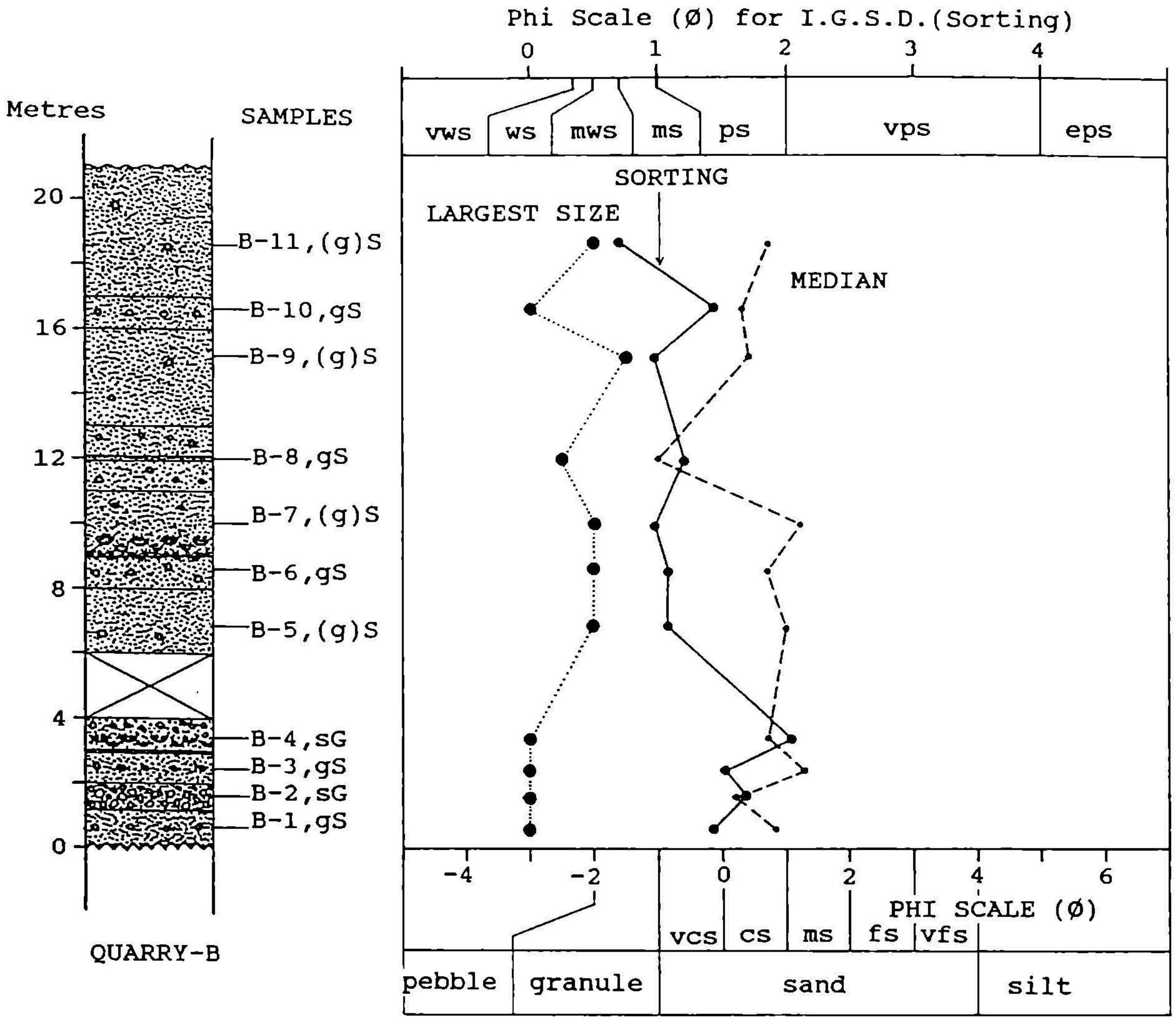
Phi Scale (Ø) for I.G.S.D.(Sorting)
0
1
2
3
4
vws
ws
mws
ms
ps
vps
eps
Metres
SAMPLES
22
16
12
8
4
0
A-1,gmS
A-2,sG
A-3,(g)mS
A-4,gmS
A-5,gS
A-6,gS
A-7,sG
A-8,gmS
A-9,gS
A-10,sG
A-11,gS
A-12,gS
A-13,sG
MEDIAN
LARGEST SIZE
SORTING
-4
-2
0
2
4
6
PHI SCALE (Ø)
vcs
cs
ms
fs
vfs
pebble
granule
sand
silt
QUARRY-A
SECTION-II

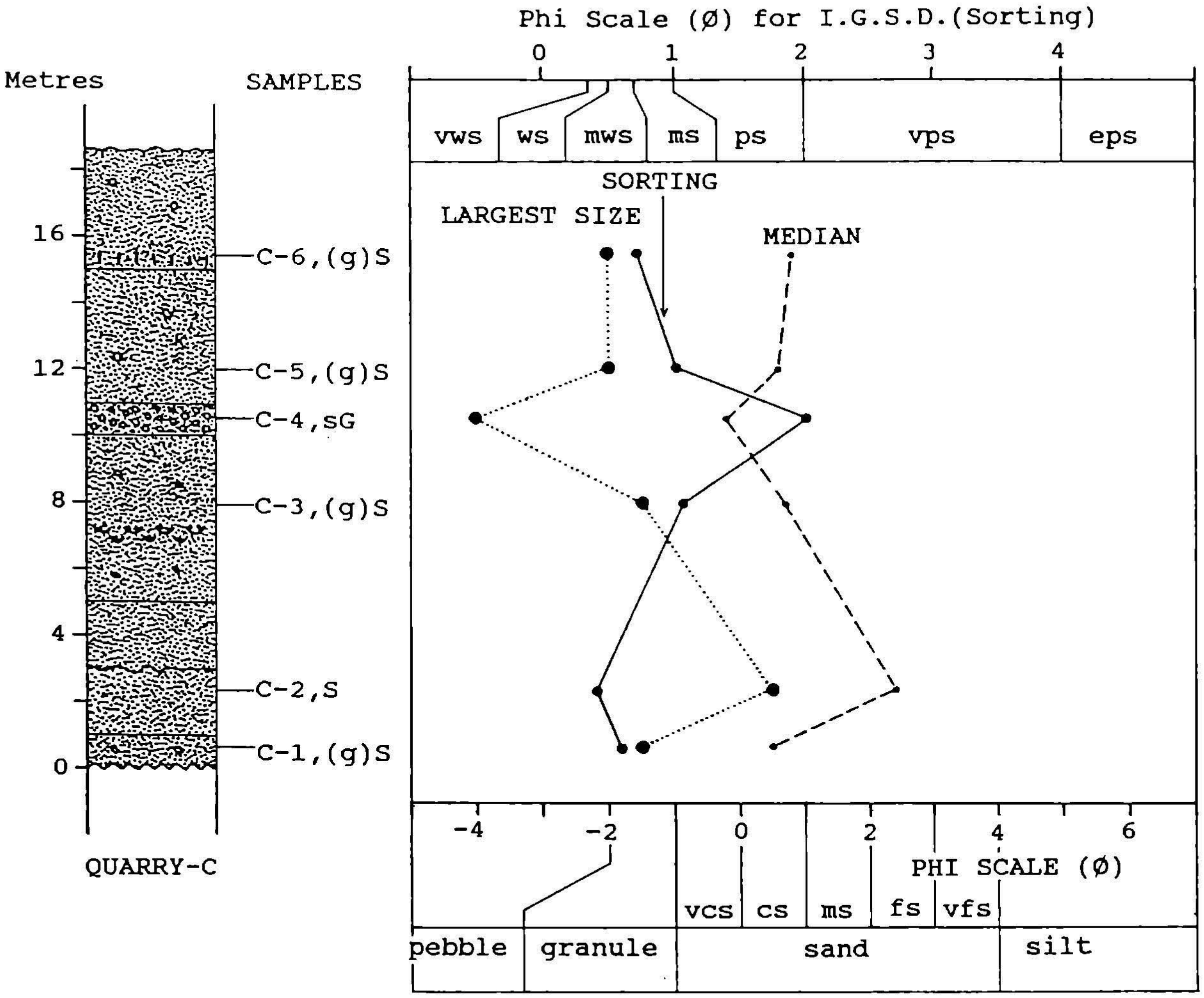

SAMPLES
Phi Scale (Ø) for I.G.S.D.(Sorting)
0
1
2
3
4
vws
ws
mws
ms
ps
vps
eps
SORTING
LARGEST SIZE
MEDIAN
ST-34,gS
ST-33,(g)mS
R-1,msG
ST-32,gS
ST-31,gS
ST-18 to 24
ST-24,(g)mS
ST-23,gmS
ST-13 to 17
ST-14,(g)mS
ST-30,gS
ST-29,sG
ST-28,(g)S
ST-9 to 12
ST-9,(g)mS
ST-27,gS
R-3,gS
ST-1 to 8
ST-1,gS
ST-26,sG
F-1 to 5
F-3,gS
ST-25,sG
-4
-2
0
2
4
6
PHI SCALE (Ø)
vcs
cs
ms
fs
vfs
pebble
granule
sand
silt
QUARRY-A
ECTION-III


Metres
SAMPLES
Phi Scale (Ø) for I.G.S.D.(Sorting)
0
1
2
3
4
vws
ws
mws
ms
ps
vps
eps
LARGEST SIZE
SORTING
MEDIAN
32
28
24
20
16
12
8
4
0
ST-35,msG
ST-49,sG
ST-48,gS
ST-47,gS
ST-46,(g)S
ST-36,sG
ST-37,sG
ST-38,sG
ST-39,gS
ST-40,sG
ST-41,gS
ST-42,sG
ST-43,gS
ST-44,gS
ST-45,gS
-4
-2
0
2
4
6
PHI SCALE (Ø)
vcs
cs
ms
fs
vfs
pebble
granule
sand
silt
QUARRY-A
SECTION-IV

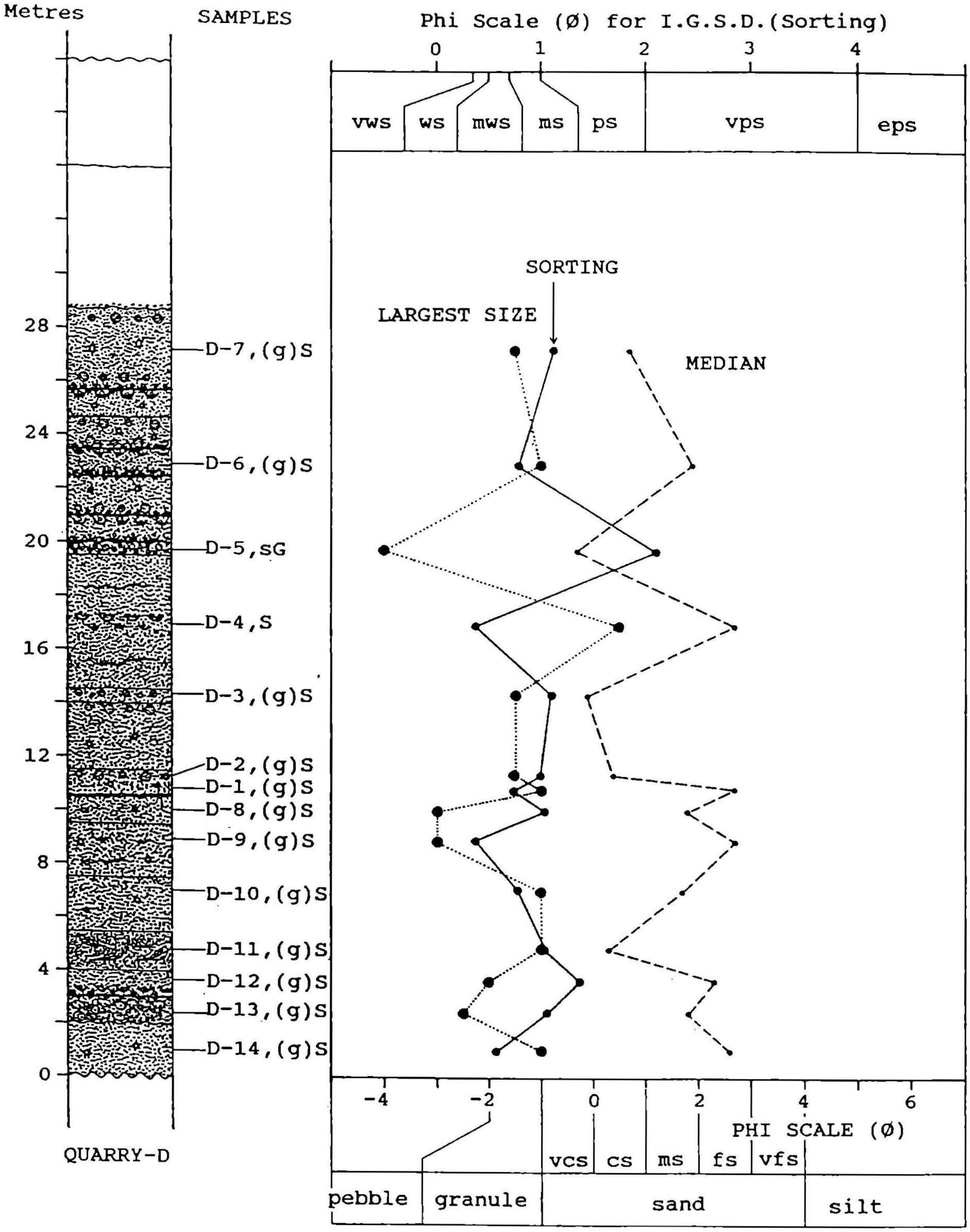
APPENDIX 4C

Vertical variations of the
statistical parameters plot
for the sections of
the Linz sand sequence

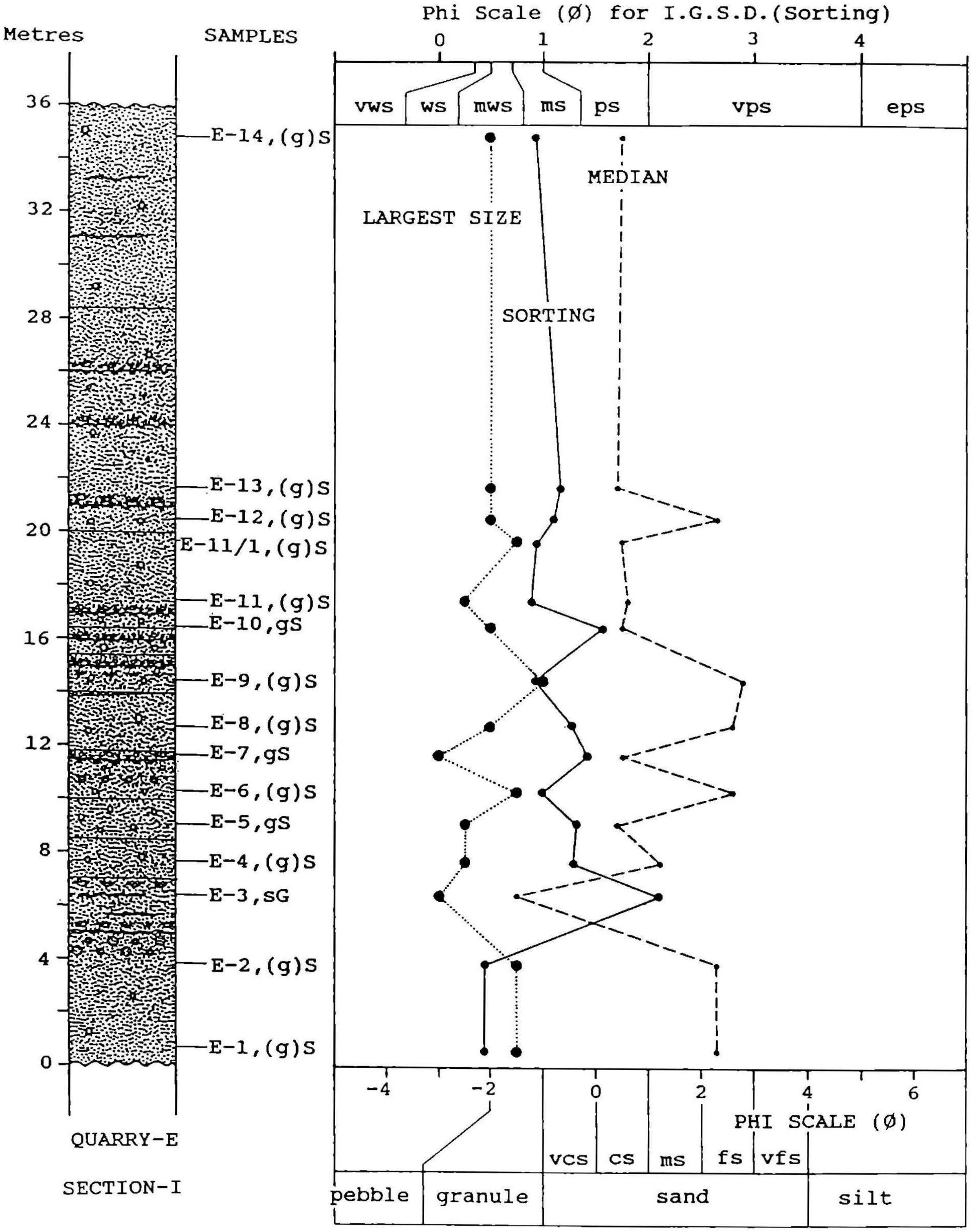

Phi Scale (Ø) for I.G.S.D.(Sorting)
0
1
2
3
4
vws
ws
mws
ms
ps
vps
eps
Metres
SAMPLES
20
16
12
8
4
0
B-11,(g)S
B-10,gS
B-9,(g)S
B-8,gS
B-7,(g)S
B-6,gS
B-5,(g)S
B-4,sG
B-3,gS
B-2,sG
B-1,gS
QUARRY-B
SORTING
LARGEST SIZE
MEDIAN
-4
-2
0
2
4
6
PHI SCALE (Ø)
vcs
cs
ms
fs
vfs
pebble
granule
sand
silt

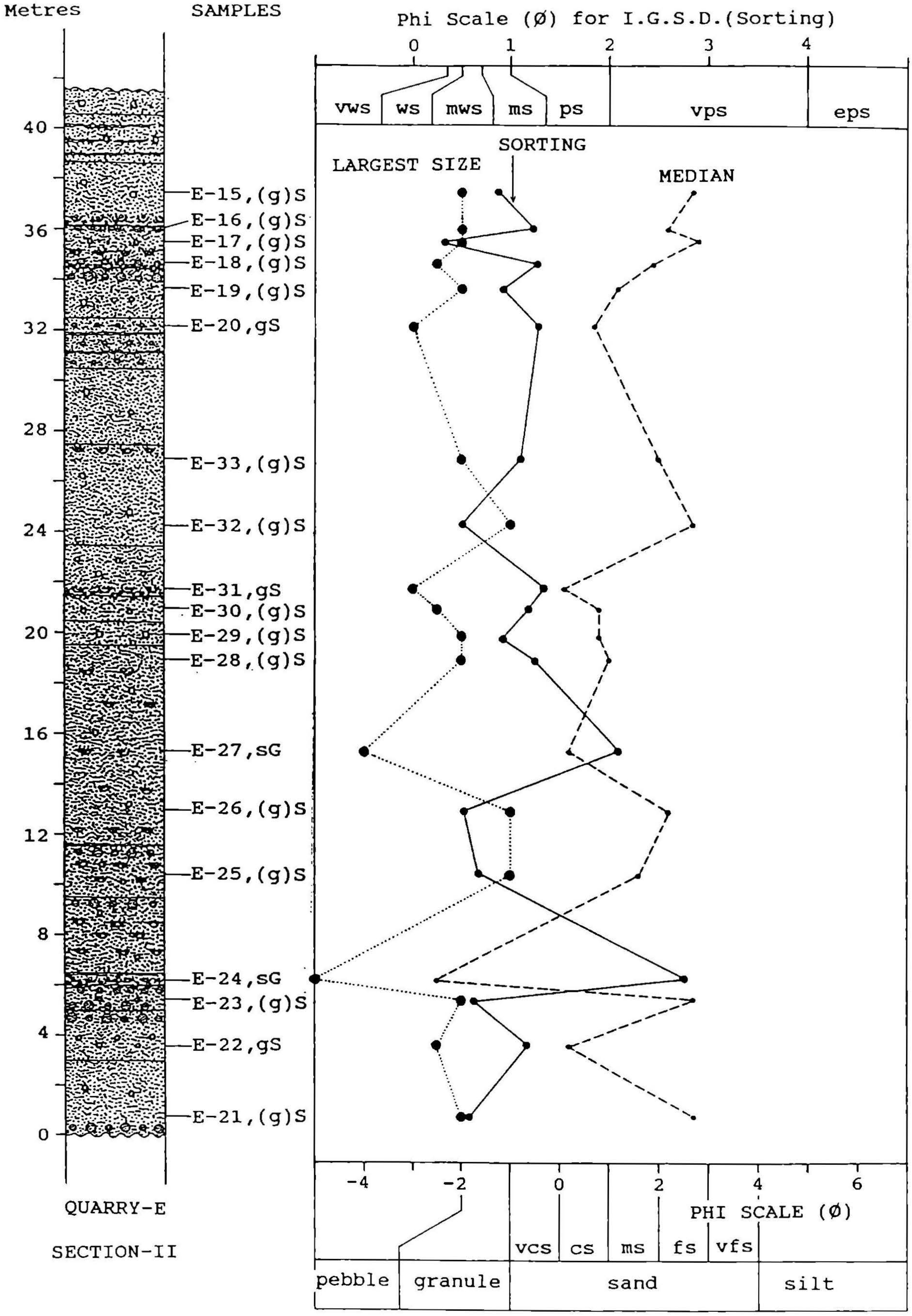


Phi Scale (Ø) for I.G.S.D.(Sorting)
0
1
2
3
4
vws
ws
mws
ms
ps
vps
eps
Metres
SAMPLES
SORTING
LARGEST SIZE
MEDIAN
16
12
8
4
0
C-6,(g)S
C-5,(g)S
C-4,sG
C-3,(g)S
C-2,S
C-1,(g)S
QUARRY-C
-4
-2
0
2
4
6
PHI SCALE (Ø)
vcs
cs
ms
fs
vfs
pebble
granule
sand
silt

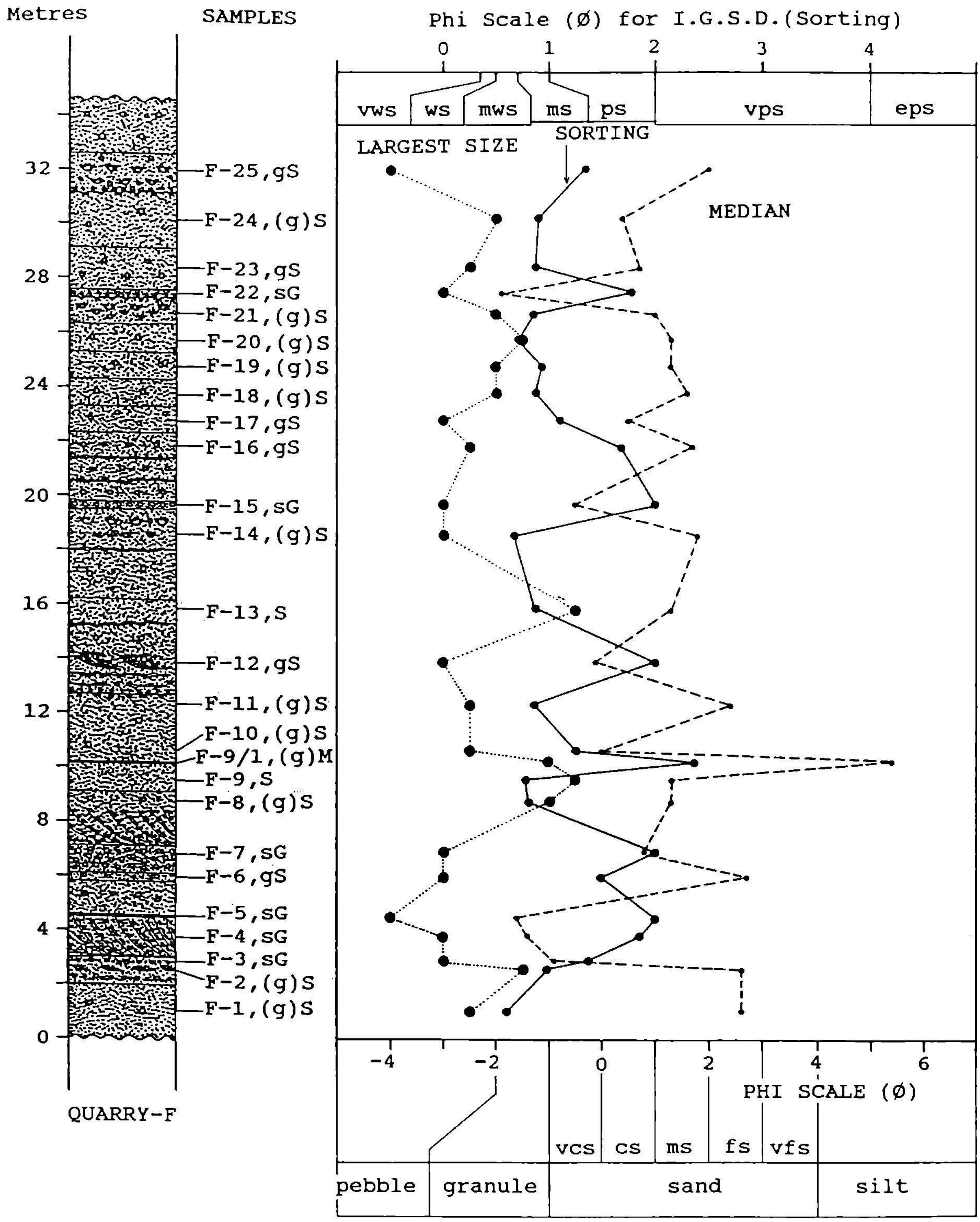


Metres
SAMPLES
Phi Scale (Ø) for I.G.S.D.(Sorting)
0
1
2
3
4
vws
ws
mws
ms
ps
vps
eps
SORTING
LARGEST SIZE
MEDIAN
28
24
20
16
12
8
4
0
D-7,(g)S
D-6,(g)S
D-5,sG
D-4,S
D-3,(g)S
D-2,(g)S
D-1,(g)S
D-8,(g)S
D-9,(g)S
D-10,(g)S
D-11,(g)S
D-12,(g)S
D-13,(g)S
D-14,(g)S
-4
-2
0
2
4
6
PHI SCALE (Ø)
vcs
cs
ms
fs
vfs
pebble
granule
sand
silt
QUARRY-D

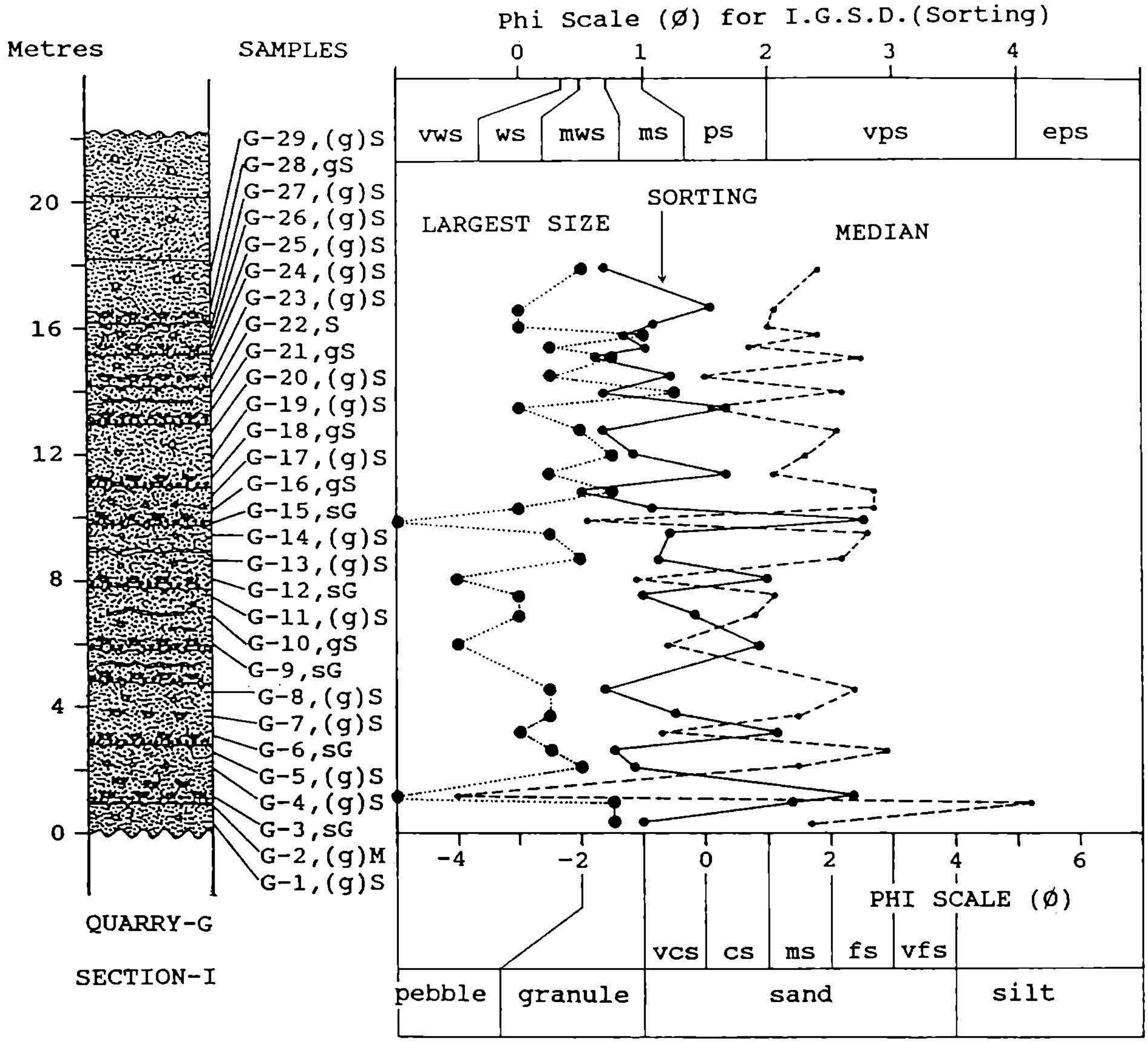

Phi Scale (Ø) for I.G.S.D.(Sorting)
0
1
2
3
4
vws
ws
mws
ms
ps
vps
eps
Metres
SAMPLES
36
32
28
24
20
16
12
8
4
0
E-14,(g)S
E-13,(g)S
E-12,(g)S
E-11/1,(g)S
E-11,(g)S
E-10,gS
E-9,(g)S
E-8,(g)S
E-7,gS
E-6,(g)S
E-5,gS
E-4,(g)S
E-3,sG
E-2,(g)S
E-1,(g)S
MEDIAN
LARGEST SIZE
SORTING
-4
-2
0
2
4
6
PHI SCALE (Ø)
vcs
cs
ms
fs
vfs
pebble
granule
sand
silt
QUARRY-E
SECTION-I



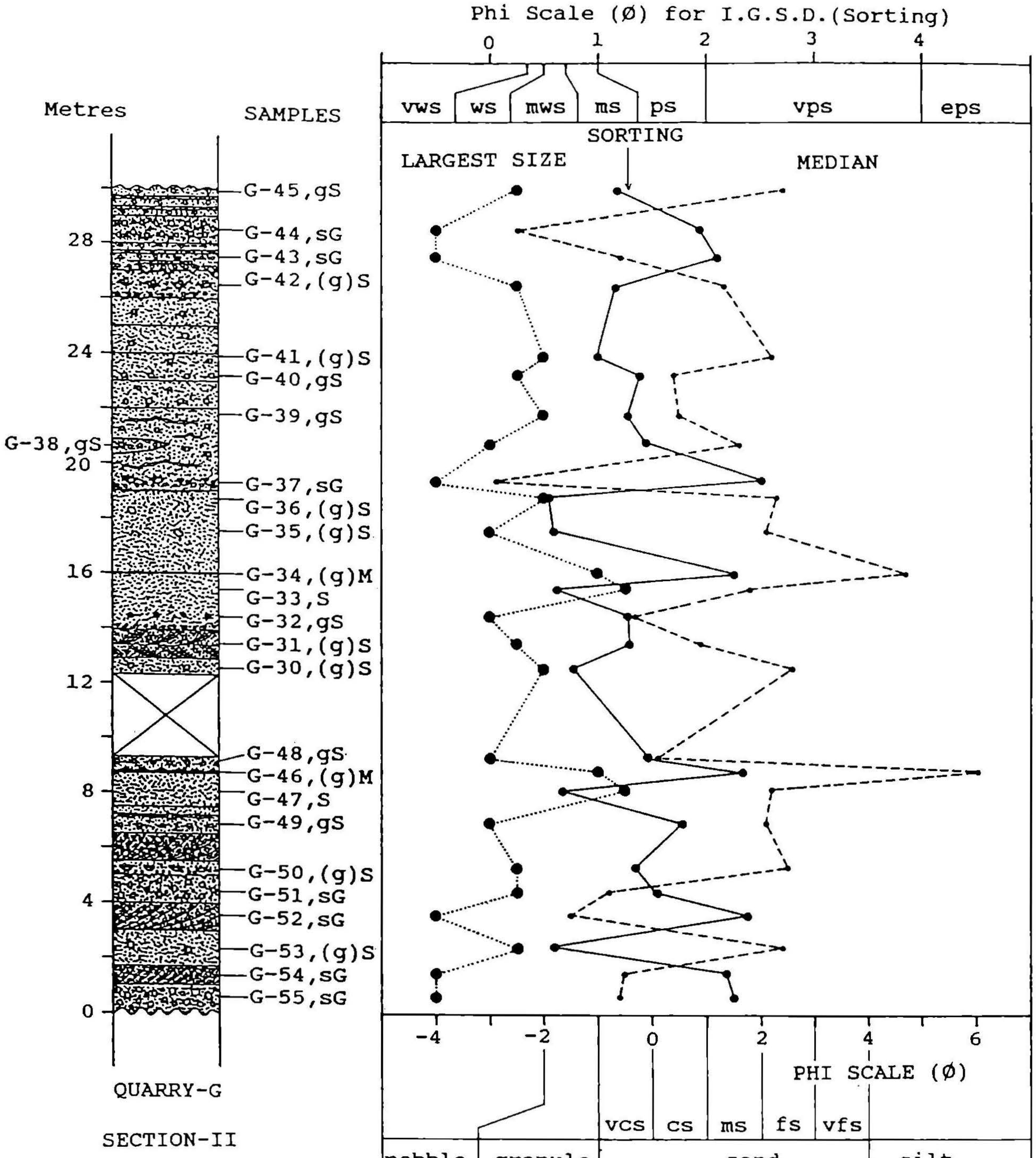
Metres
SAMPLES
Phi Scale (Ø) for I.G.S.D.(Sorting)
0
1
2
3
4
vws
ws
mws
ms
ps
vps
eps
SORTING
LARGEST SIZE
MEDIAN
40
36
32
28
24
20
16
12
8
4
0
E-15,(g)S
E-16,(g)S
E-17,(g)S
E-18,(g)S
E-19,(g)S
E-20,gS
E-33,(g)S
E-32,(g)S
E-31,gS
E-30,(g)S
E-29,(g)S
E-28,(g)S
E-27,sG
E-26,(g)S
E-25,(g)S
E-24,sG
E-23,(g)S
E-22,gS
E-21,(g)S
-4
-2
0
2
4
6
PHI SCALE (Ø)
vcs
cs
ms
fs
vfs
pebble
granule
sand
silt
QUARRY-E
SECTION-II



Metres
SAMPLES
Phi Scale (Ø) for I.G.S.D.(Sorting)
0
1
2
3
4
vws
ws
mws
ms
ps
vps
eps
LARGEST SIZE
SORTING
MEDIAN
32
28
24
20
16
12
8
4
0
F-25,gS
F-24,(g)S
F-23,gS
F-22,sG
F-21,(g)S
F-20,(g)S
F-19,(g)S
F-18,(g)S
F-17,gS
F-16,gS
F-15,sG
F-14,(g)S
F-13,S
F-12,gS
F-11,(g)S
F-10,(g)S
F-9/1,(g)M
F-9,S
F-8,(g)S
F-7,sG
F-6,gS
F-5,sG
F-4,sG
F-3,sG
F-2,(g)S
F-1,(g)S
QUARRY-F
-4
-2
0
2
4
6
PHI SCALE (Ø)
vcs
cs
ms
fs
vfs
pebble
granule
sand
silt



Phi Scale (Ø) for I.G.S.D.(Sorting)
Metres
SAMPLES
0 1 2 3 4
vws ws mws ms ps vps eps
G-29,(g)S
G-28,gS
G-27,(g)S
G-26,(g)S
G-25,(g)S
G-24,(g)S
G-23,(g)S
G-22,S
G-21,gS
G-20,(g)S
G-19,(g)S
G-18,gS
G-17,(g)S
G-16,gS
G-15,sG
G-14,(g)S
G-13,(g)S
G-12,sG
G-11,(g)S
G-10,gS
G-9,sG
G-8,(g)S
G-7,(g)S
G-6,sG
G-5,(g)S
G-4,(g)S
G-3,sG
G-2,(g)M
G-1,(g)S
20
16
12
8
4
0
SORTING
LARGEST SIZE
MEDIAN
-4 -2 0 2 4 6
PHI SCALE (Ø)
vcs cs ms fs vfs
pebble granule sand silt
QUARRY-G
SECTION-I



Phi Scale (Ø) for I.G.S.D.(Sorting)
0
1
2
3
4
vws
ws
mws
ms
ps
vps
eps
Metres
SAMPLES
SORTING
LARGEST SIZE
MEDIAN
G-45,gS
G-44,sG
28
G-43,sG
G-42,(g)S
24
G-41,(g)S
G-40,gS
G-39,gS
G-38,gS
20
G-37,sG
G-36,(g)S
G-35,(g)S
16
G-34,(g)M
G-33,S
G-32,gS
G-31,(g)S
G-30,(g)S
12
G-48,gS
G-46,(g)M
8
G-47,S
G-49,gS
G-50,(g)S
4
G-51,sG
G-52,sG
G-53,(g)S
G-54,sG
G-55,sG
0
-4
-2
0
2
4
6
PHI SCALE (Ø)
vcs
cs
ms
fs
vfs
pebble
granule
sand
silt
QUARRY-G
SECTION-II

APPENDIX 5

Methods for X-Ray Diffraction (XRD) in the clay mineral study

1. Oriented samples.
2. Ethylene glycol treatment.
3. Heating treatment.

APPENDIX 5

METHODS FOR X-RAY DIFFRACTION (XRD) IN THE CLAY MINERAL STUDY

The clay mineralogy was investigated by using oriented samples on a ceramic plate. Determinations were carried out on a PHILLIPS X-Ray Diffractometer with Cu K_α radiation and Ni-filter at 40 kV, 20 mA.

1. **Oriented samples** (Basal spacing air-dried specimens).

Oriented specimens were prepared after wet sieving of muds from sands and gravels. A small amount of clay-sized suspension was transferred with a pipette into setting tubes where the suspended particles were allowed to settle through a column of water onto the porcelain (ceramic) plate under suction (Gibbs, 1965; 1968) and air-dried for 24 hours. Specimens were then scanned initially from 3° 2θ to 22° 2θ and/or 30° 2θ using a recorder speed of 0.5° 2θ/minute, for all steps.

2. **Ethylene glycol treatment** (Glycolation).

After the first X-ray of oriented specimens, these samples were introduced into a desiccator, containing about a quarter litre of ethylene glycol (ethanediol) due to Brunton (1955). Placing the desiccator in an oven at 105°C, for about 24 hours was recommended here, then X-rayed to determine the presence of swelling clays such as smectite minerals.

3. **Heating treatment**.

After the second X-ray, the specimens were heated at 550°C in the high temperature oven for at least 1 hour. The glycol and water were, then, removed. So, re-examined by X-rays across the sample to observe any change. This heating treatment will collapse the peaks of kaolinite and also halloysite, if present.

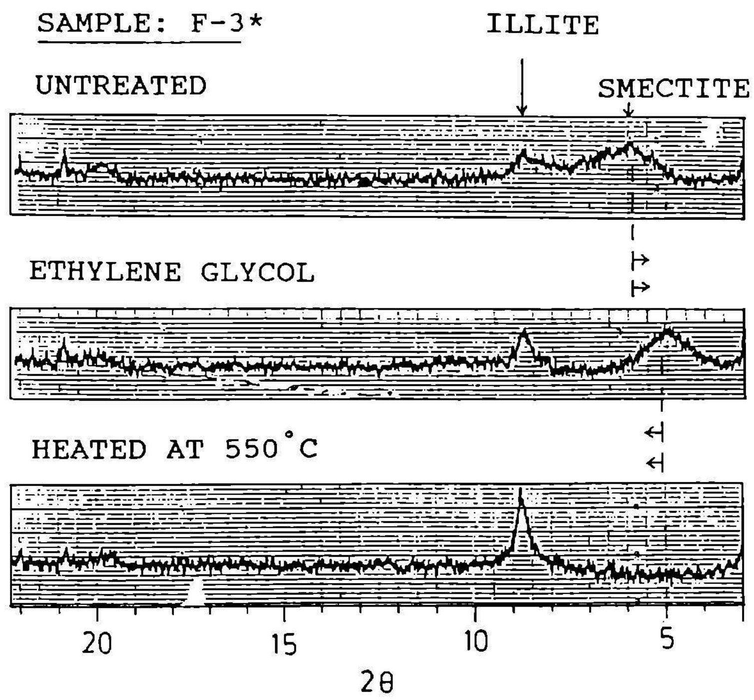
APPENDIX 6

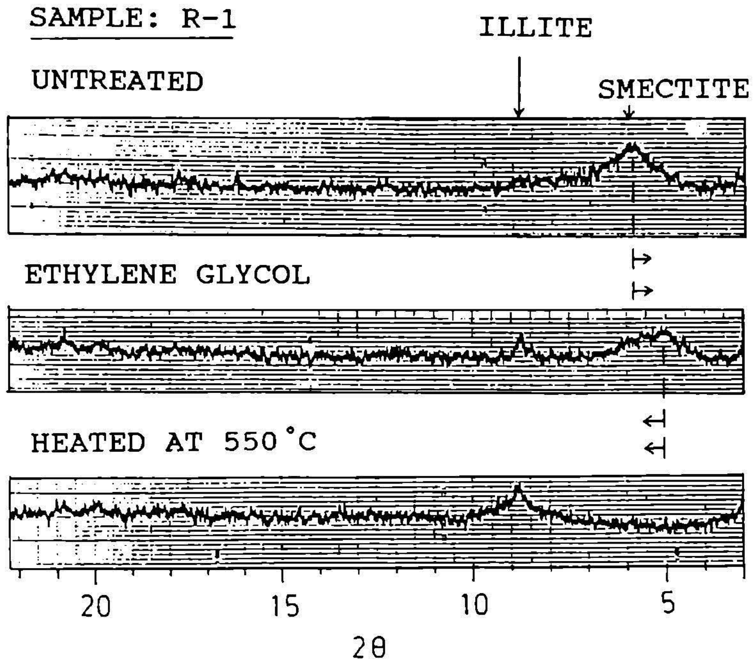
X-Ray Diffractograms of the clay mineralogy

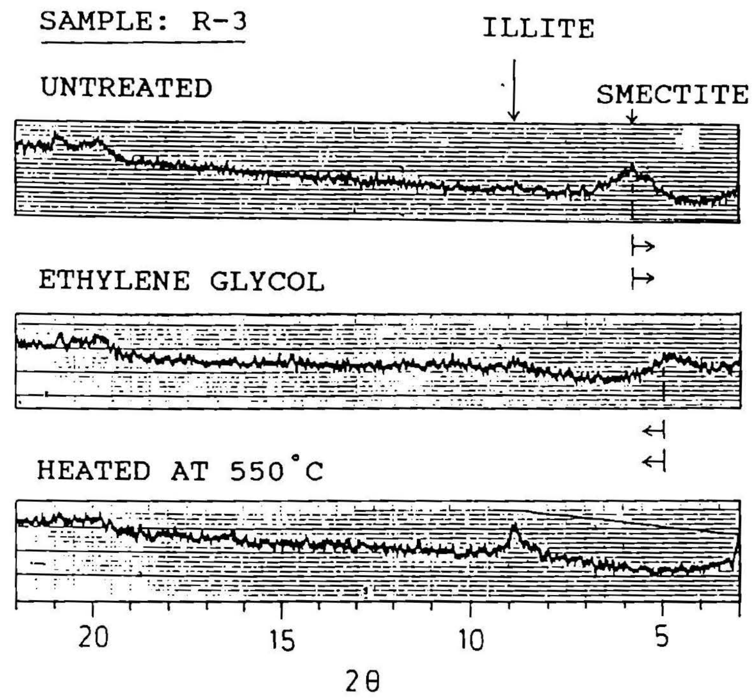
for samples of

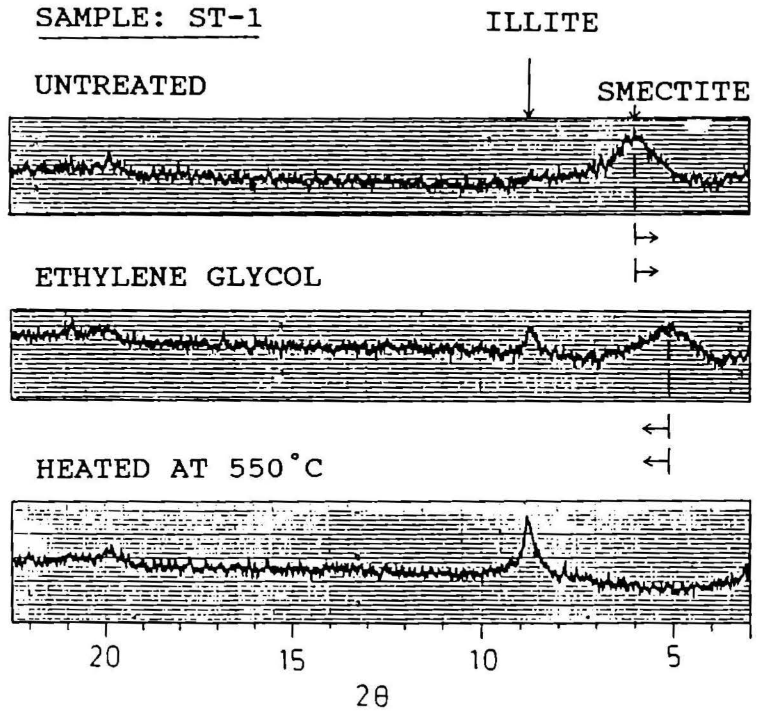
the terrigenous mixed carbonate sequence

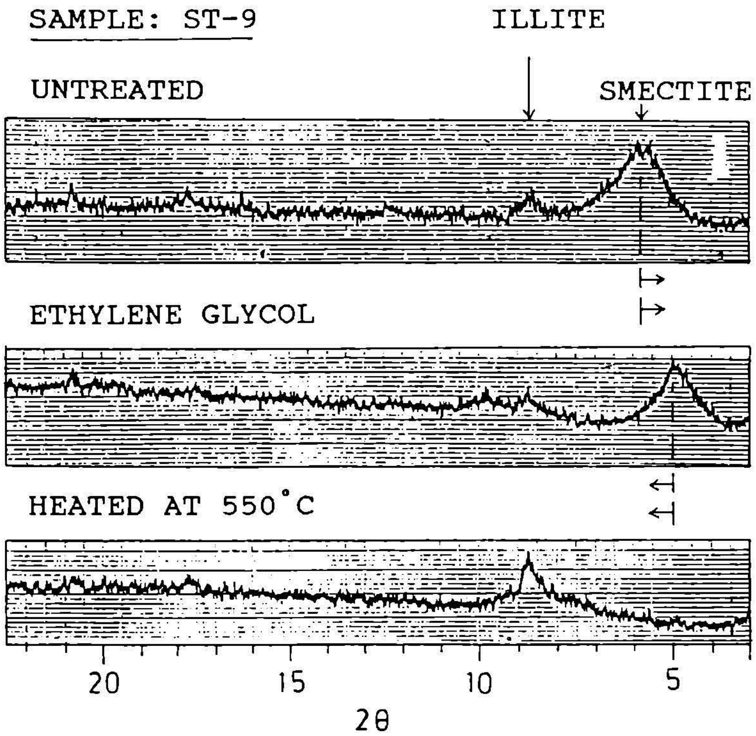
of Steyregg

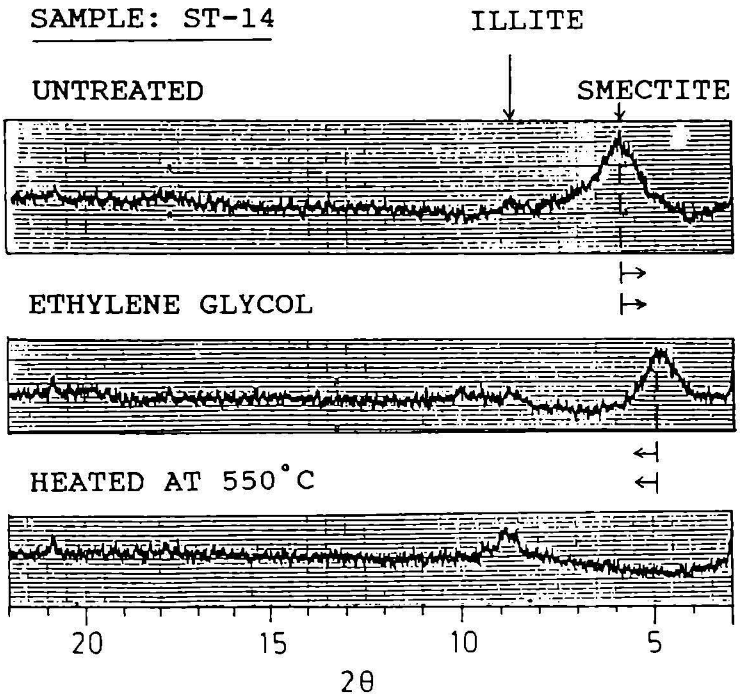

SAMPLE: F-3*
ILLITE
UNTREATED
SMECTITE
ETHYLENE GLYCOL
HEATED AT 550°C
20
15
10
5
2θ

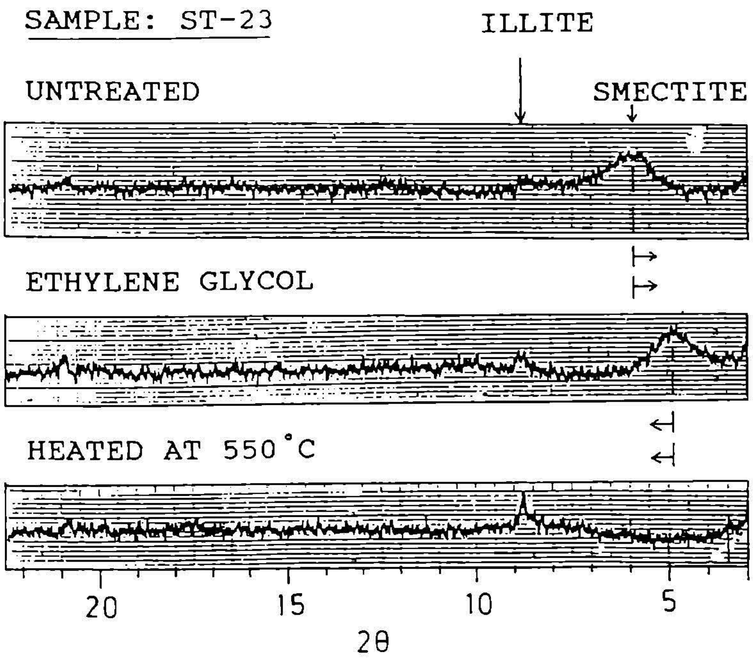

SAMPLE: R-1
ILLITE
UNTREATED
SMECTITE
ETHYLENE GLYCOL
HEATED AT 550°C
20
15
10
5
2θ

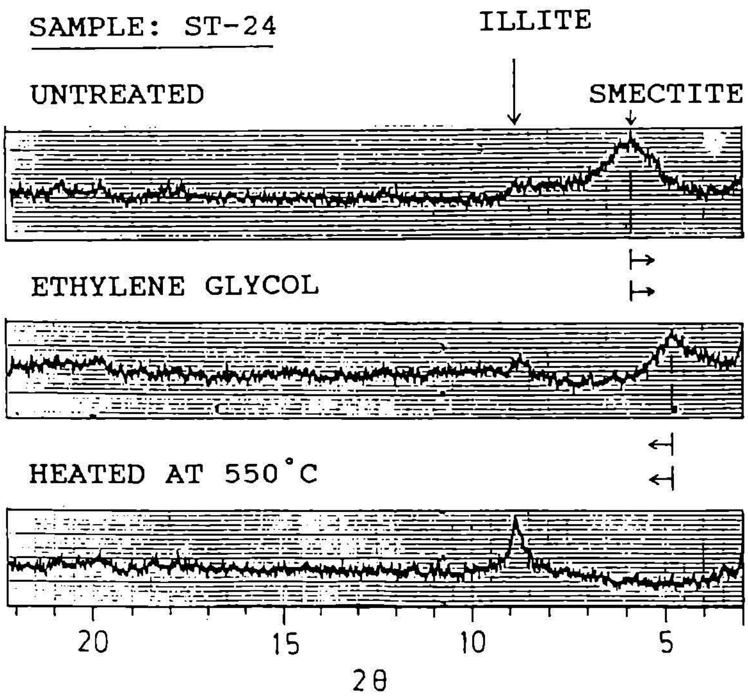

SAMPLE: R-3
ILLITE
UNTREATED
SMECTITE
ETHYLENE GLYCOL
HEATED AT 550°C
20
15
10
5
2θ

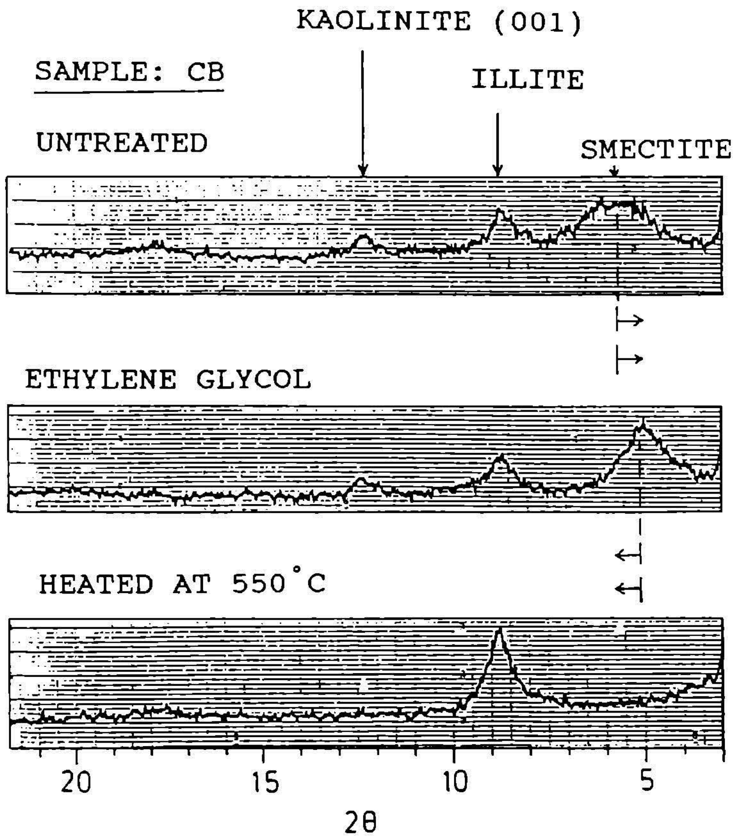

SAMPLE: ST-1
ILLITE
UNTREATED
SMECTITE
ETHYLENE GLYCOL
HEATED AT 550°C
20
15
10
5
2θ


SAMPLE: ST-9
ILLITE
UNTREATED
SMECTITE
ETHYLENE GLYCOL
HEATED AT 550°C
20
15
10
5
2θ


SAMPLE: ST-14
ILLITE
UNTREATED
SMECTITE
ETHYLENE GLYCOL
HEATED AT 550°C
20
15
10
5
2θ

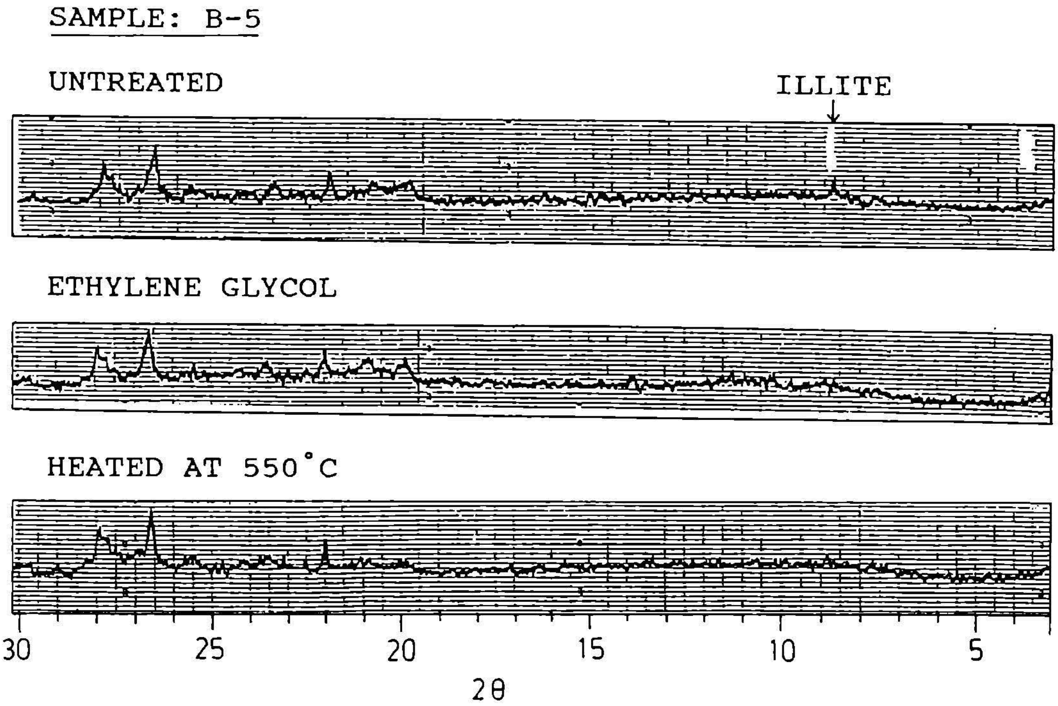

SAMPLE: ST-23
ILLITE
UNTREATED
SMECTITE
ETHYLENE GLYCOL
HEATED AT 550°C
20
15
10
5
2θ

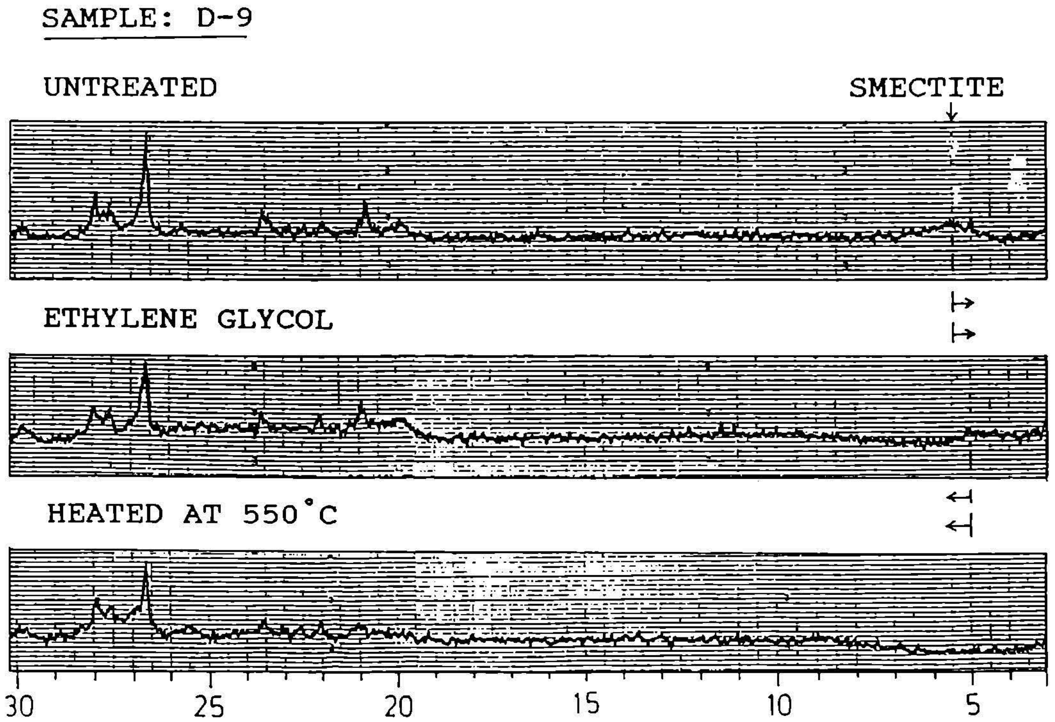

SAMPLE: ST-24
ILLITE
UNTREATED
SMECTITE
ETHYLENE GLYCOL
HEATED AT 550°C
20
15
10
5
2θ

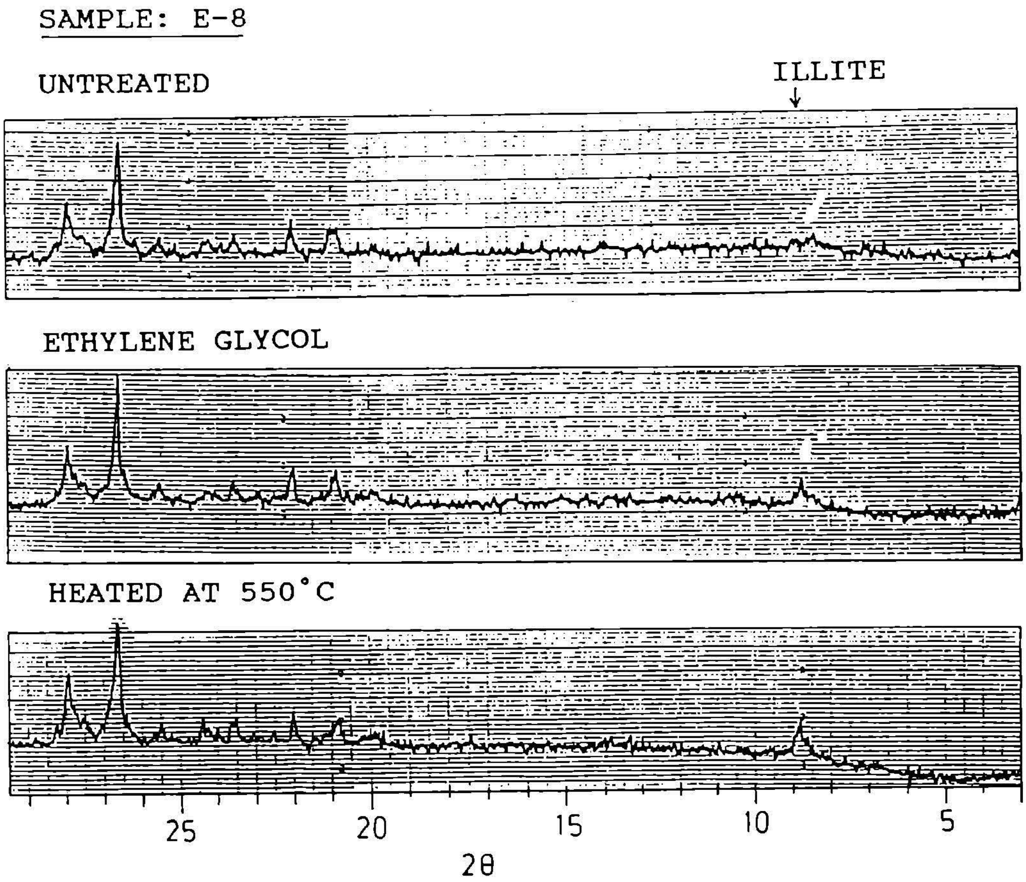

KAOLINITE (001)
SAMPLE: CB
ILLITE
UNTREATED
SMECTITE
ETHYLENE GLYCOL
HEATED AT 550°C
20
15
10
5
2θ

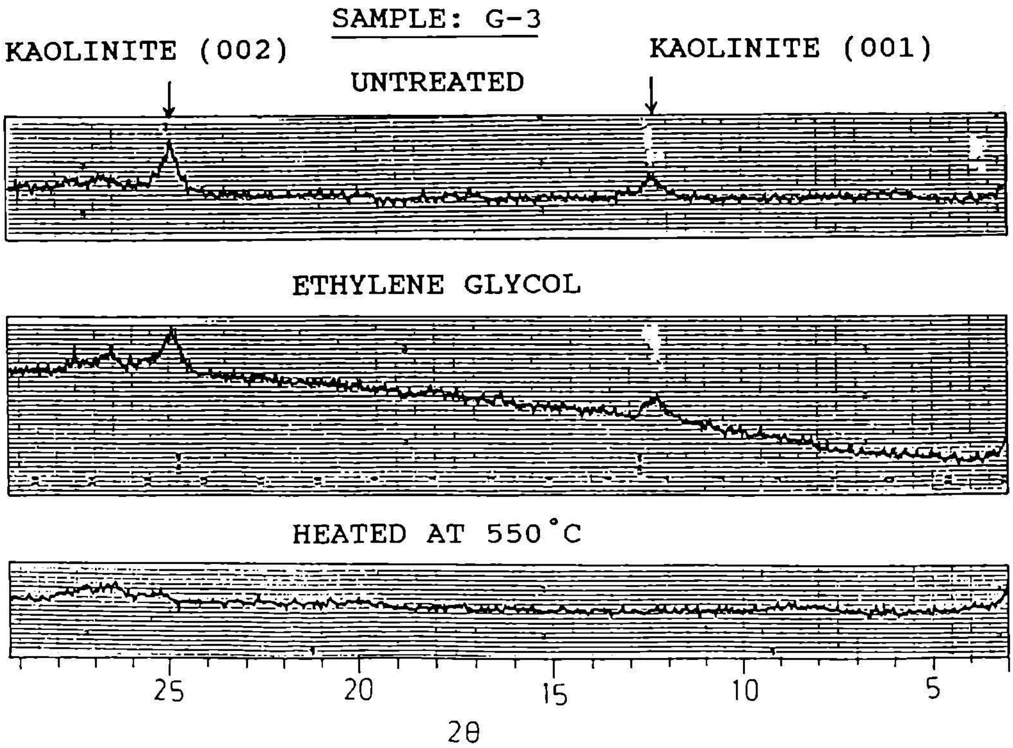
APPENDIX 6

X-Ray Diffractograms of the clay mineralogy
for samples of
the Linz sand sequence


SAMPLE: B-5
UNTREATED
ILLITE
ETHYLENE GLYCOL
HEATED AT 550°C
30
25
20
15
10
5
2θ


SAMPLE: D-9
UNTREATED
SMECTITE
ETHYLENE GLYCOL
HEATED AT 550°C
30
25
20
15
10
5


SAMPLE: E-8
UNTREATED
ILLITE
ETHYLENE GLYCOL
HEATED AT 550°C
25
20
15
10
5
2θ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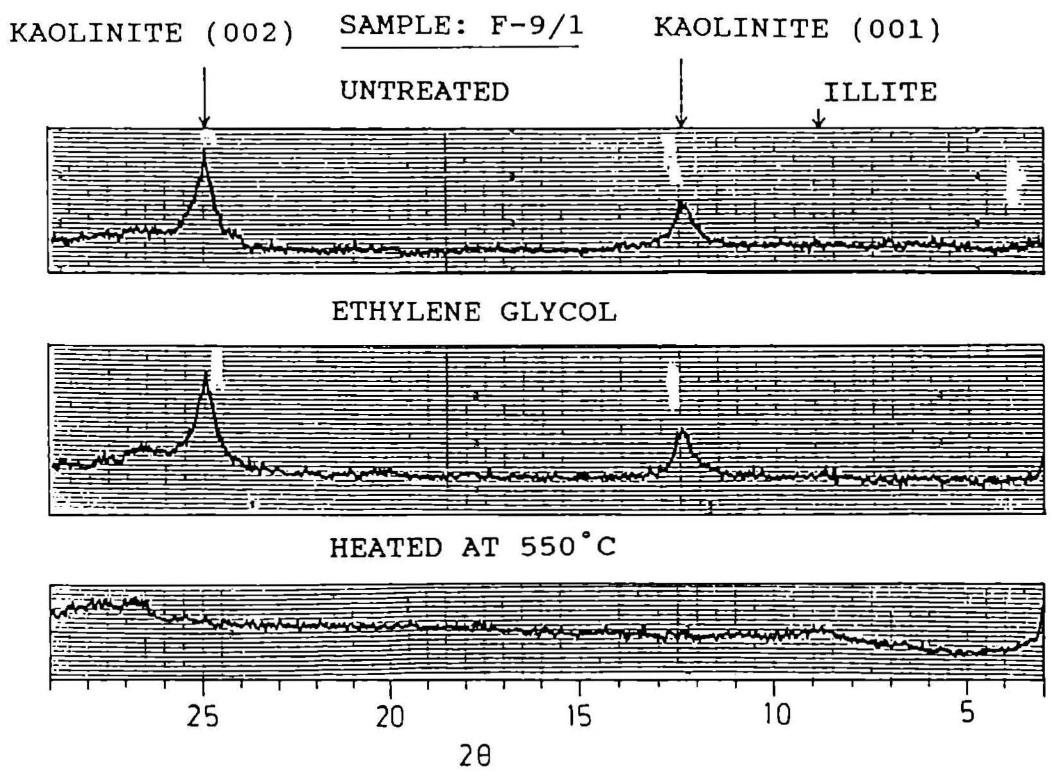
KAOLINITE (002)
KAOLINITE (001)
UNTREATED
ETHYLENE GLYCOL
HEATED AT 550°C
25
20
15
10
5
2θ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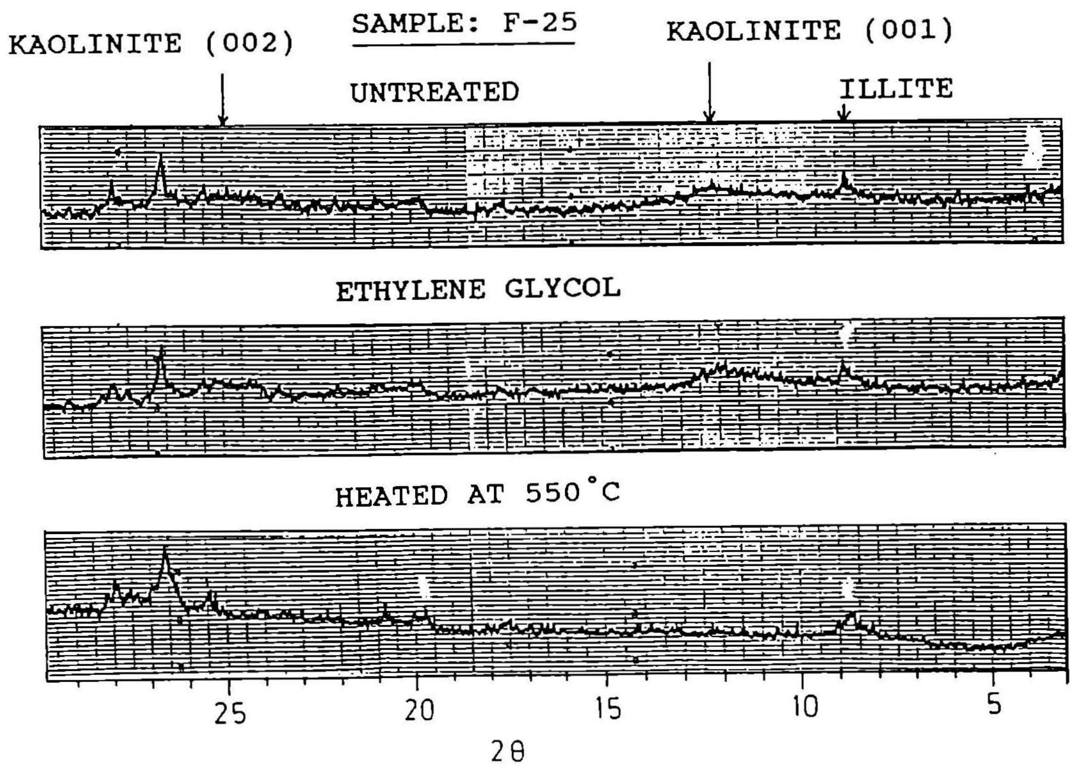
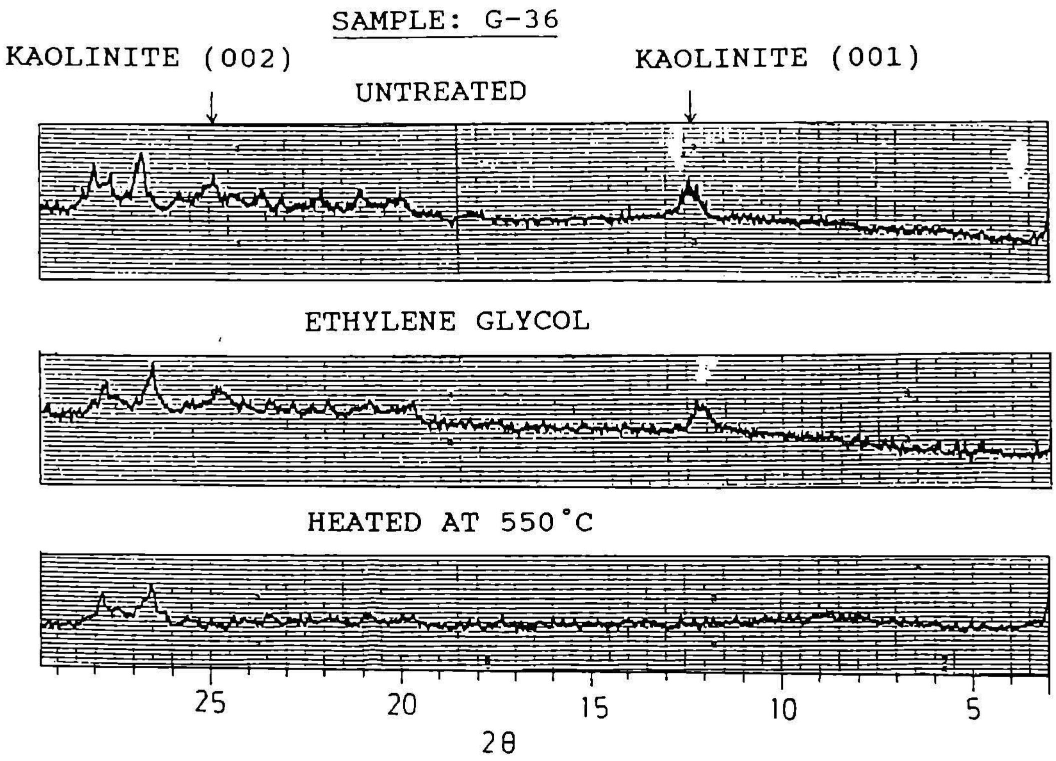
SAMPLE: F-9/1
KAOLINITE (001)
UNTREATED
ILLITE
ETHYLENE GLYCOL
HEATED AT 550°C
25
20
15
10
5
2θ


KAOLINITE (002)
SAMPLE: F-25
KAOLINITE (001)
UNTREATED
ILLITE
ETHYLENE GLYCOL
HEATED AT 550°C
25
20
15
10
5
2θ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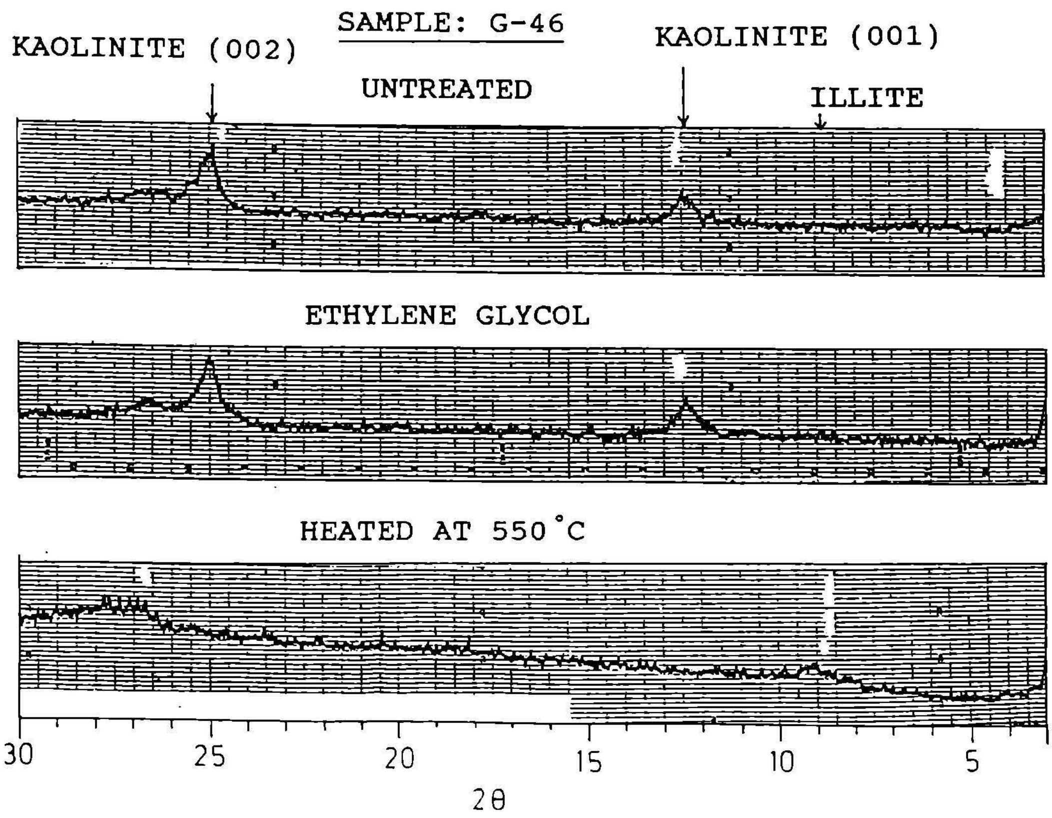
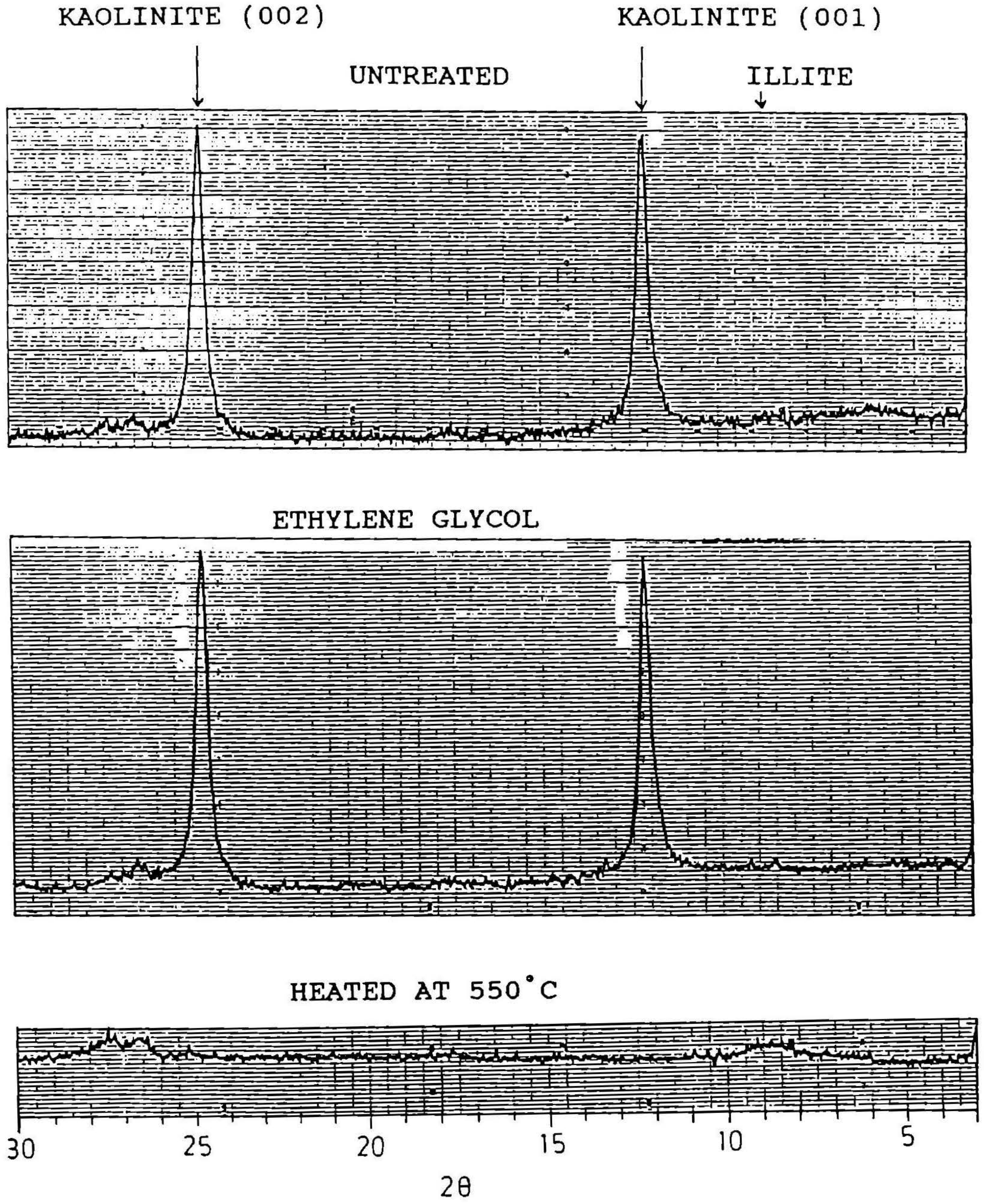
KAOLINITE (001)
UNTREATED
ETHYLENE GLYCOL
HEATED AT 550°C
25
20
15
10
5
2θ


SAMPLE: G-46
KAOLINITE (002)
KAOLINITE (001)
UNTREATED
ILLITE
ETHYLENE GLYCOL
HEATED AT 550°C
30
25
20
15
10
5
2θ

SAMPLE: G-2


KAOLINITE (002)
KAOLINITE (001)
UNTREATED
ILLITE
ETHYLENE GLYCOL
HEATED AT 550°C
30
25
20
15
10
5
2θ

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APPENDIX 7A

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Raw petrographical data

for samples of

The consolidated calcarenites

of Steyregg

APPENDIX 7-A

CONSOLIDATED CALCARENITES OF STEYREGG MOLASSE

	Thin-section No.	A-9	F-2	F-3	Q-6	Q-8	Q-10.4	Q-12	Q-14	Q-17.2	Q-17.4	R-1	R-2	R-4	ST-1
DETRITAL CALCAREOUS GRAINS (ALLOCHEMS)	All bioclastic grains (%)	41.7	30.4	31.6	13.5	46.0	60.8	44.0	62.9	12.0	24.0	47.2	80.5	83.5	35.5
	Benthic foraminifers %	25.7	8.8	23.2	0.5	11.6	37.6	13.2	19.6	9.1	15.2	14.8	20.0	10.0	12.0
	Planktic foraminifers %	-	-	-	-	rare	rare	rare	rare	rare	rare	rare	rare	rare	rare
	Calcareous algae														
	- Lithothamnium fragments %	-	-	-	-	28.0	21.2	30.4	42.1	-	-	31.6	59.0	69.5	21.5
	- Other algae %	-	-	rare	-	rare	-	-	-	rare	-	-	-	-	-
	Echinoderms %	rare	-	rare	0.5	5.2	0.8	-	0.8	0.4	0.4	rare	-	1.0	rare
	Bryozoans %	-	-	-	-	-	-	-	v.rare	-	-	-	-	rare	rare
	Ostracods %	0.7	1.2	-	rare	0.4	0.4	rare	rare	rare	rare	-	-	0.5	rare
	Molluscs														
	- Bivalves %	15.3	20.4	8.0	6.0	0.8	0.8	0.4	0.4	2.5	2.4	0.8	1.5	2.5	2.0
	- Gastropods %	-	-	-	5.5	-	-	-	-	-	6.0	-	-	-	-
	Brachiopods %	-	-	0.4	1.0	-	-	-	-	-	-	-	-	-	-
	Unidentified bioclasts %	-	-	-	-	-	-	-	-	-	-	-	rare	-	-
	Maximum grain-size	f.pebble	c.pebble	granule	m.pebble	m.pebble	granule	f.pebble	granule	f.pebble	granule	f.pebble	m.pebble	granule	granule
	Minimun grain-size	m.sand	m.sand	m.sand	m.sand	m.sand	m.sand	f.sand	f.sand	m.sand	v.f.sand	f.sand	f.sand	f.sand	f.sand
	Modal grain-size	granule	c.sand	v.c.sand	v.c.sand	v.c.sand	v.c.sand	v.c.sand	v.c.sand	v.c.sand	c.sand	v.c.sand	v.c.sand	v.c.sand	v.c.sand
	Roundness	s.abraded	m.abraded	m.abraded	s.abraded	s.abraded	s.abraded	s.abraded	m.abraded	s.abraded	s.abraded	s.abraded	s.abraded	s.abraded	s.abraded
	Sphericity	low	low	low	low	low	low	low	moderate	low-moderate	low-moderate	low-moderate	moderate	low-moderate	low-moderate
	Sorting	v.poor	v.poor	v.poor	v.poor	v.poor	v.poor	v.poor	m.poor	v.poor	v.poor	v.poor	v.poor	m.poor	m.poor
	Fragmentation	v.common	v.common	v.common	v.common	v.common	v.common	v.common	v.common	v.common	v.common	v.common	v.common	v.common	v.common
	Intraclasts (%)	rare	-	-	-	rare	rare	-	-	rare	-	rare	rare	rare	rare
DETRITAL NON-CALCAREOUS GRAINS	All terrigenous grains (%)	36.5	38.4	39.6	54.5	33.2	26.0	43.6	23.3	56.9	50.0	31.2	5.5	4.5	47.5
	Total quartz %	9.3	13.2	15.6	17.5	12.4	7.2	18.0	12.9	28.9	20.0	7.2	4.0	2.5	20.5
	- Monocrystalline %	8.1	12.3	14.3	15.7	11.8	6.5	15.8	11.2	26.1	18.4	6.6	3.8	2.4	19.1
	- Undulatory extinction %	1.7	3.8	3.5	3.2	2.1	1.6	3.0	1.9	7.4	4.2	1.5	0.5	0.4	2.3
	- Non extinction %	6.4	8.5	10.8	12.5	9.7	4.9	12.8	9.3	18.7	14.2	5.1	3.3	2.0	16.8
	- Polycrystalline %	1.2	0.9	1.3	1.8	0.6	0.7	2.2	1.7	2.8	1.6	0.6	0.2	0.1	1.4
	- less than 3 crystals %	0.6	0.4	0.4	0.6	0.2	0.2	0.4	0.9	0.9	0.5	0.2	-	-	0.9
	- more than 3 crystals %	0.6	0.5	0.9	1.2	0.4	0.5	1.8	0.8	1.9	1.1	0.4	0.2	0.1	0.5
	Total feldspar %	5.0	8.0	5.2	10.5	4.0	4.4	16.8	7.5	16.9	12.0	3.2	1.0	1.0	12.5
	- Alkali feldspar %	4.5	6.9	4.6	9.8	3.6	4.1	13.7	7.1	15.6	9.9	3.1	1.0	0.9	10.4
	- Orthoclase %	1.8	0.8	0.9	0.7	0.8	3.0	3.5	2.0	1.6	2.1	0.3	0.2	0.2	2.6
	- Microcline %	2.7	6.1	3.7	9.1	2.8	1.1	10.2	5.1	14.0	7.8	2.8	0.8	0.7	7.8
	- Plagioclase %	0.5	1.1	0.6	0.7	0.4	0.3	3.1	0.4	1.3	2.1	0.1	rare	0.1	2.1
	Total rock fragments %	20.3	16.0	18.4	24.0	16.4	14.0	8.4	2.9	10.7	17.2	20.4	0.5	0.5	13.5
	- <2 mm unstable rk.frag. %	1.0	1.2	0.9	0.7	0.5	0.6	0.7	0.2	0.4	1.0	0.2	0.1	0.1	0.3
	- >2 mm unstable rk.frag. %	14.6	11.2	13.3	19.5	13.4	11.9	4.4	2.3	8.2	13.3	18.5	0.4	0.4	10.1
	- >2 mm stable rk.frag. %	4.7	3.6	4.2	3.8	2.5	1.5	3.3	0.4	2.1	2.9	1.7	-	-	3.1
	Muscovite %	-	rare	v.rare	-	-	v.rare	-	-	v.rare	-	v.rare	v.rare	rare	-
	Biotite %	1.3	0.8	0.4	2.5	-	0.4	0.4	rare	0.4	0.8	0.4	rare	0.5	1.0
	Transparent heavy minerals %	0.3	0.4	rare	v.rare	v.rare	rare	rare	rare	rare	rare	rare	v.rare	rare	rare
	Opaque minerals %	0.3	rare	rare	-	v.rare	rare	rare	rare	rare	rare	rare	v.rare	-	-
	Maximum grain-size	f.pebble	f.pebble	m.pebble	granule	f.pebble	f.pebble	granule	granule	granule	f.pebble	m.pebble	v.c.sand	granule	m.pebble
	Modal grain-size	v.c.sand	granule-v.cs	v.c.sand	v.c.sand	v.c.sand	v.c.sand	v.c.sand	v.c.sand	v.c.sand	v.c.sand	granule	c.sand	v.c.sand	v.c.sand
	Roundness	ang-subang	subangular	ang-subang	subangular	subangular	subangular	subangular	subangular	subangular	subangular	subangular	subangular	subangular	subangular
	Sphericity	moderate	moderate	low-moderate	low-moderate	low	low	low-moderate	low-moderate	low	low	low-moderate	low-moderate	low-moderate	low
	Sorting	v.poor	m.poor	v.poor	m.poor	v.poor	v.poor	m.poor	m.poor	m.poor	v.poor	v.poor	m.poor	m.poor	v.poor
Sandstone's classified by composition	BY McBRIDE (1963)	arkose	arkose	subarkose	arkose	subarkose	arkose	arkose	arkose	arkose	arkose	arkose	subarkose	arkose	arkose
	Matrix (%)	1.7	2.4	2.4	2.5	3.6	2.0	1.2	1.7	5.0	1.6	2.8	0.5	0.5	4.0
	Micrite (%)	1.0	0.8	0.8	1.0	1.6	1.2	1.6	1.3	1.7	1.2	1.6	3.0	4.0	2.0
	Cement (%)	19.0	23.2	21.2	28.0	11.6	7.6	8.4	8.3	22.3	23.2	15.6	8.0	5.5	6.5
	Diagenetic components														
	- Cement types (sparite)	calcite (C)	calcite (C)	calcite (C)	calcite (C)	calcite (C)	C-fibrous	C-fibrous	C-fibrous	calcite (C)	calcite (C)	calcite (C)	calcite (C)	calcite (C)	calcite (C)
	- Cement-crystal sized	f-medium	f-v.coarse	f-medium	f-medium	f-medium	v.f - v.c	v.f - v.c	v.f - v.c	f-medium	f-medium	f-medium	f-medium	f-medium	f-medium
	Other authigenic (%)	v.rare	v.rare	rare	v.rare	-	-	-	-	trace	v.rare	v.rare	rare	-	v.rare
	- other authiqenic types	glauconite	glauconite	glauconite	glauconite	-	-	-	-	-	-	-	-	-	-
	Intrinsic materials	C,FeO,G,cly	C,G,cly	C,FeO,G,cly	C,G,cly	C,cly	C,cly	C,FeO,cly	C,FeO,cly	C,cly	C,cly	C,cly	C,FeO,cly	C,FeO,cly	C,FeO,cly
	Extrinsic materials	C,glau.	granular-C	C,glau.	granular-C	granular-C	granular-C	C,FeO	C,FeO	C,glau.	C,glau.	C,glau.	C,FeO,glau.	C,FeO	C,FeO,glau.
	Grain to grain contacts														
	- Allochem relationships	point-long	point-long	point-long	point-long	point-long	point-long	point-long	point-long	point-long	point-long	point-long	point-long	point-long	point-long
	- Siliciclast relationships	float-long	float-point	float-point	float-point	float-point	float-point	float-point	float-point	float-point	float-point	float-point	float-point	float-point	float-point
	Observed porosity (%)	rare	4.8	4.4	0.5	4.0	2.4	1.2	2.5	2.1	rare	1.6	2.5	2.0	4.5
	- Primary porosity	intrafossil	intrafossil	intrafossil	intrafossil	intrafossil	intrafossil	intrafossil	intrafossil	intrafossil	intrafossil	intrafossil	intrafossil	intrafossil	intrafossil
	- Secondary porosity	-	veinlet	microcrack	-	& also pore	& also pore	& also pore	& also pore	& also pore	& also pore	-	& also pore	microcrack	& also pore
CARBONATE - ROCK NAME by FOLK(1959,1962)		BIOSPARITE (UNSORTED)	BIOSPARITE (UNSORTED)	BIOSPARITE (UNSORTED)	BIOSPARITE (UNSORTED)	BIOSPARITE (UNSORTED)	BIOSPARITE (UNSORTED)	BIOSPARITE (UNSORTED)	BIOSPARITE (UNSORTED)	BIOSPARITE (UNSORTED)	BIOSPARITE (UNSORTED)	BIOSPARITE (UNSORTED)	(POORLY-WASHED) BIOSPARITE	POORLY-WASHED BIOSPARITE	BIOSPARITE (UNSORTED)
	- by DUNHAM in HAM ed.(1962)	PACKSTONE	PACKSTONE	PACKSTONE	PACKSTONE	PACKSTONE	PACKSTONE	PACKSTONE	PACKSTONE	PACKSTONE	PACKSTONE	PACKSTONE	PACKSTONE	PACKSTONE	PACKSTONE
TERRIGENOUS MIXED CARBONATE	- by LEWIS (1984)	SANDY BIO-CALCARENITE	BIOCLASTIC-ARENITE	BIOCLASTIC-ARENITE	BIOCLASTIC-ARENITE	SANDY BIO-CALCARENITE	SANDY BIO-CALCARENITE	SANDY BIO-CALCARENITE	SANDY BIO-CALCARENITE	BIOCLASTIC-ARENITE	BIOCLASTIC-ARENITE	SANDY BIO-CALCARENITE (RUDITE)	BIOCALC-ARENITE	BIOCALC-ARENITE	BIOCLASTIC-ARENITE

APPENDIX 7-A

Thin-section No.	ST-9	ST-14	ST-21	ST-23	ST-24	ST-30	ST-33	ST-35	W-1	W-2	W-3	W-4
DETRITAL CALCAREOUS GRAINS (ALLOCHEMS)												
All bioclastic grains (%)	76.4	81.5	80.1	71.5	74.0	50.8	67.2	31.6	30.4	42.4	56.8	45.2
Benthic foraminifers %	18.6	13.0	19.0	15.5	23.5	20.4	22.8	24.8	24.4	38.0	14.0	34.4
Planktic foraminifers %	v.rare	rare	rare	v.rare	rare	rare	0.4	0.4	-	rare	rare	rare
Calcareous algae												
- Lithothamnium fragments %	50.8	65.5	60.7	55.0	50.0	30.0	37.2	5.2	0.8	-	40.0	2.4
- Other algae %	-	-	-	v.rare	-	-	-	rare	-	-	-	-
Echinoderms %	4.5	0.5	rare	0.5	0.5	rare	5.2	0.8	rare	0.8	0.4	0.8
Bryozoans %	-	rare	-	-	-	-	rare	-	-	-	rare	-
Ostracods %	v.rare	rare	rare	v.rare	rare	rare	rare	-	-	rare	-	-
Molluscs												
- Bivalves %	2.5	2.5	0.4	0.5	-	0.4	1.6	0.4	5.2	3.2	2.4	7.6
- Gastropods %	-	-	-	-	-	-	-	-	-	-	-	-
Brachiopods %	-	-	-	-	-	-	-	-	-	0.4	-	-
Unidentified bioclasts %	-	-	-	-	-	-	-	-	-	-	-	rare
Maximum grain-size	f.pebble	f.pebble	granule	granule	granule	granule	c.pebble	f.pebble	granule	granule	granule	granule
Minimun grain-size	m.sand	m.sand	f.sand	f.sand	f.sand	m.sand	f.sand	f.sand	m.sand	f.sand	f.sand	f.sand
Modal grain-size	v.c.sand	v.c.sand	v.c.sand	v.c.sand	v.c.sand	v.c.sand	granule	v.c.sand	v.c.sand	v.c.sand	v.c.sand	v.c.sand
Roundness	s.abraded	s.abraded	s.abraded	s.abraded	s.abraded	s.abraded	s.abraded	s.abraded	s.abraded	s.abraded	s.abraded	s.abraded
Sphericity	low-moderate	moderate	moderate	low-moderate	low-moderate	moderate	moderate	low-moderate	low	moderate	low-moderate	low-moderate
Sorting	v.poor	v.poor	m.poor	m.poor	m.poor	v.poor	v.poor	v.poor	v.poor	m.poor	v.poor	v.poor
Fragmentation	v.common	v.common	v.common	v.common	v.common	v.common	v.common	v.common	v.common	v.common	v.common	v.common
Intraclasts (%)	-	rare	rare	rare	-	rare	-	-	-	-	-	-
DETRITAL NON-CALCAREOUS GRAINS												
All terrigenous grains (%)	3.7	5.0	4.1	13.5	7.5	32.4	14.4	49.6	41.2	25.6	31.2	29.6
Total quartz %	2.9	3.5	2.5	3.5	4.5	14.0	7.2	19.2	23.6	15.2	16.4	16.0
- Monocrystalline %	2.8	3.4	2.5	3.3	4.4	12.7	6.8	17.8	22.8	14.4	15.7	15.2
- Undulatory extinction %	0.3	0.5	0.4	0.8	1.2	2.4	0.9	4.1	4.7	2.1	3.8	3.3
- Non extinction %	2.5	2.9	2.1	2.5	3.2	10.3	5.9	13.7	18.1	12.3	11.9	11.9
- Polycrystalline %	0.1	0.1	-	0.2	0.1	1.3	0.4	1.4	0.8	0.8	0.7	0.8
- less than 3 crystals %	-	-	-	-	-	0.8	0.4	0.9	0.3	0.4	0.2	0.2
- more than 3 crystals %	0.1	0.1	-	0.2	0.1	0.5	-	0.5	0.5	0.4	0.5	0.6
Total feldspar %	0.8	1.0	0.4	2.5	1.0	7.2	2.0	13.6	6.0	6.8	8.4	8.0
- Alkali feldspar %	0.8	1.0	0.4	2.4	1.0	6.0	1.8	12.8	5.3	6.4	7.4	6.7
- Orthoclase %	0.3	0.2	0.1	0.5	0.1	1.8	0.7	3.6	2.9	1.5	3.2	3.9
- Microcline %	0.5	0.8	0.3	1.9	0.9	4.2	1.1	9.2	2.4	4.9	4.2	2.8
- Plagioclase %	rare	v.rare	rare	0.1	rare	1.2	0.2	0.8	0.7	0.4	1.0	1.3
Total rock fragments %	-	0.5	1.2	7.0	2.0	9.6	4.0	16.0	10.4	2.8	5.6	3.2
- <2 mm unstable rk.frag. %	-	0.1	0.1	0.2	0.1	0.7	0.3	1.2	0.9	0.2	0.7	0.2
- >2 mm unstable rk.frag. %	-	0.4	1.0	6.3	1.7	6.7	2.8	11.7	7.0	1.4	3.1	1.6
- >2 mm stable rk.frag. %	-	-	0.1	0.5	0.2	2.2	0.9	3.1	2.5	1.2	1.8	1.4
Muscovite %	-	-	v.rare	rare	-	-	-	-	-	-	-	-
Biotite %	-	rare	rare	0.5	rare	1.6	1.2	0.8	0.8	0.8	0.8	2.0
Transparent heavy minerals %	rare	rare	rare	rare	-	rare	rare	rare	rare	rare	rare	rare
Opaque minerals %	-	-	-	-	-	rare	rare	rare	0.4	rare	rare	0.4
Maximum grain-size	granule	granule	f.pebble	granule	granule	f.pebble	granule	f.pebble	m.pebble	m.pebble	m.pebble	v.c.sand
Modal grain-size	c.sand	c.sand	v.c.sand	v.c.sand	v.c.sand	v.c.sand	c.sand	granule	v.c.sand	v.c.sand	granule	c.sand
Roundness	subangular	subangular	subangular	subangular	subangular	subangular	subangular	subangular	subangular	subangular	subangular	subangular
Sphericity	low	low-moderate	low-moderate	low-moderate	low-moderate	low-moderate	moderate	low-moderate	low-moderate	low-moderate	low-moderate	moderate
Sorting	m.poor	m.poor	v.poor	m.poor	m.poor	v.poor	m.poor	m.poor	v.poor	v.poor	v.poor	m.poor
Sandstone's classified by composition BY McBRIDE (1963)	subarkose	subarkose	subarkose	arkose	subarkose	arkose	subarkose	arkose	subarkose	arkose	arkose	arkose
Matrix (%)	1.2	1.5	1.2	2.0	1.5	2.0	2.4	5.2	6.4	5.2	2.0	2.4
Micrite (%)	3.3	3.5	3.7	3.5	3.0	1.6	2.0	2.4	1.6	3.2	4.0	2.8
Cement (%)	11.6	7.0	9.1	8.0	10.5	10.8	11.2	9.2	18.0	22.4	2.4	20.0
Diagenetic components												
- Cement types (sparite)	calcite (C)	calcite (C)	calcite (C)	calcite (C)	calcite (C)	C-fibrous	calcite (C)	calcite (C)	calcite (C)	calcite (C)	calcite (C)	calcite (C)
- Cement-crystal sized	f-medium	f-medium	f-medium	f-medium	f-medium	v.f - v.c	f-medium	f-medium	f-medium	f-medium	f-medium	f-medium
Other authigenic (%)	rare	rare	rare	rare	rare	trace	rare	rare	rare	1.2	-	rare
- other authigenic types	-	-	-	-	-	-	-	-	-	-	-	-
Intrinsic materials	C,FeO,G,cly	C,G,cly	C,G,cly	C,G,cly	C,G,cly	C,cly	C,G,cly	C,FeO,cly	C,FeO,cly	C,cly	C,FeO,cly	C,cly
Extrinsic materials	C,FeO,glau.	C,glau.	C,glau.	C,glau.	C,glau.	granular-C	C,glau.	C,FeO	C,FeO,G	C,G	C,FeO	C,G
Grain to grain contacts												
- Allochem relationships	point-long	point-long	point-long	point-long	point-long	point-long	point-long	point-long	point-long	point-long	point-long	point-long
- Siliciclast relationships	float-point	float-point	float-point	float-point	float-point	float-point	float-point	float-point	float-point	float-point	float-point	float-point
Observed porosity (%)	3.7	1.5	1.7	1.5	3.5	2.4	2.8	2.0	2.4	-	3.6	-
- Primary porosity	intrafossil	intrafossil	intrafossil	intrafossil	intrafossil	intrafossil	intrafossil	intrafossil	intrafossil	-	intrafossil	-
- Secondary porosity	& also pore	& also pore	& also pore	& also pore	& also pore	& also pore	& also pore	& also pore	& also pore	-	& also pore	-
CARBONATE - ROCK NAME by FOLK(1959,1962)	BIOSPARITE (UNSORTED)	BIOSPARITE (UNSORTED)	BIOSPARITE (UNSORTED)	BIOSPARITE (UNSORTED)	BIOSPARITE (UNSORTED)	BIOSPARITE (UNSORTED)	BIOSPARITE (UNSORTED)	BIOSPARITE (UNSORTED)	BIOSPARITE (UNSORTED)	BIOSPARITE (UNSORTED)	(POORLY-WASHED) BIOSPARITE	BIOSPARITE (UNSORTED)
- by DUNHAM in HAM ed.(1962)	PACKSTONE	PACKSTONE	PACKSTONE	PACKSTONE	PACKSTONE	PACKSTONE	PACKSTONE	PACKSTONE	PACKSTONE	PACKSTONE	PACKSTONE	PACKSTONE
TERRIGENOUS MIXED CARBONATE - by LEWIS (1984)	BIOCALC-ARENITE	BIOCALC-ARENITE	BIOCALC-ARENITE	SANDY BIO-CALCARENITE	BIOCALC-ARENITE	SANDY BIO-CALCARENITE	SANDY BIO-CALCARENITE	BIOCLASTIC-ARENITE (RUDITE)	BIOCLASTIC-ARENITE	SANDY BIO-CALCARENITE	SANDY BIO-CALCARENITE (RUDITE)	SANDY BIO-CALCARENITE

APPENDIX 7B

Raw petrographical data

for samples of

The non-calcareous Linz sand sediments

APPENDIX 7-B	UNCONSOLIDATED NON-CALCAREOUS LINZ SAND			
Thin-section No.	D-4	E-13	F-6	G-7
All terrigenous grains %	82.3	91.0	88.0	94.2
Total quartz %	61.3	47.5	61.6	52.9
- Monocrystalline %	58.0	41.0	59.1	48.8
- Undulatory extinction %	18.0	11.5	14.1	8.8
- Non extinction %	40.0	29.5	45.0	40.0
- Polycrystalline %	3.3	6.5	2.5	4.1
- less than 3 crystals %	1.3	2.5	1.6	4.1
- more than 3 crystals %	2.0	4.0	0.9	-
Total feldspar %	19.3	35.0	19.0	33.0
- Alkali feldspar %	13.0	29.0	12.4	28.9
- Orthoclase %	8.3	22.5	7.4	23.1
- Microcline %	4.7	6.5	5.0	5.8
- Plagioclase %	6.3	6.0	6.6	4.1
Total rk.frag. % (granite)	1.7	8.5	3.3	5.8
Muscovite %	rare	rare	rare	0.8
Biotite %	rare	rare	2.1	1.7
Transparent heavy minerals %	rare	rare	0.8	v.rare
Opaque minerals %	rare	-	1.2	rare
Maximum size	c.sand	f.pebble	v.f.pebble	v.f.pebble
Minimum size	silt	silt	silt	silt
Modal size	f.sand	v.c.sand	f,v.c.sand	f,v.c.sand
Roundness	angular to subangular	subround to subangular	subangular to subround	subangular to subround
Sphericity	m.high	m.high	low-moderate	low-moderate
Sorting	m.well	m.poor	poor	poor
Matrix %	1.0	1.5	2.1	0.8
- Matrix components	qtz,felds (rare cly)	qtz,felds (rare cly)	qtz,felds, & cly.	qtz,felds (rare cly)
Cement %	non	non	non	non
Porosity %	16.7	7.5	9.9	5.0
- Primary	intergrains	intergrains	intergrains	intergrains
- Secondary	-	-	-	-
Grain to grain contacts	point-long	point-long	point-long	point-long
Sandstone's classification by composition: BY FOLK,et.al.(1970)	felds-arenite	felds-arenite	felds-arenite	felds-arenite
BY McBRIDE (1963)	subarkose	arkose	subarkose	arkose
BY WILLIAMS,et.al.(1982)	feldspathic arenite	feldspathic arenite	feldspathic arenite	feldspathic arenite

APPENDIX 8

Additional samples and Grid-references

APPENDIX 8: ADDITIONAL SAMPLES AND GRID-REFERENCES.

SAMPLE	GRID-REFERENCE Sheet BMN-5803 (STEYREGG)	ROCK NAME
CB	270508	Green colour MUD between granitic boulders of colluvium sediments
K-1	298514	GRANITE
K-2	278498	GRANITE
K-3	298514	GRANITE
K-4	269516	GRANITE
R-2	Quarry A,Steyregg	BIOCALCARENITE
R-4	Quarry A,Steyregg	BIOCALCARENITE
W-1	279513	BIOCLASTIC ARENITE
W-2	269503	SANDY BIOCALCARENITE
W-3	260504	SANDY BIOCALCARENITE
W-4	265505	SANDY BIOCALCARENITE
W-5	298497	Slightly consolidated calcarenites
W-6	262505	Slightly consolidated calcarenites
W-7	261504	Slightly consolidated calcarenites

CURRICULUM VITAE

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1967 to 1968 - Pre-school education at Sri-Vittaya School, Chiang Mai, THAILAND.
1968 to 1975 - Primary education at Sri-Vittaya School, Chiang Mai, THAILAND.
1975 to 1978 - Lower secondary education at Chairote-Vittaya School, Chiang Mai, THAILAND.
1978 to 1980 - Upper secondary education at Yuparat-Vittayalai, Chiang Mai, THAILAND.
1980 to 1983 - Bachelor of Science (B.S.), Degree in Geology, at Chiang Mai University, THAILAND.
1985 - Certificate on Aspects of Quaternary Geology: sedimentology with special reference to lignite bearing sequences, Chiang Mai University, THAILAND.
1986 - Certificate of Proficiency in the English Language, Department of Technology and Economic Co-operation, Bangkok, THAILAND.
1986 - Certificate of Proficiency in the English Language, English Language Institute, The Victoria University of Wellington, NEW ZEALAND.
1987 to 1989 - Master of Science (M.Sc.), Degree in Geology, at The University of Auckland, NEW ZEALAND.

EMPLOYMENT RECORDS:

1983 - Geologist, Crown Enterprise Co., Ltd., Bangkok, THAILAND.
1990 to 1992 - Geologist, Kenber Geotechnic (Thailand) Co., Ltd., Chiang Mai, THAILAND.
1983 to Present - Instructor, Department of Geological Sciences, Faculty of Science, Chiang Mai University, THAILAND.

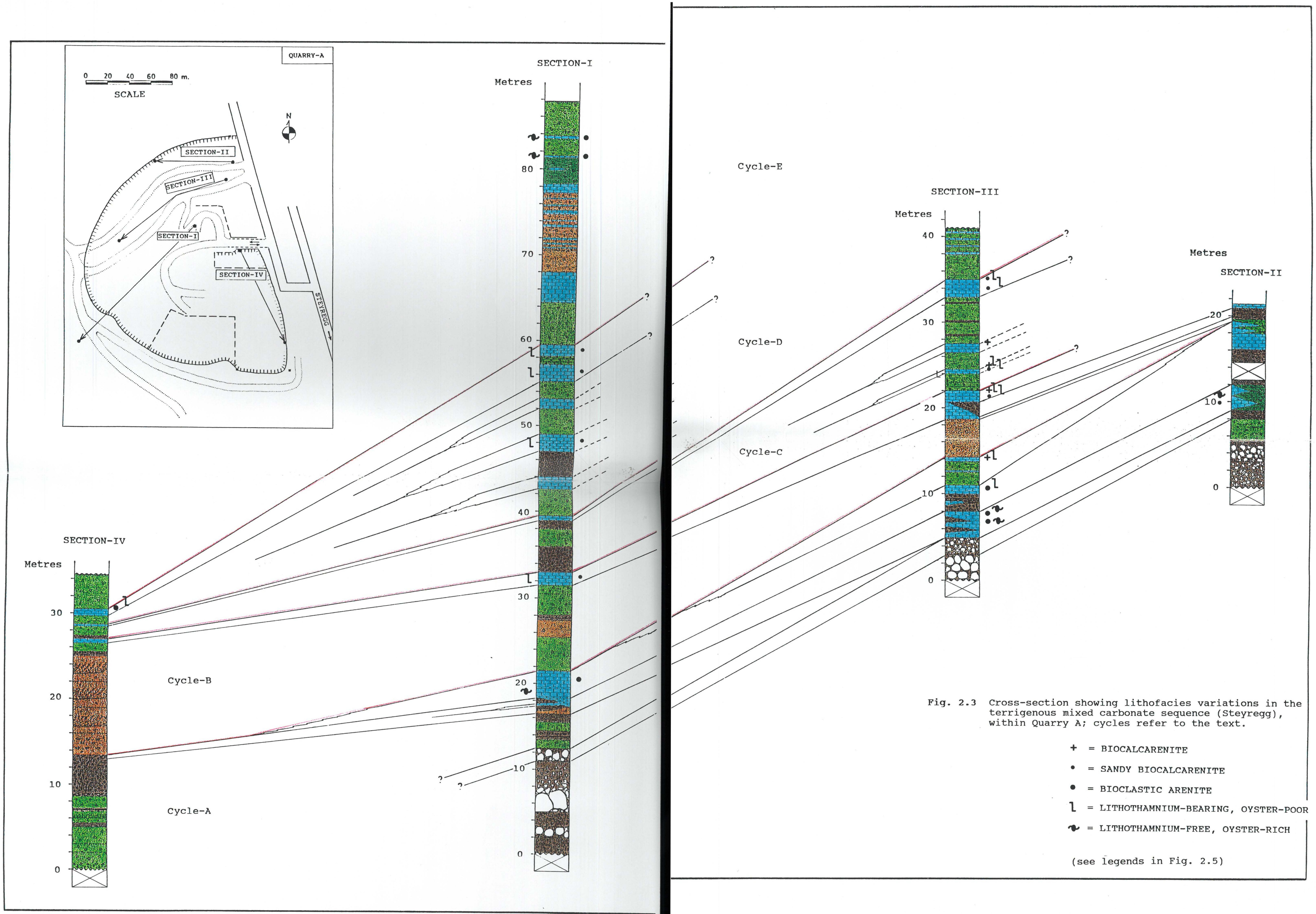

Fig. 2.3 Cross-section showing lithofacies variations in the terrigenous mixed carbonate sequence (Steyregg), within Quarry A; cycles refer to the text.

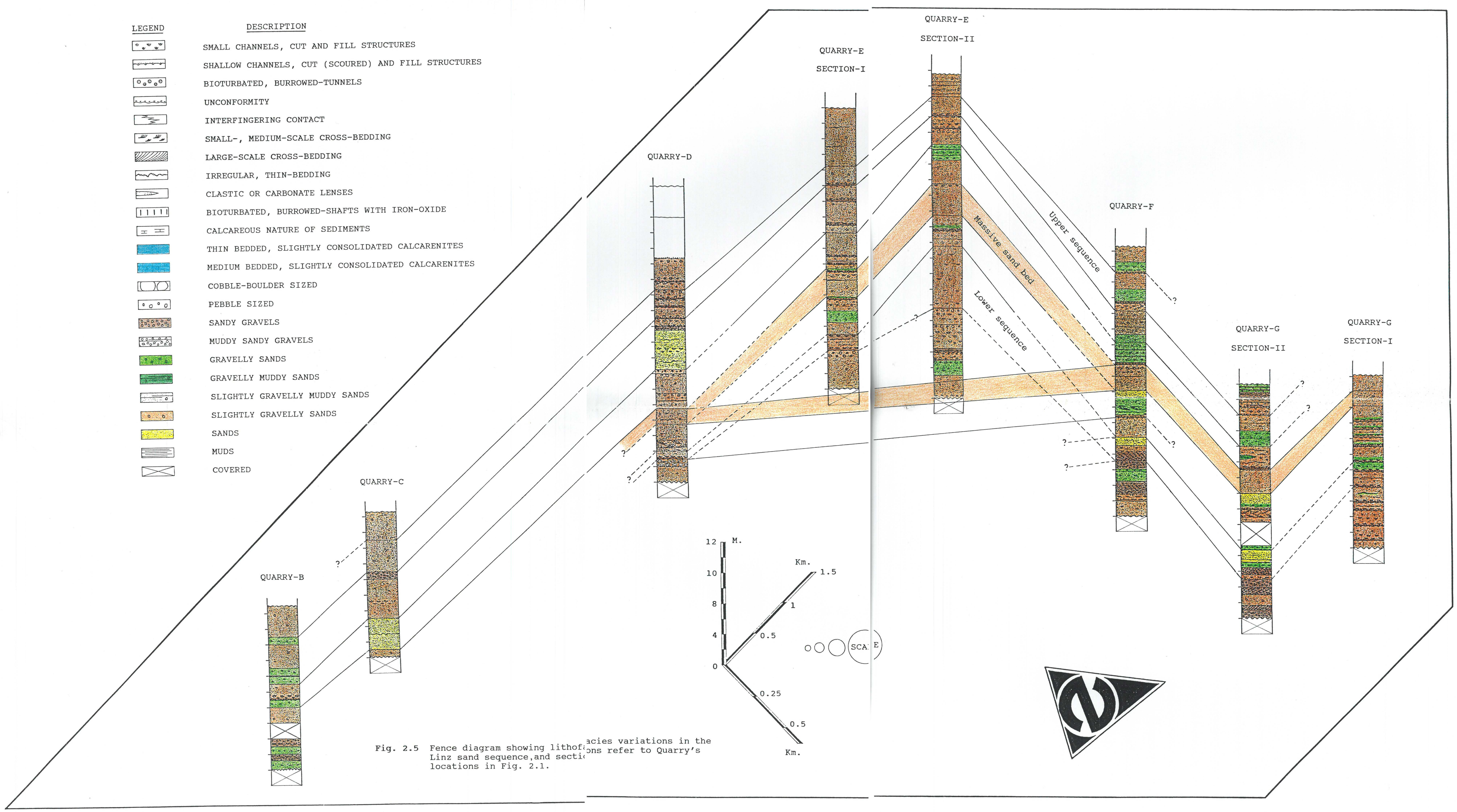

Fig. 2.5 Fence diagram showing lithofacies variations in the Linz sand sequence,and sections refer to Quarry's locations in Fig. 2.1.

GEOLOGIC MAP OF STEYREGG AREA