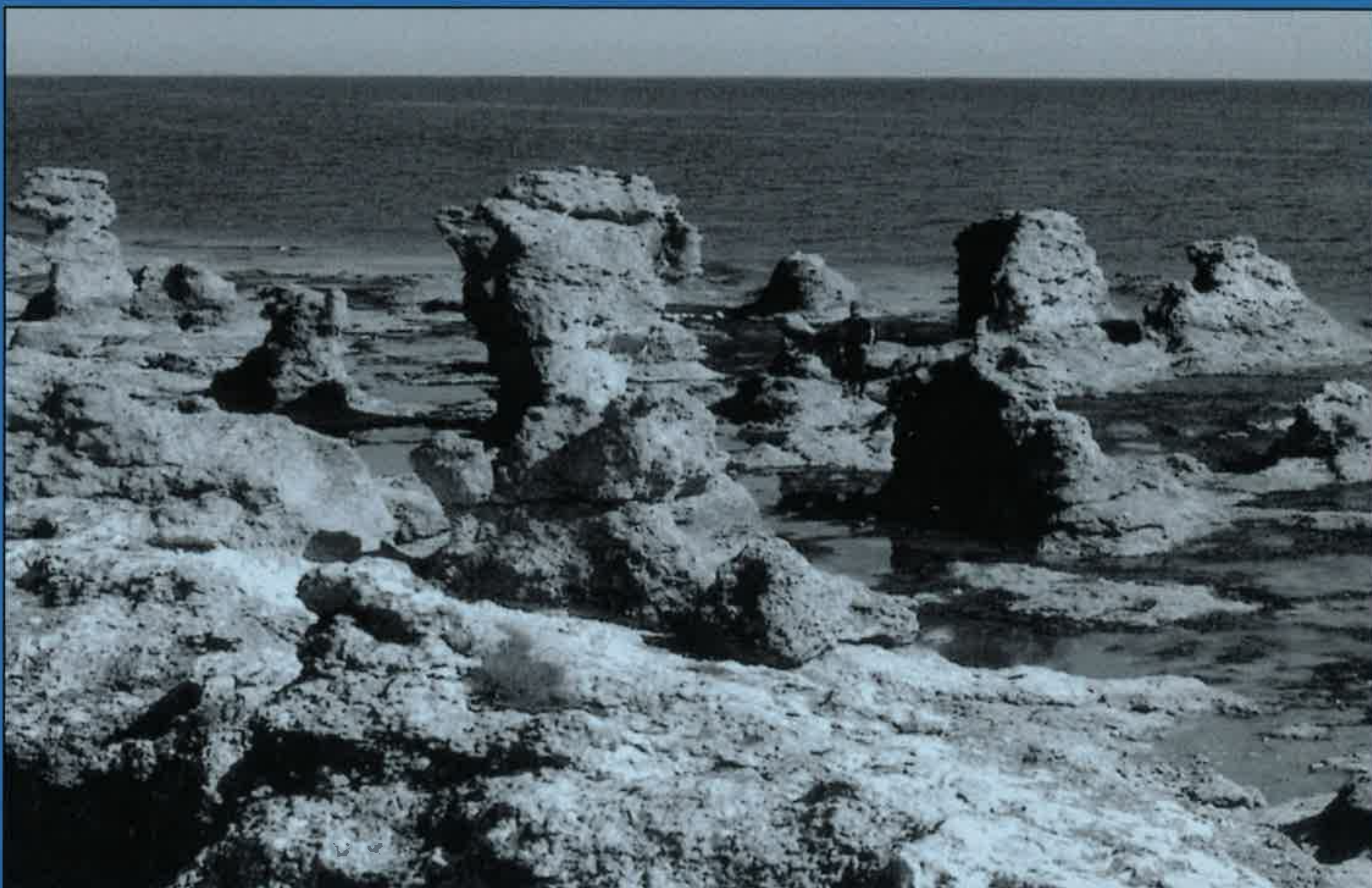
SILURIAN LANDS AND SEAS

Paleogeography Outside of Laurentia



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SILURIAN LANDS AND SEAS

PALEOGEOGRAPHY
OUTSIDE OF LAURENTIA

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Cover illustration: Coastal outcrops along the Baltic Sea in southeastern Gotland, southern Sweden. These sea stacks eroded in the Sundre beds (Upper Silurian, upper Ludlow) are similar to those described by Linnaeus during his 1741 visit to Kyllaj, northeastern Gotland (see title page).

SILURIAN STRATIGRAPHY AND PALEOGEOGRAPHY OF GONDWANAN AND PERUNICAN EUROPE

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ABSTRACT — The modern geographical distribution of north Gondwanan regions with Silurian sediments and faunas shows a rather complex and disorganized picture. This apparent disorganization mainly resulted from tectonism during the Variscan orogeny and, to a minor degree, later modifications by the Alpine orogeny. We infer that the pre-orogenic paleogeography of the north Gondwanan Silurian featured a continuous shelf that can be divided into proximal and distal parts. The Perunica microcontinent (i.e., the present-day Bohemian Massif) was incorporated into the Variscan orogen as terrane between the Gondwana and Baltica continents. The existence of Perunica is supported by paleomagnetic data and by the distribution of Ordovician and Silurian fossil communities.

INTRODUCTION

North African Gondwana was influenced in the Early Silurian by eustatic rise that resulted from the melting of the Gondwana ice cap, and probably also by related deep-water anoxia which was ameliorated slightly during the late Wenlock (Paris and Robardet, 1990). Later development of carbonates, starting in the Wenlock and particularly in the Ludlow and Pridoli, indicates a better ventilation of bottom waters and a climate warming. This area had a Silurian paleoposition of ca. 40°–50° S latitude (J. Kříž, unpublished data, 1996).

Close faunal relationships exist between the Silurian of Morocco, Spain and the Pyrenees, the Mouthoumet Massif, Montagne Noire, the Aquitaine Basin, the Armorican Massif, Sardinia, and the Carnic Alps (Kříž, 1996, 1999; Kříž and Serpagli, 1993). These relationships suggest the location of these areas on the northern margin of Gondwana during the Silurian (Fig. 1). The northern position of the Perunica microcontinent (Havlíček et al., 1994) in the Silurian is reflected by carbonate facies that have very rich brachiopod-dominated communities with other benthic elements (e.g., corals, crinoids, trilobites, and mollusks). Bivalve-dominated communities of Sardinia and the south Armorican Domain, Prague Basin, Carnic Alps, Mouthoumet Massif, and Montagne Noire (Kříž and Paris, 1982; Kříž, 1991, 1996, 1997a, 1997b, in press; Kříž and Serpagli, 1993)) show closer relationships along the northern margin of Gondwana than to communities from the Prague Basin on the Perunica microcontinent. Moreover, bivalve-dominated communities show a generally higher diversity in Perunica than in Gondwana.

SEDIMENTARY ROCKS

The Silurian of North African Gondwana and Perunica is characterized by two types of successions. The first succession, which occurs in most of the Armorican regions (except the south Armorican Domain) and in most of the Hesperian Massif (except the Ossa-Morena Zone), is

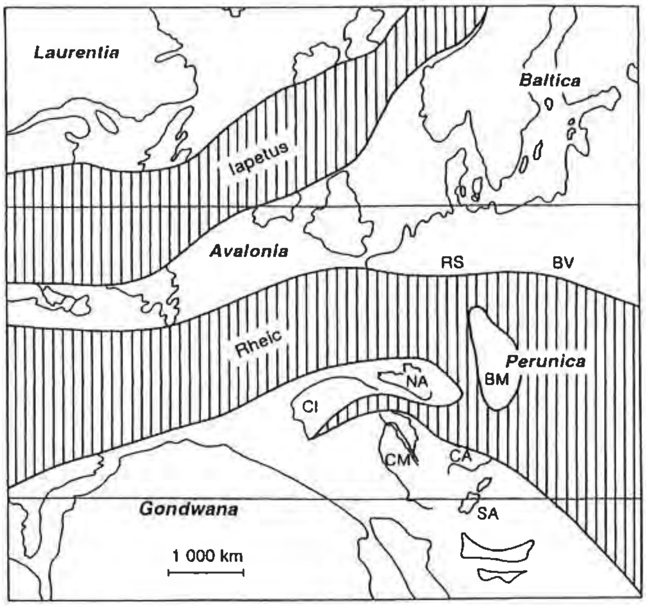

FIGURE 1 — Middle Silurian paleogeography of North African Gondwana, Perunica, Baltica, and Avalonia [based on Cocks and Fortey (1982), Paris and Robardet (1990), and Havlíček et al. (1994)]. Abbreviations: BM, Bohemian Massif; BV, Brunovistulicum; CA, Carnic Alps; CI, Central Iberian Domain; CM, Cantabrian Mountains; NA, North Armoricain Domain; RS, Rheinisches Schiefergebirge (Rhenish Slate Mountains of text); SA, Sardinia.

largely characterized by siliciclastics (see Gutiérrez-Marco et al., 1998). These successions typically begin with sandstones that probably include the Ordovician–Silurian boundary and "lower" Llandovery; continue as graptolitic black shales through the Llandovery, Wenlock, and Ludlow; and end with sandstone–siltstone alternations (Ludlow and Pridoli) that pass into Lower Devonian (Lochkovian) sandstones. The important characteristic of this succession is the predominance of rather coarse-grained siliciclastics that were derived from emergent land areas. This terrigenous influx probably indicates that these depositional areas were on the proximal parts of the North Gondwana shelf (J. Kříž, unpublished data, 1996).

The second type of Silurian succession characterizes all other Gondwanan European regions and reflects low terrigenous influx. It is typically composed of black shales or calcareous shales and limestones (Berry and Boucot, 1967). Such successions apparently developed in more distal, outer-shelf environments. Within this type of succession, it is possible to distinguish three main types of facies development: the "Shelly Fauna," Prague Basin, and Thuringian facies.

The shallow-water, "Shelly Fauna Facies" is often characterized by great thicknesses of calcareous shales with limestone nodules and lenses with a shelly fauna. Especially important features include cephalopod limestones that occur through the Homerian–Gorstian boundary and in the upper Gorstian, lower and upper Ludfordian, and lowest and uppermost Pridoli (Kříž, 1998). This lithofacies was deposited below wave base, but within the reach of surface currents which ventilated the sea bottom. It is characterized by the presence of recurring communities dominated by bivalves (*Cardiola* Community Group, Kříž, in press), and by very abundant cephalopods and other mainly molluscan faunal elements whose larvae were transported by surface currents across the north Gondwana and Perunica basins (Kříž, 1998). This facies is developed, for example, in the Prague Basin (Bohemia) (Kříž, 1991); the Carnic Alps (Austria and Italy) where it is known as the Plöcken facies and Wolayer facies (Schönlaub, 1980); in southwest Sardinia (Italy); in the Montagne Noire (France); in the Central Iberian Zone and the Catalonian Coastal Ranges (Spain), and in Germany (Bavarian facies; Kurze and Tröger, 1990). Correlations of the Shelly Fauna Facies are based on graptolites, conodonts, chitinozoans, bivalves, and cephalopods.

The very shallow-water, shell-rich carbonate "Prague Basin Facies" apparently represented favorable conditions for distal-shelf benthic communities dominated by brachiopods, crinoids, corals, and trilobites (J. Kříž, unpublished data, 1996). This facies developed on the gentle slopes of the Wenlock–Ludlow volcanic archipelago in the Prague Basin (Kříž, 1991). Similarly, this facies appeared on the slopes of a Ludlow volcanic center near Graz, Austria (Fritz and Neubauer, 1988; Neubauer, 1989), and in the middle Llandovery of the Cantabrian Zone (Spain), where the facies developed on basaltic volcanoes (see Truzols and Julivert, 1983). Correlations of the Prague Basin Facies with the Shelly Fauna Facies and Thuringian Facies (described below) can only be made by a combination of conodont and chitinozoan successions. Direct correlation is also possible between the Shelly Fauna and the Prague Basin facies with graptolites, chitinozoans, ostracodes, cephalopods, and bivalves which occur in both facies.

The deep-water Thuringian Facies is represented by relatively thin sequences of Lower Silurian shales with chert (Jeger, 1976, 1977b). The absence of current orientation and the character of the rocks indicate a calm, relatively deep-sea environment (Jaeger, 1976, 1977). This anoxic or dysaerobic environment changed during the later Silurian with deposition of the Ockerkalk (a blue-gray, argillaceous limestone that weathers to ochre and is characterized by thick beds with thin quartzite intercalations). In Germany, these quartzites may be interpreted as distal turbidites. This facies is developed in the Saxothuringian Basin (Germany), Bohemia, Carnic Alps (Bischofalm facies), Ossa-Morena Zone (Spain), and southeast Sardinia (Italy). Correlations of the Thuringian facies are based predominantly on graptolites, and in the Upper Silurian on conodonts (Jaeger, 1976, 1977a). The development of the Thuringian and Shelly Fauna facies suggests that most of the Variscan regions (e.g., Germany, Carnic Alps, Sardinia) were close to the north Gondwana margin and represented an unstable shelf region (Hammann, 1992).

The Thuringian, Shelly Fauna, and Prague Basin facies all developed on the Perunica microcontinent, but the Thuringian Facies developed across the majority of the area. The Shelly Fauna facies is known only from the Prague Basin, and a unique Prague Basin facies is developed in the Prague Basin on volcanic edifices (Kříž, 1991).

Correlations

Silurian graptolitic shale is readily correlated by graptolites and chitinozoans. In the carbonate facies where graptolites are rare or missing, conodonts and chitinozoans may be used for correlations. The wide distribution of the cephalopod limestone lithofacies allows correlation of the Shelly Fauna facies in north Gondwana. Cephalopod limestones form horizons in the upper Wenlock (*Testograptus testis* Zone), lower Ludlow (*Colonograptus colonus* Zone), Gorstian (upper *Saetograptus chimaera* Zone), lower Ludfordian (lower *Saetograptus linearis* Zone), Ludlow–Pridoli boundary interval (*Pristiograptus fragmentalis* and *Pristiograptus ultimus* Zones), and in the Pridoli (upper *Monograptus transgrediens* Zone) (Kříž, 1998).

Deposition of the cephalopod limestones (Gnoli *et al.*, 1980; Kříž, 1991, 1992, 1998, in press; Ferretti and Kříž, 1995) took place below normal wave base, where surface currents reached the bottom. The biofacies originated during early phases of Silurian sea-level rises (Kříž, 1998), when the bottom was affected periodically by laterally shifting surface currents that transported cephalopods, bivalves, and larval stages of other organisms into the basins. Current-oriented cephalopod shells in the Prague Basin reflect southwest–northeast surface currents from late Wenlock to the latest Pridoli (Ferretti and Kříž, 1995). These currents ventilated the originally anoxic or dysaerobic bottom and periodically slowed the rate of sediment accumulation by winnowing out the lime mud. Thick beds of fossiliferous limestones alternate with thin micritic limestones, the latter of which probably represent long periods of quiet sedimentation in contrast to the rapid episodes of higher energy, fossil hash sediment accumulation.

Surface currents were apparently responsible for the distribution of the cephalopod limestones in northern Gondwana (Morocco, Algeria, Montagne Noire, Carnic Alps, Sardinia) and Perunica (Prague Basin) (Kříž, 1984, 1991, 1992, 1996, 1998; Kříž and Serpagli, 1993; Ferretti and Kříž, 1995). The distribution of the Bohemian-type bivalve fauna in Gondwana (Bolivia, Florida, Morocco, Algeria, Guinea, Spain, Montagne Noire, Armorican massif, Carnic Alps, Sardinia, eastern Serbia, Turkey), Perunica (Prague Basin), Baltica (southern Sweden, Poland), the Taimir block, the Tien Shan region, and the Caucasus are also linked to surface currents (Kříž, 1996, 1998; Kříž and Bogolepova, 1995). These surface currents provided a connection with the eastern Australian Yass Basin, where the Bohemian bivalve fauna has its easternmost occurrence (Rainbow Hill section, Black Bog Formation, Booroo Ponds Group; D. L. Strusz, personal commun., 1996). The currents probably derived from the South Tropical Current (Wilde *et al.*, 1991), which reached the northwestern Taimir Basin in eastern Siberia where a Bohemian-type fauna also occurs (Kříž and Bogolepova, 1995). This circulation agrees with the reconstruction of the summer South Subpolar and South Tropical Currents during the Ludlow (Wilde et al., 1991).

Silurian of the Iberian Peninsula

On the Iberian Peninsula (Fig. 2), Silurian rocks occur in the Hesperian Massif (or Iberian Massif) in the southwest Variscan fold belt. These rocks are known from all of the distinct tectonostratigraphic "Zones" defined by Lotze (1945) and subsequently modified (Julivert et al., 1974; Robardet and Gutiérrez-Marco, 1990b) in Iberia, with the exception of the South Portuguese Zone (Fig. 2G). The South Portuguese Zone shows outcrops only of Upper Devonian and Carboniferous. Silurian rocks occur in other Variscan areas that were also affected by the Alpine orogeny, such as in the Pyrenees, Catalonian coastal ranges, the Iberian Cordillera in the northeast, and the Betic Cordillera in the south. During the Silurian, the Iberian Peninsula was part of the northern African margin of Gondwana. Detailed reviews on Silurian stratigraphy and paleogeography of the Iberian Peninsula are available (Gutiérrez-Marco et al., 1998; Robardet et al., 1998; Štorch et al., 1998).

The latitude and climate of Iberia cannot be defined precisely from Silurian lithofacies (almost entirely terrigenous) or faunas (mainly graptolites). However, latitudinal position can be estimated as roughly intermediate between the rather high latitudes of this area during the latest Ordovician (i.e., Hirnantian glacio-marine sediments with dropstones derived from the African ice cap) and the warm temperate to subtropical latitudes of Early

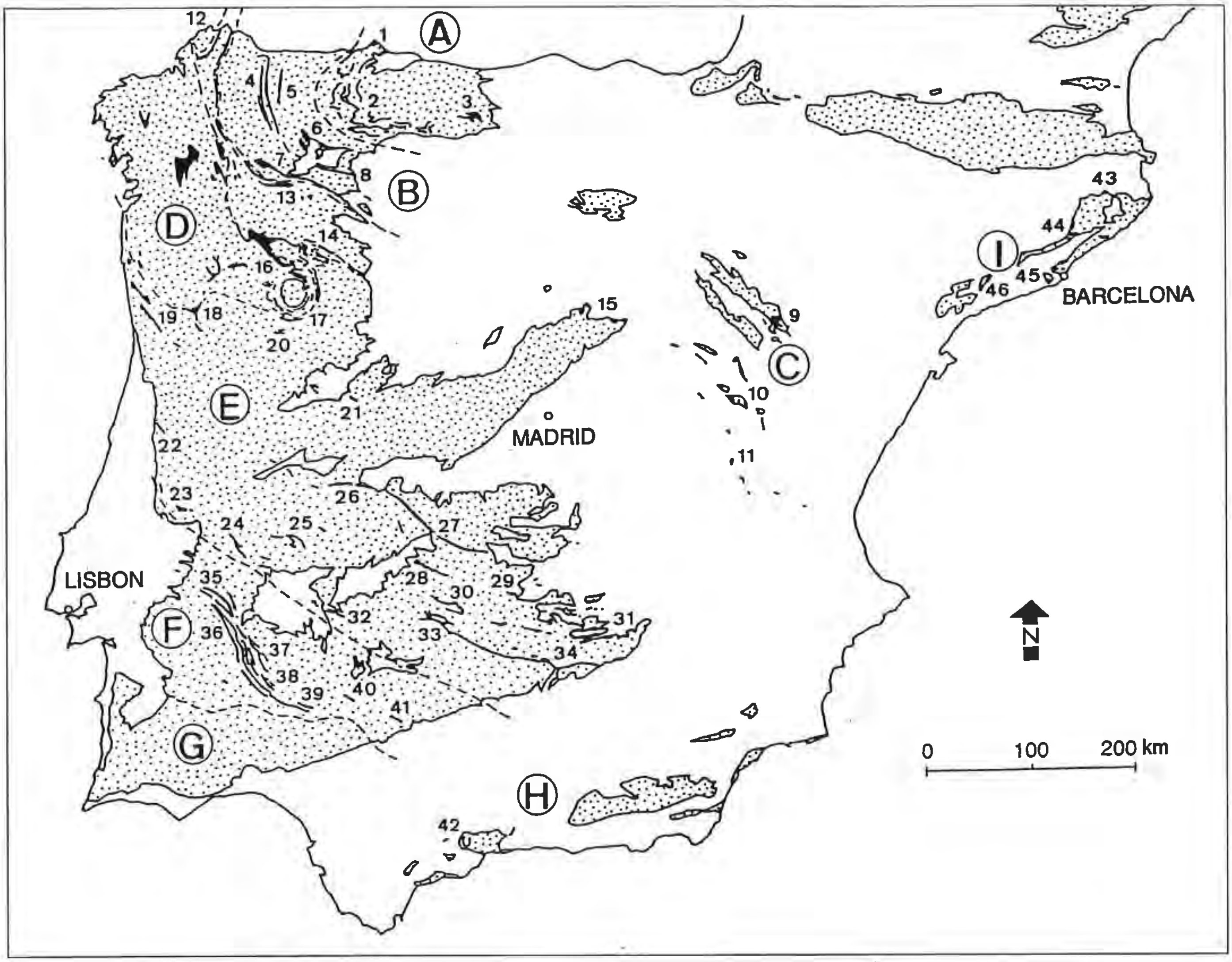

FIGURE 2 — Geological map of the Iberian Peninsula showing Silurian (in black) and main Precambrian and Paleozoic exposures (stippled). Abbreviations: AG, Hesperian Massif (A, Cantabrian Zone [Z.]; B, West Asturian–Leonese Z.; C, Iberian Cordillera Z.; D, GaliciaTrás os Montes Z.; E, Central Iberian Z.; F, Ossa–Morena Z.; G, South Portuguese Z.); H, Betic Cordilleras; I, Catalonian Coastal Ranges. Silurian of the Pyrenees omitted. 1–46, Main Silurian fossil localities and reference sections in Spain and Portugal: 1, Cabo Penas; 2, Silurian outcrops in "fold and nappe" region; 3, Ibid. in Palentian region; 4, Rececende and Villaodrid synclines (Mondonedo nappe); 5, Los Oscos thrust sheet; 6, Vega de Espinareda synclinorium; 7, Caurel-Penalba syncline; 8, Castrillo syncline; 9, Eastern Iberian Chains; 10, Albarracín anticlinorium; 11, Serranía de Cuenca anticlinorium; 12, Cabo Ortegal area; 13, Sil and Truchas synclines; 14, Alcanices synclinorium; 15, Riaza and Atienza areas ; 16, Verín–Bragança region; 17, Mogadouro and Morais area; 18, Vila Real (Marâo); 19, Porto-Valongo; 20, Moncorvo syncline; 21, Tamames syncline; 22, Serra do Buçaco; 23, Dornes–Maçâo areas; 24, Portalegre; 25, Sierra de San Pedro and Cáceres syncline; 26, Canaveral syncline; 27, Guadarranque syncline; 28, Herrera del Duque syncline; 29, Corral de Calatrava; 30, Almadén syncline; 31, Torre de Juan Abad; 32, Alange; 33, Cabeza del Buey–San Benito; 34, El Centenillo-Guadalmena; 35, Estremoz anticline; 36, Terena syncline; 37, Villanueva del Fresno; 38, Barrancos area; 39, Hinojales area; 40, Valle syncline; 41, Cerrón del Hornillo syncline; 42, Malágide region; 43, Guilleries; 44, Montseny; 45, Barcelona; 46, Serra de Miramar.

Devonian limestones and reefs. On the other hand, no diagnostic or unequivocal Silurian paleomagnetic data are available for Iberia. Indeed, Silurian volcanics from the Almadén area (southern Central Iberian Zone) were remagnetized just prior to the Variscan orogeny (i.e., probably in the Late Devonian or Early Carboniferous; see Perroud et al., 1991; Pares and Van der Voo, 1982). The paleogeography proposed in the world maps of Scotese and McKerrow (1990), which is mainly based on Gondwanan lithofacies (Scotese and Barrett, 1990), is acceptable for the Iberian Peninsula, and suggests movement from ca. 45–50° S in the Early Silurian to ca. 35–40° S in the Late Silurian.

Cantabrian Zone.—The Cantabrian Zone in the Hesperian Massif (Fig. 2A) shows thin-skinned tectonic structures with complex thrust systems (Pérez Estaún and Bastida, 1990). Silurian rocks, which have been recognized since the end of the last century (see Truzols and Julivert, 1983), occur both in the "fold and nappe" region and in the allochthonous Palentian region (=Pisuerga-Carrión Unit) in the southeast (Fig. 2, localities 2 and 3).

In the "fold and nappe" region, the oldest Silurian rocks occur only in the Cabo Peñas area (Fig. 2, locality 1). In this area, the upper El Castro Formation (i.e., Viodo Member limestones, 30 m) overlies basalt volcanics and has a rich, diverse fauna with brachiopods, bryozoans, tabulate and rugose corals, trilobites, sponges, ostracodes, and conodonts (Fig. 3). Conodonts indicate that the lower and middle Viodo Member is Rhuddanian (*Distomodus kentuckyensis* Zone) and the upper part is Aeronian (*Distomodus staurognathoides* Zone) (Sarmiento et al., 1994). Brachiopods, which are mostly new species, are considered an early Telychian *Stricklandia* fauna (Villas and Cocks, 1996).

The Formigoso Formation (Fig. 3) lies above the Viodo Member in the Cabo Peñas area and directly overlies Lower or Middle Ordovician rocks in most of the Cantabrian regions. The formation consists of 100–300 m of black and gray siltstone and shale with a few thin, sandy intercalations. The Formigoso Formation, with abundant graptolites and palynomorphs and rare brachiopods, bivalves and trilobites, extends from the upper Aeronian *Demirastrites convolutus* Zone to the lower Sheinwoodian *Cyrtograptus centrifugus-Cyrtograptus murchisoni* Zone (Truyols et al., 1974; Aramburu et al., 1992). These age assignments are based on graptolites and are confirmed by such organic-walled microfossils as chitinozoans (Truyols et al., 1974).

The Formigoso Formation is overlain by the Furada (=San Pedro) Formation (Fig. 3), which consists of 80–200 m of gray or reddish ferruginous sandstones with shale intercalations, thin oolitic ironstones, and sandy limestone lenses in the upper part. The Furada Formation yields late Wenlock palynomorphs in its lower part and Ludlow brachiopods, graptolites, and palynomorphs in its middle part. Ichnofossils are very common and diverse at many levels. The uppermost 30 m contains Pridoli chitinozoans (Priewalder, 1997). Higher levels with Lochovian brachiopods, trilobites, and conodonts indicate that the Silurian–Devonian boundary lies in the upper Furada Formation (Truyols et al., 1974; Aramburu et al., 1992).

In the Palentian region (Fig. 2, locality 3), the lithologic succession is different. The white sandstones of the Robledo Formation (ca. 160 m) are certainly Silurian and yield Wenlock chitinozoans near their top. The overlying siltstones and black shales of the Las Arroyacas Formation (ca. 300–450 m) have benthic faunas, graptolites, and chitinozoans that are Wenlock, Ludlow, and questionably Pridoli. The sandstones and carbonates of the Carazo Formation (sensu stricto, 250–380 m) have Pridoli chitinozoans and higher Lochkovian brachiopods and scyphocrinoids (Schweineberg, 1987; García Alcalde et al., 1990; Aramburu et al., 1992).

West Asturian–Leonese Zone — The Silurian in the West Asturian–Leonese Zone (Fig. 2B) conformably overlies a presumed uppermost Ordovician quartzite unit (Vega Quartzite and equivalents), except in the Los Oscos region (Fig. 2, locality 5) where the Silurian disconformably overlies Arenigian quartzites. The succession comprises a thick unit (La Garganta Beds, up to 500–600 m) of black shales with sparse intercalations of sandstone, argillaceous nodules, and chloritoid slates. The La Garganta Beds are overlain by at least 40 m of ferruginous sandstone (Queixoiro Beds), a possible equivalent of the Furada Formation of the Cantabrian Zone. Known fossils are restricted to the lower half of the La Garganta Beds and include abundant graptolites of the *Cystograptus vesiculosus–C. lundgreni* Zones (Rhuddanian–basal Homerian) in the Mondoñedo nappe (Walter, 1968; Romariz, 1968; Fig. 2, locality 4), Los Oscos thrust sheet (Marcos and Philippot, 1972), and Vega de Espinareda synclinorium and Castrillo syncline (Pérez Estaún, 1978; Gutiérrez-Marco and Robardet, 1991; Fig. 2, localities 6, 8).

Silurian is known in the core of the Caurel–Peñalba syncline (Fig. 2, locality 7) at the southern limit of the West Asturian–Leonese Zone. The lithologies and faunas of this region are similar to those of the Silurian in the northern Central Iberian Zone and include ca. 200 m of black chloritoid shales that overlap different Ordovician formations The black shales yield late Ludlow trilobites with Bohemian affinities in their upper part (Rábano et al., 1993).

Iberian Cordillera — Silurian rocks crop out in the western (Castilian Branch) and eastern (Aragonian Branch) parts of the Iberian Cordillera (Fig. 2C) as part of the Hesperian Massif under the Mesozoic and Cenozoic. The eastern and western Iberian Cordillera (Fig. 2, localities 9–11) can be simply considered as eastern extensions of the West Asturian–Leonese and Cantabrian Zones.

The Silurian of the Iberian Cordillera (see Gutiérez-Marco et al., 1998) begins with the massive, white Los Puertos Quartzite, with an average thickness of 20–35 m, that unconformably overlies Late Ordovician (Hirnantian) diamictites of the Orea Formation. The overlying Bádenas Formation, predominantly black shale with nodules and frequent arenaceous horizons toward the top, reaches a thickness of 850–1,400 m in the Aragonian Branch. Two main sandstone intervals divide the Báde-

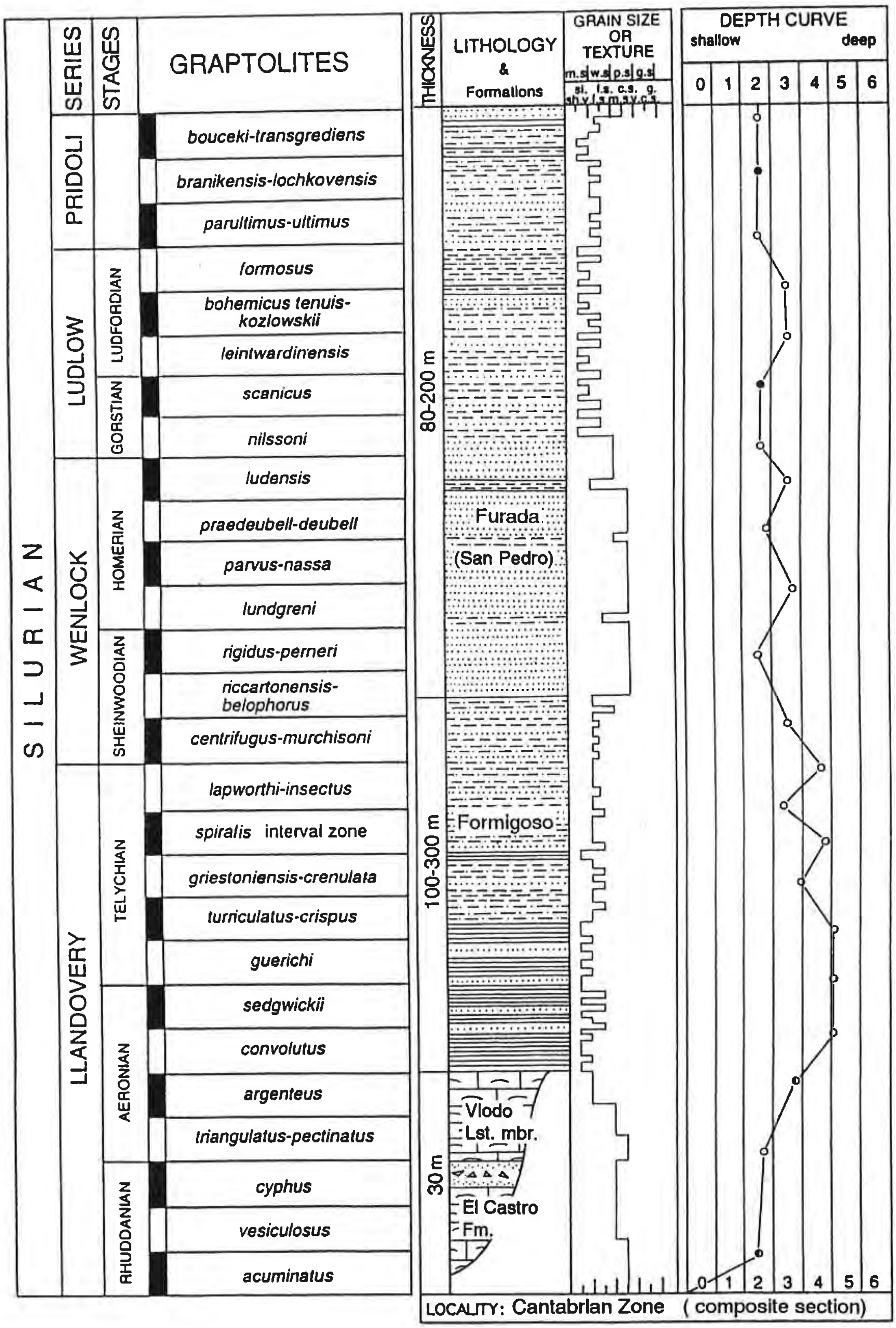

FIGURE 3 — Silurian of the Cantabrian Zone (composite section of the "fold and nappe region") in the Iberian Peninsula.

nas Formation into five members. In the western Iberian Cordillera, the Bádenas Formation is thinner (maximum 300–400 m) and crops out discontinuously in the core of the Alpine anticlinoria of Albarracín and Serranía de Cuenca (Fig. 2, localities 10, 11). Overlying the Bádenas Formation, the Silurian continues in the Eastern Iberian Chains as a dominantly sandstone unit (Luesma Formation, ca. 200 m) with quartzites, sandy shales, and ferruginous sandstones and with sparse limestone lenses in the upper part. The unit correlates with the Alcolea Formation of the "Central System" of the Central Iberian Zone, and with the Furada Formation of the Cantabrian Zone.

The oldest Silurian fossils in the above succession were found in shale intercalations within the upper Los Puertos Quartzite, and include Rhuddanian and Aeronian graptolites (*Parakidograptus acuminatus–Coronograptus cyphus, Demirastrites triangulatus,* and *Demirastrites convolutus* Zones). The black shales of the Bádenas Formation have abundant graptolites that range from the basal Telychian *Spirograptus guerichi* Zone to the basal Ludfordian *Saetograptus leintwardinensis* Zone. The non-graptolite fauna of the black shales and nodules of this formation includes brachiopods, bivalves, cephalopods, eurypterids, phyllocarids, peltocarids, cornulitids, trilobites, and conodonts. In the upper sandstones of the Bádenas Formation in the Aragonian Branch, shallow-water brachiopods, echinoderms, conodonts, trilobites, and ichnofossils occur. Finally, the Luesma Formation of the Eastern Iberian Chains has Pridoli brachiopods and Lochkovian conodonts and brachiopods in its upper part (Carls and Gandl, 1967; Truyols and Julivert, 1983; Gutiérrez-Marco and Štorch, 1998; Štorch, 1998).

Central Iberian Zone — This zone (Fig. 2, region E) comprises two structural and paleogeographic parts (or domains) with different types of Silurian successions. These include the "Domain of Recumbent Folds" in the north and the "Domain of Vertical Folds" in the south (Díez Balda et al., 1990). The first domain includes at least three types of Silurian successions, and the latter is lithologically more uniform.

The first type of sequence crops out east and north of the Ollo de Sapo anticlinorium and comprises a lower unit of graptolitic black shales (Llagarino Formation, 80–150 m) that is overlain by a very thick unit of chloritoid shales with calcareous nodules and some sandstone beds (Salas Beds, ca. 1,000 m; Piçarra et al., 1998). Between these units, a sandstone (Yeres Quartzite, 5–25 m) occurs, but only in the eastern part of the Sil syncline (Fig. 2, locality 13). Graptolites show that the base of the Silurian succession is markedly diachronous and overlies different Ordovician formations (see Rábano et al., 1993, for references). However, in the Truchas synclinorium (Fig. 2, locality 13), the Llagarino Formation lies conformably on Hirnantian sandstones (Losadilla Formation) and has *Parakidograptus acuminatus* Zone graptolites at its base (Gutiérrez-Marco and Robardet, 1991). The upper Llagarino Formation is Gorstian (*Neodiversograptus nilssoni* Zone; Rábano et al., 1993). The Yeres Quartzite has trilobites, brachiopods, echinoderms, solitary rugose corals, bivalves, and cephalopods comparable with uppermost Ludlow assemblages of the Kopanina Formation in Bohemia (Rábano et al., 1993). Pridoli graptolites and scyphocrinoids occur in the Salas Beds, which must contain the Silurian–Devonian boundary in their upper part, and are conformably overlain by Pragian limestones.

West and south of the Ollo de Sapo anticlinorium, the second type of Silurian succession includes a thick unit of black shales with intercalations of chert (lydite), quartzites, conglomerates, and limestones (Manzanal del Barco Formation, ca. 200 m). The graptolite of this formation (Jiménez Fuentes and Quiroga, 1981) are Aeronian to lower Homerian (*Monograptus argenteus* to *Cyrtograptus lundgreni* Zones). The Manzanal del Barco Formation is overlain in the eastern Alca_ices synclinorium (Fig. 2, locality 14) by 300 m of gray shales and limestones of the Almendra Formation, with some flysch intervals that have yielded Ludlow, Pridoli, and Lower Devonian conodonts (García-López et al., 1996). This formation is replaced westwardly in this synclinorium by a thick flysch succession (San Vitero Formation, over 1,500 m of greywacke, shale, and conglomerate with olistoliths and transported plant remains).

A much shallower type of Silurian succession is located in the northeastern Central Iberian Zone near Atienza and Riaza (Fig. 2, locality 15), and is similar to the sequence known further east in the Iberian Cordillera. The Santibáñez Quartzite (20–30 m), supposedly of Rhuddanian age, lies conformably on Hirnantian shales and siltstones near Atienza and Riaza. The quartzite is succeeded by black shales and siltstones with quartzite interbeds in the upper part (Cañamares Formation, 190–250 m) with graptolites (Rhuddanian *Coronograptus cyphus* to lowest Gorstian *Neodiversograptus nilssoni* Zones). A thin limestone near the top of the Cañamares Formation has Pridoli conodonts. The Cañamares Formation is overlain by a 750–800 m sandy unit (Alcolea Formation) with upper Pridoli brachiopods and trilobites in its upper member. The Alcolea Formation is then overlain by a unit with Devonian assemblages (see Fernández Casals and Gutiérrez-Marco, 1985, for references).

The "Domain of Vertical Folds" includes the large Silurian outcrops in the southern Central Iberian Zone. Toward the northwest of this domain, the core of the Tamames syncline (Fig. 2, locality 21) has a succession with a variety of lithological types that resemble those on the south limb of the Ollo de Sapo anticlinorium. In the Moncorvo syncline (Portugal; Fig. 2, locality 20), a succession of Silurian black shales with a pelagic limestone rich in scyphocrinoids and orthocerids and with Pridoli conodonts has been described (Piçarra et al., 1995a).

The Silurian in the southern Central Iberian Zone begins with a lower unit of quartzites (Criadero Formation, 7–70 m) that rests conformably on Hirnantian shales and glacio-marine diamictites. The Criadero is overlain by 5–50 m of graptolitic black shales with sparse nodules and thin sandstone horizons near their top (Fig. 4). The next overlying thick sequence (150–400 m) includes nonfossiliferous sandstones and micaceous shales that continue into the Devonian. The entire succession shows intercalations of volcanic rocks, especially in the area around Almadén (Fig. 2, locality 30), with mercury mineralization related to Aeronian volcanism. Other areas with Silurian rocks in the Central Iberian Zone are the Portuguese outcrops near Porto, Serra do Bussaco, Maçáo-Dornes, and Portalegre (Fig. 2, localities 22–24), as well as the Spanish regions of Guadarranque, Cáceres, San Benito-El Centenillo, and the western Sierra Morena (Fig. 2, localities 25, 27; Sarmiento and Rodríguez Núñez, 1991; Štorch et al., 1998).

Faunas from the top of the Criadero Formation (and its partial equivalent, the Portuguese Vale da Ursa Formation) include rare assemblages of Rhuddanian and Aeronian graptolites (Coronograptus cyphus–Stimulograptus sedgwickii Zones; Brenchley et al., 1991; García Palacios et al., 1996a). The overlying black shales include abundant graptolites indicative of most of the zones between the basal Telychian and Homerian (*Spirograptus guerichi–Pristiograptus dubius parvus-Gothograptus nassa?* Zones; Romariz, 1962; García Palacios et al., 1996b) and sparse brachiopods, bivalves, cephalopods, trilobites, eurypterids, phyllocarids, peltocarids, cornulitids, and conodonts (Sarmiento and Rodríguez Núñez, 1991; García Palacios and Rábano, 1996). Graptolite biostratigraphy clearly shows a hiatus of variable duration at the base of the black shale unit and a clear diachroneity of the base of the overlying sandstone unit, which becomes older to the northwest (Rodríguez Núñez et al., 1989).

Galicia–Trás-os-Montes Zone — This zone (Fig. 2D) constitutes a great allochtonous sheet in the northwest Central Iberian Zone. Its uppermost ophiolitic sequences are overlain by exotic continental terranes (Cabo Ortegal, Órdenes, Bragança, and Morais complexes; Martínez Catalán et al., 1996). The autochthonous unit in this region is a very thick metasedimentary succession termed the "Schistose Domain of Galicia–Trás os Montes," which includes several Silurian intervals with rare, poorly preserved graptolites (see Farias, 1992, for references). Graptolites are more abundant around the Bragança Massif (Romariz, 1968; Fig. 2, locality 16). The local presence of these fossils allow Silurian rocks to be identified in the Nogueira Group (900–1,000 m, with Telychian graptolites in its lower part) and in the Paraño Group (2900–3200 m, with Llandovery–Wenlock graptolites in its lower part; Romariz, 1968).

Ossa–Morena Zone — Silurian rocks are known in the Spanish and Portuguese parts of the Ossa–Morena Zone in southern Iberia (Fig. 2F). The best-preserved and -documented reference successions are in Spain in the Cerrón del Hornillo and Valle synclines (Seville Province) in the eastern part of this zone (Fig. 2, localities 40, 41). In other areas of the Ossa–Morena Zone where outcrops are rarer and where tectonic structures are complicated, the Silurian is not as well known, even though the Barrancos area (Portugal; Fig. 2, locality 38) provides interesting information.

Lithology, faunas, and stratigraphy are almost identical in the Cerrón del Hornillo and Valle synclines (Jaeger and Robardet, 1979; Robardet and Gutiérrez-Marco, 1990a). The Silurian conformably overlies the late Ashgillian Valle Formation, which is composed of dark shales and siltstones that include clast-bearing horizons regarded as Hirnantian glacio-marine sediments (see Gutiérrez-Marco et al., 1998, p. 22). The Silurian–Lochkovian succession consists of 130–150 m of black, argillaceous shales with intercalations of siliceous slates and chert. The lowermost part of the succession shows sandy shale levels; a thin (0.5–0.8 m), black limestone with orthocerids and bivalves occurs in the Ludlow (Jaeger and Robardet, 1979). The most important lithologic change is shown by the Pridoli "*Scyphocrinites* Limestone" (S.Lst. in Fig. 5; 10–15 m). This unit of alternating limestones and shales divides the black shale succession into "Lower Graptolite Shales" (Fig. 5) and "Upper Graptolite Shales" (U.G.S. in Fig. 5). The Silurian–Lochkovian is fossiliferous throughout. The fauna is composed almost entirely of graptolites. Most of the Silurian–Lower Devonian graptolite zones have been recognized, and this indicates a continuous succession that extends from the base of the Rhuddanian (*Parakidograptus acuminatus* Zone), through the uppermost Pridoli (*Monograptus transgrediens* Zone), and into the Lochkovian (up to the *Monograptus hercynicus* Zone) (Jaeger and Robardet, 1979; Lenz et al., 1996; Piçarra et al., 1998). Orthocerids and bivalves are known in the Ludlow limestone; scyphocrinoids, trilobites, bivalves, conodonts, ostracodes, graptolites, and rare solitary corals and brachiopods also occur in the "*Scyphocrinites* Limestone." Anoxic or strongly dysaerobic conditions persisted through the earliest Rhuddanian–late Lochkovin, with the exception of the Pridoli, when bottom oxygenation probably increased.

The tripartite succession of the eastern Ossa–Morena

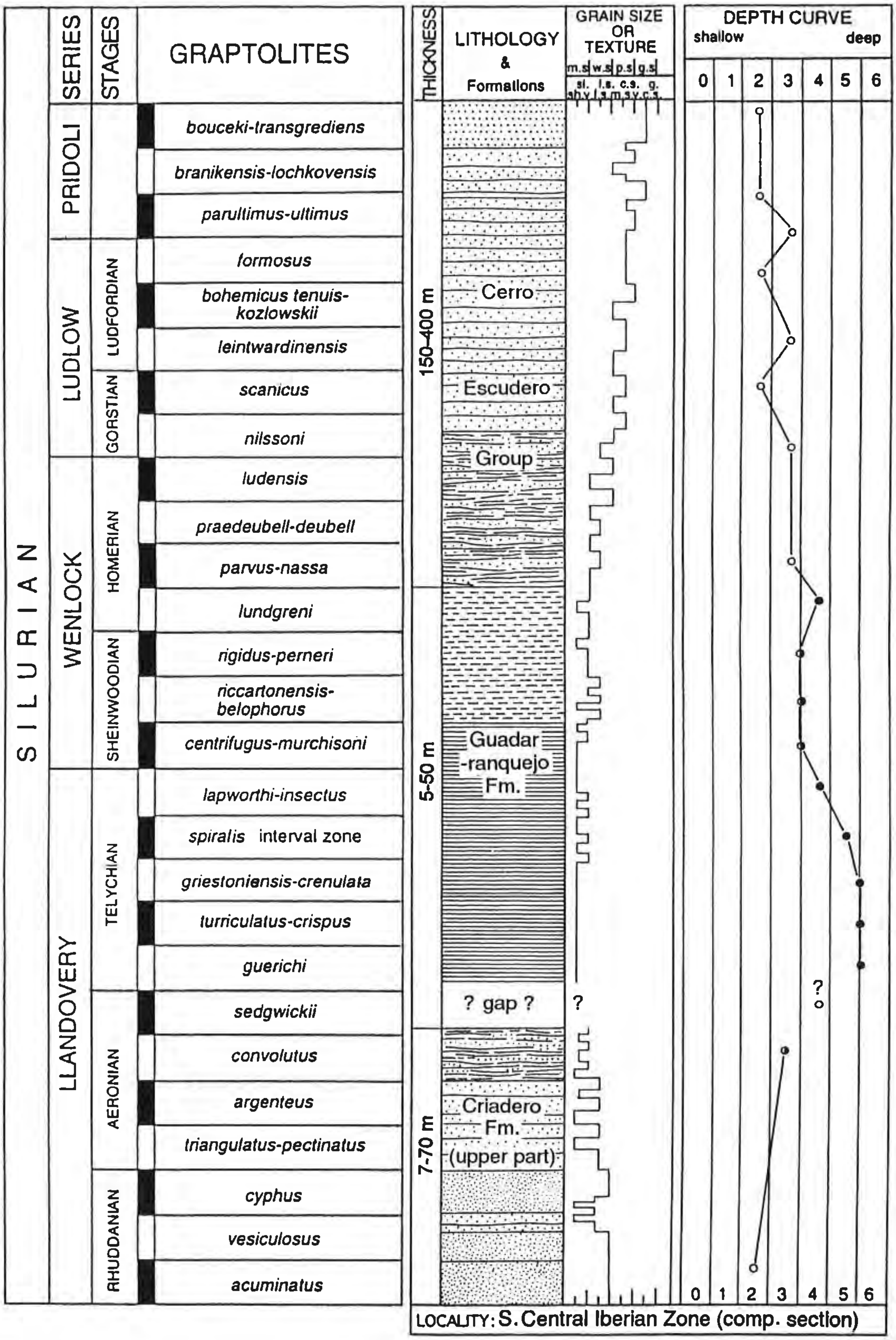

FIGURE 4 — Silurian of the Central Iberian Zone (composite section for the Almadén–Corral de Calatrava area, Iberian Peninsula.

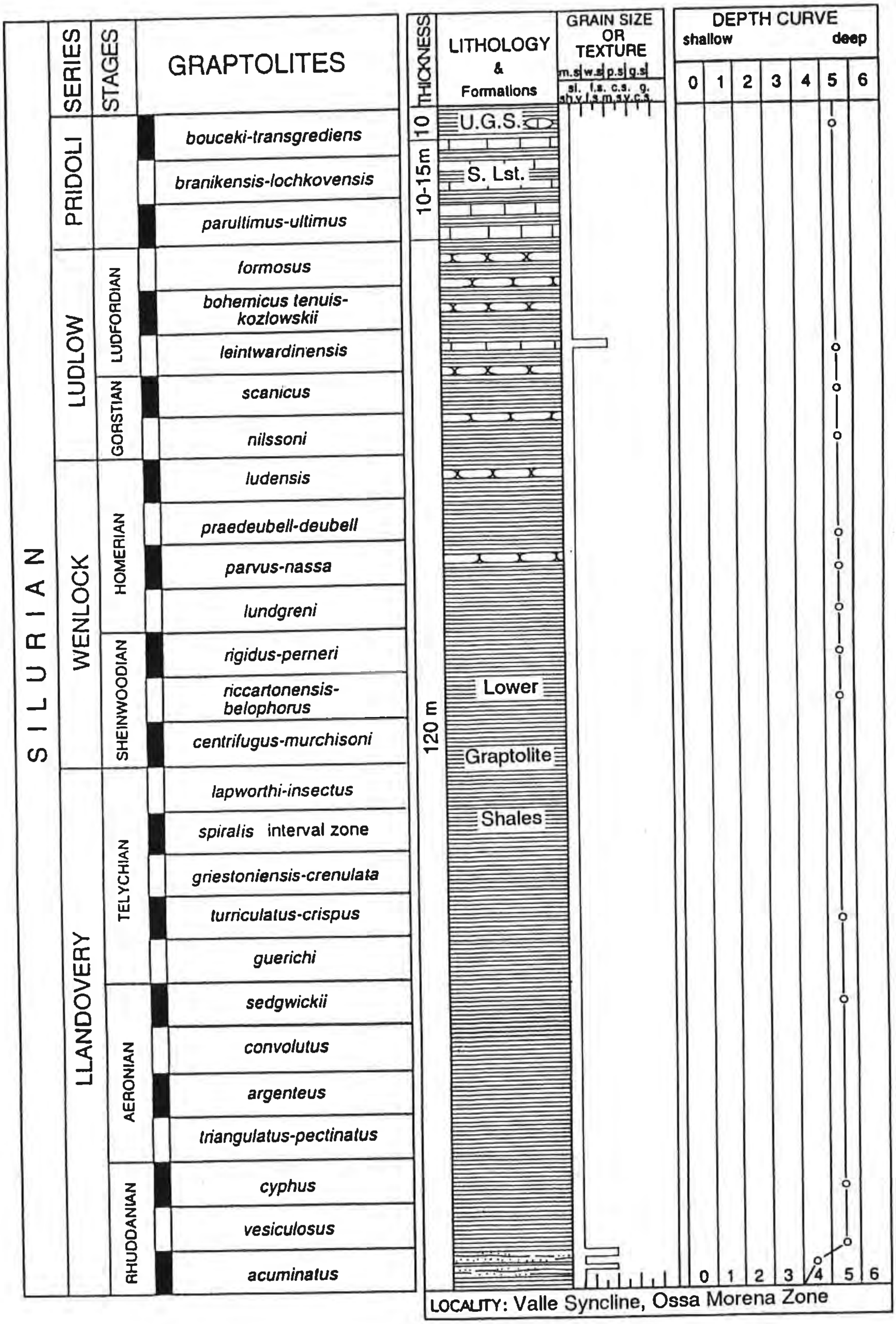

FIGURE 5 — Silurian of the Valle syncline, Ossa–Morena Zone (LGS, lower graptolitic shales; S. Lst., *Scyphocrinites* Limestone) in the Iberian Peninsula.

Zone is very similar lithologically and faunally to the typical "Thuringian triad" (Jaeger, 1976, 1977b). The "*Scyphocrinites* Limestone" appears to be the precise equivalent of the "Ockerkalk" in Germany (Robardet, 1982; Robardet and Gutiérrez-Marco, 1990a). Anoxic or strongly dysaerobic sedimentation ended in the eastern Ossa–Morena Zone and Germany after the late Lochkovian with deposition of green–brown shales and siltstones with trilobites, ostracodes, and brachiopods in the Cerrón del Hornillo and Valle synclines of the Ossa-Morena Zone (Racheboeuf and Robardet, 1986; Robardet et al., 1991).

To the west, Silurian rocks also occur in the Hinojales and Villanueva del Fresno areas (Spain; Fig. 2, localities 37 and 39), and in the Barrancos and Estremoz areas (Portugal; Fig. 2, localities 35 and 38). In these areas, the Silurian succession is not very well known. However, it must be noted that the "*Scyphocrinites* Limestone" has never been observed in these areas, and that unfossiliferous sandstones and quartzites occur in the lowermost part of the succession in the northwest (Villanueva del Fresno and Estremoz). In the Barrancos, Portugal, area, the base of the Silurian (*Parakidograptus acuminatus* Zone) has been recognized (Piçarra et al., 1995b) in the lowermost "Xistos com Nódulos" Formation (30–50 m of black shale and chert; Llandovery to Ludlow; *Parakidograptus acuminatus–Lobograptus scanicus* Zones). The succeeding "Xistos Raiados" Formation (100 m of banded chloritoid shales and siltstones; Oliviera et al., 1991) extends from the Ludfordian into the Lochkovian. Pridoli graptolites from the *Monograptus parultimus* to *M. bouceki* Zones were discovered in its lower part (Piçarra et al., 1998), and the uppermost 12 m yield *Monograptus uniformis* (see Robardet et al., 1998). The general succession of graptolite faunas from Barrancos is very similar to that of the Valle syncline, especially through the Homerian *Lundgreni* Event (see Jeppsson, 1998), when distinct lithologies and non-graptolite faunas developed in both areas (Gutiérrez-Marco et al., 1996; Rigby et al., 1997).

The Silurian succession in the Ossa–Morena Zone thus appears to be clearly different from the Silurian of other Iberian regions. It is particularly different from the successions in the now juxtaposed Central Iberian Zone (Robardet, 1976; Robardet and Gutiérrez-Marco, 1990b).

Catalonian Coastal Ranges — In this area of northeast Spain (Fig. 2I), small Silurian outcrops are known in the Barcelona area. The Silurian overlies Upper Ordovician quartzites, siltstones, and black shales with late Caradocian to middle Ashgillian faunas (Villas et al., 1987). Hirnantian glaciomarine sediments have not been recognized, but the upper Ashgillian may be represented by several tens of meters of unfossiliferous dark shale (Julivert and Durán, 1992).

The Silurian features a lower black shale unit (150–300 m) with chert intercalations in its lower part, sandy levels in the middle, and limestone beds and lenses in the upper part. The base of the Silurian has not yet been determined, but may correspond to a hiatus or occur within a sequence of unfossiliferous quartzites. The graptolitic black-shale sequence extends from the *Cystograptus vesiculosus* Zone and possibly to the *Saetograptus leintwardinensis* Zone (i.e., from the Rhuddanian to the lower Ludfordian) (Julivert et al., 1985; Julivert and Durán, 1990).

The carbonate sequence that overlies the graptolitic black shales comprises two formations. The lower one (La Creu Formation) consists of 30–40 m of gray, massive, nodular limestones with thin shale interbeds. Crinoids, orthocerids, bivalves, and conodonts indicate that most of the La Creu Formation is Pridoli (*Ozarkodina eosteinhornensis* Zone). The lowermost beds of the formation are Ludlow, and the upper part is Lochkovian (García López et al., 1990).

The overlying 35–40 m of the Olorda Formation consist mainly of nodular limestones and marls with Lochkovian brachiopods, dacryoconarids, and conodonts. Graptolites from the *Monograptus uniformis* to *M. hercynicus* Zones occur in shales in the lowest part of the formation (Lenz et al., 1996), and higher faunas range from the Pragian into the Emsian.

Betic Cordilleras — The Betic Cordilleras of southeast Spain (Fig. 2H; see references in Gómez Pugnaire, 1992) are part of the Mediterranean Alpine Belt and the so-called "Malaguide Complex" (= "Betic" of Málaga) and have Paleozoic rocks. The Morales Formation (minimum thickness 200 m) is Upper Ordovician to lowest Devonian. Its middle part (probably Llandovery–lower Ludlow) consists of shale and siltstone with chert and limestone intercalations; the latter lithologies have yielded tintinnids and conodonts. The upper Morales Formation (probably upper Ludlow–Lochkovian) consists of limestones with tentaculitids, cephalopods, and conodonts. Silurian conodonts have also been recorded from limestone olistoliths within the younger (Devonian–Carboniferous) Sancti Petri and Almogía Formations in the same area (García-López et al., 1996).

Overview of Iberian Silurian — All the Silurian regions that now compose the Iberian Peninsula were part of the north Gondwanan marine shelf, which extended north of the African margin of Gondwana (Fig. 1). The distinct sedimentological and faunal features that characterize the different regions give an impression of their relative position on the north Gondwanan shelf and of pre-Variscan paleogeography.

The Ossa–Morena Zone (OMZ) is clearly distinct from the central Iberian regions now situated to the north. OMZ features include: 1) a continuous transition between the Ordovician and Silurian; 2) anoxic or strongly dysaerobic black shale sedimentation that started as early as the *Parakidograptus acuminatus* Chron and persisted through the Silurian into the Lochkovian; 3) chert interbeds; 4) an important lithofacies change in the Pridoli with deposition of the "*Scyphocrinites* Limestone," an exact equivalent of the "Ockerkalk" of other European regions; and 5) re-appearance of oxygenated conditions in the Pragian.

The Silurian of the OMZ is obviously similar to the Thuringian Facies, and the OMZ appears to have been located on the outer part of the north Gondwanan shelf. The present juxtaposition of the Ossa–Morena and Central Iberian zones along the Badajoz–Córdoba Shear Zone does not reflect Silurian paleogeography, and most probably resulted from sinistral strike-slip movements during the Variscan orogeny.

The Silurian of the southern part of the Central Iberian Zone is different from that of the OMZ and is characterized by: 1) sandy lithofacies near the Ordovician–Silurian transition, although the lack of fossils does not necessarily reflect either hiatuses or continuous sediment accumulation; 2) a first occurrence of Silurian graptolite faunas in the Aeronian or Telychian; 3) anoxic or strongly dysaerobic black shale sedimentation from the early Telychian to late Homerian that apparently took place in shallower environments than is usual for this type of facies; and 4) deposition of alternating sandstones, siltstones, and shales during the Ludlow and Pridoli in more normally oxygenated environments. This coarser terrigenous influx announced the initiation of Lower Devonian sand deposition. The sedimentary evolution of the Cantabrian Zone (with the exception of the Palentine Domain), parts of the West Asturian–Leonese Zone, and the Iberian Cordillera is relatively similar to that of the Central Iberian Zone.

Within the Hesperian Massif, there is a general trend from shallow deposits in the southern Central Iberian Zone to deeper, more distal sedimentation both in the northern Central Iberian Zone and in the southern West Asturian–Leonese Zone. Pridoli "*Scyphocrinites* Limestone" occurs in the Moncorvo area (Portugal) and in the northern Central Iberian Zone. In the boundary between the Central Iberian and West Asturian–Leonese Zones, Silurian successions are mostly shale, are silty, with a few limestones (Alcañices syncline), and have Ludlow trilobites with Bohemian affinities (Peñalba and Sil synclines). These features are more reminiscent of the Silurian of the Pyrenees and Catalonia. These Hercynian magnafacies are also recognized in the Palentian Domain of the Cantabrian Zone (which is supposedly of Asturian–Leonese provenance). If the San Vitero Formation is actually Silurian–Devonian (and not a younger flysch unit), its occurrence in a western position is an additional argument in favor of deeper environments to the west. Despite complications that resulted from Variscan tectonism (but with the exception of the Cantabrian Zone), there is a general trend to deeper and more distal areas from south to north and toward the northwest in Iberia.

A good biogeographic marker for the shallowest areas of the Silurian shelf is the graptolite *Metaclimacograptus flamandi* (LeGrand, 1993), which is abundant in Telychian black shale facies (from the *Monograptus crispus*–lower *Torquigraptus tullbergi* Zones) of the southern Central Iberian Zone, Iberian Cordillera, Central System, and Castrillo syncline of the West Asturian–Leonese Zone. This graptolite is unknown in coeval deposits of the Ossa–Morena Zone, the boundary region between the Asturian–Leonese and Central Iberian Zones, the Pyrenees, and Catalonian Coastal Ranges. This graptolite, which was not distinguished from *Paraclimacograptus innotatus brasiliensis* (Ruedemann) in older studies, has a wide distribution related to more inshore environments around the African part of Gondwana. In Iberia, Llandovery black shales with *M. flamandi* also show a number of features that probably reflect shallow conditions, and these black shales are probably not very different bathymetrically from the storm-influenced sandstones that usually underlie this facies (García Palacios et al., 1996b; Gutiérrez-Marco and Štorch, 1998). *Paraclimacograptus innotatus brasiliensis* sensu stricto is restricted to older levels (Rhuddanian–Aeronian) of the South American part of the Perigondwana shelf in Brazil, Argentina, and Paraguay, where it is indicative of shallow-shelf areas (Jaeger, 1976).

The Silurian of the Catalonian Coastal Ranges consists of black shales (Rhuddanian–Ludfordian) and limestones (upper Ludlow–lowest Lochkovian). These shales were probably deposited in outer-shelf environments, and this interpretation accords with the proposed paleogeographic reconstruction.

Silurian of the Pyrenees

Most of the Silurian occurs in the High Paleozoic Range, in the Paleozoic massifs of the north Pyrenean Zone, and in the Mouthoumet Massif (Figs. 6, 7). Silurian units, generally a dark-colored pelitic facies, provide stratigraphic markers in the Paleozoic of the Pyrenees. Unfortunately, the Silurian is highly tectonized, and its outcrops are generally poor. The lithosequence is problematical, and many outcrops are needed to reconstruct a composite lithostratigraphic column. Such a reconstruction is allowed by Llandovery and Wenlock graptolites and

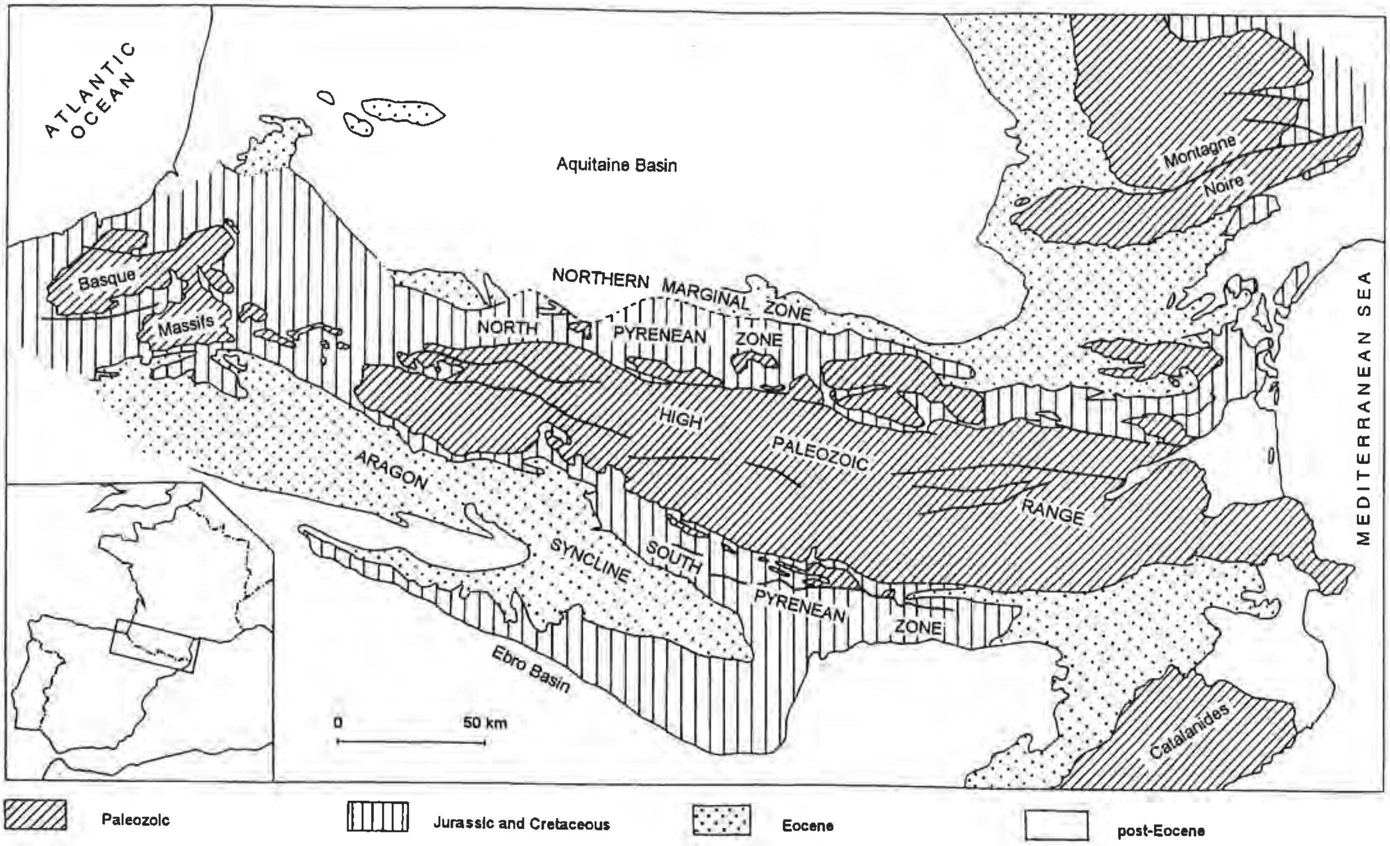

FIGURE 6 — Major structural divisions of the Pyrenees.

Upper Silurian conodonts (Dégardin, 1988).

LITHOSTRATIGRAPHY — Stratigraphic columns (Figs. 8–14) show significant changes in lithology and thickness. Black pelites are developed from the base of the Silurian up to the Wenlock. Towards the top of the Silurian, carbonate sediments appear and continue into the Lower Devonian.

Throughout the Pyrenees, the Lower Silurian (i.e., Rhuddanian and Aeronian) is characterized by organic-rich black pelites. However, some interbedded limestones are developed in the central Pyrenees, and a pelitic sequence with sandstone lenses is known from the the Camprodon area (Fig. 10). In general, pelitic sedimentation continued during the Telychian, except in Mouthoumet Massif, where carbonates were deposited.

During the Sheinwoodian and Homerian, pelitic sedimentation was ubiquitous across the Pyrenees, except in the eastern and central Pyrenees where carbonate sedimentation also took place. During the Gorstian and Ludfordian, important lateral facies changes took place. Toward the west in the Pays Basque, intercalations of sandstones occur within pelitic rocks. In the eastern Pyrenees, carbonate sedimentation took place locally with thin-bedded siltstone deposition. Except in the southern area (Sallent de Gallego region, Andorre, Bar-Toloriu, and Camprodon areas) where carbonate nodules are scattered in pelites, pelitic sedimentation prevailed in all other regions.

During the Pridoli, the diversity of the facies was an important feature. In the west, rhythmic pelite and sandstone sedimentation was continuous from the Pays Basque to the Argeles–Gazost area. Somewhat different facies in the central Pyrenees feature dominantly siliciclastic mudstones with carbonate intercalations in thin beds or nodule horizons. In the eastern Pyrenees, carbonate facies were abundant until the Early Devonian (Centéne and Sentou, 1975).

BIOSTRATIGRAPHY IN THE PYRENEES — Silurian biostratigraphy in the Pyrenees is based mainly on graptolites from the pelites and conodonts from the carbonates. Eighty-six graptolite species assigned to thirteen genera are recognized in the Silurian of the Pyrenees (Dégardin, 1988).

Nine graptolite zones are recognized: Aeronian *Demirastrites triangulatus*, *D. convolutus*, and *Stimulograptus sedgwickii* Zones; Telychian *Spirograptus turriculatus*,

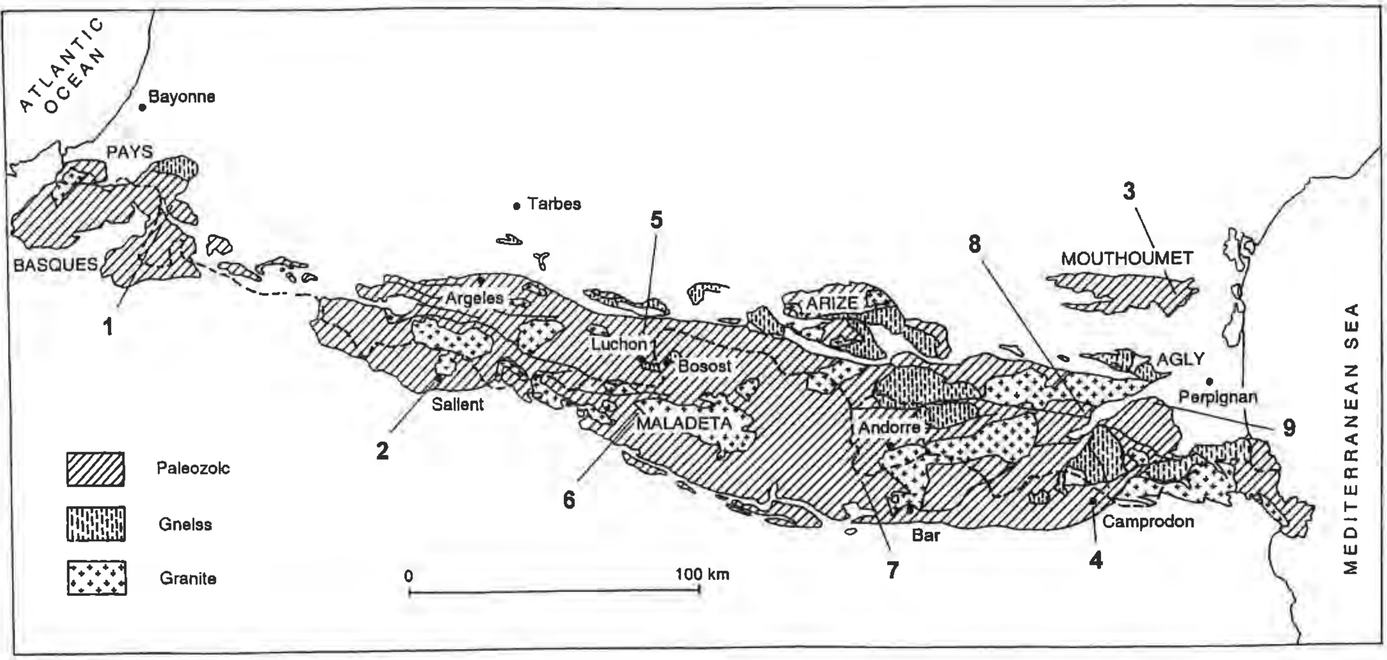

FIGURE 7 — Distribution of the Paleozoic and correlation charts in the Pyrenees (see Figs. 8–14) and the Mouthoumet Massif. Localities: *1*, St. Martin d´Arrosa; *2*, Sallent de Gallego; *3*, Mouthoumet Massif; *4*, Camprodon; *5*, Pale de Burat; *6*, Sierra Negra; *7*, Querforadat-Toloriu; *8*, Villefranche; *9*, Castelnou.

Monoclimacis griestoniensis, and *Oktavites spiralis* Zones; Sheinwoodian *Monograptus riccartonensis* Zone; Gorstian *Neodiversograptus nilssoni* Zone; Ludfordian *Bohemograptus bohemicus* Zone. Correlations are based essentially on the association of species. The first association includes *Demirastrites triangulatus, D. delicatulus, Monograptus intermedius, M. lobiferus,* and *Campograptus communis communis,* which indicates the base of the Aeronian Stage of the Llandovery. This association is present in the Pays Basque, central Pyrenees, and Camprodon region. Another association with *Stimulograptus sedgwickii, M.? involutus,* and *Pristiograptus regularis* is upper Aeronian (Dégardin, 1988).

A later group of species with *Torquigraptus proteus, T. planus, Monograptus undulatus,* and *Spirograptus turriculatus* is lower Telychian, whereas *Oktavites spiralis* and *Stimulograptus halli* indicate the upper Telychian. These graptolites are frequent in the central Pyrenees where they are associated with *M. priodon* and *Retiolites geinitzianus geinitzianus* (Dégardin, 1988).

Monograptus lamarmorae, M. mutuliferus mutuliferus, and *M. uncinatus* var. *tariccoi* occur at the top of the Wenlock in the Pyrenees. This assemblage is present in the Pays Basque and central Pyrenees (Benasque area) with *M. flemingii.* The youngest group, with *Pristiograptus dubius, Monograptus uncinatus orbatus, Colonograptus colonus,* and *Neodiversograptus nilssoni,* characterizes the Gorstian (Dégardin, 1988).

Conodonts have been extracted only from the carbonates commonly found at the top of the Wenlock and in the Ludlow and Pridoli of the eastern Pyrenees, and on the Spanish side of the central Pyrenees. The faunas corroborate the biostratigraphy denoted by the graptolites in the pelitic levels.

Kříž (1996) described eight species of bivalves from the Mouthoumet Massif that are known or closely related to the bivalves of the Prague Basin, Bohemia. They range from late Wenlock to Pridoli and show the close faunal relationships between both regions. *Cardiobeleba thorali* and C. sp. aff. *C. ava* show very close relationships to upper Wenlock faunas of the Carnic Alps (Austria, Italy).

PALEOGEOGRAPHY — The Silurian of the Pyrenees includes inner-shelf deposits, as documented by the low thickness and local presence of such benthos as bivalves, cephalopods, brachiopods, and echinoderms. The environment was commonly anoxic, as shown by high pyrite and organic matter content.

On the Scotese et al. (1979, 1990a, 1990b) paleogeographic reconstruction, the Pyrenees are positioned on the northern margin of Gondwana. It is possible to place the Pyrenean area, as in the model of Pickering et al. (1988), somewhere between Brittany and Iberia, but its precise position remains uncertain. Furthermore, it seems that the north Gondwanan platform was tectonically

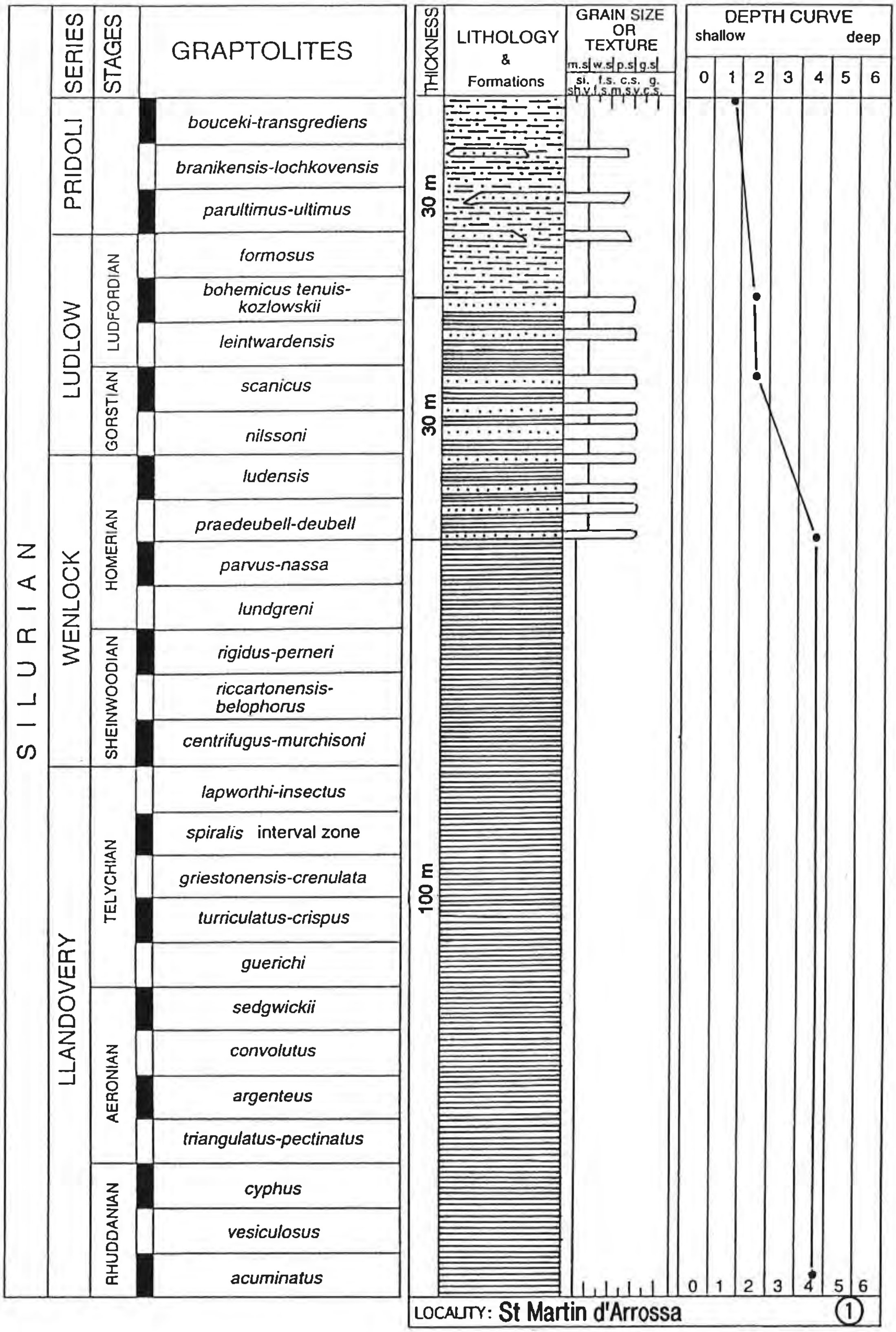

FIGURE 8 — Silurian correlation chart of St. Martin d´Arrosa. For location, see Fig. 7 (locality 1).

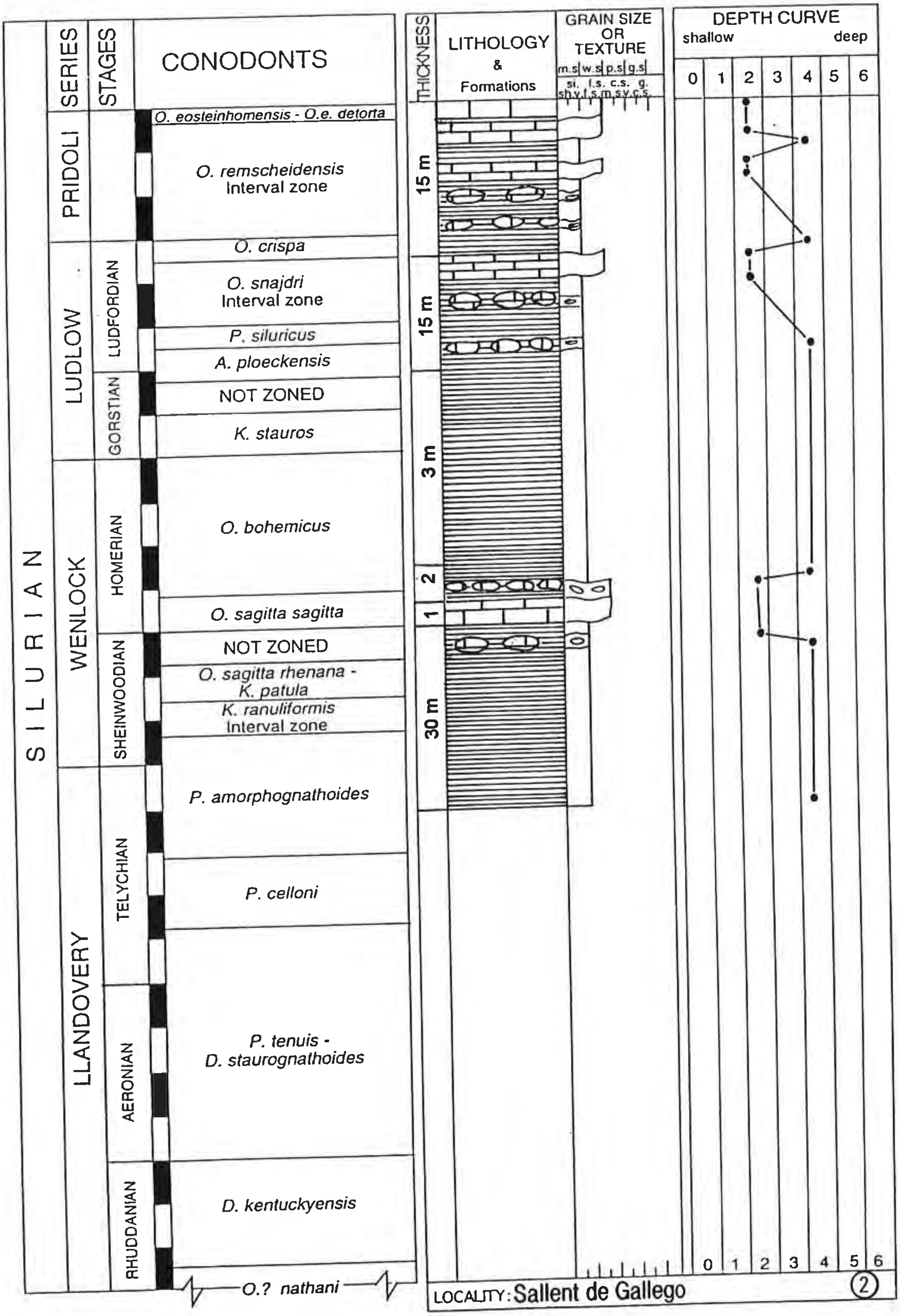

FIGURE 9 — Silurian of Sallent de Gallego. For location, see Fig. 7 (locality 2).

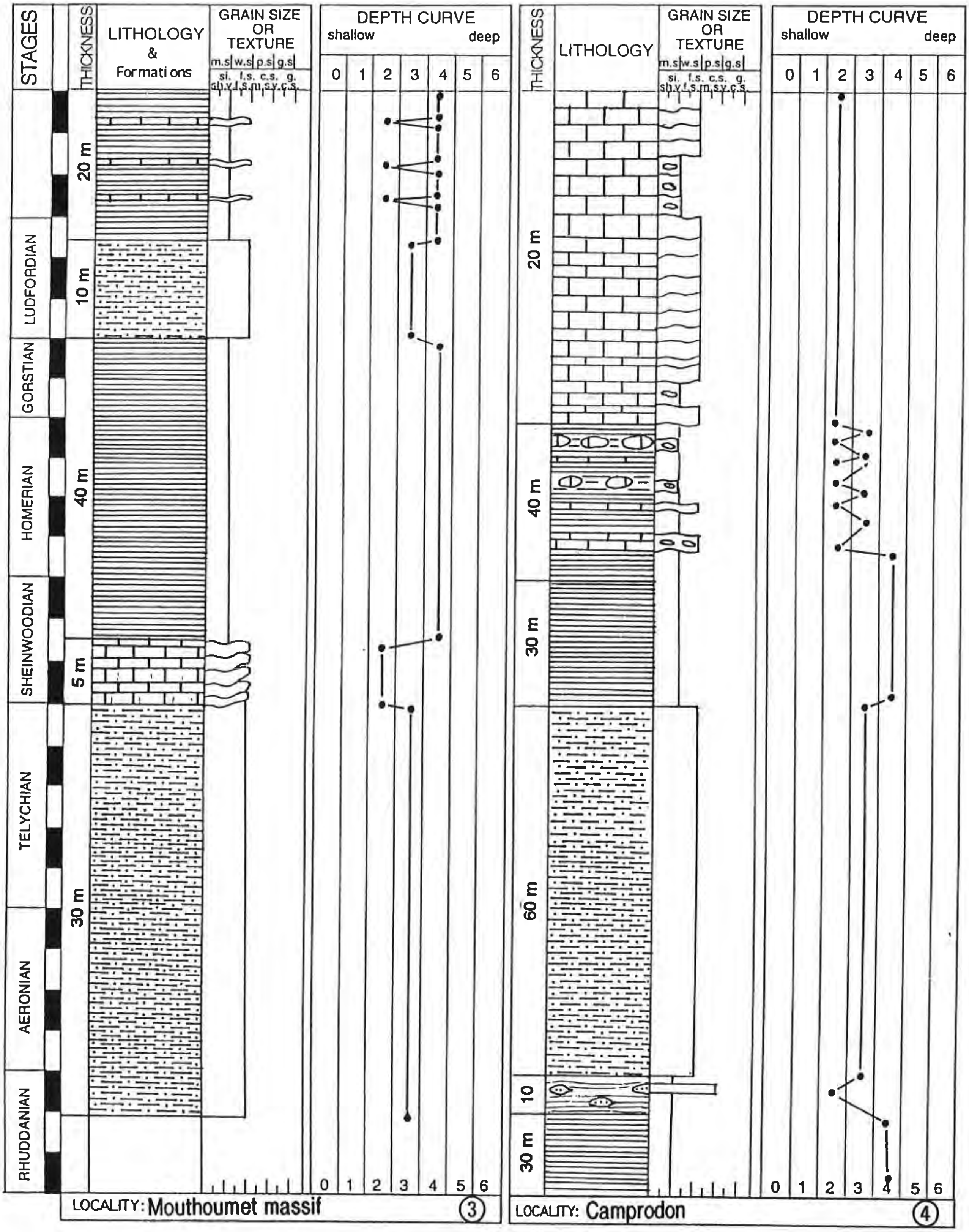

FIGURE 10 — Silurian of the Mouthoumet Massif and Camprodon. For locations, see Fig. 7 (localities 3, 4).

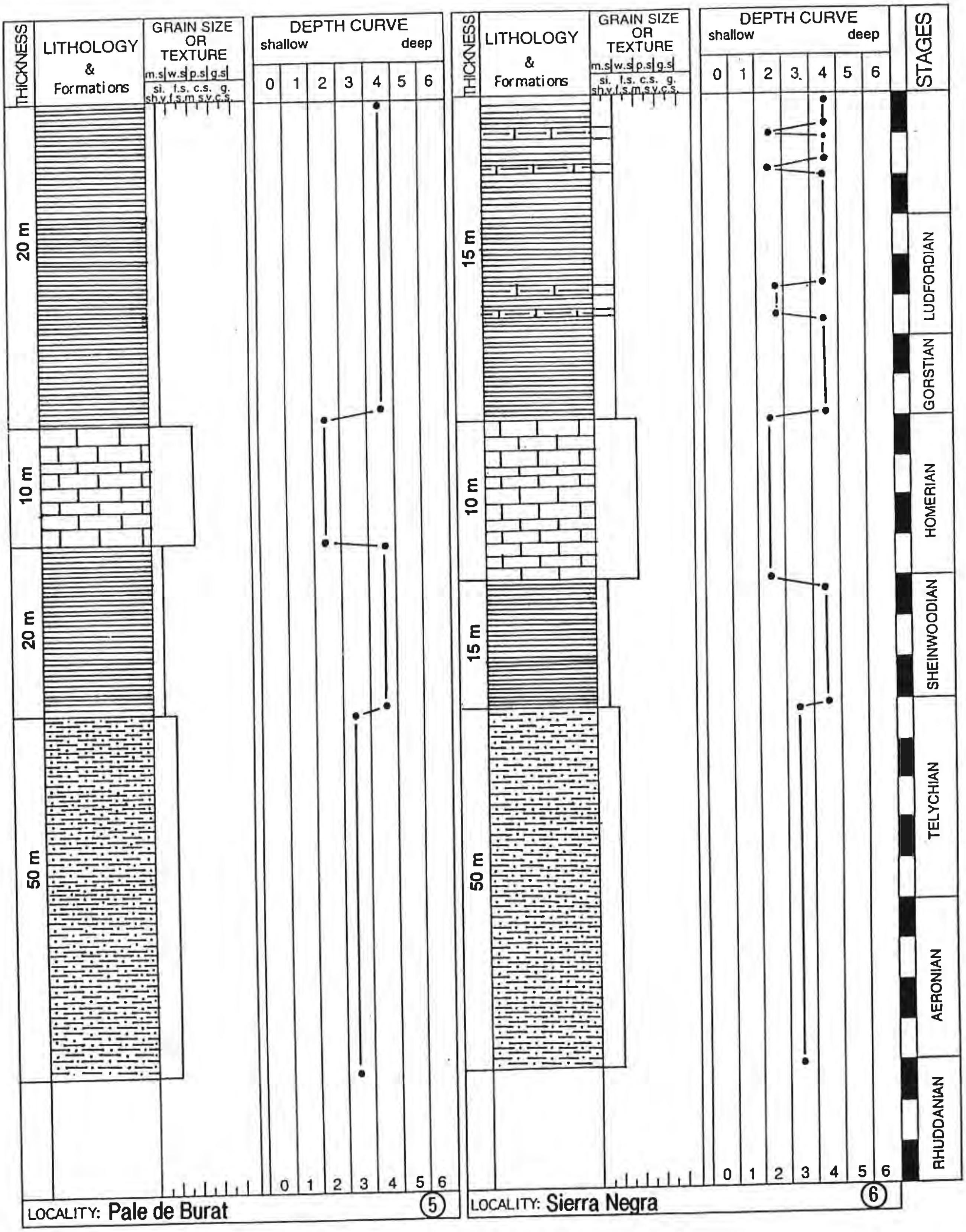

FIGURE 11 — Silurian Pale de Burat and Sierra Negra. For locations, see Fig. 7 (localities 5, 6).

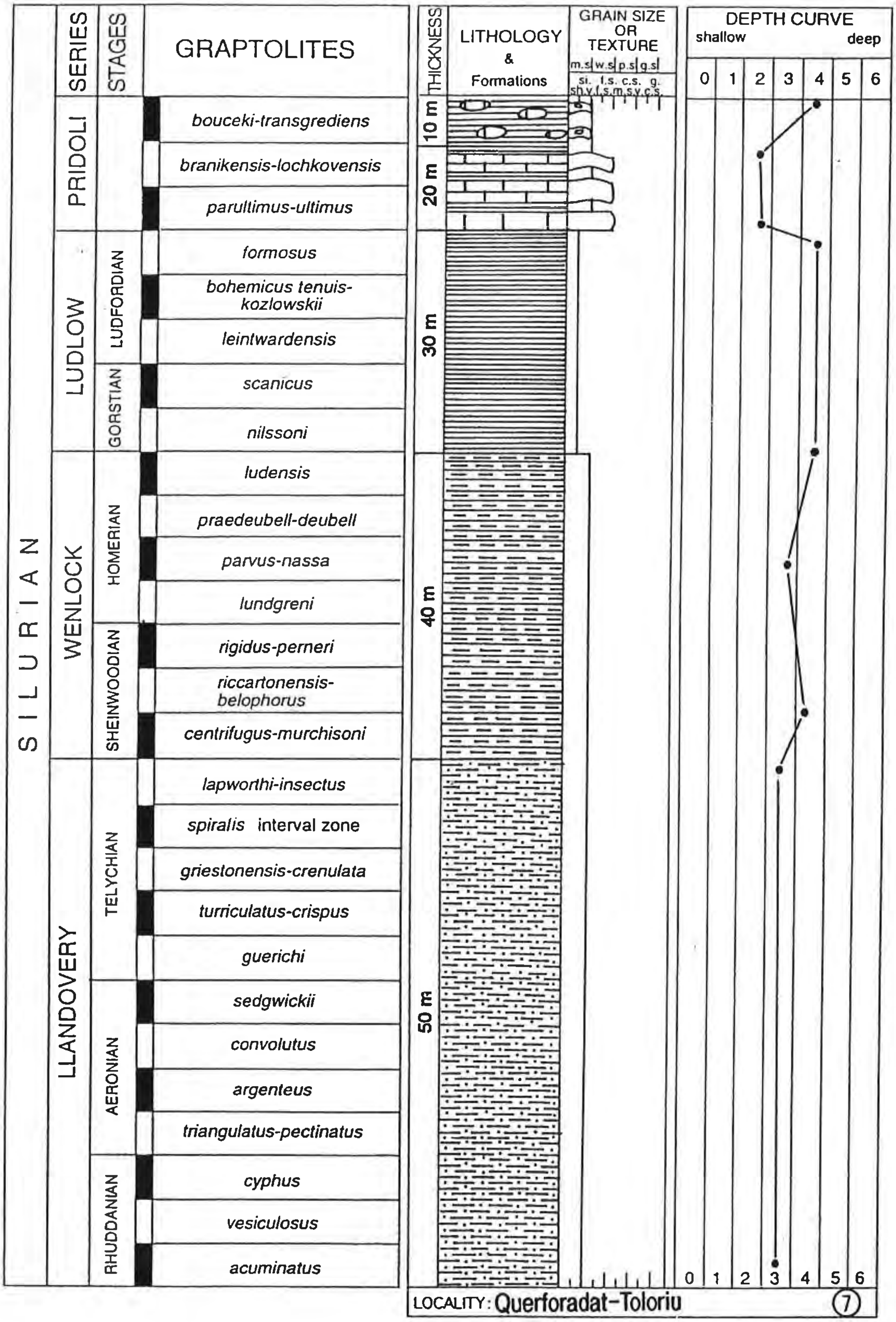

FIGURE 12 — Silurian of QuerforadatToloriu. For location, see Fig. 7 (locality 7).

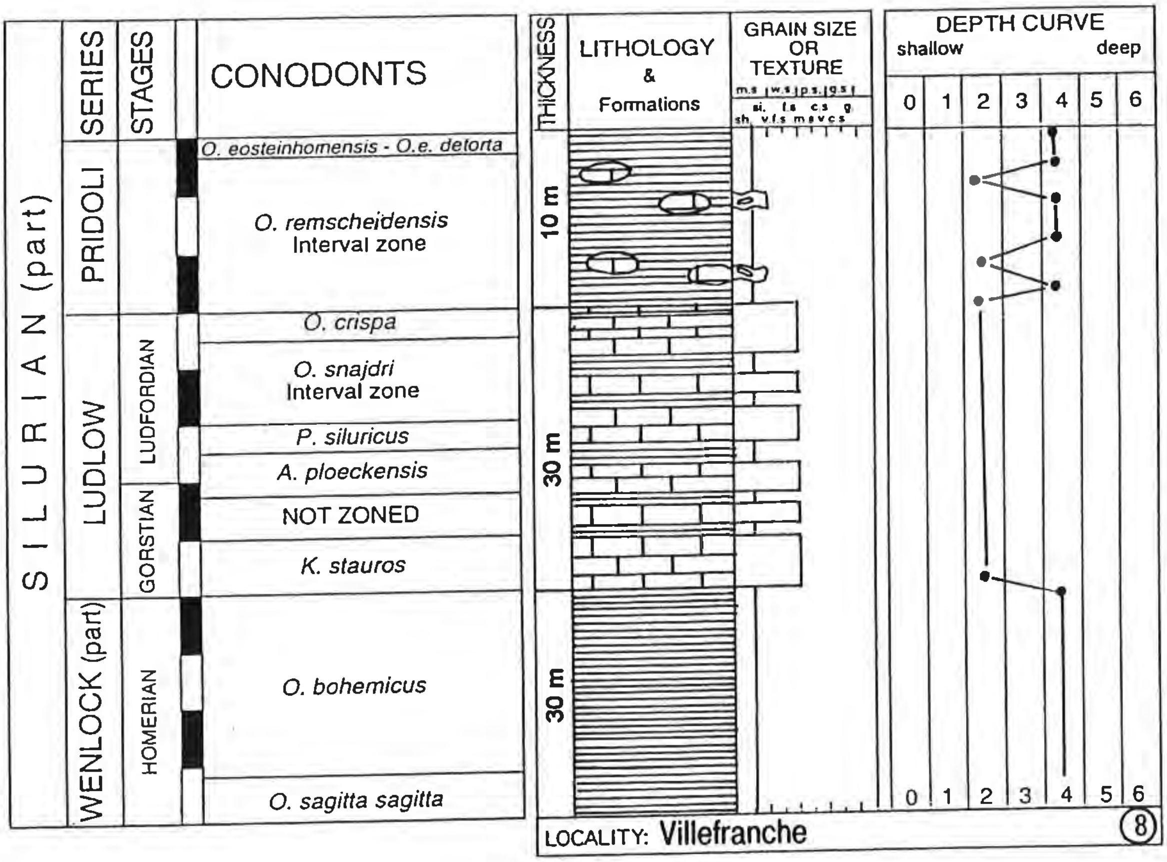

FIGURE 13 — Silurian of Villefranche. For location, see Fig. 7 (locality 8).

complex, with numerous small emergent areas in Brittany and the northwestern Iberian Peninsula, as suggested by Babin et al. (1980), who envisioned a number of islands which could have been the source of the coarser siliciclastics that are common in the Silurian of the Pyrenees.

Silurian of France

The main Silurian outcrops in France (Fig. 15) are in the Variscan massifs (i.e., Armorican Massif and Massif Central) and in the old Variscan cores of more recent orogens (i.e., the Pyrenees). More geographically restricted relics that are tentatively referred to the Silurian are in the Vosges, Alps, Maures Massif, and Corsica. Additional Silurian sequences are documented in the subsurface of the Aquitaine Basin and northern France (Artois and Boulonnais). All these Silurian strata are folded, and have suffered anchizonal to epizonal metamorphism, or even higher grades of metamorphism. The main features of these sedimentary and metamorphic rocks are given below, except those of the Pyrenees, which are documented above.

With the unique exception of the Artois sequence, which is regarded as part of the southern edge (eastern Avalonia) of the Baltica plate during the Silurian, the Silurian of France was deposited on the northern margin of Gondwana (Paris and Robardet, 1990). It shares, therefore, most of the basic sedimentological and climatic features of this huge paleogeographic province.

Northern France (Artois and Boulonnais) — Artois is located in northwestern France and lies in the French part of the Namur syncline, which extends into Belgium (Fig. 15). Additional Silurian subcrops (not documented herein) lie a few tens of kilometers west near the English Channel in the Boulonnais area (Fig. 15), where they are overlain disconformably by Middle Devonian conglomerates of the Caffiers Formation (Brice, 1988).

In the Artois area, several boreholes and coal pits expose the Upper Silurian part of the Angres Member of the Noulette Formation, as defined by Racheboeuf (1986). The formation, up to 200 meters thick, is part of the Pridoli and Lochkovian. It is a sequence of dark shales with local calcareous shales and/or limestone in the lower

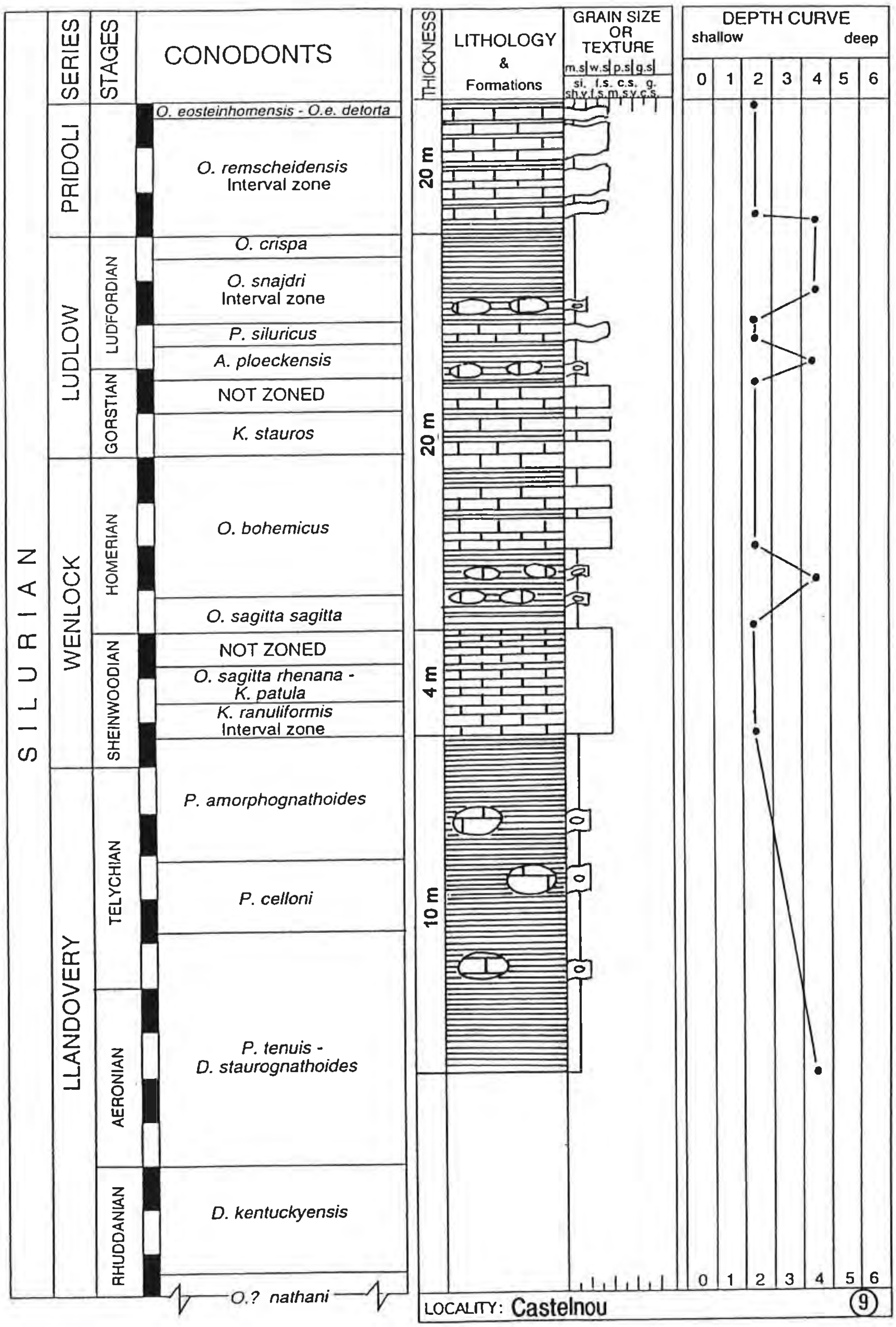

FIGURE 14 — Silurian of Castelnou. For location, see Fig. 7 (locality 9).

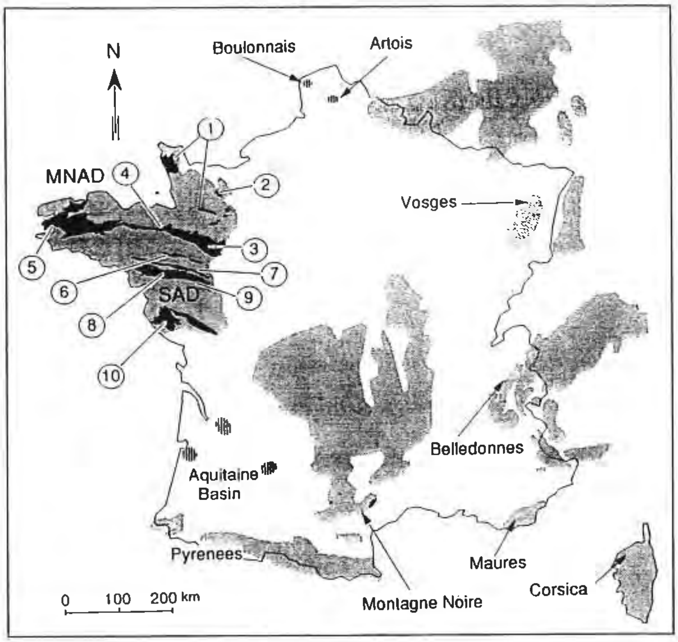

FIGURE 15 — Silurian of France. Variscan massifs (stippled); Silurian outcrops and subcrops (black); covered Silurian (vertical ruling). Armorican synclines and localities: *1*, Cotentin; *2*, Normandy; *3*, Laval; *4*, Ménez–Belair; *5*, Chateaulin; *6*, Martigné–Ferchaud; *7*, Angers; *8*, Candé and Saint-Georges-sur-Loire; *9*, Ancenis; 10, Vendée. Silurian of Mouthoumet and Pyrenées not indicated. MNAD is Medio–North Armorican Domain; SAD is South Armorican Domain.

Angres Member. The base of the formation is not known, and is always cut off by the Midi thrust fault (see Chalard, 1986).

The macrofauna of the Angres Member is fairly abundant and diverse. It includes numerous brachiopods, tentaculitids, bryozoans, bivalves, ostracodes, and trilobites. Microfossils, including conodonts, spores, acritarchs, and chitinozoans, also have been reported from the Silurian part of the Noulette Formation (see Racheboeuf, 1986).

The Artois and the Boulonnais areas are usually regarded as part of the southern edge of eastern Avalonia, and therefore belonged to Baltica in the Silurian. The Late Silurian map of Scotese and McKerrow (1990) locates the Artois and the Boulonnais at very low latitudes (ca. 15° S). However, no local paleomagnetic control is available.

No correlation chart is provided herein for the Artois area because its Silurian sequence is restricted to part of the Pridoli. The most diagnostic taxon is *Urnochitina urna*, a Pridoli chitinozoan reported from the lower and middle Angres Member, whereas *Eisenackitina bohemica*, a typical Lochkovian chitinozoan, has its lowest occurrence in the upper part of the member (Paris, 1986). This age is consistent with the occurrence of *Ozarkodina remscheidensis eosteinhornensis* Zone conodonts in the lower and middle Angres Member (Bultynck, 1986). No graptolites have been recorded in this succession.

Based on a detailed sedimentological study of the Noulette core drill (Pelhate, 1986), a shallowing trend is indicated from the base to the upper Noulette Formation, a unit which was deposited on the outer shelf. Evidence of numerous distal storm deposits is documented in the Angres Member. The Noulette Formation was deposited in a poorly oxygenated, but not anoxic, environment. The Noulette Formation has, especially in the upper Mericourt Member (Lochkovian), several condensed levels with phosphatic nodules.

The faunal associations are consistent with an outer-shelf environment for the Upper Silurian part of the Noulette Formation. This shelf was likely on the southern edge of the eastern Avalonian part of Baltica, as documented by paleobiogeographic affinities. Brachiopods and vertebrates, which are found mainly in the Lochkovian part of the Noulette, have close faunal relationships with Baltica, and especially with Podolia (Ukraine) (Racheboeuf and Babin, 1986). Less obvious paleobiogeographic affinities with Armorican, Iberian, and North African faunas that correspond to the northern Gondwana Province are consistent with the existence of a closing, but still fairly wide, Rheic Ocean in the Pridoli (Paris and Robardet, 1990).

Well-developed limestones in the Angres Member indicate a fairly low latitudinal location for northern France during the Pridoli. Such a location is consistent with a rather warm environment (F. Paris, unpublished data, 1998), and similar to the climate that prevailed in Podolia during the Pridoli However, no reefs developed in Artois.

ARMORICAN MASSIF — Silurian deposits are widely distributed in the Armorican Massif (Fig. 15), and likely extend under the Mesozoic cover of the Paris Basin and offshore to the west. Two main paleogeographic units are usually identified in the Armorican Massif; these are the Medio-North Armorican Domain (MNAD) and the South Armorican Domain (SAD) (sensu Paris and Robardet, 1994). The MNAD includes the Normandy, Cotentin, and the northern and central Brittany synclines (i.e., Chateaulin, Ménez-Bélair, Laval, and Martigné-Ferchaud synclines). The northern limb of the Angers syncline, located north of the northern branch of the South Armoican Shear Zone (i.e., Malestroit-Angers Fault) also belongs to the MNAD.

The SAD includes the southern Brittany (Candé anticline and Saint-Georges-sur-Loire syncline), as well as the Ligerian (Ancenis syncline) and Vendean (Vendée coast and Bas Bocage) terranes. The Medio-North and the South Armorican Domains correspond to northern

Gondwana terranes, but their original location on the northern margin of this paleocontinent is still unknown. However, obvious lithologic and geodynamic differences exist between the Silurian deposits of these two domains, which are discussed below.

MEDIO-NORTH ARMORICAN DOMAIN (MNAD) — The Silurian of the MNAD is usually transgressive on latest Ordovician glacio-marine deposits formed with melting of the late Ashgillian ice cap that covered the North African part of Gondwana (see Paris et al., 1995). A hiatus of various local durations is documented above the Ordovician units (Figs. 16, 17). This gap is likely due to an absence of deposition, but Variscan tectonic disturbance may also be implicated, as Silurian black shales frequently acted as a décollement surface. The hiatus corresponds to part of the Llandovery (Rhuddanian to lower Telychian) in the Ménez-Bélair and Martigné-Ferchaud synclines (Fig. 15, localities 4, 6). It may extend into the early Wenlock in western Brittany and into the Laval syncline (Fig. 15, locality 3). However, local (central Chateaulin syncline and Cotentin; Fig. 15, locality 5) poorly preserved graptolites of early Rhuddanian affinities are found (Robardet, 1970; F. Paris, unpublished data, 1996). No gaps or disconformities have been documented at the Silurian–Devonian boundary in the MNAD.

With only local exceptions (e.g., the Wenlock Feuguerolles Limestone in Normandy and calcareous nodules or lenses in the Upper Silurian of the Chateaulin and Laval synclines), the MNAD Silurian is exclusively siliciclastic. It displays anoxic or strongly dysaerobic features that become less prominent in the Pridoli. Significant enrichment in such trace elements as vanadium (up to 5,600 ppm) are noted in black shales (Debard and Paris, 1986) that have TOC values ranging from ca. 10–40%.

At the base of the MNAD succession are pyritic and/or siliceous sandstones with interbedded graptolitic black shales. This type of sandy sequence is known from the Cotentin ("gres culminant" and lower Saint-Sauveur-le-Vicomte Formation, a few tens of meters thick), the Ménez-Bélair syncline (lower member of La Lande Murée Formation, up to 15 m), and the Martigné-Ferchand syncline (Poligné Formation with a prominent sandy lower member, or "gres culminant," ca. 80 m) (Fig. 15, localities 1, 4, 6). At other localities, similar sandstones are missing, either because of a sedimentary gap or tectonic disturbance (i.e., Crozon Peninsula in the Laval syncline and western Chateaulin syncline; Fig. 15, localities 3, 5). These sandstones are replaced by siltstones in eastern Normandy ("Schistes a Fucoides" Formation in the Caen area, ca. 40 m). Other examples of anoxic, condensed rocks developed in the Wenlock (e.g., laminated black shales of the middle member of La Lande Murée Formation or Veniec Member of La Tavelle Formation; a few meters thick); during the Ludlow and early Pridoli in the Chateaulin syncline (La Tavelle Formation, ca. 50 m, and Lostmarc'h Formation, 90 m); in the Menéz-Bélair and Laval synclines (upper member of the La Lande Murée Formation, up to 50 m); and in the Cotentin and Normandy areas (respectively, the Saint-Sauveur-le-Vicomte Formation, about 100 m, and Quesnay Formation, close to 200 m, but extending into the Pridoli). Several hiatuses probably occur within these sequences because only a few graptolite zones have been documented (Philippot, 1950; Jaeger et al., 1967; Paris et al., 1980).

By the early Pridoli or slightly later, depending upon the area (e.g., the northern Armorican Massif), the marine environment became normally oxygenated, as indicated by the litho- and biofacies. By that time, the subsidence rate increased drastically and allowed formation of thick sequences of alternating siltstones and sandy beds (Figs. 16, 17). These sequences correspond to the Plougastel Formation (at least 250 m of Pridoli) in the Chateaulin syncline and the Val Formation (ca. 200 m) and lower Gahard Formation in the Menéz-Bélair (ca. 250 m of uppermost Pridoli; F. Paris, unpublished data, 1998) and Laval synclines. In the Cotentin area, normal marine siliciclastic sedimentation is represented by the lower Saint-Germain-sur-Ay Formation, whereas in Normandy anoxic conditions persisted into the later Pridoli, which is the youngest Paleozoic in this area (Jaeger et al., 1967).

SOUTH ARMORICAN DOMAIN (SAD) — Anoxic or highly dysaerobic Silurian sequences of the SAD display fairly distal characteristics and have black cherts. In some areas, the cherts occur as olistoliths within a Carboniferous matrix (Dubreuil, 1986; Colchen and Poncet, 1989). At other localities, the Silurian includes volcaniclastics (e.g., in the Vendée; Peucat et al., 1986) or shales and siltstones interbedded with limestones, as in the Ancenis syncline (Cavet et al., 1971). A less common facies is the condensed black limestone and calcareous mudstone of the La Meignanne Formation (<20 m) that crops out on the northeast limb of the Candé anticline. These calcareous sedimentary rocks contrast sharply with the siliciclastic Silurian exposed nearby in the suburb of Angers, immediately north of the MNAD–SAD boundary (see Kříž and Paris, 1982).

Because of its tectonized setting (i.e., the different elements are not in stratigraphic continuity and are likely composed of exotic blocks), most of the SAD Silurian cannot be set into a stratigraphic succession. In addition, no formal formations have been designated, and sedimentologic data are not available.

No indisputable paleomagnetic data are available for the Silurian of the Armoricain Massif. However, on the Scotese and McKerrow (1990) maps, the Armorican Massif is regarded as a single terrane that shifted from 45° S to

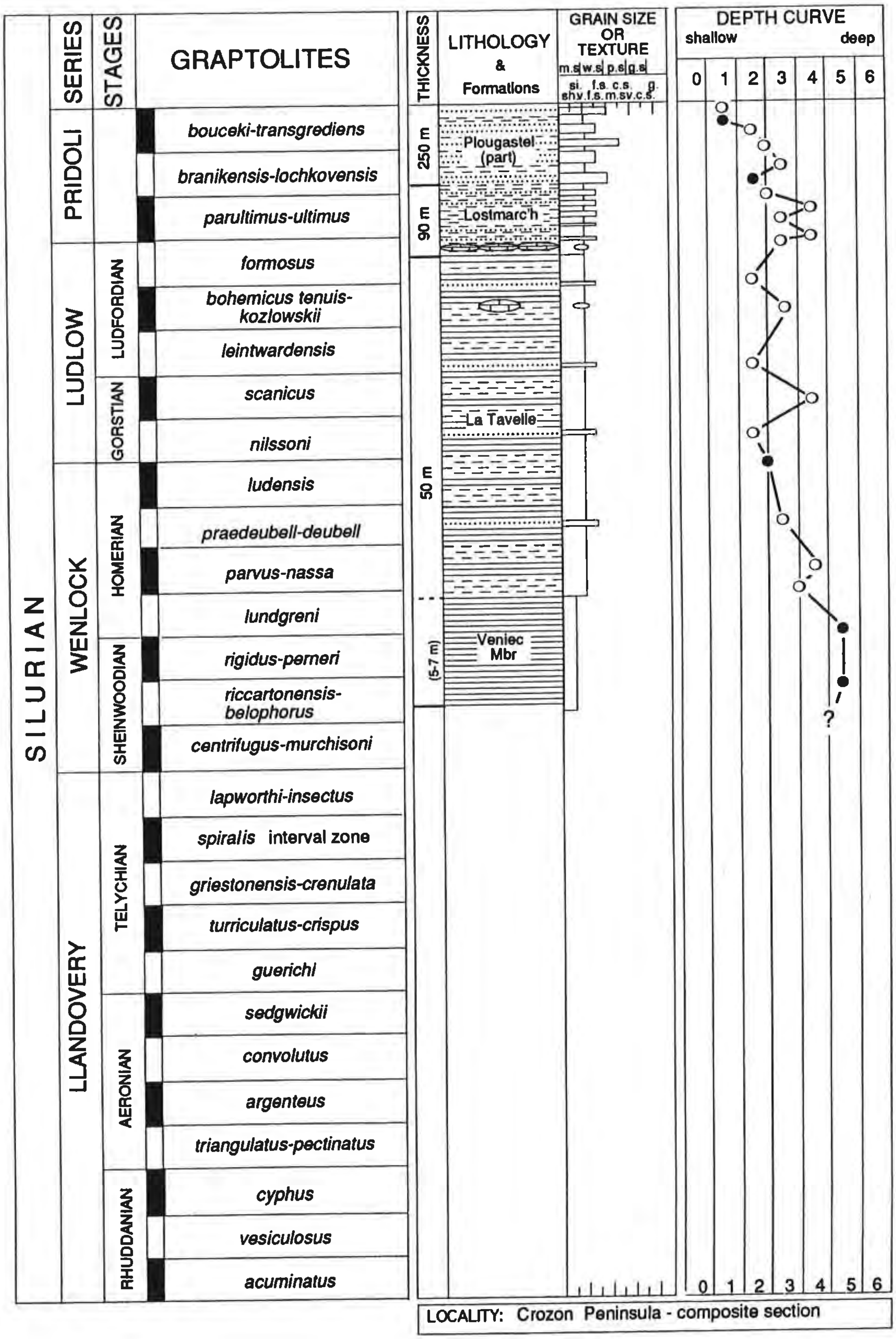

FIGURE 16 — Silurian of western Chauteaulin syncline (Crozon Peninsula, western Brittany), France.

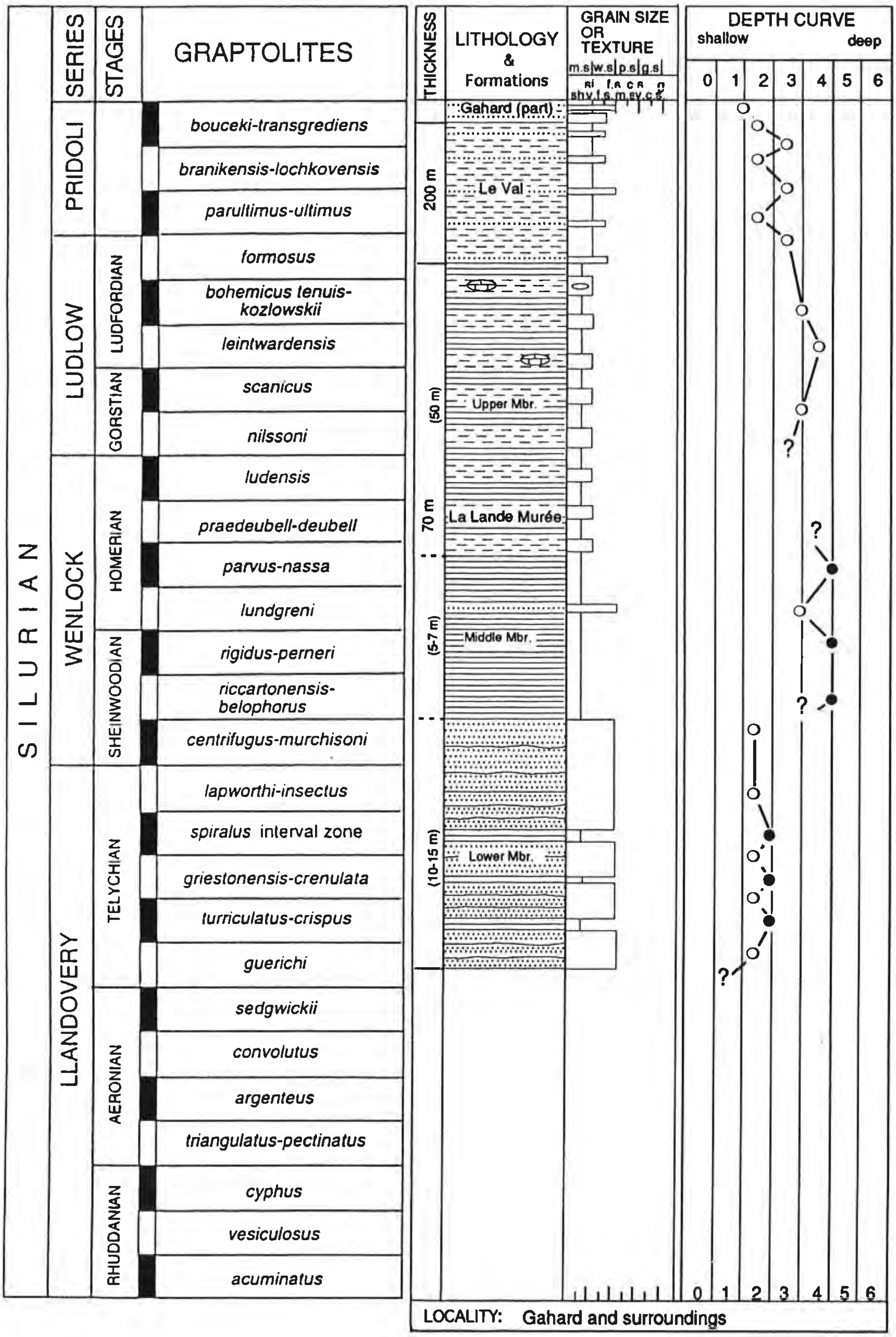

FIGURE 17 — Silurian of Gahard and surrounding area, Ménez–Belair syncline, France.

35° S between the Early and Late Silurian. Therefore, a temperate to fairly warm climate was probable in the area during the Silurian.

CORRELATION CHARTS — Two correlation charts are proposed for the MNAD. One deals with the Crozon Peninsula of western Brittany (Fig. 16), and the other with the central part of the median synclinorium (i.e., the Ménez-Bélair syncline in the area of Gahard; Fig. 17). Because of the discontinuous character of the succession in the olistolith-bearing sequences of the SAD, no correlation chart is given for this domain.

MEDIO-NORTH ARMORICAN DOMAIN (MNAD) CORRELATIONS — Limited biostratigraphic information is available because of the local occurrences of diagnostic fossils in the MNAD. Graptolites are the most useful fossils in the local Llandovery and Wenlock (Figs. 16, 17), but chitinozoans are also useful in the Ludlow and Pridoli.

The best-documented Telychian graptolite record is from the lower member of the Lande Murée Formation, where the *Spirograptus turriculatus-Monograptus crispus* and *Monoclimacis griestonensis-M. crenulata* Zones have been identified (Paris et al., 1980). The Sheinwoodian *Monograptus riccartonensis-M. belophorus* Zone is widely documented in the Chateaulin, Ménez-Bélair, and Laval synclines. The lower Homerian is probably present because *Cyrtograptus lundgreni* Zone graptolites have been reported from various localities (Philippot, 1950). Gorstian graptolites of the *Neodiversograptus nilssoni* and *Lobograptus scanicus* Zones have been identified in the Chateaulin and Laval synclines, where the Ludfordian *Bohemograptus bohemicus tenuis-Neocuculograptus kozlowskii* Zone is likely present in the upper member of the Lande Murée Formation (F. Paris, unpublished data, 1996). In the Cotentin and Normandy areas, dark shales of the upper Saint-Sauveur-le-Vicomte Formation and the Quesnay Formation yield lower Pridoli graptolites (*Monograptus parultimus-M. ultimus* Zone) (Jaeger et al., 1967; Roardet, 1970). Some or all of the chitinozoan zones defined recently in the Pridoli (Verniers et al., 1995) have also been identified in the Le Val and Gahard Formations (Paris, 1981; F. Paris, unpublished data, 1998), the lower Saint-Germain-sur-Ay Formation (Rauscher and Robardet, 1975), and the Lostmarc'h Formation (Paris, 1979). These chitinozoan data agree with a Pridoli age (*Ozarkodina remscheidensis eosteinhornensis* Zone) indicated by conodonts (Racheboeuf, 1979).

SOUTH ARMORICAN DOMAIN (SAD) CORRELATIONS — Diagnostic fossils are usually sparse in the SAD Silurian. At some localities (Candé anticline and Ancenis syncline; Fig. 15, localities 8, 9), black cherts have yield abundant lower Telychian graptolites (*Monograptus, Rastrites, Climacograptus, Petalograptus*) (Cavet et al., 1971; Lardeux and Cavet, 1994). This fauna, which needs taxonomic revision, likely corresponds to the lower *Spirograptus turriculatus-Monograptus crispus* Zone. In other localities in the Candé unit, late Telychian–earliest Sheinwoodian graptolites have been identified in Le Houx black shale (Cavet et al., 1986). Gorstian graptolites (*Neodiversograptus nilssoni* Zone) are reported from shales and limestones exposed near Chalonnes (Ancenis syncline) (Cavet et al., 1971; Lardeux and Cavet, 1994). The most precise biostratigraphic data on the SAD Silurian are given by the graptolites, bivalves, ostracodes, and chitinozoans recovered in the La Meignanne Formation (Kříž and Paris, 1982). This formation extends as high as the Lochkovian. The oldest known strata are ostracode-bearing Ludlow limestones with *Entomozoe (Richteria) migrans,* and they are overlain by black shale with numerous Pridoli bivalves (e.g., *Cheiopteria bridgei* and *Snoopia insolita* Communities with fairly abundant infaunal elements; Kříž and Paris, 1982). This age assignment is confirmed by the presence of *Urnochitina urna,* a chitinozoan which had an acme in the late Pridoli (Paris, 1981).

In the Vendée, modern paleontological data are absent for the Silurian. Poorly preserved chitinozoans, mazuelloids (phosphatic and organic-walled microfossils), and a few graptolites are known from black cherts and/or phosphatic nodules at localities along the Vendean coast (Ters, 1979; Le Hérissé et al., 1991) and from the Bas Bocage (Chalet et al., 1983). In the latter area, a U-Pb age of 405±5 m.y. was obtained (Peucat et al., 1986) on the Mareuil-sur-Lay Formation (ignimbrites and interbedded black cherts).

PATTERNS IN LITHOSTRATIGRAPHIC CHANGES — During the Silurian, sedimentation in the MNAD recorded a number of successive events: 1) eustatic rise resulting from melting of the northern Gondwanan ice cap, and Llandovery anoxia possibly related to this melting; 2) a phase of very restricted siliciclastic input (late Llandovery and Wenlock); 3) a slight increase in subsidence and a slow reduction in anoxia during the Ludlow; and 4) regional shallowing despite a rapid increase in subsidence (Figs. 16, 17).

The lowest Silurian sandy deposits represent high-energy environments, whereas the interbedded black shales correspond to very quiet, deeper environments (but probably not very deep, as suggested by the occurrence of eurypterids) (Figs. 16, 17). Sedimentologic evidence, with exception of a distal storm deposit observed in the Ménez-Bélair syncline (Fig. 17), cannot give a precise depth control for the Wenlock black shale environments. These laminated organic-rich shales were likely deposited in a fairly deep and quiet environment with only pelagic faunas and palynomorphs (Figs. 16, 17). Temporary breaks in sedimentation probably occurred in this condensed sequence. A shallowing trend took place during the Ludlow, and distal storm deposits and even ripples, indicative of normal wave-base, are recorded in the siltstones and shales of the upper Tavelle Formation (Fig. 16). This shallowing persisted during the Pridoli, as shown by a *Salopina-Clarkeia* Community and the occurrence of numerous ripplės in the thin-bedded sandstones, siltstones, and dark shales of the Lostmarc´h Formation (Fig. 16). At the same time, a fairly similar environment, with a record of distal storm waves and ripples, prevailed in the east during deposition of the Val Formation (Fig. 17). Abundant endichnial and epichnial trace fossils in the Plougastel Formation show the end of an oxygen-deficient environment. This shallowing trend ended in the Lochkovian (Guillocheau and Rolet, 1982) with the advent of deltaic sedimentation at some localities (e.g., Landevennec Formation of western Brittany). Nearby emergent areas, possibly located northward in terms of modern geography (but different from the "Old Red Continent") provided land-derived palynomorphs (spores and tracheids), which are abundant close to the Pridoli–Lochkovian boundary (Deunff and Chateauneuf, 1976; F. Paris, unpublished data, 1998).

Patterns in biofacies changes — The anoxic Llandovery and Wenlock rocks yield pelagic or epipelagic faunas, including graptolites (*Monograptus, Pristiograptus, Cyrtograptus, Petalograptus, Retiolites* as the most common genera; Philippot, 1950; Jaeger et al., 1967; Paris et al., 1980), a few thin-walled epifaunal brachiopods, and fairly abundant palynomorphs (chitinozoans, acritarchs, leiospheres). Eurypterid remains (e.g., Megalograplidae) must be stressed because these fossils usually indicate fairly shallow, near-shore environments of the Eurypterid Community. Anoxic conditions became progressively less severe during the Ludlow, and graptolites (e.g., *Saetograptus, Bohemograptus*), bivalves (Cardiolidae), myodocopid ostracodes (e.g., *Bolbozoe*), and orthocone cephalopods were typical parts of the fauna. They are frequently preserved in well-bedded nodules ("sphaeroids"). Later in the Pridoli, the normally oxygenated environments of the Lostmarc´h (uppermost part), Plougastel, Le Val, Gahard, and Saint-Germain-sur-Ay Formations supported brachiopods, crinoids, a few trilobites (Homalonotidae), ceratiocarids, bivalves, orthocone cephalopods, and very abundant and diverse palynomorphs (acritarchs, spores, a few tracheids), chitinozoans, and scolecodonts (Rauscher and Robardet, 1975; Deunff and Chateauneuf, 1976; Paris, 1981). The macrofossils and most of the palynomorphs are indicative of fairly shallow marine, near-shore environments.

Adequate sedimentological and faunal data for an accurate reconstruction of the SAD marine environment during the Silurian are mostly absent. However, the common record of mazuelloids and possible radiolarians in the black cherts of the Vendée (see references in LeHérissé et al., 1991) suggests a rather deep environment. On the other hand, the depositional environment at La Meignanne was deep enough that it was not obviously affected by the Pridoli–early Lochkovian regression.

Climatic indicators and variations — The occurrence of a cold-water *Clarkeia* fauna and the lack of important limestones suggest that MNAD was located at high to moderate latitudes (Paris and Robardet, 1990). Therefore, the successive latitudinal positions proposed by Scotese and McKerrow (1990) for the Armorican Massif for the Early–Late Silurian seem to be acceptable. However, the black micrites at La Meignanne in the SAD (see Kříž and Paris, 1982) suggest more moderate to low latitudinal locations of this area with regard to the MNAD regions during the Ludlow and Pridoli. Moreover, faunal affinities and lithologic features suggest that a closely related paleogeographic position of the La Meignanne area, Sardinia, Bohemia, Carnic Alps, and the Montagne Noire is likely (Kříž, 1996, 1999; Kříž and Serpagli, 1993; Paris, in press).

Montagne Noire — With the exception of a local occurrence of black carbonates and shales in the south of the Albigeois, Silurian strata are only recorded in the southeast Montagne Noire (Fig. 15), in the Falgairas and Laurens areas of the Cabrières klippes (Feist and Echtler, 1994). In the rest of the Montagne Noire (or the "nappes" domain), the Lower Cambrian to Lower Ordovician are unconformably overlain by the lowermost Devonian. The complete Silurian sequence of the Cabrières klippes (Chaubet, 1937) is interpreted to be part of a huge olistolith in a Visean matrix (Engel et al., 1982). This tectonic association is mainly developed in the southeastern Montagne Noire.

From the late Llandovery–early Wenlock, the local sedimentary rocks include condensed black shales and subordinate limestone nodules ("Roquemaillère black shales," ca. 5,070 m; Fig. 18). These shales are overlain by Wenlock platy to nodular limestones with minor calcareous black shales (Fig. 18). The Ludlow is reduced to less than 5 m of black calcareous mudstones with calcareous nodules and a few bedded or nodular limestones (Fig. 18). The Pridoli is much thicker (Feist, 1977; De Bock, 1982). In the lower Pridoli, black shales are progressively replaced upward by dolostones and limestones. In the upper part of this black shale and pelagic carbonate sequence ("Falgairas shales and limestones," ca. 5,060 m), the sandy limestones pass up into calcareous sandstones and sandstones (Falgairas Sandstone, 9 m), with shallowing and increased siliciclastic input (Feist, 1977).

Correlation chart of Montgne Noire — A composite chart of the Roquemaillère and Falgairas Silurian is given in Fig. 18. Because a detailed sequence stratigraphy

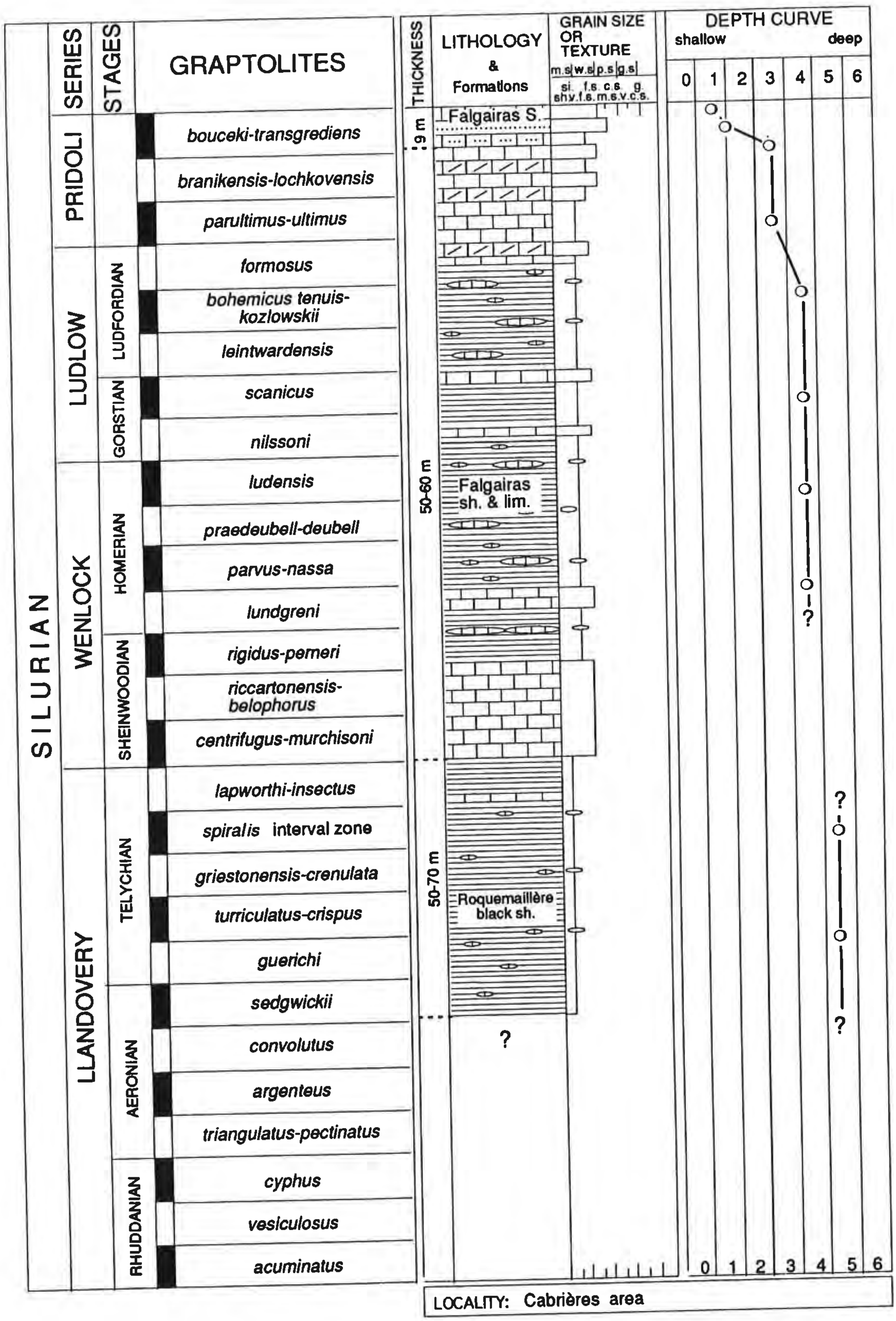

FIGURE 18 — Silurian of Cabrières area (southeast Montagne Noire), France.

is not available on these sequences, the proposed depth curve is tentative and generalized.

In addition to an abundant and diverse macrofauna with trilobites, brachiopods, bivalves, ostracodes, and crinoids (Feist, 1977), biostratigraphically diagnostic graptolites of the *Stimulograptus sedgwickii, Neodiversograptus nilssoni, Lobograptus scanicus, Bohemograptus bohemicus,* and *Monograptus ultimus* Zones have been recorded in this area (Centene and Sentou, 1975). The occurrence of a fairly diverse trilobite fauna in the Wenlock, and less diverse faunas in the Ludlow and Pridoli (Feist, 1977), has to be stressed because trilobites are virtually absent in other Silurian strata of France. Bivalves (see Kříž, 1996) represent an important group for detailed correlation with other regions of Gondwana and Perunica. Kříž (1996) described 41 bivalve species known from the Prague Basin from the Wenlock, Ludlow, and Pridoli of the Montagne Noire, and recognized five distinct bivalve-dominated communities also known from the Prague Basin, Sardinia, and the Carnic Alps (Austria, Italy). The bivalves show that the Silurian of the Montagne Noire has the closest faunal relationship with the Silurian of Sardinia. Three communities known from Sardinia occur in the Montagne Noire (Kříž and Serpagli, 1993). These are the *Cardiola figusi* (Wenlock–Ludlow boundary), *Cardiola donigala* (lower Ludlow), and *Cardiolinka sardiniana* (lower Přídolí) Communities. Diagnostic conodonts have also been recorded from the Telychian to the uppermost Pridoli in the Falgairas area (Feist and Schönlaub, 1974; Centene and Sentou, 1975). A number of conodont zones have been identified (e.g., *Pterospathodus celloni, P. amorphognathoides, Kockelella patula, Ozarkodina sagitta, Ancoradella ploeckensis, Polygnathoides siluricus, Ozarkodina snajdri, O. crispa, and O. remscheidensis eosteinhornensis* Zones; Centene and Sentou, 1975; Feist, 1977). Acritarchs and chitinozoans have been reported by Deflandre (1942) from the "Roquemaillre Limestone" (probably Wenlock). The distribution of *Urnochitina urna* and *Eisenackitina bohemica* — chitinozoans diagnostic, respectively, of the Pridoli and Lochkovian — allowed De Bock (1982) to locate the Silurian–Devonian boundary fairly precisely in the Falgairas and Laurens areas.

Lithostratigraphy and biofacies of the Montagne Noire — No modern sedimentologic investigations have been done on the Silurian of the Cabrières klippes. A low-energy environment shown by pelagic and epipelagic faunas and the generally condensed succession prevailed from the late Llandovery to early Pridoli. Bivalve-dominated communities (Kříž, 1996) show that the environment was episodically ventilated by currents to depths similar to those in other northern Gondwanan terranes. The first evidence of a significant shallowing is given by the input of detrital quartz, and later by the deposition of sandstones in the latest Pridoli ("Falgairas Sandstone") in a high-energy environment (Fig. 18).

The faunas indicate this shallowing by the predominance of benthic taxa during the Pridoli. At that time, icriodontid conodonts, which are usually regarded as shallow-water, replaced the deeper water ozarkodinid species (Feist, 1977).

Climate — The major development of carbonates, especially in the Pridoli, indicates a moderate to fairly low latitudinal location for the Silurian of the Cabrières klippen. In addition, obvious paleogeographic similarities exist with other "Mediterranean" regions (e.g., Sardinia, Carnic Alps, eastern Pyrenees, Mouthoumet, Aquitaine basin, and the South Armorican Domain [La Meignanne]) (Kříž, 1996, 1999). These similarities suggest a northern Gondwanan margin location for these areas in the Silurian, but with a lower latitudinal position than the MNAD (Robardet et al., 1994, Paris, in press).

Aquitaine Basin — In the Aquitaine Basin (Fig. 15), the Silurian has been encountered in only a few bore holes through the Mesozoic. Llandovery graptolitic black shales, probably of the *Spirograptus turriculatus-Monograptus crispus* or *Monoclimacis griestonensis-Monoclimacis crenulata* Zones; and Pridoli black shales with a few mazuelloids and poorly preserved chitinozoans, have been observed in the Castelsarrasin well (Cs. 102 of Paris and Le Pochat, 1994). Other Silurian rocks occur in the Saint-Martin-du-Bois borehole (SMB.1). Tuffaceous sedimentary rocks from SMB. 1 yield *Spinachitina fragilis?*, the index of the lowest Rhuddanian chitinozoan zone. Reworking cannot be excluded, but the sequence continues with black shale, and dolostone appearing only as minute cuttings. This anoxic or strongly dysaerobic succession ends with sandy limestones with *Eisenackitina bohemica* (Paris and Le Pochat, 1994). This Lochkovian chitinozoan was reported by De Bock (1982) from similar rocks in the Montagne Noire. Northwest and close to the Bay of Biscay shoreline, the slightly metamorphosed, black laminated shales of the Le Teich Formation are tentatively referred to the Silurian on the basis of limited graptolite evidence (Monograptidae) (Paris and le Pochat, 1994). No paleoenvironmental interpretation is possible due to the lack of suitable core samples.

Possible Silurian elsewhere in France — In several areas, rocks referred to the Silurian are strongly affected by folding, cleavage, and a fairly high-grade metamorphism. Original sedimentological features are not preserved, and fossils are generally lacking. These possible Silurian sequences are briefly listed below from north to south.

Part of the greenish to purple Steige Slate that crops out in the northern Vosges Massif (Fig. 15) has been referred to the Silurian based on chitinozoans (Doubinger, 1963). However, these palynomorphs were too poorly preserved to allow a firm generic identification, and the Steige Slate is not discussed further.

In the Paleozoic basement of the Alps, black and green schists crop out in the western Belledonne Massif (see Ménot et al., 1994). No firm evidence of Silurian fossils has been reported from this material. In southeastern France, lenses of crinoidal limestone and a black shale of Middle Silurian age are reported from the western Maures Massif (Crevola and Pupin, 1994; Fig. 15). These sedimentary rocks are not discussed further because Variscan epizonal metamorphism and tectonics obscure their lithology and relationship to surrounding formations.

In northern Corsica (Fig. 15), the Silurian is recorded by the Monte Martinu Formation, which has dark slates in the Campo Orbu Member that yield chitinozoans and acritarchs regarded as Silurian (Baudelot et al., 1976). However, additional paleontological work is necessary to document a more precise age for these slates and for the overlying sandstones and black cherts of the Capu Russellu Member.

SILURIAN OF SARDINIA

Silurian rocks are exposed only in southern Sardinia (Fig. 19). Two distinct outcrop belts occur in the southwest (Iglesiente and Sulcis sub-regions) and southeast (Gerrei and Sarrabus sub-regions) of the island. They resemble the Silurian of Bohemia and Thuringia, respectively. Their mutual relationship is unclear, and this justifies their separate treatment and the use of distinct correlation charts (Figs. 21–24). Although formal lithostratigraphic units have been proposed for southwest Sardinia (Gnoli et al., 1990), informal names adopted from Thuringia and used mostly as facies indicators are still used in southeast Sardinia.

Strong tectonism which affected Sardinia largely explains the fact that a complete Silurian section is unknown on the island. This is reflected also in the definition of lithostratigraphic units, which are largely based on several discontinuous outcrops. The use of graptolites and conodonts as zonal fossils is necessary because of the peculiar lithologies in the exposures. Corradini and Serpagli (1998) proposed a conodont zonation for the upper Llandovery–Pridoli of Sardinia. Their scheme has been adopted in the discussion of this report, but the figures used herein follow the standard conodont-graptolite zonation (Silurian Times, No. 3, 1995), and used in all the reports in this bulletin. For the relationship between the two zonations, see Fig. 20.

LITHOSTRATIGRAPHY AND BIOSTRATIGRAPHY — The Silurian of Sardinia begins with graptolitic sandy to siliceous shale, which are organic-rich and pyritic, especially in southeast Sardinia ("alum slates" of Jaeger, 1977b) and are interbedded with chert in the lowest part of the succession. The Genna Muxerru Formation of southwest Sardinia (2,025 m; Fig. 21) has Llandovery graptolites (*Parakidograptus acuminatus, Cystograptus vesiculosus, Coronograptus cyphus, Demirastrites triangulatus-D. pectinatus, D. convolutus, Spirograptus turriculatus-Monograptus crispus,* and *Monoclimacis griestoniensis-M. crenulata* Zones) (Gnoli et al., 1990; Štorch and Serpagli, 1993). Nine more species were reported by Rickards et al. (1995) from these zones. Graptolites of the *Cyrtograptus lapworthi* Zone have been discovered by P. Štorch (unpublished data, 1998). The lower and upper boundaries of the Genna Muxerru Formation are not well exposed, but appear to be gradational.

The "lower graptolitic shales" of southeast Sardinia (3,040 m; Fig. 22) represent a long time interval, and range upward to the Wenlock and lower Ludlow. An undisturbed lower contact of the formation with the Ordovician is not known. Chert, otherwise rare in southwest Sardinia, is well developed in the Llandovery. They extend up to the *S. turriculatus-M. crispus* Zone and are generally thick-bedded, frequently radiolarian-rich, and have thin shale interbeds. Phosphorites are present in the middle–upper part of the formation from the *Cyrtograptus lundgreni–Neodiversograptus nilssoni* Zones, where they occur as nodules, lenses, or beds (Barca and Jaeger, 1990). Llandovery graptolites of the *Cystograptus vesiculosus, Demirastrites triangulatus-D. pectinatus, Monograptus argenteus (Coronograptus gregarius), Demirastrites convolutus, Spirograptus turriculatus-Monograptus crispus, Monoclimacis griestoniensis-M. crenulata,* and *Oktavites spiralis* Zones are known. This formation extends into the lower Ludlow, at least as high as the *N. nilssoni* Zone (Barca and Jaeger, 1990). The base of the overlying calcareous formation has *Ozarkodina excavata hamata* Zone conodonts (Corradini et al., 1998), and seems to be equivalent to the lower *Lobograptus scanicus* (graptolite) Zone.

The Fluminimaggiore Formation (Fig. 23) overlies the Genna Muxerru Formation in southwest Sardinia and roughly corresponds to the "calcari a *Orthoceras, Cardiola, Monograptus*" of early reports (e.g., Meneghini, 1881). The approximate thickness of the Fluminimaggiore Formation can be estimated only indirectly due to strong tectonism, but is ca. 4,550 m. The formation is upper Llandovery–lowest Lochkovian. Black, calcareous nodule-like structures, generally ellipsoidal and up to 1 m in size (Fig. 23) alternate with dark, non-calcareous shales. Plastic deformation and cleavage have strongly altered the shales, while the limestone bodies have well-preserved fossils (Gnoli et al., 1980). The black color and the peculiar bituminous smell indicate high organic matter con-

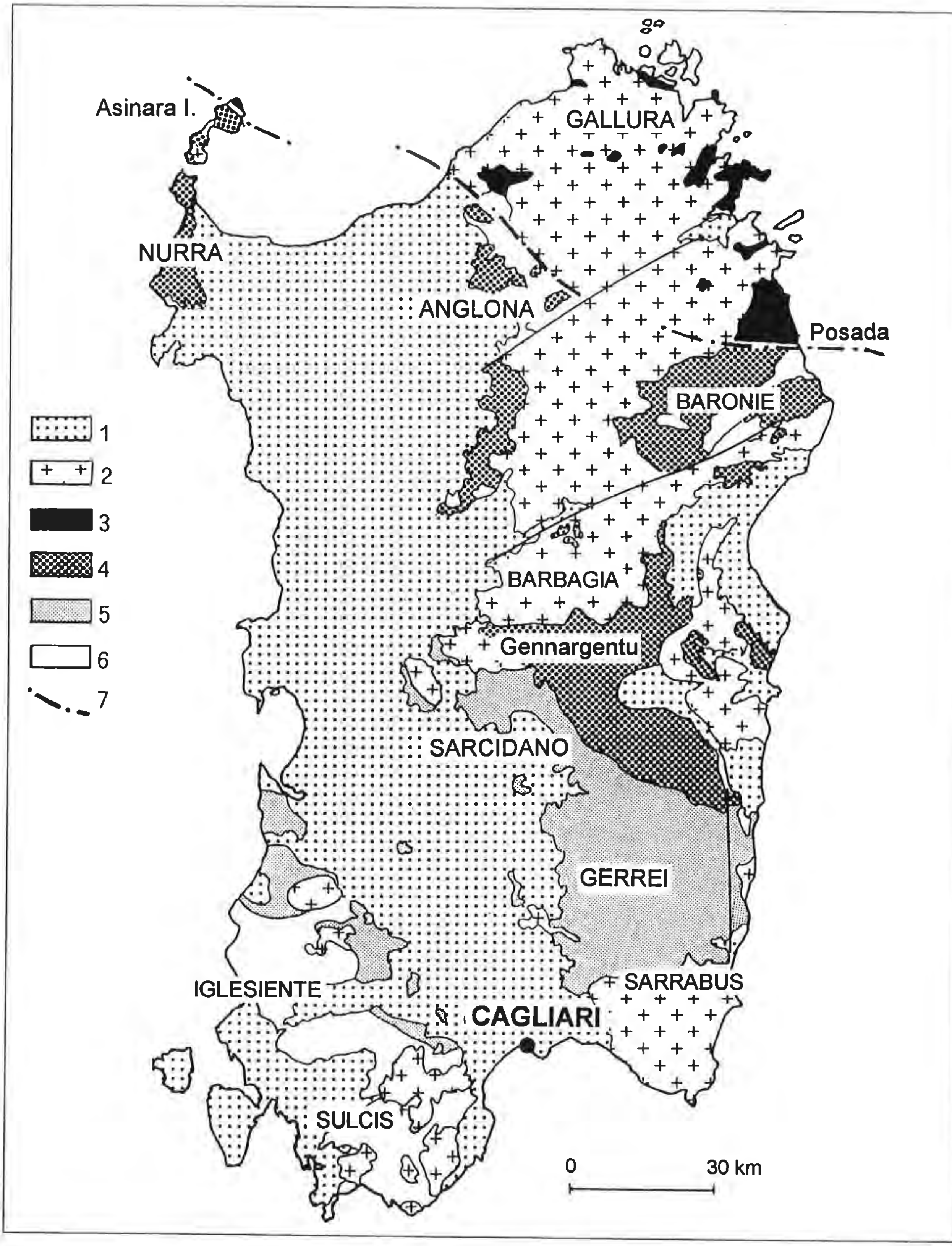

FIGURE 19 — Primary structural elements of Sardinia. *1*, post-Variscan cover; *2*, Variscan batholith; *3*, high-grade metamorphic complex; *4*, internal nappes; *5*, external nappes (including the Silurian); *6*, external zone; *7*, Posada–Asinara Line. After Carmignani et al. (1992).

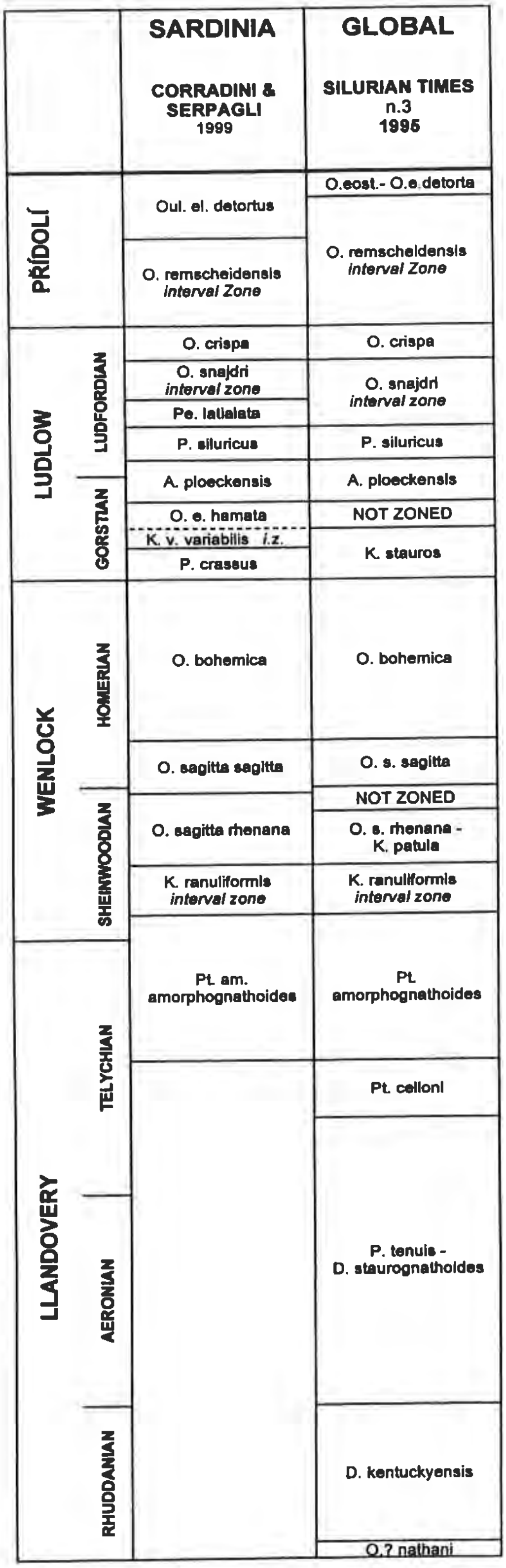

FIGURE 20 — Comparison between the the upper Llandovery–Pridoli conodont zonation of Sardinia and the standard zonation (after Corradini and Serpagli, in press).

tent. The fauna is dominated by cephalopods with associated bivalves, pelagic ostracodes, graptolites, conodonts, foraminiferans, chitinozoans, and muellerisphaerids. Gastropods, brachiopods, trilobites, and eurypterids are rare. Graptolites are frequently found packed together in the calcareous bodies. A single graptolite species, or a few at most, occurs in each calcareous body. Diverse *Saetograptus* or *Monograptus* species dominate the Wenlock–Ludlow and lower Pridoli associations (Ferretti and Serpagli, 1996b). Bivalves are the only important benthic forms, and almost no trilobites and brachiopods have been found. This suggests limited oxygenation, which could not be tolerated by these latter organisms. The carbonates are characterized by dominant fossiliferous wackestone–packstones that pass into sparse fossiliferous mudstones at the top of the formation. A crinoid packstone horizon with scyphocrinitids appears at the top of the Fluminimaggiore Formation. The *Pterospatodus amorphognathoides amorphognathoides, Kockelella ranuliformis, Ozarkodina sagitta sagitta, O. bohemica bohemica, Polygnathoides crassus, O. excavata hamata, Ancoradella ploeckensis, Polygnathoides siluricus, O. remscheidensis, Oulodus elegans detortus, Icriodius woschmidti woschmidti* and *I. woshmidti postwoshmidti* (conodont) Zones have been documented (Ferretti et al., 1998). Graptolites of the *Cyrtograptus lundgreni, Neodiversograptus nilssoni, Lobograptus scanicus, Saetograptus leintwardensis,* and *Monograptus parultimus-M. ultimus* Zones (H. Jaeger, personal commun., 1987; Rickards et al., 1995) have been reported from the limestones.

The limestones with cephalopods of the Fluminimaggiore Formation of southwest Sardinia have correlatives in southeast Sardinia (Gerrei sub-region) in the uppermost "lower graptolitic shales," in a calcareous unit ("Ockerkalk;" Fig. 24), and probably in the lowermost part of another shaly unit, the "upper graptolitic shales." The "Ockerkalk" (30 m), a blue-gray argillaceous limestone that weathers to an ochre color on which its name is based, is stylolitic. The fauna is composed largely of few nautiloids (Gnoli, 1993), with rare ostracodes, brachiopods, thin-shelled bivalves, trilobite fragments, gastropods, sponge spicules, phyllocarids (mainly mandibles), and crinoids. Trace fossils and very small solitary corals were reported from the "Ockerkalk" by Jaeger (1977b). These remains are scattered in a micritic matrix, and are locally concentrated in thin wackestone bands with disarticulated debris. Rich conodont faunas of the *Ozarkodina excavata hamata, Ancoradella ploeckensis, Polygnathoides siluricus, Pedavis latialata, Ozarkodina snajdri, O. crispa, O. remscheidensis,* and *Oulodus elegans detortus* Zones have been documented (Corradini et al., 1998). These conodont zones are in good agreement with the graptolite zones from the shales at the base and top of the

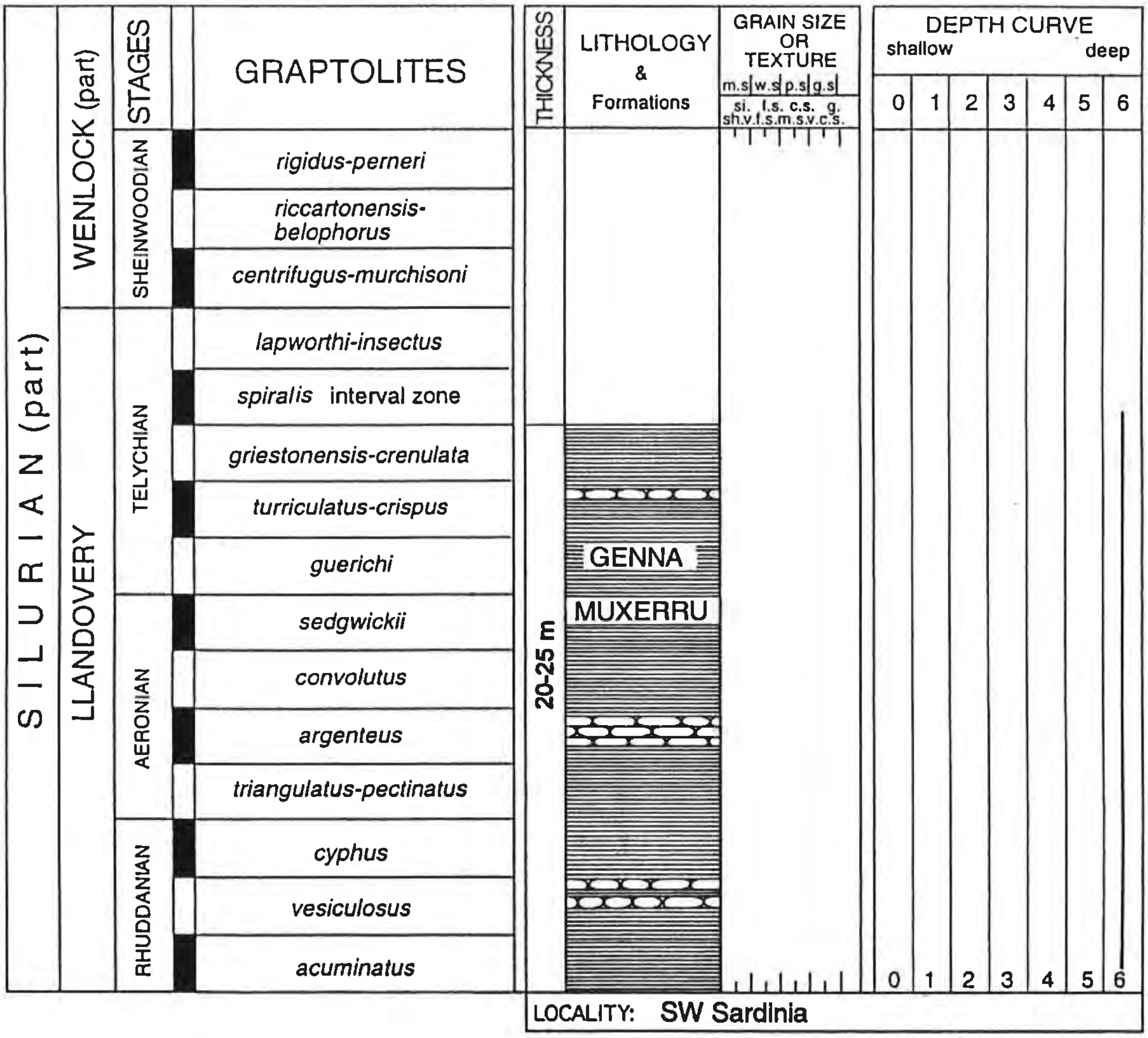

FIGURE 21 — Lower Silurian of southwest Sardinia.

unit (Jaeger, 1976). A lobolith horizon with the pelagic crinoid *Scyphocrinites* that is known along the northern Gondwana margin in the Silurian–Devonian boundary interval occurs in the Upper Silurian *Oulodus elegans detortus* Zone (Barca et al., 1995) of southeast Sardinia (Helmcke, 1973; Jaeger, 1976, 1977b; Barca and Jaeger, 1990). A similar lobolith horizon (*Camarocrinus?*) occurs in the uppermost Devonian of southwest Sardinia (Gnoli et al., 1988). In the Sarrabus sub-region of southeast Sardinia, Silurian and Devonian olistoliths and olistostromes are embedded in flysch-type rocks of probable Early Carboniferous age (Barca, 1991; Barca and Olivieri, 1991). Graptolitic black slates with interbedded cherts (Barca and Jaeger, 1990) and calcareous blocks (Barca et al., 1986; Barca and Olivieri, 1991) are part of this complex. This foredeep basin facies has many similarities to Culm-type, Hercynian flysches of southern Europe (Spalletta and Vai, 1982; Vai and Cocozza, 1986).

The Silurian–Devonian boundary in southwest Sardinia occurs in the calcareous Fluminimaggiore Formation (Gnoli et al., 1988). However, in southeast Sardinia (Gerrei sub-region, Fig. 24), it seems to be present at the base of the "upper graptolitic shales" and yields the index graptolite *Monograptus uniformis* (Jaeger, 1976). These "shales" are actually alum slates without chert or phosphorite. Based on the composite section of Barca and Jaeger (1990), *Scyphocrinites* also occurs in the lower part of this formation. These shales grade upward into fine-grained, nodular limestones of late Early to Middle Devonian age.

SILURIAN PALEOECOLOGY IN SARDINIA — The lowest Silurian of Sardinia consists of more or less uniform, dark

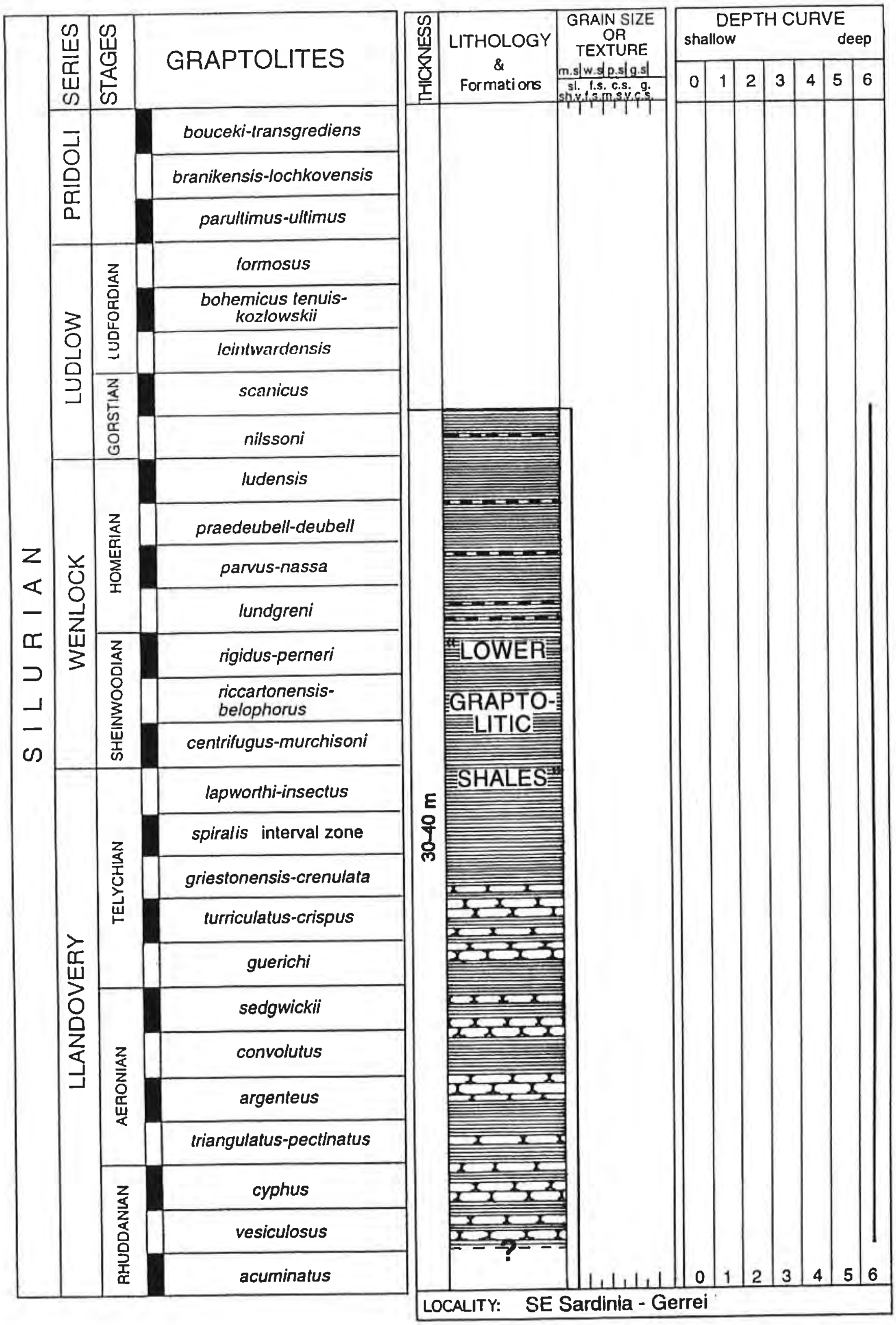

FIGURE 22 — Lower Silurian of Gerrei, southeast Sardinia.

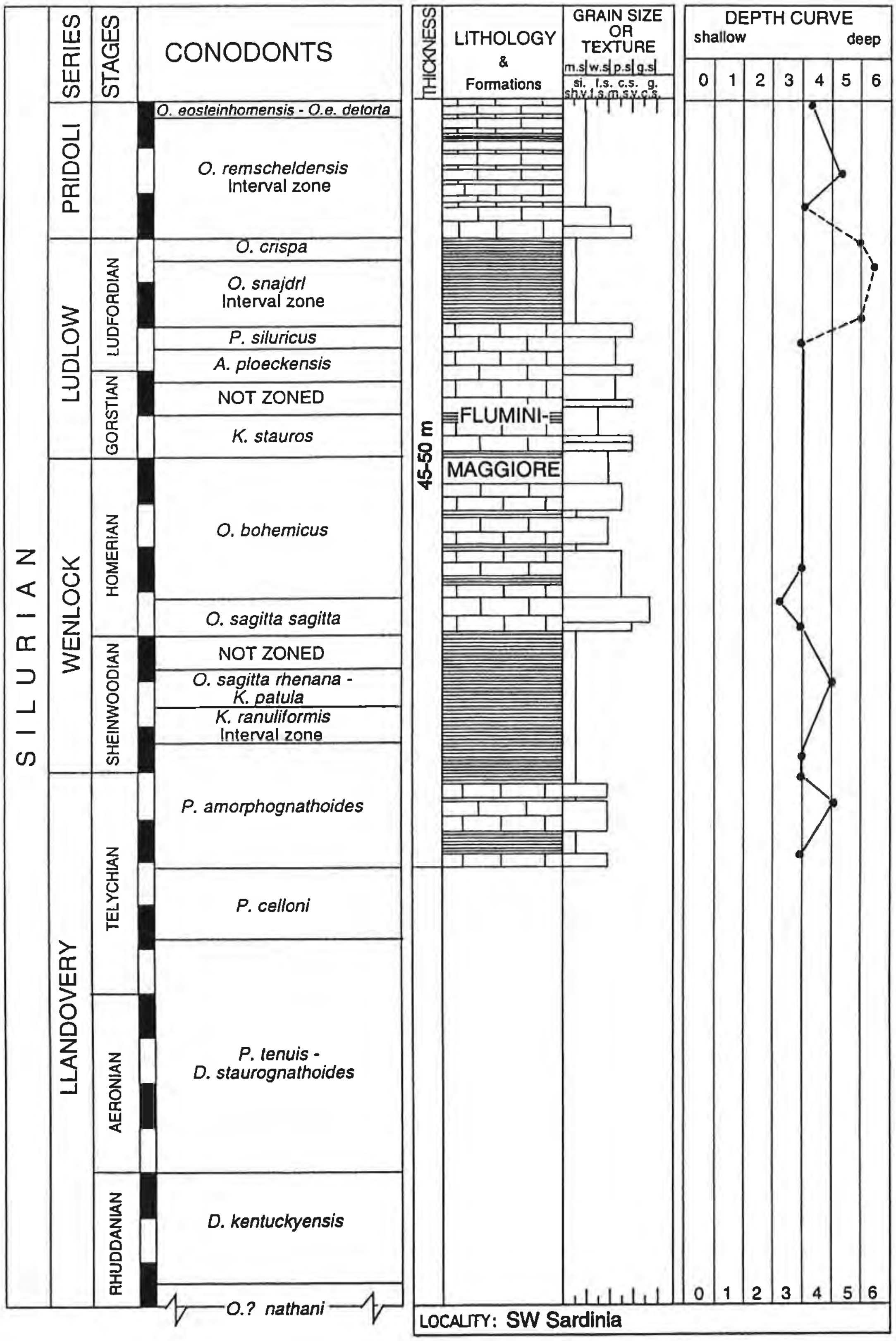

FIGURE 23 — Middle and Upper Silurian of Fluminimaggiore–Galemmu, southwest Sardinia.

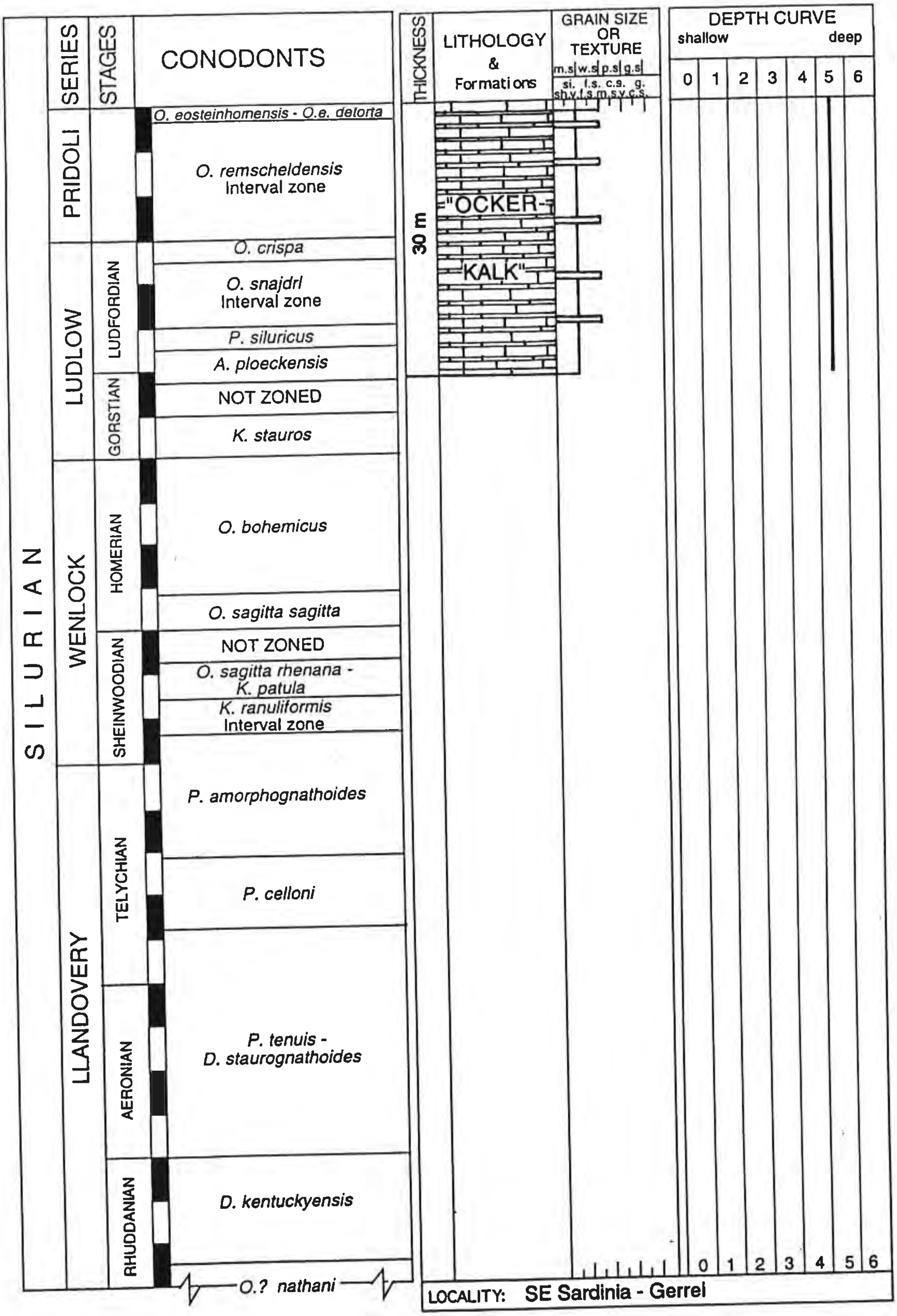

FIGURE 24 — Upper Silurian at Gerrei, southeast Sardinia.

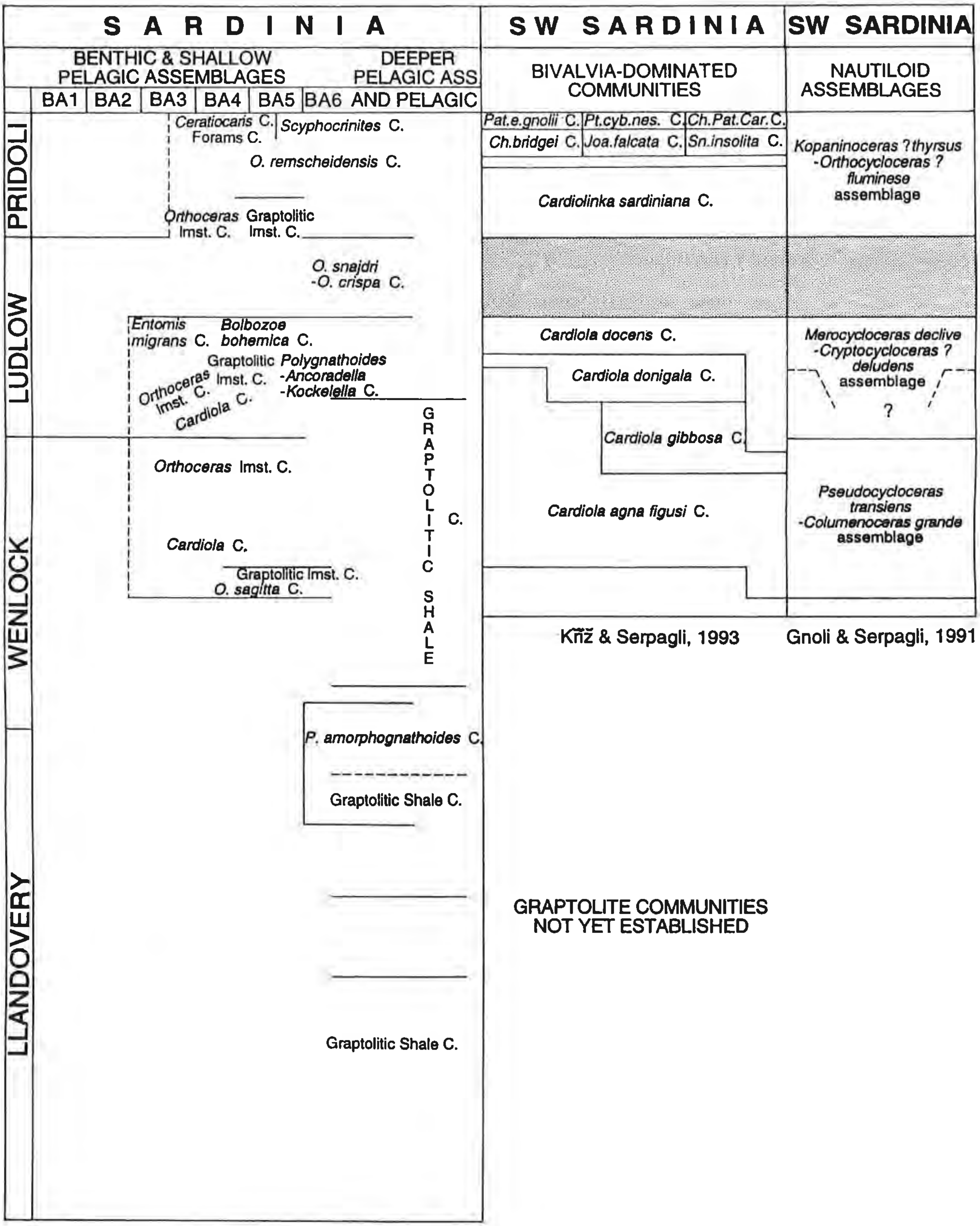

FIGURE 25 — Silurian communities in Sardinia.

shales that are rich in graptolites (Figs. 21–24). The same facies occur at the base of many other south European sequences, and indicate a common oceanographic domain along the northern margin of Gondwana after the marked provincialism of the Late Ordovician. Shale deposition occurred in an anoxic, sapropelitic basin (Jaeger, 1977b; Gnoli et al., 1990). Local calcareous deposition began diachronously in the late Llandovery, and became dominant in the Wenlock in southwest Sardinia and in the late Ludlow in southeast Sardinia (Fig. 25). Cephalopod-rich limestones from southwest Sardinia are lens-shaped beds intercalated with shales. They probably represent relatively short sedimentation events in the quiet depositional environments of the shales. Wave-oriented orthocones have been reported by Gnoli et al. (1980). A constant SSE-NNW conch orientation has been described from an upper Wenlock locality (Ferretti et al., 1995). This suggests uniformly oriented currents that carried cephalopod conchs along many parts of the northern Gondwana shelf. Local randomly oriented orthocones indicate that a current was not constantly active. Graptolitic limestones of southwest Sardinia are represented by centimeter-thick, graptolite-packed layers with a sharp base. These limestones are intercalated with fine-grained calcareous mudstones with sparse graptolite fragments and small cephalopods with abundant geopetal infills. Most of the cephalopod conchs still preserve body chambers, which are sometimes filled with graptolites. Both random- and current-oriented concentrations are present, even for graptolite rhabdosomes of the same genus and with similar hydrodynamic behaviour. These graptolitic concentrations represents discrete event horizons of individuals which were probably living in an environment adjacent to that of cephalopods (Ferretti and Serpagli, 1996a).

Five different microfacies have been recognized in the Wenlock–upper Ludlow limestones of southwest Sardinia. These include a shallow-water, high-energy depositional regime for the dominant peloid-cephalopod-ostracode packstone–wackestones (typical of the cephalopod limestone); the graptolitic packstones; and the coated-grain grainstone–packstones. Deposition below normal wave-base, but probably above storm wave-base, is indicated for the rare Ludlow mudstones with intercalated shell-lags and for the dark, laminated, fossiliferous mudstones. Pridoli sedimentation featured a shift to deeper waters, as shown by dark fossiliferous mudstones with occasional winnowed shell lags of disarticulated, thin-shelled, convex-up bivalves and ostracodes, small orthocones, and rare crinoid fragments (Ferretti, 1989).

The limestones from southeast Sardinia are largely represented by massive sequences of micritic limestone with millimeter-thick shell-lags of disarticulated debris. A quiet pelagic environment below wave-base has been suggested for these limestones (Barca et al., 1995).

As noted above, the transition into the Devonian takes place in a calcareous facies in southwest Sardinia, whereas in southeast Sardinia it appears to correspond to the lithologic change from the "Ockerkalk" limestone to the overlying "upper graptolitic shales."

SILURIAN COMMUNITIES IN SARDINIA — Ferretti and Serpagli (1996b) proposed a revised sketch of Silurian communities in Sardinia (Fig. 25, left side). Graptolite associations have been studied in the Lower Silurian of southwest Sardinia by Štorch and Serpagli (1993).

Twelve Silurian–lower Devonian bivalve-dominated benthic communities were recognized in the Fluminimaggiore Formation (Kříž and Serpagli, 1993; Fig. 25). The strong affinity between southwest Sardinia and Bohemia is shown by the common occurrence of 69 bivalve species. Four recurring, medium-diversity communities dominated by epifaunal forms were described within the *Cardiola* Community Group of latest Wenlock to late Ludlow age. Adaptation to conditions represented by the cephalopod limestone biofacies was achieved in these communities through an epibyssate life on a cephalopod shell substrate (Kříž, 1998). Pridoli communities that lived on soft micrite bottoms feature low-diversity infaunal and semi-infaunal taxa. Monospecific or very low-diversity communities developed in severe habitats (e.g., limited current activity and low oxygen content). More favorable habitats had communities with higher diversity and lower population density (Kříž and Serpagli, 1993).

Three nautiloid assemblages with potential stratigraphic value were recognized in the Middle to Upper Silurian of southwest Sardinia (Gnoli and Serpagli, 1991; Fig. 25). The *Pseudocycloceras transiens-Columenoceras grande* assemblage occurs in the *Ozarkodina sagitta sagitta–O. bohemica* Zones; the *Merocycloceras declive-Cryptocycloceras? deludens* assemblage is found in the *Ancoradella ploeckensis–Polygnathoides siluricus* Zones, and the *Kopaninoceras? thyrsus-Orthocycloceras? fluminese* assemblage extends from the *Ozarkodina remscheidensis* Zone to the *Icriodus woschmidti* Zone. Each nautiloid assemblage is widespread, and is similar to nautiloid assemblages from the Prague Basin, with several species in common (Gnoli, 1990; Gnoli and Serpagli, 1991).

The Silurian of Austria

In the Austrian Alps, fossiliferous Silurian strata are irregularly distributed (Fig. 26). They form a mosaic-like pattern of isolated units in the Alpine nappe system. Si-

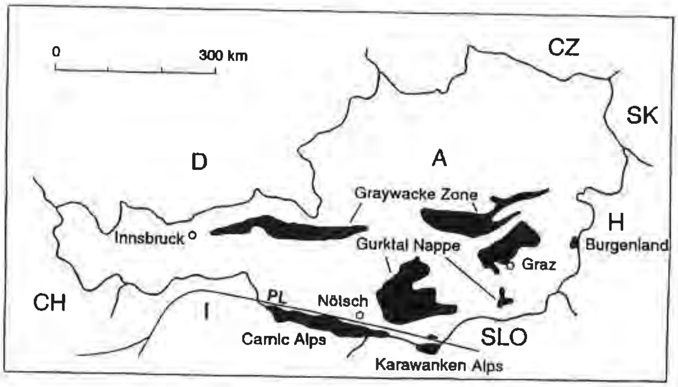

FIGURE 26 — Main regions of fossiliferous Paleozoic in the eastern and southern Alps. Abbreviations: A, Austria; CH, Switzerland; CZ, Czech Republic; D, Germany; H, Hungary; I, Italy; PL, Periadriatic Line; SLO, Slovenia; SK, Slovakia.

lurian outcrop areas include the Gurktal Nappe of middle Carinthia and southern Styria; the Graz region; and the Graywacke Zone of Styria, Salzburg, and Tyrol. Coeval rocks are exposed south of the Periadriatic Line along the northern margin of the southern Alps (i.e., in the Carnic and Karawanken Alps). In addition, some of the sedimentary precursors of quartz phyllites and even amphibolite-grade metamorphic rocks may also be Silurian, but it is not yet possible to correlate these non-fossiliferous units.

Since the discovery of Silurian fossils in the Alps by von Hauer (1847), the knowledge of Silurian rocks and organic remains has increased considerably. Microfossil research and field work by different working groups have elaborated a more detailed biostratigraphic framework and has documented the lithology of the Silurian.

Silurian deposits range from shallow-water carbonates to graptolitic shales. The thicknesses are regionally similar and generally do not exceed ca. 60 m. The main differences across the Periadriatic Line involve the distribution of fossils, facies patterns, rates of subsidence, supply areas, amounts of volcanism, and the spatial and temporal relationships of climate-sensitive rocks (Schönlaub, 1993).

The biostratigraphically important groups are primarily graptolites and conodonts. Other groups of almost equal importance in correlation are trilobites, bivalves, chitinozoans, and acritarchs. However, acritarchs are useful only in the Lower Silurian (upper Llandovery–lower Wenlock). Brachiopods, bivalves, and nautiloids provide further data and are useful in paleoecologic and paleogeographic syntheses.

The area north of the Periadriatic Line shares only a few lithologic features with the southern Alps. Shared features include thick siliciclastic sequences in the Ordovician–Devonian; local reefs during the Silurian and Devonian; and basic magmatism in the Ordovician, Early Silurian, and Middle Devonian. The increased input of siliciclastic material suggests proximity to a land area. On the other hand, intense volcanism may be related to crustal extension. However, this activity may also be responsible for the different facies which occurred in most areas north of the Periadriatic Line during the Silurian and part of the Devonian.

CARNIC AND KARAWANKEN ALPS — In the Carnic Alps, the Silurian transgression started in the earliest Llandovery *Akidograptus acuminatus* Chron. Due to the unconformity which separates the Ordovician and Silurian in the Carnic and Karawanken Alps, a varying thickness of sedimentary rocks is locally missing, which corresponds to several Llandovery and Wenlock conodont zones. Locally, the lowest Lochkovian rests disconformably on Upper Ordovician limestone (Schönlaub, 1971).

The Silurian is subdivided into four major facies belts that reflect different depth and energy conditions. The Plöcken facies represents a moderately deep-marine environment characterized, from bottom to top, by the pelagic Kok Formation, the Cardiola Formation, and the Alticola–Megaerella Limestones. The key section is the 60 m-thick Cellonetta profile (Fig. 27), well known for its classic Silurian conodont zonation (Walliser, 1964).

The Wolayer facies represents an apparently shallower environment. It is characterized by fossiliferous limestones with abundant orthoconic nautiloids, trilobites, bivalves, small brachiopods, gastropods, crinoids, and a few corals. Due to a hiatus at the base, this facies is represented by only 10–15 m of variegated limestones. The classical sections are located in the Lake Wolayer region of the central Carnic Alps (Von Gaertner, 1931; Schönlaub, 1971, 1980; Fig. 28).

The stagnant-water, graptolite facies is the Bischofalm facies. It is represented by 60–80 m of black siliceous shales, black cherty beds, and clayey alum shales (Fig. 29), which contain abundant graptolites. The graptolite succession has been clearly outlined (Jaeger, 1975; Flügel et al., 1977; Jaeger and Schönlaub, 1980, 1994; Schönlaub, 1985). According to Jaeger (1975), the Bischofalm facies can be subdivided into the lower, middle, and upper Bischofalm Shale.

The Findenig facies is intermediate between the shallow-water and the starved basinal environments. It comprises interbedded, black graptolitic shales, marls, and blackish limestone beds. At its base, a quartzose sandstone occurs locally (Fig. 30).

These four Silurian lithofacies reflect different rates of subsidence. Sediments from the Llandovery to the earliest Ludlow suggest steady basin subsidence and accompanying transgression. Subsidence and transgression apparently decreased and perhaps stopped during the Pridoli and led to balanced conditions with uniform lime-

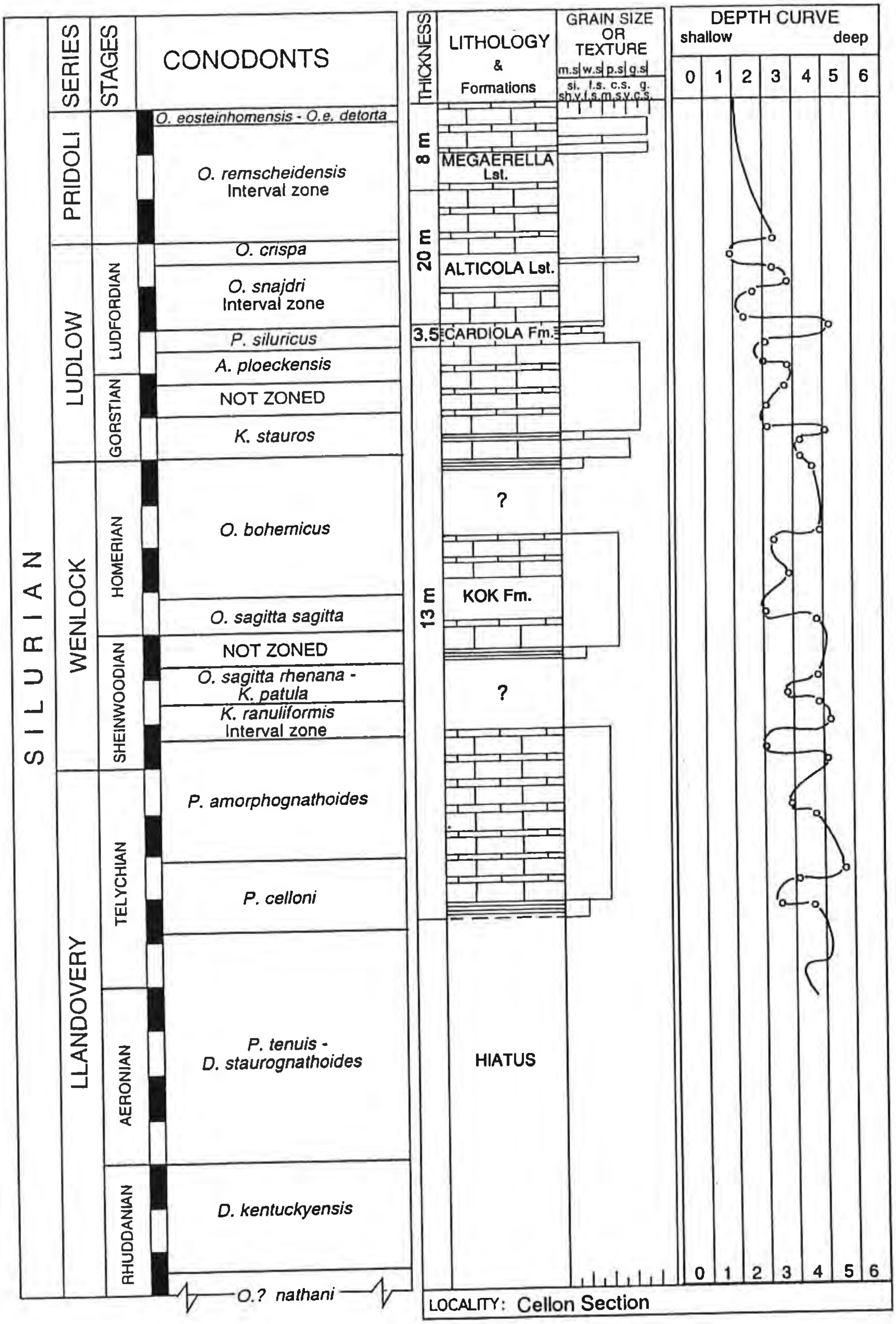

FIGURE 27 — Silurian at the Cellon section, Carnic Alps, Austria.

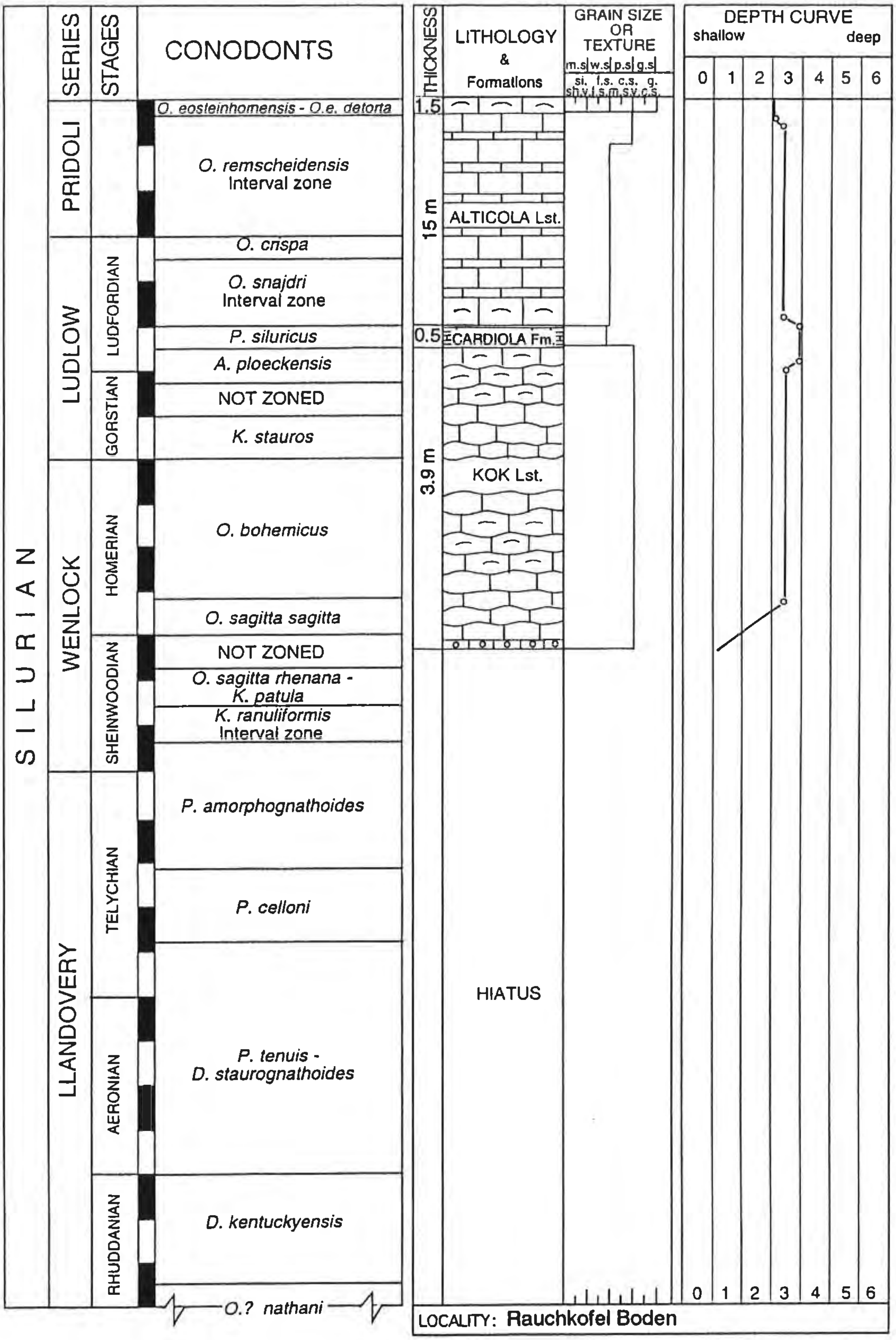

FIGURE 28 — Silurian at the Rauchkofel Boden section, Carnic Alps, Austria.

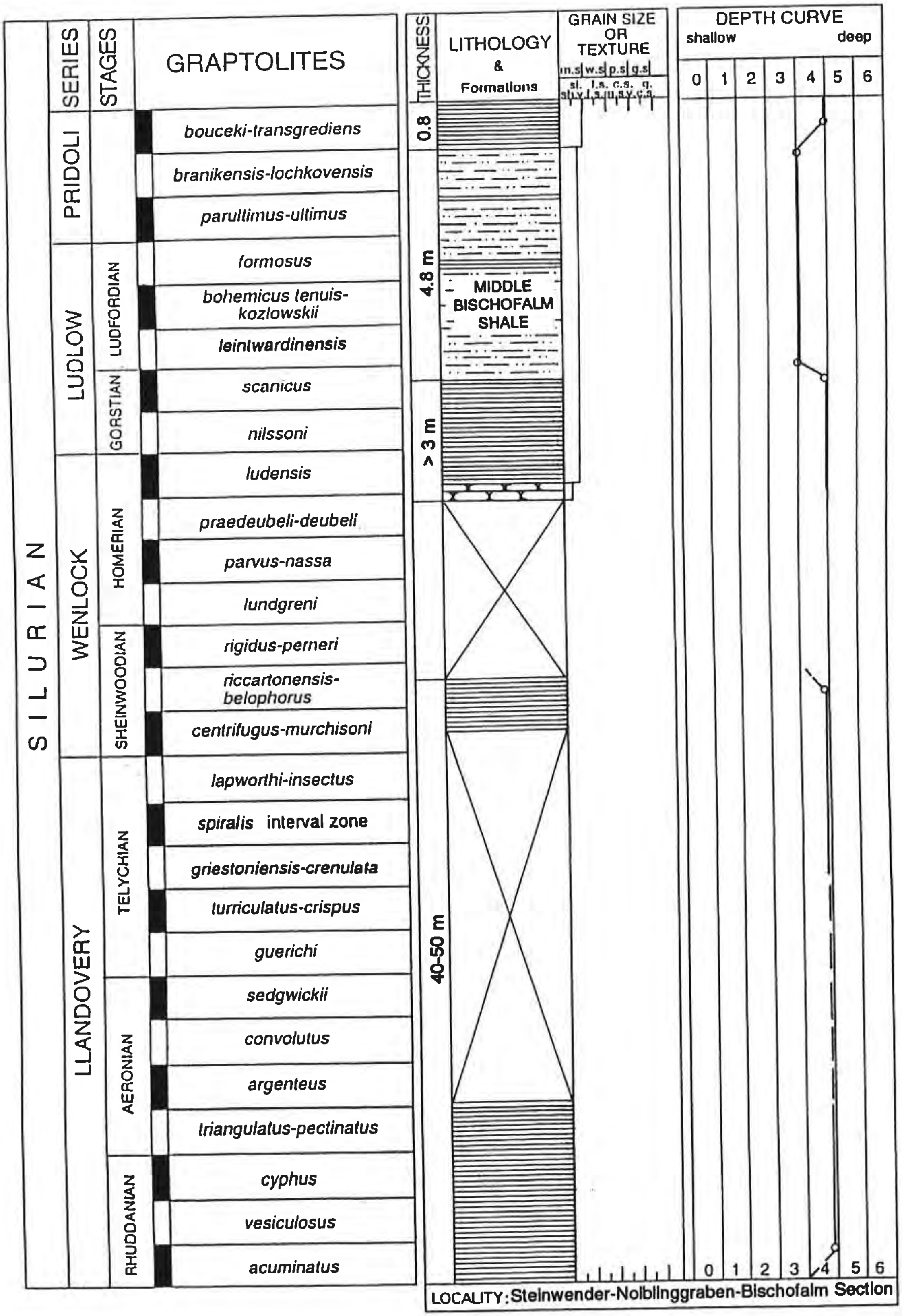

FIGURE 29 — Silurian at Steinwender–Nolblinggraben–Bischofalm section, Carnic Alps, Austria.

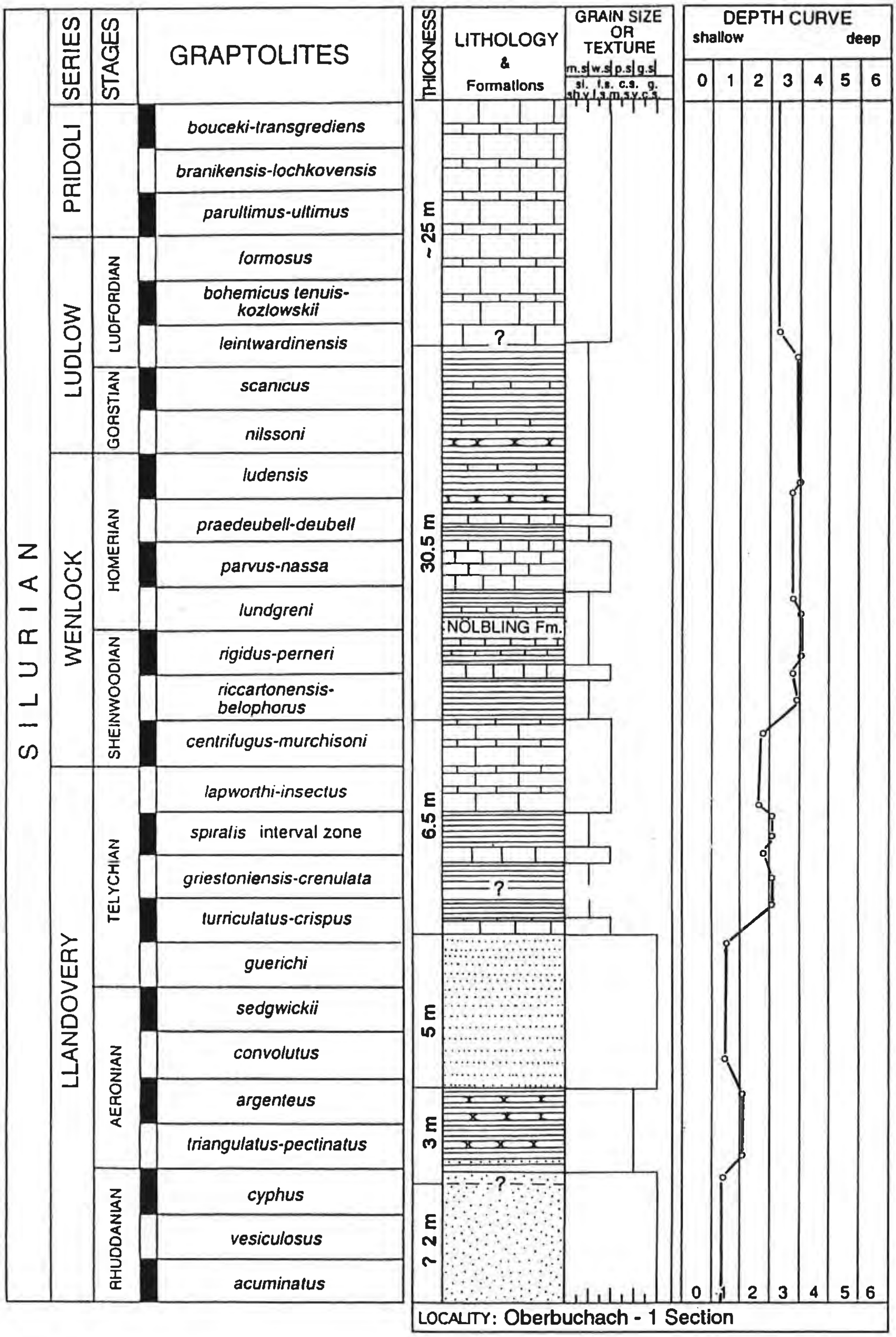

FIGURE 30 — Silurian at the Oberbuchach-1 section, Carnic Alps, Austria.

stone deposition. Simultaneously, the black graptolitic shale of the Bischofalm facies was replaced by green and gray shales called the middle Bischofalm Shale. At the base of the Devonian in the Bischofalm facies, the deep-water graptolitic environment reappeared and persisted until the end of the Lochkovian.

The Cellon section in the Carnic Alps (Fig. 27) has served since Walliser's (1964) work as a standard for global conodont zonation that has been further refined and partly revised in other areas. In fact, this section represents the stratotype for the Silurian of the eastern and southern Alps (Schönlaub, 1994a). The conformable sequence suggests continuity from the Ordovician to the Devonian. However, in recent years, several small hiatuses have been recognized which reflect sea-level changes within an overall shallow to moderately deep environment. From top to base, the uppermost Ordovician–Silurian of the Cellon section is subdivided into the following formations: the Megaerella Limestone (gray, somewhat fossiliferous limestone, Pridoli, 8 m); Alticola Limestone (gray and pink, nautiloid-bearing limestone, Ludlow–Pridoli, 20 m), Cardiola Formation (alternating black limestone, marl, and shale, Ludlow, 3.5 m), Kok Formation (ferruginous nautiloid limestone with shale interbeds at the base, upper Llandovery–Wenlock, 13 m), and Plöcken Formation (calcareous sandstone, Ashgillian [Hirnantian], 4.8 m).

According to Schönlaub (1985, 1988), the Ordovician–Silurian boundary separates the Plöcken and Kok Formations. Conodonts and graptolites from the lower Kok Formation indicate that at least six graptolite and two conodont zones are missing in the Lower Silurian. Deposition began in the late Llandovery *Pterospathodus celloni* Chron.

The Llandovery–Wenlock boundary cannot be defined precisely in the Cellon section. Based on graptolites and conodonts, this boundary should be between Walliser's (1964) sample horizons 11 and 12. Consequently, the thickness of the Llandovery does not exceed ca. 3 m (Schönlaub, 1997).

The Wenlock–Ludlow boundary is drawn precisely between Walliser's (1964) conodont samples 15B1 and 15B2. This level closely corresponds to the Wenlock–Ludlow boundary stratotype at Pitch Coppice quarry near Ludlow, England. The entire Wenlock at the Cellon section has an overall thickness of 5.0 m. By comparison with the Bohemian sections, strata equivalent to the range of the index conodont *Ozarkodina bohemica* are extremely condensed at Cellon, and this suggests that deposition occurred mainly during the early Homerian. As noted by Schönlaub (1994) on the underlying Sheinwoodian Stage, it may be inferred that the lowest Homerian is missing. *Cyrtograptus rigidus* Zone graptolites are found in the shale interbed between samples 12B and 12C, and indicate the upper Sheinwoodian.

Correlation with the Bohemian sequences and the occurrence of the basal Pridoli index graptolite *Monograptus parultimus* locate the Ludlow–Pridoli boundary a few centimeters (Walliser, 1964) above conodont sample number 32 (see H. P. Schönlaub *in* Kříž et al., 1986). The lowest Pridoli *Cardiolinka bohemica* Community appears just above sample horizon 32 (Kříž, 1999). This level is 8.0 m above the base of the Alticola Limestone, and suggests that the thickness of the Ludlow is about 16.45 m.

The Silurian–Devonian boundary at Cellon is placed at the bedding plane between Walliser's (1964) samples 47A and 47B. At sample 47A, the lowest specimens of the index conodont *Icriodus woschmidti* occur. The lowest occurrence of diagnostic lowest Lochkovian graptolites is 1.5 m higher. However, Jaeger (1975) recorded the lowermost occurrences of *Monograptus uniformis, M. sp.* cf. *M. microdon*, and *Linograptus posthumus* in sample horizon 50. In total, the Pridoli at the Cellon section may reach 20 m. Data about the distribution of acritarchs, chitinozoans, brachiopods, bivalves, and taxonomically unrevised nautiloids and trilobites are included in the report edited by Schönlaub and Kreutzer (1994).

Two types of facies can be recognized in the Carnic Alps as early as the Late Ordovician. According to Dullo (1992), the Wolayer Limestone represents a near-shore, cystoid-rich facies, and the Uggwa Limestone is its offshore, basinal counterpart. Following a depositional gap at the base of the Silurian caused by glacially induced sea-level fall, renewed sedimentation started in a moderately shallow environment which may have lasted until the earliest Wenlock. This environmental interpretation is suggested by Walliser's (1964) sample number 11, a bioturbated wackestone with algae and lumachelles (i.e., shell hash layers) that indicate a very shallow to intertidal environment. Later in the Wenlock, there was a progressive deepening. However, at the Wenlock–Ludlow boundary, a hiatus is present.

During deposition of the Cardiola Formation, a pelagic off-shore environment is indicated by radiolarian-bearing, black, marly interbeds and pelagic limestones with a diverse *Cardiola docens* Community and *Cardiola pectinata* Subcommunity (Kříž, 1999). The overlying Alticola Limestone reflects stable conditions in a pelagic setting that ended with a short regressive pulse recorded by Walliser's (1964) sample 40 (a laminated grainstone with lumachelles). A further deepening trend can be assumed at the base of the Megaerella Limestone. More details are available in L.H. Kreutzer (*in* Schönlaub et al., 1994).

Graptolites have been known in the Alps since their discovery by Stache (1872). The pure graptolitic facies is best exposed in the so-called "Graptolithengraben" north of the Obere Bischofalm in the central Carnic Alps. The graptolite-bearing rocks form a monotonous sequence of interbedded radiolarian-bearing cherts and alum shales. The cherts dominate the Llandovery and Wenlock; the shales prevail in the upper part of the succession. The intermediate green and gray shales yield only a few graptolites in very thin layers (H. Jaeger *in* Flügel et al., 1977).

The thickness of the graptolite-bearing Silurian–Lochkovian ranges from 50–100 m. It is an extremely condensed sequence due to a very low, but nevertheless continuous, rate of sediment accumulation. This conclusion is supported by the very complete graptolite zonal succession. The environmental conditions were anoxic or strongly dysaerobic except for the short interval when the middle Bischofalm Shale was deposited.

Graptolites and a few conodonts on bedding planes are the only fossils to be found in the "Graptolithengraben" facies. The graptolites are common in many layers, both in the alum shales and in the cherts. Some intervals, however, are almost barren of graptolites.

Due to intense Variscan and Alpine tectonism, longer undisturbed sections are rare. By far the best exposed and least disturbed section is the "main section," or Hauptprofil (Fig. 29), which has been studied in great detail by H. Jaeger since 1965. This tectonic block is almost 20 m thick and covers the interval from the Wenlock *Pristiograptus ludensis* Zone to the Lower Devonian *Monograptus hercynicus* Zone. In the vicinity of the Hauptprofil, older strata are also well exposed, but they are in fault contact with the main section.

The main graptolite section is virtually undisturbed, except for a fault at the critical horizon between the *Monograptus uniformis* and the *M. transgrediens* Zones (i.e., at the Silurian–Devonian boundary). By comparison with other sections, it is concluded that there is no significant loss of strata at this fault (H. Jaeger *in* Flügel et al., 1977).

According to H. Jaeger (*in* Flügel et al., 1977), a number of important features are shown by the Hauptprofil. The Silurian–Devonian boundary is within a homogenous black shale facies. Obviously, there was no physical break at this boundary. A distinct change in facies from green and gray to black shales preceded the faunal change at the boundary by one graptolite zone. There is no evidence that the ranges of *Monograpatus transgrediens* and *M. uniformis* overlap. Finally, middle Bischofalm Shale occupies the same stratigraphic position as the non-graptolitic "Ockerkalk" of Thuringia and, presumably, Sardinia.

The intermediate facies between the shallow-water and basinal settings is best developed at the Oberbuchach section (Fig. 30). This facies is termed the "Findenig facies." The Silurian here is a mixed argillaceous–calcareous lithology referred to the Nölbling Formation. This almost 50 m-thick Llandovery–Ludlow unit is underlain by the Upper Ordovician Uggwa Limestone and the 10 m-thick siliciclastic Plöcken Formation of Hirnantian age. The latter formation is overlain by interbedded laminated pyritic sandstone, bedded black chert, and black shale with lower middle Llandovery *Coronograptus gregarius* Zone and *Demirastrites triangulatus* Subzone graptolites. It is not clear whether the lower Llandovery is missing, or whether this portion of the section is barren of fossils.

A second horizon of graphitic sandstones occurs in the upper Llandovery. Its age is inferred from diagnostic *Pterosphatodus celloni* Zone conodonts from limestones that overlie this siliciclastic interval. These limestones are followed by alternating dark argillaceous limestone, black graptolite shale, and chert that range through the Wenlock into the Ludlow. Conodonts in this interval are associated with uppermost Llandovery–Wenlock graptolites. In the overlying shales, graptolites occur at several levels, and include the Sheinwoodian *Monograptus riccartonensis* Zone and range up to the lowest Gorstian *Neodiversograptus nilssoni* Zone. The Wenlock–Ludlow boundary may thus be placed some 40 m above the base of the graptolite-bearing sequence.

At the Oberbuchach section, fossils other than graptolites and conodonts are very rare. Conodont assemblages are dominated by *Dapsilodus* and *Decoriconus*. Ramiform elements only occur in the lower part of the section (Schönlaub, 1980). Strata corresponding to the remaining part of the Ludlow and Pridoli are up to 20 m thick. This interval consists of lithologically distinct, gray, almost unfossiliferous, pyritiferous limestones with a characteristic weathered surface (Schönlaub, 1980).

The Rauchkofel Boden section (Fig. 28) represents the Silurian Wolayer facies. This facies is named after the Upper Ordovician, cystoid-bearing Wolayer Limestone and is overlain by highly fossiliferous Middle–Upper Silurian limestones. Strata corresponding to the Upper Ordovician Hirnantian Stage through the Lower Silurian are missing in this facies belt. The sedimentary gap may be ascribed to the glacially induced, terminal Ordovician eustatic fall.

The Wolayer Limestone is disconformably overlain by the gray, fossiliferous, cephalopod-bearing *Orthoceras* Limestone, a unit equivalent to the Kok Limestone at Cellon. Besides the dominant nautiloids, trilobites and bivalves are quite common (Gaertner, 1931; Ristedt, 1968; Kříž, 1979, 1999; Schönlaub, 1980). In addition, conodonts are fairly abundant and represent the Wenlock *Ozarkodina sagitta* Zone (basal Homerian). About 1.2 m above the Wenlock–Ludlow unconformity, the index conodont *Kockelella variabilis* appears, and this suggests the base of the Ludlow Series by comparison with Bohemia

(H. P. Schönlaub *in* Kříž et al., 1993). The overlying Cardiola Formation (Fig. 27) corresponds to the *Polygnathoides siluricus* Zone of the Cellon section. It is succeeded by pinkish and grayish limestones, which correspod to the Alticola and Megaerella Limestones at Cellon. However, no diagnostic conodonts have been found at Rauchkofel, except in the uppermost limestones with *Scyphocrinites* sp. This highest conodont fauna has common forms of the *Ozarkodina remscheidensis eosteinhornensis* Zone. Based on recent field data (J. Kříž, A. Ferretti, C. Histon, O. Bogolepova, and H. P. Schönlaub, unpublished data, 1997, and Kříž, 1999) bed number 331 is uppermost Pridoli (Schönlaub, 1980), and the Silurian–Devonian boundary lies just above, but below the beds with *Scyphocrinites*. *Antipleura bohemica* Community bivalves (Kříž, 1999) occur at the base of the Lochkovian, 40 cm above bed number 331 (Schönlaub, 1980).

Preliminary paleoecologic and paleogeographic analysis of the Wenlock–Pridoli at the Rauchkofel section (Fig. 28) indicate a shallow-water depositional environment dominated by the South Equatorial Current. This current may have been responsible for the exchange of faunas between such separated areas as northern Siberia, Perunica, the Carnic Alps, and Sardinia (Kříž and Bogolepova, 1995). Indeed, there is a SW–NE orientation of orthoconic cephalopod conchs in the Kok Limestone, and this changes to a NNE–SSW direction in the overlying Lochkovian (O. K. Bogolepova *in* Schönlaub and Kreutzer, 1994).

GURKTAL NAPPE — The Gurktal nappe (Fig. 26) is composed of several hundred meters of volcanic and siliciclastic rocks with intercalated limestones. The Silurian includes coral-bearing, fossil-fragment limestone lenses at the transition from the Llandovery to the Wenlock, and local 5–10 m-thick, Upper Silurian limestones and dolostones. Due to poor fossil control and exposure, it is not yet possible to reconstruct a composite Silurian section. However, the facies suggest a subdivision into a carbonate-dominated and a carbonate-poor facies (Buchroithner, 1979; Ebner et al., 1990; Schönlaub and Heinisch, 1994).

The Lower Paleozoic of the Gurktal nappe system is characterized by volcanic rocks. Volcanism occurred at different times, and was of varying intensity and of different geochemical character as a consequence of different paleotectonic settings (Loeschke and Heinisch, 1993).

GRAZ REGION — The Paleozoic of the Graz area (Fig. 31) is best displayed in the Rannach nappe, the uppermost nappe of the Graz thrust complex. The Silurian is dominated by alkaline mafic lavas and volcaniclastics, which suggest an initial rift stage. These volcani- and siliciclastics are succeeded by increased carbonate production during the Late Silurian and Devonian.

According to Fritz and Neubauer (1988) and Neubauer (1989), sedimentation of the Silurian Kehr Formation was controlled mainly by volcanism. During the early Ludlow, a more easterly area was characterized by a proximal shallow-water setting with lavas and coarse lapilli tuffs (Fig. 31), while the western distal facies shows intercalations of lapilli-rich beds, agglomerates, shales, and pelagic limestones. The interesting Kehr Agglomerate has 13% quartzite, dolostone, chert, and reworked limestone clasts.

During the Late Silurian, the volcanic centers were blanketed by fossiliferous carbonates that include approximately 4.0 m-thick bedded dolostones, with lenses of fossiliferous (crinoids, brachiopods, trilobites, nautiloids) dolomitic limestones interbedded with tuffs and tuffaceous shales. Based on conodonts, this sequence is Ludlow (Ludfordian) to Pridoli (Ebner, 1994).

Similar environmental conditions are suggested for the Upper Silurian of the other nappes of the Graz Paleozoic. In these nappes, pelagic, nodular limestones persisted from the Late Silurian to the Devonian.

The Silurian of the Graz area is best displayed in the Eggenfeld section (Fig. 31). In this area, the distribution of the Upper Silurian and Lower Devonian was controlled by Silurian volcanism. Despite poor outcrops, a well-constrained lithostratigraphic framework can be established (Ebner, 1994). Massive green basalts that interfinger with pinkish to greenish tuffs with the graptolite *Bohemograptus bohemicus tenuis* form the base of the succession. A overlying unit of dark dolostones (unit D/1) has common crinoids, brachiopods, nautiloids, and tabulate corals (*Favosites* sp.), and is succeeded by tuffs and tuffaceous shales. A second interval of dark dolostones (D/2 unit) has lens-like accumulations of crinoids, brachiopods, trilobites, nautiloids, and a few corals (e.g., *Syringaxon* sp.). The uppermost Silurian consists of tuffs and tuffaceous shales with intercalated dark dolostones (D/3 unit), with shell hash accumulations that include crinoids, brachiopods, trilobites, and nautiloids.

Biostratigraphically important macro- and microfossils at Egenfeld include conodonts and brachiopods. Conodonts are fairly abundant in all of the calcareous levels. Diagnostic species include *Polygnathoides siluricus*, *P. emarginatus*, and *Kockelella variabilis* in the dolostones immediately above the basalts. This indicates an end of basalt volcanism in the Ludfordian. *Bohemograptus bohemicus tenuis* from the lowest volcaniclastic layer (Hiden, 1996) is also Ludfordian. *Ozarkodina snajdri* has been identified in the second carbonate (D/2) and indicates the Ludfordian *O. snajdri* Zone. This index species is associated with *Ozarkodina remscheidensis eosteinhornensis*. In addition, the brachiopod *Septatrypa subsecreta* occurs in

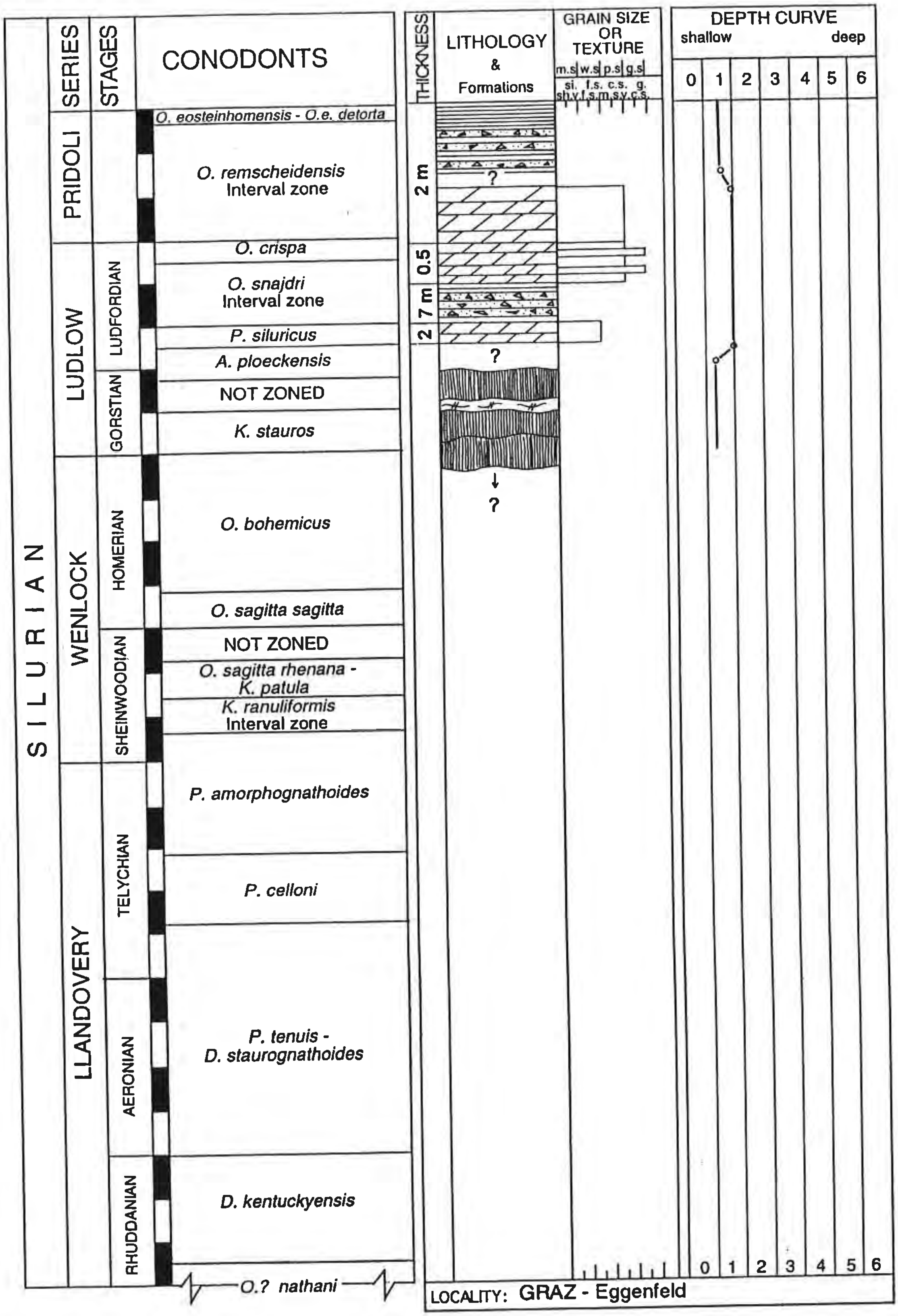

FIGURE 31 — Silurian at the Eggenfeld section near Graz, Austria.

thin carbonate beds in the overlying tuffaceous shales. Based on the occurrence of *Icriodus woschmidti, Septatrypa subsecreta* appears in the lowermost Lochkovian. However, index conodonts of the *Pedavis latialata* and *Ozarkodina crispa* Zones were not recovered.

The Eggenfeld section is of particular importance for dating Silurian volcanism in the eastern Alps. Based on its fossils, this section is an excellent example of a volcanic island surrounded and buried by fossiliferous carbonates during the Late Silurian. Carbonate production and volcanism increased later in the Devonian.

The Graywacke Zone — According to Schönlaub (1979) and Schönlaub and Heinisch (1994) the Silurian in the thick Lower Paleozoic of the Graywacke Zone of Styria (Fig. 26) shows vertically distinct facies that ranges from a lower 50 m of crinoid- and nautiloid-bearing limestone to overlying black graptolite shale. These two facies change laterally and vertically into interbedded limestone and shales overlain by pure limestones in the upper Ludlow and Pridoli. Local intercalations of Llandovery basic volcanics occur near the southern margin of the Graywacke Zone.

These facies changes also seem to be valid for the Tyrol and Salzburg segments of the Graywacke Zone. According to Heinisch (1988), two distinct facies can be distinguished within short distances. They are preserved in two nappes named the Wildseeloder and the Glemmtal Units. In the Silurian, the general facies range from black shale with local graptolites to chert; siliceous, pelagic limestone; condensed cephalopod limestone; and even dolomitic rock.

The Wildseeloder Unit in the western Graywacke Zone is characterized by the thick Upper Ordovician Blasseneck quartz porphyry, which is overlain by several meters of middle and upper Llandovery pelagic limestone. These limestones are overlain by the so-called "Dolomit–Kieselschiefer-Komplex" (Bedded Dolostone–Chert Formation). In the Late Silurian, a carbonate platform developed which lasted until the early Late Devonian.

The Glemmtal Unit in the western Graywacke Zone comprises more than 1,000 m of mainly siliciclastic units, which are known as the Wildschönau Group. Locally, up to 50 m of intercalated condensed pelagic limestone, marl, chert, siliceous shale, and basalt form the Klingler Kar Formation. Based on conodonts, the lower Klinger Kar Formation is Upper Silurian. This facies laterally grades into the turbiditic Löhnersbach Formation. In the latter formation, however, age determinations are not yet available.

With a few exceptions in Styria, Silurian conodonts and graptolites of the Graywacke Zone in Tyrol and Salzburg are fairly well known. However, no detailed biostratigraphic data are available on the exact position of the Ordovician–Silurian boundary (Schönlaub and Kreutzer, 1994).

The Spießnägel section south of Kirchberg, Tyrol, is one of the few sections in which the transition of presumably Upper Ordovician graywackes into the basal Silurian is exposed. According to Al-Hasani and Mostler (1969), the Silurian starts with 0.85 m of arenaceous and tuffaceous limestones with *Pterospathodus celloni* Zone conodonts. The lower part of these limestones feature bioturbated mudstones with varying amounts of siliciclastic and tuffaceous material. These mudstones grade into wackestones 0.7 m above the base of the Silurian. Of special interest is the occurrence of coated grains in the upper part of this bed. The nucleii of the grains are formed of crinoid ossicles or shell debris. This lowest part of the Silurian is succeeded by 1.1 m of limestone with interbedded shale and thin limestone lenses. This part consists of packstones with thin hash layers of bivalves, brachiopods, ostracodes, and echinoderms. These limestones are sharply overlain by grayish laminated dolostone assigned to the lower Wenlock *Kockelella patula* Zone.

The Spießnägel sequences correspond to the *Pterospathodus celloni–P. amorphognathoides* (conodont) Zone. They reflect late Llandovery–earliest Wenlock environments in this segment of the Graywacke Zone.

Another important Lower Silurian locality has long been known as the "Lachtal-Grundalm section" near the village of Fieberbrunn (Fig. 32). This classic graptolite-bearing sequence in the Graywacke Zone is a mixed shale–limestone succession known in the literature as "Lydit–Kieselkalk-Komplex." It is overlain by the 5.0 m-thick "Dolomit–Kieselschiefer-Komplex" (Mostler, 1966).

The basal cherty interval at Lachtal-Grundalm is formed of black, massive cherts known as "lydite" in the Alpine terminology. It is composed of radiolarian-bearing dolostones and reddish, cherty limestones that grade vertically into crinoidal limestones. The total thickness does not exceed 5.0 m. The accompanying microfauna consists of ostracodes, foraminiferans, brachiopods, radiolarians, conodonts, and echinoderms. In addition, bivalves, solitary corals, trilobites, and orthoconic nautiloids occur sparsely in the lower part of the 1.4 m-thick crinoidal limestone. The lower 2.1 m of the crinoidal limestones are assigned to the *Pterospathodus celloni* Zone; the upper part belongs to the *P. amorphognathoides* Zone.

According to Jaeger (1978), the only identifiable graptolites in the "Dolomit–Kieselschiefer-Komplex" occur in the upper Lachtal-Grundalm section. The lithology resembles the Silurian Nölbling Formation in the Carnic Alps. *Bohemograptus bohemicus* is most abundant in an upper horizon of the Dolomit–Kieselschiefer-Komplex.

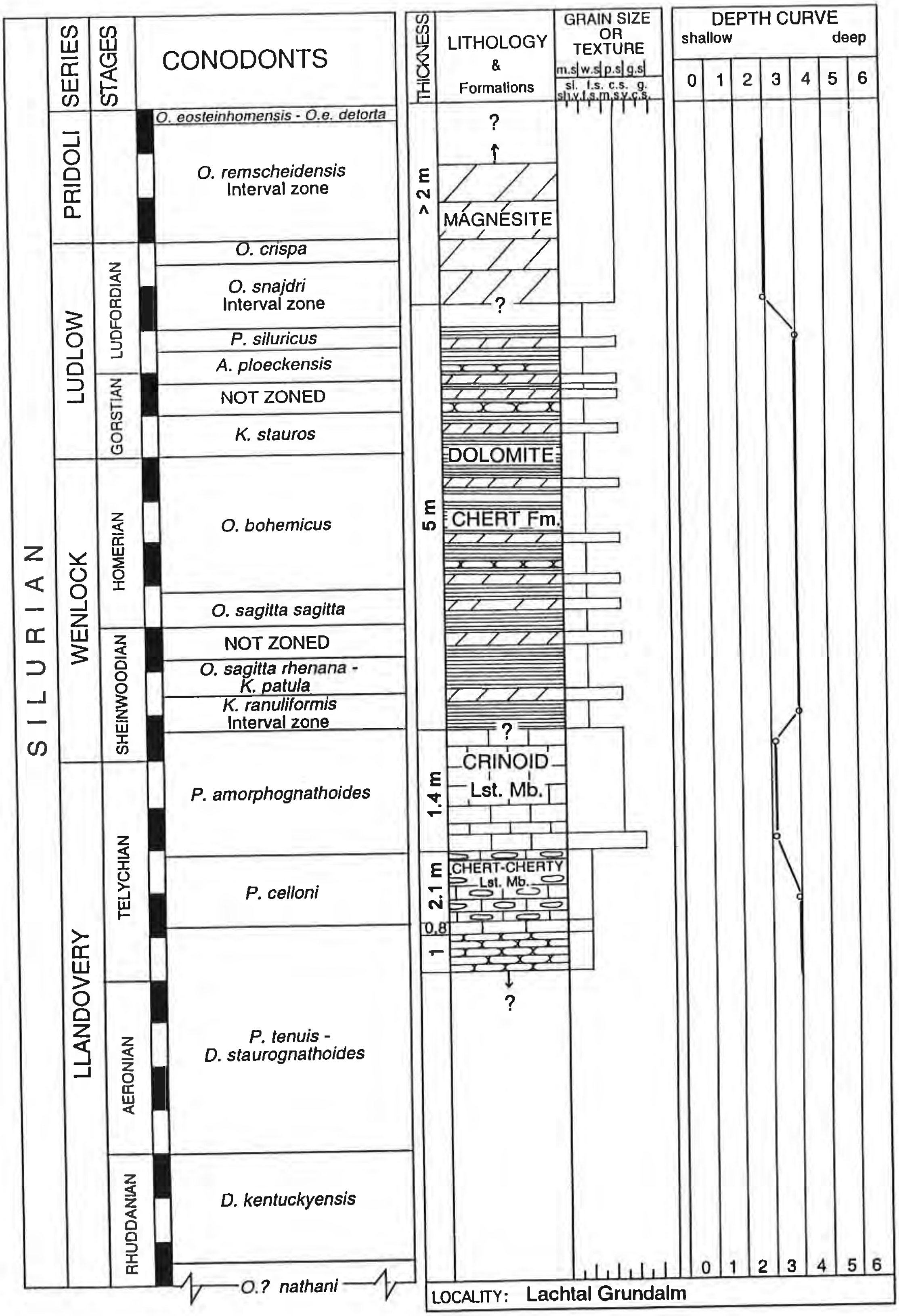

FIGURE 32 — Silurian at the Lachtal Grundalm section in the Graywacke Zone, Austria.

This species characterizes the basal Gorstian *Neodiversograptus nilssoni* Zone. Co-occurring conodonts are long-ranging forms that do not refine of this age assignment. Other graptolites include *Pristiograptus dubius* sp. cf. *P. frequens* and *Colonograptus* sp. cf. *C. colonus*.

In the Graywacke Zone in Tyrol, the "Dolomit–Kieselschiefer-Komplex" is overlain by dolomitic rocks and magnesite. According to Mostler (1966), the base of these carbonates can be assigned to the *Polygnathoides crassa* Zone or to the base of the overlying *Ancoradella ploeckensis* Zone at the Gorstian–Ludfordian boundary.

In summary, the data from the Lachtal-Grundalm section show that it represents a composite succession that extends through most of the Silurian. Biostratigraphically dated rocks start in the middle Llandovery and can be followed through the Wenlock to the middle Ludlow. In the Graywacke Zone in Tyrol, no record of the Pridoli is known, although the Pridoli may be represented by recrystallized dolostones.

Silurian faunas and climate in Austria — The Alpine Silurian is characterized by a wide range of lithofacies. The strata are locally fossiliferous and feature distinct faunal assemblages that include nautiloids, trilobites, bivalves, brachiopods, graptolites, conodonts, foraminiferans, acritarchs, chitinozoans, and ostracodes. During the last few decades, most of these groups have been revised. Available data suggest a complete but condensed succession in the carbonate-dominated facies and a continuous record in the graptolite-bearing sequences. This is particularly true in the Carnic and Karawanken Alps. In other areas, stratigraphic continuity has yet not been demonstrated, and this may be due to poor preservation, original lack of fossils, and metamorphic overprints.

Silurian faunas after the terminal Ordovician mass extinction are generally regarded as cosmopolitan, and provide little evidence to reconstruct the paleolatitudinal position of individual areas (Schönaub, 1992). Lithologic data and improved information on fossil assemblages may improve this situation.

Conodonts from the Alpine Silurian have a close affinity with coeval faunas from central, southern, and southwestern Europe. Avalonian Britain and Baltic Gotland occupied a more equatorial position; consequently, the conodonts are more diverse (Bergström, 1990; Aldridge and Schönlaub, 1989).

The distribution of acritarchs suggests an intermediate position of the Alpine Silurian between the high latitude *N. carminae* and the tropical *Domasia-Deunffia* biofacies. Chitinozoans show close relationships with those from Bohemia, a connection most strongly shown in the upper Ludlow–lower Lochkovian (Paris and Kříž, 1984; Kříž et al., 1986; Dufka, 1992; Kříž, 1992).

Silurian trilobites from the Carnic Alps are closely related to those from Bohemia and other central European regions (Alberti, 1970). Affinities with Moroccan trilobites exist, but the trilobites are not yet studied in detail (Alberti, 1970).

According to Berry and Boucot (1967), Silurian graptolites show little endemism, and this suggests intercontinental dispersal. Their distribution may have been controlled mainly by surface oceanic currents that flowed between Silurian continents and volcanic islands. As noted by Jaeger (1976), essentially uniform Ludlow and Pridoli graptolite faunas developed in Europe. The changing environment of this time as seen in coeval changes in African and Baltic lithofacies includes a characteristic vertical change from black graptolitic shale to limestone and back to shale. Sea-level rises and falls are considered to have been responsible for these changes.

In the late Llandovery, nautiloids became the predominant organisms in Alpine carbonate facies. The abundant Wenlock and Ludlow orthoceratids then decreased in the Pridoli (Ristedt, 1968, 1969). These diverse Alpine faunas seem closely related to those of Bohemia, the Montagne Noire, and Sardinia (Kříž and Serpagli, 1993; Kříž, 1996, 1998, 1999). Ongoing studies show that Silurian cephalopod biofacies even reflect close links to northern Siberia. Supposedly, this relationship resulted from activity of a South Equatorial Current that flowed along the southern margin of Siberia and Laurussia (Kříž and Bogolepova, 1995).

The distribution of other mollusks, particularly bivalves, generally resembles that of nautiloids. According to Kříž (1979), Silurian cardiolids from the Carnic Alps and the western Graywacke Zone inhabited a warm equatorial belt or were dispersed by surface currents. Kříž (1999) recognized the oldest Silurian bivalve-dominated community of the *Cardiola* Community Group from the Carnic Alps (Kříž and Serpagli, 1993; Kříž, 1996, in press). This is the *Carnalpia nivosa* Community in the *Cyrtograptus rigidus* Zone (Wenlock). Other recurring communities of the *Cardiola* Community Group are also known from the Bohemian Prague Basin and other regions in Europe. In the Wenlock (*Cyrtograptus lundgreni* Zone), the *Cardiola agna* Community and its *Slava pelerina-Isiola zila* Subcommunity occur at the Rauchkofel Boden section. The lower Ludlow is characterized by the *Cardiola consanguis* Community, which is also known from the Prague Basin. The Cardiola Formation is characterized by the *Cardiola docens* and *Cardiola alata* Communities, which are known from the Prague Basin (Bohemia), Sardinia, eastern Serbia, the Montagne Noire, Spain, and Morocco. In the lowest Pridoli (*Monograptus parultimus* Zone), the *Cardiolinka bohemica* Community occurs at the Cellon section; at Nagelschmieddpalfen near Dienten in the

Graywacke Zone; in the Prague Basin (Bohemia); and at Elbersreuth, Frankenwald (Germany). In the uppermost Pridoli, a *Patrocardia-Dualina* Community (*Dualina nigra-Patrocardia* Subcommunity) occurs at the Rauchkofel Boden section. This latter community is related to the *Patrocardia evolvens evolvens* Community of the *Patrocardia* Community Group in the Lower Devonian (Lochkovian) of the Prague Basin, Sardinia, and South Armorican Domain (La Meignanne) in France. The *Cardiola* Community Group is characterized by epibyssate bivalves, which were adapted to the cephalopod limestone biofacies and indicate episodically ventilated, relatively shallow bottom conditions (=Boucot's [1975] Benthic Assemblage 2–3). The *Patrocardia* Community Group is characterized by epibyssate *Patrocardia* with infaunal and reclining Dualina, and also lived in the cephalopod limestone facies.

Silurian corals from the Alps were prominent constituents of a probable shallow-water facies in the tropical belt. During the Early Silurian, only weak indications of provincialism are seen among tabulate and rugose corals at the generic level. However, long-living teleplanic larvae might also have been transported by ocean currents over great distances (Kaljo and Klaamann, 1973; Pickett, 1975; McLean, 1985; Pedder and Oliver, 1990). Rugose and tabulate corals occur in the upper Llandovery of middle Carinthia and the Upper Silurian (Ludlow) near Graz. However, they are very rare in the shallow-water and local coated-grain-bearing limestones in the upper Llandovery of the Tyrolean Graywacke Zone (Schönlaub, 1994b).

Lithologic and faunal data from the Alps can be used to infer Silurian climates and to provide insights into such parameters as light, temperature, salinity, water agitation, and other factors that controlled organism distribution. During the Silurian, the Alpine facies belts shifted from higher to lower latitudes. Paleomagnetic data from Gondwana seem to support rather rapid northward plate movements (Schönlaub, 1992). Based on the evidence presented above, we estimate that Alpine Silurian deposition was at ca. 30–40° S. During the Silurian, close faunal relations existed with northern Europe, but minor links existed with other southern Europe regions.

Silurian of Germany

In Germany, the Silurian occurs in the Rhenohercynian Zone and, in particular, in the Saxothuringian–Lugian Zone of the Variscan orogen. Other occurrences are known from the intermediate area of the Mid-German Crystalline Rise and from the German part of the southern Variscan orogen, or Moldanubian Zone (Fig. 33).

Rhenohercynian Zone — In the Rhenohercynian Zone, the Silurian is exposed in the Harz Mountains (Fig. 32A) and Rhenish Slate Mountains (Figs. 32B). Wells drilled between Flechtingen and Rosslau also encounter the Silurian. These core rocks are similar to the Silurian of the Harz Mountains.

Harz Mountains — The Silurian crops out in the area of Bad Lauterberg, Hasselfelde, and Harzgerode in the lower Harz Mountains, and there are a few more northern occurrences in the central Harz Mountains. The Lower Silurian in the Harz Mountains consists of black to green shales, and the Upper Silurian is predominantly calcareous shales and dark limestones. Cherts, black carbon-rich alum shales, and phosphatic nodules, which are typical of the "lower graptolitic shales" in the Saxothuringian Zone (discussed below), are nearly absent. The occurrence of a fossil-rich limestone lentil in the bed of the Wieda River near Zorge (Fig. 33) is remarkable, but this lentil is no longer accessible. At least the lower part of it is Pridoli (Maronde, 1968). The fauna consists mainly of brachiopods, trilobites, bivalves, and orthoconic nautiloids; the lithology is that of a typical cephalopod limestone (Heritsch, 1930).

Graptolite studies by Jaeger (1991a) show that the base and top of the Silurian are exposed, as are sections through the upper Llandovery, Wenlock, most of the Ludlow, and the Ludlow–Pridoli transition (Maletz, 1996). It is probable that a complete Silurian succession occurs in the Harz Mountains. The thickness of the entire Silurian is between 50 m and 100 meters (Jaeger, 1991a). Nearly all Silurian occurrences in the Harz Mountains occur in Late Devonian and Early Carboniferous olistostromes.

Rhenish Slate Mountains — In the Rhenish Slate Mountains, the easternmost occurrences of Silurian graptolitic shales are known from the northeast Lahn syncline (Marburg region) and from south of the Kellerwald in an area north of Gilserberg (Figure 33). These Steinhorner Schichten are allochthonous and probably span the upper Llandovery–Pridoli.

In contrast, the Silurian of the Ebbe anticline (Herscheid area, Sauerland region) is characterized by dark shale, marly shale, and interbedded ochre-weathering limestone. These Köbbinghäuser Schichten are about 110 m thick. They are transitional into the overlying Ockrige Kalke—black shale interbedded with nodular, bluish-gray carbonate rocks. Bio- and lithofacies of the Köbbinghäuser Schichten indicate a shallowing of the basin during the Late Silurian (Timm, 1981a). In the Remscheid-Altenaer anticline (Bergisches Land), a Silurian succession comparable to that of the Ebbe anticline was deposited. The only difference may be the lesser thick-

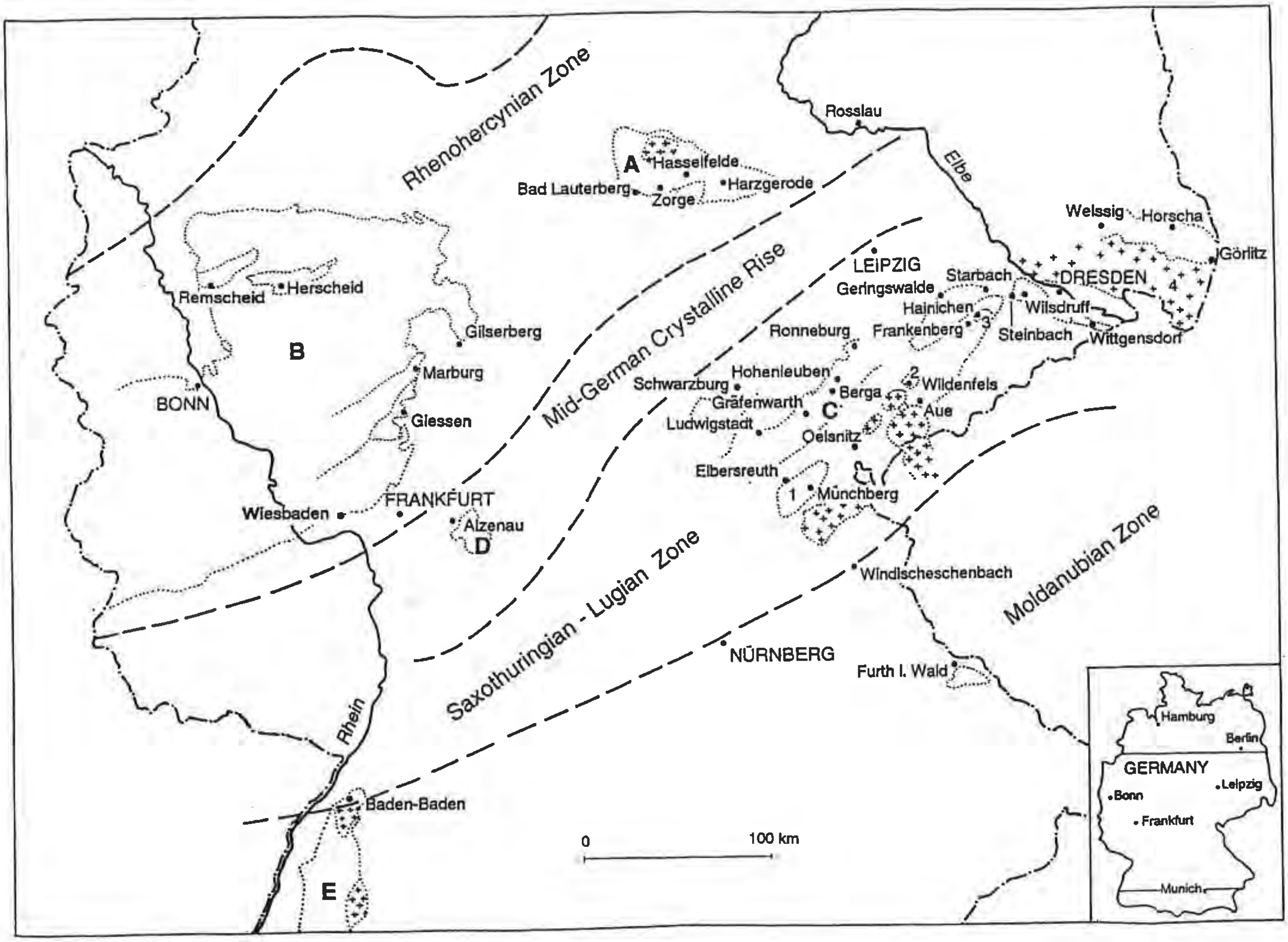

FIGURE 33 — Major tectonic units and Silurian outcrops of the Variscan orogen in Germany. Crosses indicate major Variscan and pre-Variscan plutons. A, Harz Mountains; B, Rhenish Slate Mountains; C, Thuringian–Vogtlandian Mountains; D, Spessart; E, Black Forest. 1, Munchberg gneiss massif; 2, 3, Betwixt Mountains (crystalline "Zwischengebirge") of Wildenfels and Frankenberg–Hainichen; 4, Lusatian granodiorite massif.

ness. Conodonts (Ziegler, 1960) and trilobites (Timm, 1981b) suggest the Silurian–Devonian boundary is in the lowermost Ockrige Kalke.

Silurian beds are also exposed south of Giessen in the Lindener Mark region. The upper Wenlock–Pridoli (*Monograptus transgrediens* Zone) thickness is only about 12 m. The succession starts with an ostracode-rich limestone that is thick-bedded in its lower part and interbedded with cherts in its upper part. The overlying beds consist of a 5 m-thick cephalopod limestone. According to Bahlburg (1985), a calcareous silty shale with limestone nodules in its lower part has orthoconic nautiloids, brachiopods, bivalves, and graptolites. The ostracode- and cephalopod-bearing limestones were deposited on the lower and upper subtidal shelf, respectively.

In contrast to Saxothuringia (discussed below), the Ordovician–Silurian boundary in the Rhenish Slate Mountains is marked by a distinct hiatus. Generally, most of the Llandovery is absent. The reason for this stratigraphic gap is still uncertain, but it is doubtful that it represents a real break in sedimentation. The Silurian–Devonian boundary in the Rhenish Slate Mountains lacks or has only minor breaks, and can be interpreted to represent nearly continuous shelf sedimentation at various local depths.

The southeastern margin of the Rhenish Slate Mountains abuts the metamorphic zone of the South Taunus Mountains near Wiesbaden (Fig. 33). In this area, probable Silurian rocks are metamorphosed to greenschist (Thews, 1996).

SAXOTHURINGIAN ZONE — The Lugian Zone east of the Elbe River and the Saxothuringian Zone were areas of continuous marine deposition throughout the Silurian. Northern Bavaria, Thuringia, and west Saxonia are part of the Saxothuringian Zone. East Saxonia lies in the German part of the Lugian Zone (Fig. 33). The thickness of the Silurian is no more than about 100 meters. Traditionally in the Saxothuringian–Lugian Zone, the Silurian and lowermost Devonian are regarded as a single depositional cycle composed of lower and upper graptolitic shales. These shales are separated by a widely persistent carbonate, the "Ockerkalk" (ochre limestone) (Fig. 34). Because of the mainly early Lochkovian age of the "lower graptolitic shales," these beds are not discussed herein.

Silurian strata are well documented in all of these areas. Tentaculitids (e.g., *Tentaculites scalaris*) in phyllites of the Traischbach "Series" of the Baden-Baden-Zone in the northern Black Forest (Fig. 33, region A) are probably Late Silurian (Mehl, 1989). This area is also considered to be part of the Saxothuringian Zone, while the southern Black Forest is part of the Moldanubian Zone.

Because of its relatively widespread distribution, the litho- and biofacies of the Silurian in the Saxothuringian Zone must be further detailed. The typical Silurian of the Saxothuringian Zone is graptolitic shale in the Lower Silurian, and the "Ockerkalk" is a peculiar limestone in the Upper Silurian.

"LOWER GRAPTOLITIC SHALE" — This sequence consists of black alum shales with high carbon and pyrite contents, and has black, thick-bedded cherts. The two rock types intergrade. Normally, chert is dominant in the Llandovery, and interbedded shale and chert or alum shale are predominant in the Wenlock and lower Ludlow. Because of weathering, the Llandovery cherts are often bleached.

The upper alum shales of the Ludlow are interbedded with thin layers of argillaceous shale that is transitional into the "Ockerkalk" of the Thuringian facies (Fig. 34), or into gray-green shales in the Bavarian facies. In the interval from the *Pristiograptus dubius parvus-Gothograptus nassa* Zone to the *Neodiversograptus nilssoni* Zone, but particularly in the *N. nilssoni* Zone, there is a striking concentration of phosphatic nodules. Such layers are also known in the *Stimulograptus sedgwickii* and *Cystograptus vesiculosus* Zones (Schauer, 1971). In a few Thuringian sequences, black dolomitic layers up to 0.5 m thick are intercalated in the shale. The "lower graptolitic shales" are pure sapropelites. An enrichment in such elements as vanadium, molybdenum, selenium, uranium, and sulfur is typical for its anoxic or strongly dysaerobic depositional environment.

Strongly deformed graptolites are the only abundant fossils found throughout this condensed sequence. Rare conodonts are present on bedding planes at Gümbelit. White quartz lenses in the cherts contain radiolarians. In Thuringia, beds transitional into the "Ockerkalk" have very rare bivalves (e.g., *Cardiola*), indeterminable brachiopods, very rare myodocopid ostracodes, orthoconic nautiloids, and eurypterids (Jaeger, 1959; Schauer, 1971). The absence of any typical benthic organisms suggests extremely unfavorable bottom conditions.

For the most part in the Saxothuringian–Lugian Zone, the "lower graptolitic shales" are not completely exposed. In the Görlitz Slate Mountains, Llandovery cherts occur at the Pansberg near Horscha and at the Eichberg near Weissig (Fig. 33). In the NossenWilsdruff Slate Mountains (Fig. 33), the "lower graptolitic shales" are a 25 m sequence of Llandovery chert and Wenlock alum shale. In the Slate Hills of the Elbe valley, only a few meters of graptolitic shales are exposed, as at the Sandberg near Wittgensdorf.

A few outcrops of slaty "lower graptolitic shales" are known at the margin of the granulite massif in Saxony. These include a locality at Geringswalde in the northern part, from an area north of Frankenberg (Zschopau Valley), and from Hainichen in the southern part. Upper Llandovery chert and alum shale are exposed in abandoned quarries north of Aue and between Loßnitz, Zwönitz, and Affalter in the Erzgebirge Mountains (Fig. 33). Llandovery cherts also occur near Altmannsgrün and at the Engelspöhl, southeast of Oelsnitz (Fig. 33).

"Lower graptolitic shales" are known from numerous outcrops along the flanks of the anticlines in the Thuringian and Vogtlandian Slate Mountains. Representative localities include an outcrop near Gräfenwarth (Jaeger, 1991b) and the Lichtenberg quarry near Ronneburg (Fig. 33). According to bore hole data, their thickness may be more than 50 m locally. At almost all outcrops in the slate mountains, these shales were affected by strong tectonism (Jaeger, 1959).

The "lower graptolitic shales" in the Frankenwald region of northeast Bavaria were described by Stein (1965), Greiling (1966), and Zitzmann (1968). The ca. 3,040 m-thick sequence consists predominantly of chert and alum shale. The *Stimulograptus sedgwickii* Zone (Llandovery) and, in particular, the Wenlock have tuffs and basalts.

"OCKERKALK" — The term "Ockerkalk" was introduced by Gümbel (1863). The name was later used for all calcareous beds that separate the "lower" and "upper graptolitic shales" in Thuringia and Saxony. However, there are at least minor local differences between the same limestones in different areas.

The typical "Ockerkalk" lithology occurs in the western Thuringian Slate Mountains (Schwarzburg anticline), and is a thick-bedded (up to nearly 3 m), dense, bluish-gray to grayish-black limestone with irregular nodular texture. Pyrite often occurs as framboidal aggregates up

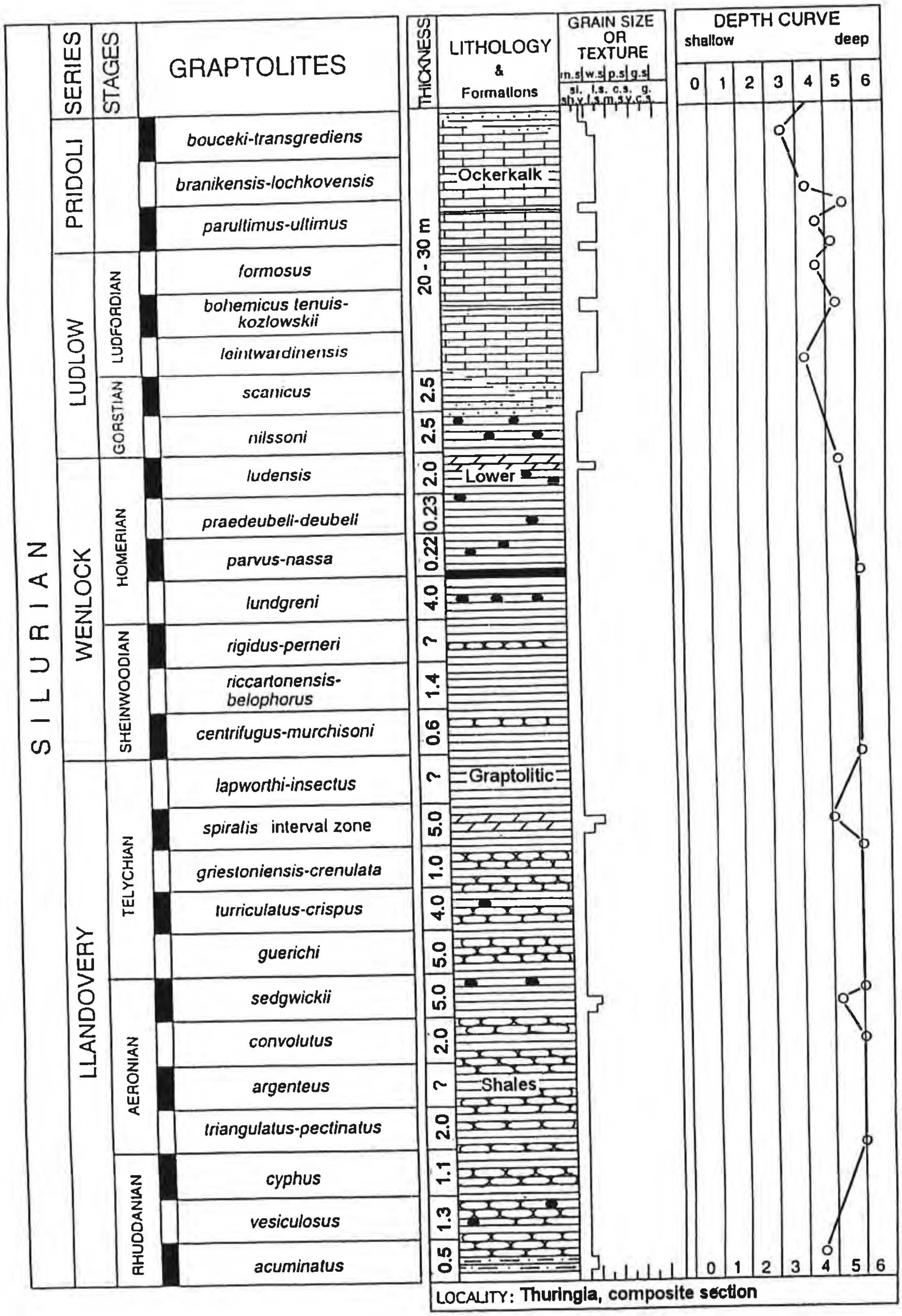

FIGURE 34 — Silurian of Thuringia, Germany. After Jaeger (1959, 1977b, 1988, 1991b), Schauer (1971), Hansch (1993a, and unpublished data).

to 3 cm in size. Insoluble residue normally forms 5–35% of the limestone and consists of quartz, pyrite, mica, and chlorite. The typical "Ockerkalk" weathers ochre. Because of the higher content of iron in the dolomite, the nodular bands discolor first with weathering.

The "Ockerkalk" differs slightly elsewhere in the Saxothuringian Zone. The limestones may not locally show the nodular texture, and the typical weathering features may be missing. Locally, there is a transition from the "Ockerkalk" to gray or light-colored marls, or the pure limestones are replaced by dolostones. Following intrusion of Late Devonian mafic rocks, the "Ockerkalk" is metamorphosed at a few outcrops in the Berga anticline.

The "Ockerkalk" contains interbeds of black alum shale, locally with phosphatic nodules, and interbeds of grayish-green argillaceous or arenaceous shale. For this reason, it has been called the Ockerkalk Group (Jaguar, 1959). The siliciclastic layers range from a few centimeters to ca. 1 m in thickness. At least two thick shale intercalations can be used to correlate between eastern and western Thuringia (W. Hansch, unpublished data, 1997). The shale content of the "Ockerkalk" varies between 10–30%. Generally, the "Ockerkalk" can be considered a typical condensed pelagic limestone.

In contrast to the "lower graptolitic shales," the fossils of the "Ockerkalk" are more diverse. On the other hand, the fauna is imperfectly known because of the lack of modern descriptions. Apparently, the fauna is impoverished. The following fossils are known: rare articulate brachiopods, a few trilobites that were blind or had highly reduced eyes, very rare conulariids and gastropods (preserved as molds), very small solitary corals, orthoconic nautiloids, indeterminable bryozoans, a few foraminiferans (*Psammosphaera* sp., *Tolypammina* sp., hyperamminoid-type forms), and very rare bivalves (Cardiola sp.). Jaeger (1977b) listed the trilobites *Ampyx* sp. cf. *A. rouaulti, Harpes* sp. cf. *H. ungulata, Cheirurus* sp. cf. *C. propinquus, Denckmannites caecus,* and *Scutellum* sp. The shale interbeds yield some graptolites and very rare eurypterids. Crinoid fragments are common and abundant in the upper "Ockerkalk" (*Scyphocrinites* horizon). Conodonts occur, but are not yet described. The most diverse faunal component is silicified ostracodes characterized by thin-shelled, smooth, or sometimes spine-bearing podocopes and a few paleocopes. At least 40 species of ostracodes are known (Hansch, 1993a). The ostracodes apparently lived in a relatively low-energy, open-marine environment. These ostracodes and conodonts may have the best biostratigraphic potential in the Thuringia Slate Mountains. Most "Ockerkalk" fossils are known from the western Thuringian Slate Mountains. This may reflect better habitats associated with the more carbonate-rich facies in the west.

The "Ockerkalk" has been used for ochre and building stone since the seventeenth century, particularly in Thuringia. After World War II, the "Ockerkalk" received study in East Germany because of its uranium content. The average content was between 1.5–5 gm/metric ton, and its mining ended in 1990.

The thickness of the "Ockerkalk" in the Saxothuringian Zone probably decreases from west to east. According to bore hole data, the greatest thickness (ca. 40 m) occurs in the Schwarzburg anticline. At present, the only well-exposed outcrop of "Ockerkalk" (24.5 m) occurs in the completely exposed Silurian in the Lichtenberg quarry near Ronneburg. In the eastern part of the Saxothuringian Zone, the "Ockerkalk" is 12 m thick in the Triebisch Valley near Steinbach in the Nossen–Wilsdruff Mountains. In northeast Bavaria, a 15-m thick "Ockerkalk" section was completely exposed at the Löhmar mill northwest of Münchberg. Additional outcrops are known in this region in the Ludwigstadt area.

OTHER SILURIAN LOCALITIES IN GERMANY — According to Reitz (1987), well-preserved Upper Silurian (probably Ludlow) spores are found in a quartzite mica schist unit in the northwest Spessart near Alzenau. The Spessart is part of the Mid-German Crystalline Rise. Pflug and Reitz (1987) described Silurian spores in the Moldanubian Zone from the southeast Hoher Bogen Mountains near Furth in Wald, eastern Bavaria. According to Pflug and Prösl (1989), Late Silurian microfossils and plant fragments were also found in paragneiss of the KTB research bore hole near Windischeschenbach, northeast Bavaria.

GERMAN SILURIAN FACIES — In the Cambrian–Lower Carboniferous of the Saxothuringian–Lugian Zone, two types of facies are distinguished. These are the Thuringian and Bavarian facies. The boundary between these facies is not sharp, and there are transitional zones (Gandl, 1992).

THURINGIAN FACIES — The "lower graptolitic shale"–"Ockerkalk" succession is the typical Silurian sequence in the Thuringian facies. This succession is widely distributed in the Saxothuringian Zone from northeast Bavaria to west Saxony. In the Lužice Zone (Fig. 35) east of the Elbe River, limited Silurian occurrences are known from the southern margin of this zone in Bohemia.

The Thuringian facies is a monotonous basinal facies with only moderate lateral changes, particularly in the Upper Silurian. In the Lower Silurian, its thinness, predominance of planktic organisms, absence of current-orientated fossils, and lithology indicate a calm, open-marine environment for the deposition of the "lower graptolitic shales." This anoxic or highly dysaerobic environment changed during deposition of the Ockerkalk

Group. Thick-bedded carbonates, intercalations of thin quartzite beds which may be distal turbidites, monospecific concentrations of ostracode valves that indicate weak bottom currents, and the greater diversity of fossil groups show a distinct upward change to a better-oxygenated environment. On the other hand, varying thicknesses of the limestones and intercalated shales, the differing abundances of fossils, and changing carbon and pyrite content in the limestones indicate that sedimentation and the environment were not uniform across the Saxothuringian Basin. However, at no time during deposition of the Ockerkalk Group were habitats suitable for a rich benthos.

BAVARIAN FACIES — As in the Thuringian facies, typical Bavarian facies rocks are interbedded black graptolitic cherts and alum shales. The main difference with the Thuringian facies is merely that carbonate sedimentation did not take place even during the Ludlow and Pridoli. Thin, gray-green shales, with a thickness of ca. 5.0 m (according to bore hole data in the Görlitz hills), correlate with the "Ockerkalk." In contrast to the wide distribution of the Thuringian facies in the Saxothuringian Zone, the Bavarian facies forms a discontinuous belt confined to narrow strips on either side of the Münchberg gneiss massif and the Betwixt Mountains near Wildenfels and Frankenberg (Jaeger, 1988). East of the Elbe River, the Bavarian facies is known from small outcrops and bore holes north of the Lusatian granodiorite massif (Fig. 33). Outside of these areas, the Bavarian facies only comprises 20m of Silurian shale in the slate mountains of the Elbe valley southeast of Dresden and in the Nossen-Wilsdruff Slate Mountains near Starbach.

A cephalopod limestone ("Elbersreuther Orthoceratenkalk") is limited to an area between Elbersreuth and Wildenstein-Triebenreuth and in the Steinbachtal, west of Münchberg (northeast Bavaria). This limestone represents Bavarian facies sedimentation on a submarine rise. It is a light gray-red, dense, fossil-rich limestone with interbedded arenaceous layers and a thickness of ca. 10 m. Its deposition probably began in the early Ludlow, following volcanic activity in this region in the late Llandovery and Wenlock.

Since the 1920s, the contrast between these facies has led to the idea that the Bavarian facies, the Münchberg gneiss massif, and the crystalline complex of the Betwixt Mountains are elements of large nappes that were transported from the Moldanubian Zone (Franke, 1984, 1995). If the Silurian alone is examined, its facies patterns can be explained without the assumption of nappes (Gandl, 1992).

In the Rhenohercynian Zone, similar facies are obvious. The Silurian of the Harz Mountains, the Kellerwald region, and part of the Giessen area show relatively close relationships with northern Gondwana facies. However, the facies in the Ebbe and Remscheid–Altenaer anticlines are probably more closely linked to the outer shelf facies of Baltica (discussed below).

In summary, the German Silurian on the northern Gondwana margin is characterized by stratigraphically continuous, widely distributed, anoxic or highly dysaerobic black shale with planktic organisms in the Early Silurian. Laterally discontinuous carbonate sedimentation took place in the Late Silurian, during which time the habitats apparently became more oxygenated.

The Late Silurian featured bathymetrically and hydrodynamically different sedimentation areas. Areas with carbonate sedimentation in shallower and well-oxygenated water allowed development of a rich shelly fauna. This facies is represented by the "Elbersreuther Ortoceratenkalk" in northeast Bavaria, by the Pridolicephalopod limestone of the Giessen area (Lindener Mark), and by the Wieda stream lens (Harz Mountains). Other areas have discontinuous, rarely thick-bedded carbonates or nodular limestones interbedded with shale or marl. This deposition took place in poorly oxygenated deeper water, which supported an impoverished benthic fauna but allowed the appearance of more diverse planktic and pseudoplanktic faunas with graptolites, crinoids, ostracodes, conodonts, orthoconic nautiloids, and foraminiferans. This facies is best represented by the Ockerkalk Group of Saxothuringia and northeast Bavaria and, possibly, the Ostracodenkalk of the Giessen area. The latter areas featured condensed but continuous shale deposition in deeper, probably poorly oxygenated water, with planktic graptolites and orthoconic nautiloids. This facies comprises gray-green shales found in small outcrops and bore holes close to the Münchberg gneiss massif near the Görlitz hills.

LITHOSTRATIGRAPHY AND BIOSTRATIGRAPHY — The Silurian Thuringian facies in the Saxothuringian Zone is compiled in Fig. 34. The Ordovician–Silurian boundary in the Thuringian facies is represented by a transition from buff-weathering, black siliciclastic mudstone with a high mica content in the uppermost Ordovician (Lederschiefer) to lowest Silurian cherts and alum shales. The Ordovician–Silurian boundary is known in the Lichtenberg quarry near Ronneburg, in the Weinberg area near Hohenleuben south of Gera, and from the Engelspöhl southeast of Oelsnitz. On the other hand, the boundary in the Bavarian facies is represented by a transition from nearly black Upper Ordovician quartzitic sandstone with shale interbeds (Döbrasandstein) into Silurian shales. It is best exposed along the northwest side of the Münchberg gneiss massif, at Döbra and at Starbach in the Nossen–Wilsdruff Mountains.

The Silurian–Devonian boundary is located within the first meter above the Ockerkalk Group. There is no distinct lithological change at the boundary, which is exposed at various outcrops in Thuringia (Jaeger, 1977a, 1977b). The most accessible section through the boundary is in the Lichtenberg quarry near Ronneburg. At the base of the "lower graptolitic shales" is the "lower shelly bed horizon" with abundant bivalves (*Pterinea* sp.), gastropods (*Platyceras* sp.), crinoids (*Camarocrinus?* sp.), and rare spiriferids.

The Llandovery–Wenlock boundary is not well defined in the Saxothuringian–Lugian Zone. Only the basal Wenlock graptolite zone is known in the Ronneburg area. The best known section of the Wenlock–Ludlow boundary is located at the Wetterberg, near Gräfenwarth (see Jaeger, 1991b). The Ludlow–Pridoli boundary is not established in the Saxothuringian–Lugian Zone because of the lack of index graptolites.

The succession and thickness of graptolite zones in the Thuringian facies column (Fig. 34) are based on Jaeger (1959), Schauer (1971), and unpublished data. According to Jaeger (1959), deposition of the "Ockerkalk" always started within the *Lobograptus scanicus* Chron. Because of the remarkable differences in thickness within the Saxothuringian Zone, it is possible that the onset of "Ockerkalk" sedimentation was diachronous. This was suggested by Stein (1965) for northeast Bavaria.

The "Ockerkalk" has lower and upper ostracode associations separated by a thick shale interval. The ostracodes of the upper "Ockerkalk" show some similarity to the Lower Devonian ostracode fauna of the tentaculite nodular limestone (Tentakulitenknollenkalk) (Hansch, 1993a).

German Silurian paleobiogeography — Comparable information on Silurian fossils is not available for the Rhenohercynian and Saxothuringian Zones. Few of the Silurian rocks, with exception of the cephalopod limestones, are rich in benthic fossils. Even the planktic faunas are impoverished or badly preserved. Only the graptolites, based largely on nearly 40 years of work by H. Jaeger, L. Greiling, V. Stein, M. Schauer, and others, are relatively well studied. Nearly all other fossil groups lack modern systematic descriptions. Nevertheless, relationships between the Silurian faunas of the Rhenohercynian and Saxothuringian Zones and other regions can be briefly summarized.

Though not recently studied (see Schindewolf, 1924; Heritsch, 1930; Kegel, 1953), Upper Silurian cephalopod limestone faunas from the Elbersreuth area (northeast Bavaria), Harz Mountains, and Lindener Mark south of Giessen are obviously comparable with other cephalopod limestone faunas of the Prague Basin, Carnic Alps, and southwest Sardinia.

As noted by Jaeger (1976) and Barca and Jaeger (1990), Silurian and lowest Devonian lithologies and faunas (graptolites) are comparable in Thuringia and southeast Sardinia. The ostracodes also confirm this similarity (W. Hansch, unpublished data, 1996). Additionally, all three major Upper Silurian facies of the Saxothuringian Zone exist in Sardinia.

Genus-level relationships exist between the ostracode fauna of the upper Wenlock–Ludlow limestone near Giessen (Lindener Mark) and faunas of Baltoscandia and the Saxothuringian "Ockerkalk." A few ostracodes of Bohemian character also occur in the Lindener Mark (Hansch, 1993a, b, 1995). The Giessen ostracode limestone only has species typical of a low-energy environment (offshore to open marine, below wave-base; Schallreuter, 1991, 1995; Hansch, 1994, 1995). The Saxothuringian Ockerkalk ostracodes are distinct at the species level from the other faunas. However, the genera have a distinct affinity with the Prague Basin fauna.

The index graptolite *Monograptus transgrediens* and a crinoidal limestone (*Scyphocrinites* horizon) in the upper Pridoli are typical for the Rhenohercynian and Saxothuringian Zones (e.g., in the Harz Mountains, Kellerwald region, and most areas of Saxothuringia). This points to a common paleogeography. The Silurian of the Ebbe and Remscheid–Altenaer anticlines is characterized by a lack of graptolites, a relatively great thickness (>110 m; Timm, 1981a), and trilobites with Baltoscandian affinity.

Lithologic and faunal data indicate that the Silurian of the Saxothuringian–Lugian zone, Harz Mountains, and Kellerwald region was deposited on the north Gondwanan shelf, whereas the Silurian of the Sauerland and Bergisches Land regions (Rheinish Slate Mountains) is more closely related to the east Avalonia–Baltica margin. The position of the Giessen area is more problematic because of its faunal similarity to Baltica and to the margin of Gondwana. Oczlon (1994) considered the Harz Mountains, Kellerwald region, and Giessen area to be parts of a Harz terrane on the outer Gondwanan shelf, and discussed the possible tectonic implications. However, Franke and Oncken (1995) assumed that the Silurian carbonates of the Harz Mountains, Kellerwald, and Giessen area were deposited on the northern margin of the Armorica microcontinent, and were separated from Avalonia by the Rheic Ocean. They considered that Armorica collided with Avalonia in the Early Devonian. Renewed rifting split the intervening Silurian arc and left Armorican sedimentary rocks stranded on the Avalonian side. The result of this tectonic history is that Silurian carbonates with Armorican (Gondwanan) fossils occur as olistoliths and displaced blocks in mud flows (olistostromes) in the Rhenohercynian Zone (e.g., Harz, Geissen area) in the Devonian and Lower Carboniferous.

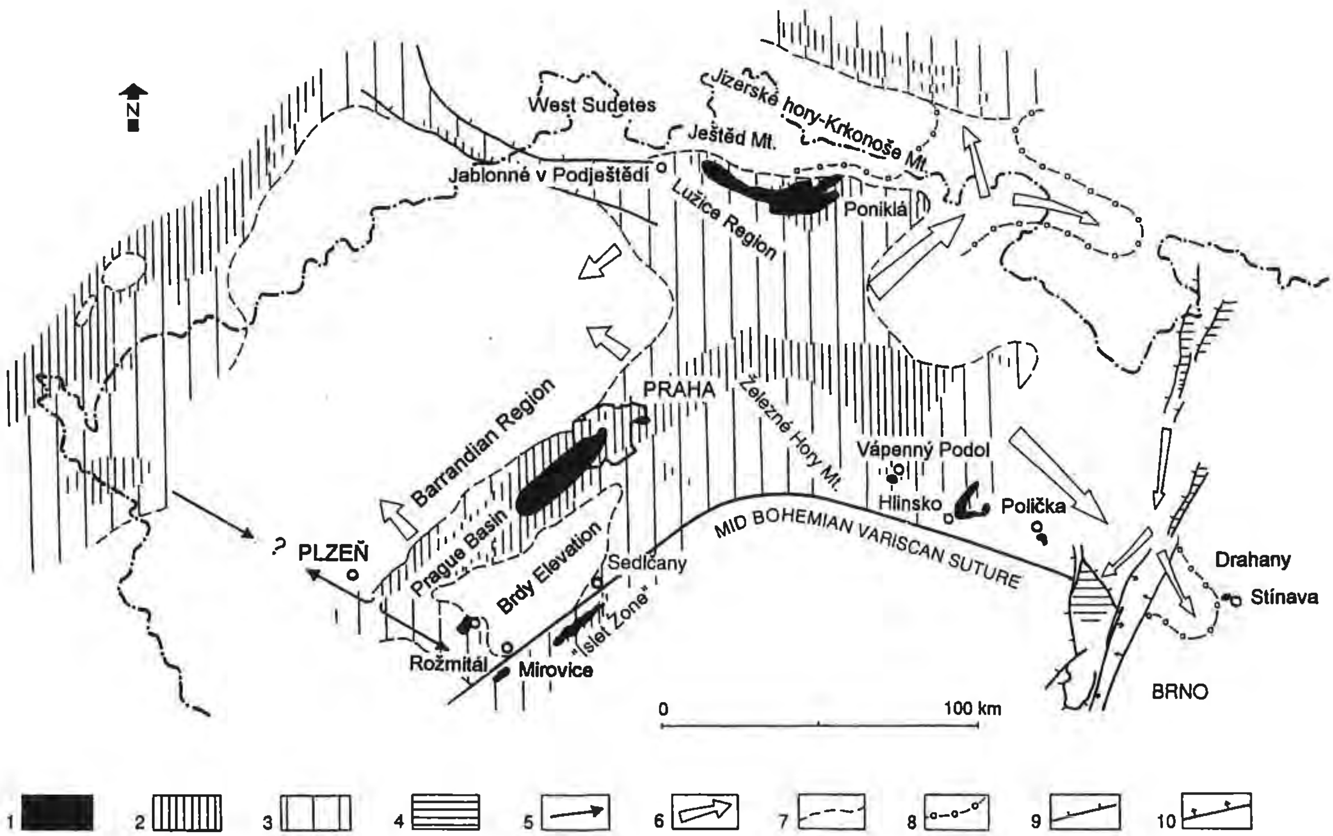

FIGURE 35 — Silurian of the Bohemian Massif. 1, Silurian outcrop and subcrop; 2, Ordovician outcrop and subcrop; 3, presumed original extent of Ordovician; 4, possible Ordovician and Silurian crystalline rocks; 5, possible transition zone between the middle Bohemian region and the Saxothuringian–Lugian Zone; 6, Silurian transgression directions outside the Ordovician basins; 7, presumed Ordovician shoreline; 8, presumed Silurian shoreline where it differs from the Ordovician shoreline; 9, faults that reduced areal extent of Paleozoic basin; 10, faults bordering limnic Permian–Carboniferous of the Boskovice Furrow (after Havlíček, 1980).

SILURIAN OF BOHEMIA (PERUNICA)

The main Silurian outcrops are distributed in the Variscan Bohemian Massif in several regions (Fig. 35). The most important outcrop area, which is little disturbed by tectonism and is the most fossiliferous, lies in the Prague Basin in the Barrandian region. The Silurian of the nearby "Islet Zone" on the central Bohemian granite pluton includes sequences altered by contact and regional metamorphism. The Silurian deposits also appears in the Železné Hory Mountains (Vápenný Podol) and in the Hlinsko Lower Paleozoic region. The Silurian also is recorded in a bore hole through the Bohemian Cretaceous basin near Jablonné in Podještědí. Metamorphosed Silurian is known from the Lužice region (Fig. 35). In the Czech part of the Krušné Hory Mountains, the Silurian is absent, although it was earlier reported (Horth, 1995). The Silurian of the Moravo–Silesian region in Drahany, Stínava, is similar to that in the Prague Basin (Kettner and Remeš, 1935). It is questionable if this latter region was originally part of the Perunica microcontinent. The Silurian there is probably referable to the Brunovistulicum microcontinent, which forms the southeast part of the Bohemian Massif (Suk, 1979; Dudek, 1980), and which was part of Baltica in the Silurian. For this reason, the Bohemian Massif is assumed to be a composite unit formed of Gondwanan, Perunican, and Baltic elements (Havlíček et al., 1994). Perunica extends northwards to the mid-European suture that originated with closure of the Rheic Ocean and now represents the boundary between the Saxothuringian and Rhenohercynian Zones in the Variscan orogen (Burrett and Griffiths, 1977). The tectonic contact between Perunica and the Brunovistulicum is associated with overthrusts and nappes, with the pronounced eastern vergenz recognized by Suess (1912). Pre-Devonian rocks of unknown original extent and thickness were deposited in the basin between Perunica and the Brunovistulicum, but were mostly destroyed during the collision of these blocks (Havlíček et al., 1994).

GEOLOGY, LITHOSTRATIGRAPHY, AND FACIES — In the Bohemian Massif, except for the Prague Basin and the Moravo–Silesian region (Drahany, Stínava), the Silurian is part of the Thuringian facies. In the central Bohemian "Islet Zone" and Železné Hory Mountains, the Silurian (Llandovery–Ludlow) features black graptolite shale and upper black crinoid limestone with cephalopods (Goldbachová and Svoboda, 1930; Svoboda and Prantl, 1950). In the "Islet Zone" (Sedlčany Krásná Hora metamorphic "islet"), Silurian rocks have undergone contact metamorphism into chiastolite-cordieritite graphitic slates and hornfels, but graptolites are locally preserved (Chlupáč, 1989). Thin carbonates with *Scyphocrinites* are developed at the Pridoli–Lochkovian boundary.

The Silurian on the Bohemian side of the west Sudetes (Fig. 35) is developed in the Thuringian facies (Chlupáč, 1993). Dark graphitic phyllites and laminated dark cherts are known from several places in the Jizerské Hory–Krkonoše Mountains (Fig. 35). A limestone at the top of the Silurian near Křižany, northeast of Malý Ještěd in the Ještěd Mountains, shows the lithology typical of the Ockerkalk Group elsewhere in the Saxothuringian Zone (Jaeger, 1977a; Chlupáč, 1993). The Silurian of the "Islet Zone," SedlčanyKrásná Hora metamorphic "islet," Rožmitál and Mirovice metamorphic "islet," (Havlíček, 1977; Štorch et al., 1984) and in the Lower Paleozoic Hlinsko region (Horný, 1956) is in the Thuringian facies. The black graptolitic shale succession is typically thin, and the entire Silurian in the Rožmitál area is only 4,050 m thick (Havlíček, 1997). Cherts are present in the Lower Paleozoic Hlinsko region (Horný, 1956).

The Thuringian facies is believed to be a deeper sea deposit. However, the Silurian of the Bohemian Massif indicates the existence of subaerial uplifts without overlying marine rocks. In the Rožmitál area, Lower Devonian conglomerates contain boulders of Cambrian sandstones and non-metamorphosed or slightly metamorphosed Proterozoic sedimentary rocks and volcaniclastics. These boulders support the idea that exposed areas of Cambrian rocks in the Brdy Mountains were not covered by Ordovician and Silurian seas (Havlíček, 1980). In the Nepasice bore hole near the town of Hradec Králové, Lower Devonian overlies Proterozoic basement (Havlíček et al., 1994).

Very shallow-water, carbonate facies that record favorable conditions for benthic faunas with brachiopods, bivalves, cephalopods, crinoids, corals, and trilobites developed in the Prague Basin on the slopes of the Wenlock–Ludlow volcanic archipelago (Kříž, 1991). The Silurian of the Prague Basin differs from the Thuringian facies by its greater thicknesses (250–580 m), the presence of thick basic volcanics (Fiala, 1970, 1976, 1982), and other lithologic developments. In the Prague Basin, the earliest Silurian rocks are pelitic (black graptolitic shale) (Figs. 36–39). During the Telychian (Llandovery), and especially in the early Sheinwoodian (Wenlock), carbonate deposition increased progressively (Figs. 36, 37). In the late Llandovery (Aeronian) and middle Wenlock–middle Ludlow, Prague Basin sedimentation featured volcaniclastic sediments, magma intrusions, and tuffs and flows (Figs. 37, 38). Several volcanic centers developed along the synsedimentary (growth) faults (Kříž, 1991; Fig. 38).

Volcaniclastic deposition around the volcanic centers led to the origin of shallow-water areas, which were occupied by rich benthic faunas during periods of minimal sediment supply. Fossil fragments produced here form a substantial part of the sedimentary rocks. The fossil fragments were also transported by currents into the deeper parts of the basin, where pelitic or tuffaceous–pelitic sedimentation was dominant. During periods of maximum volcanic activity, the tuffaceous component of the sediments increased. In the region of the Svatý Jan volcanic center, reworked limestone pebbles and fragments of algae, bryozoans, corals, and stromatoporoids document intertidal or shallow subtidal environments in the late Wenlock (Kříž, 1991), and thus suggest the existence of a volcanic island at that time (Fig. 38). Local emergence related to volcanic activity is indicated in the Kosov volcanic center (Figs. 37, 39) by reworked limestone pebbles in the middle Gorstian (Ludlow) (Kříž, 1992). In the late Wenlock (Homerian), eustatic movements were a primary cause of shallowing (Kříž, 1991, 1998). This is reflected locally by local shallow-water, fossil hash limestones with cephalopods, some of which are known from the Montagne Noire, Carnic Alps, and Sardinia (Kříž, 1984). It can be assumed that the emergence of the Svatý Jan volcano was coeval with the late Wenlock transgression. There are other similar transgressions documented by cephalopod limestones in the earliest, middle (early Ludfordian), and latest Ludlow (*Monogratus fragmentalis* Zone) and the latest Pridoli (Kříž, 1998). Locally, the cephalopod limestone biofacies also existed on submarine rises in the earliest Pridoli.

Activity of the Svatý Jan volcanic center ended in the latest Wenlock and early Ludlow (Gorstian) with repeated basaltic lava flows into shallow water (Fiala, 1982). A thick lava sheet (up to 60 m) was formed, which covered earlier volcaniclastic deposits (Fig. 38). The lava sheet was locally overlain by fossiliferous sediments only in the latest Pridoli. This indicates that the volcano was emergent during the late Homerian, Gorstian, Ludfordian, and most of the Pridoli. A land flora with a diverse assemblage of trilete miospores and cryptospores of the *Artemypyra brevicosta-Hyspanaediscus verrucatus* Assem-

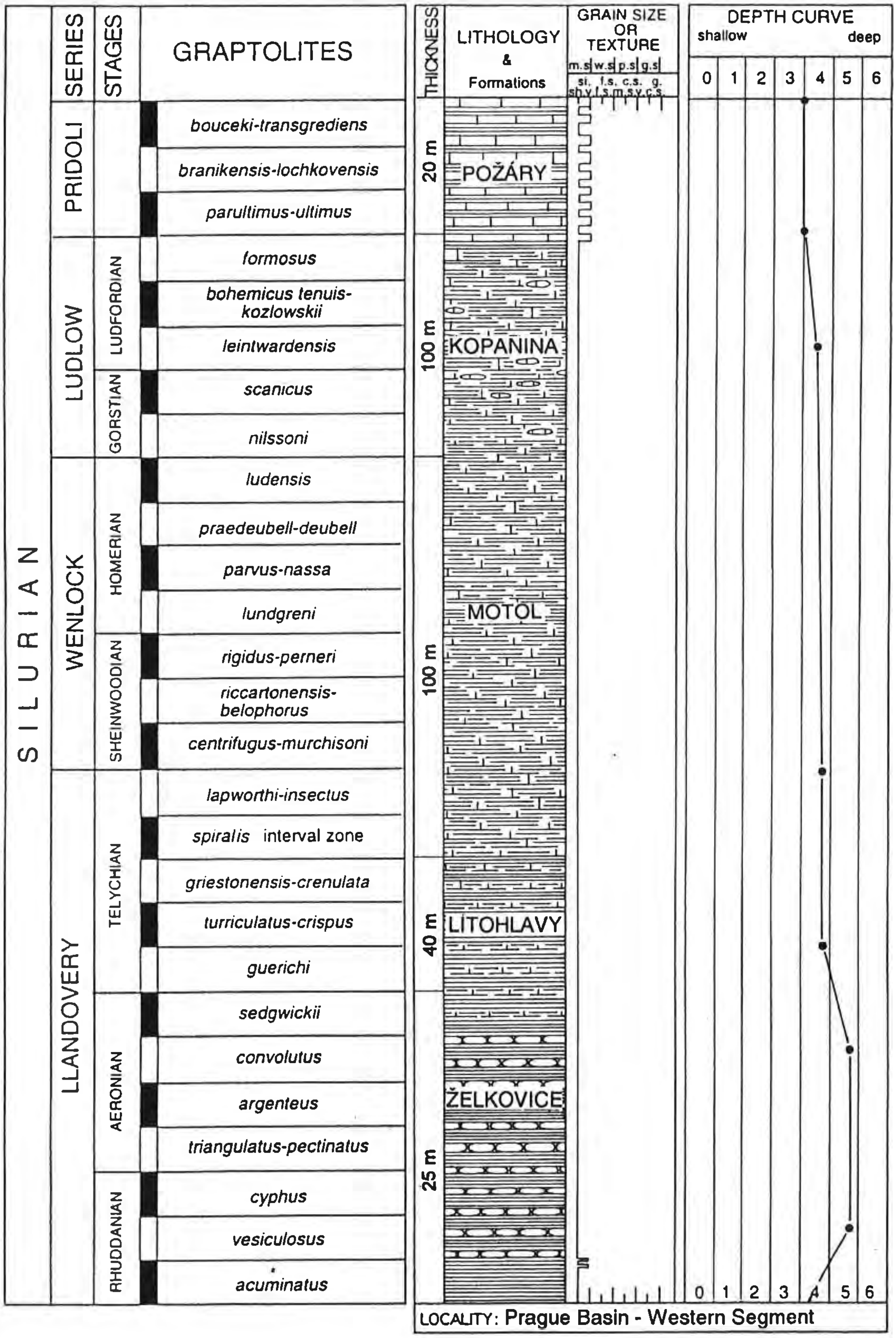

FIGURE 36 — Silurian of western Prague Basin, Bohemia. For detail, see Fig. 38.

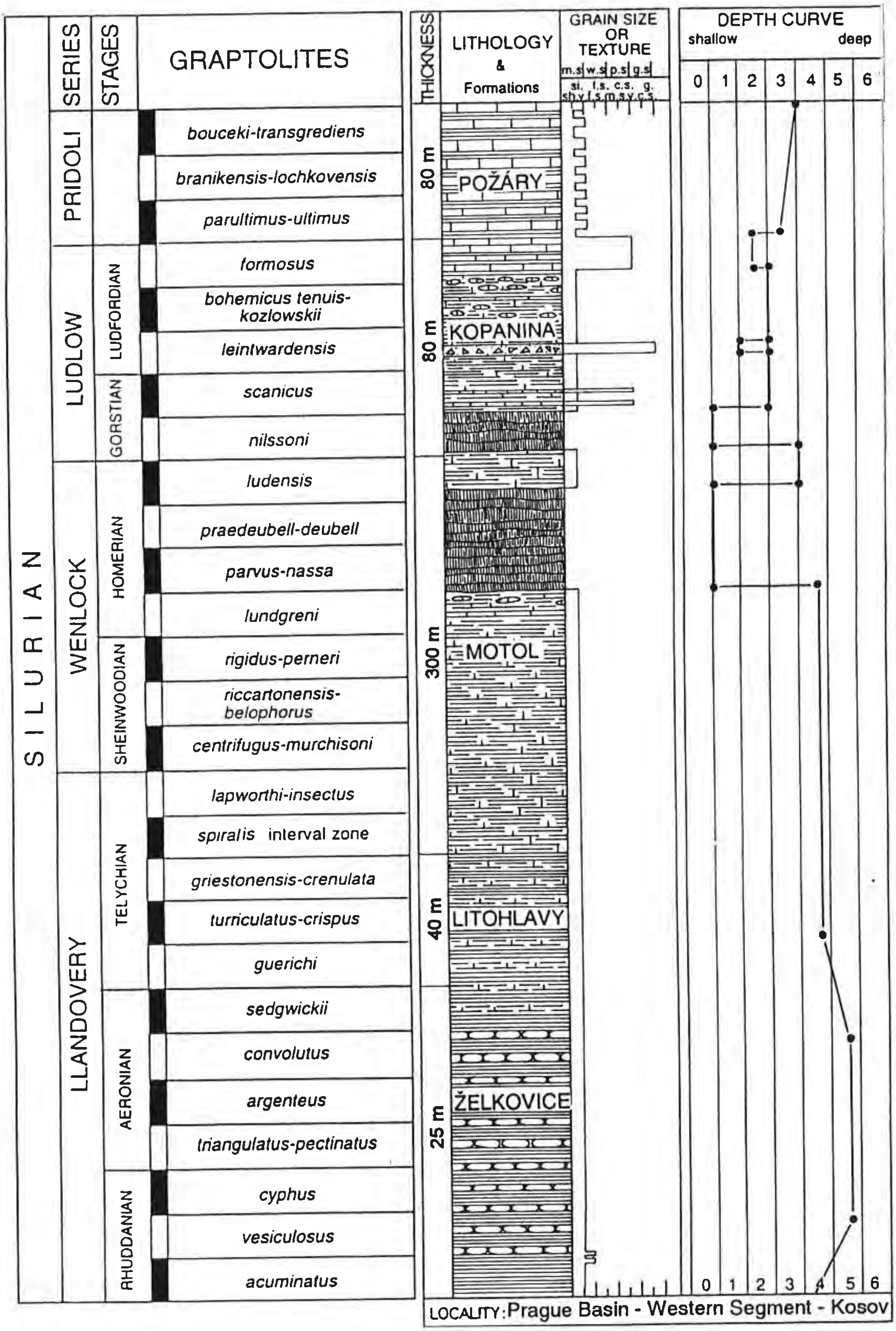

FIGURE 37 — Silurian of Kosov volcanic center, western Prague Basin, Bohemia. For detail, see Fig. 38.

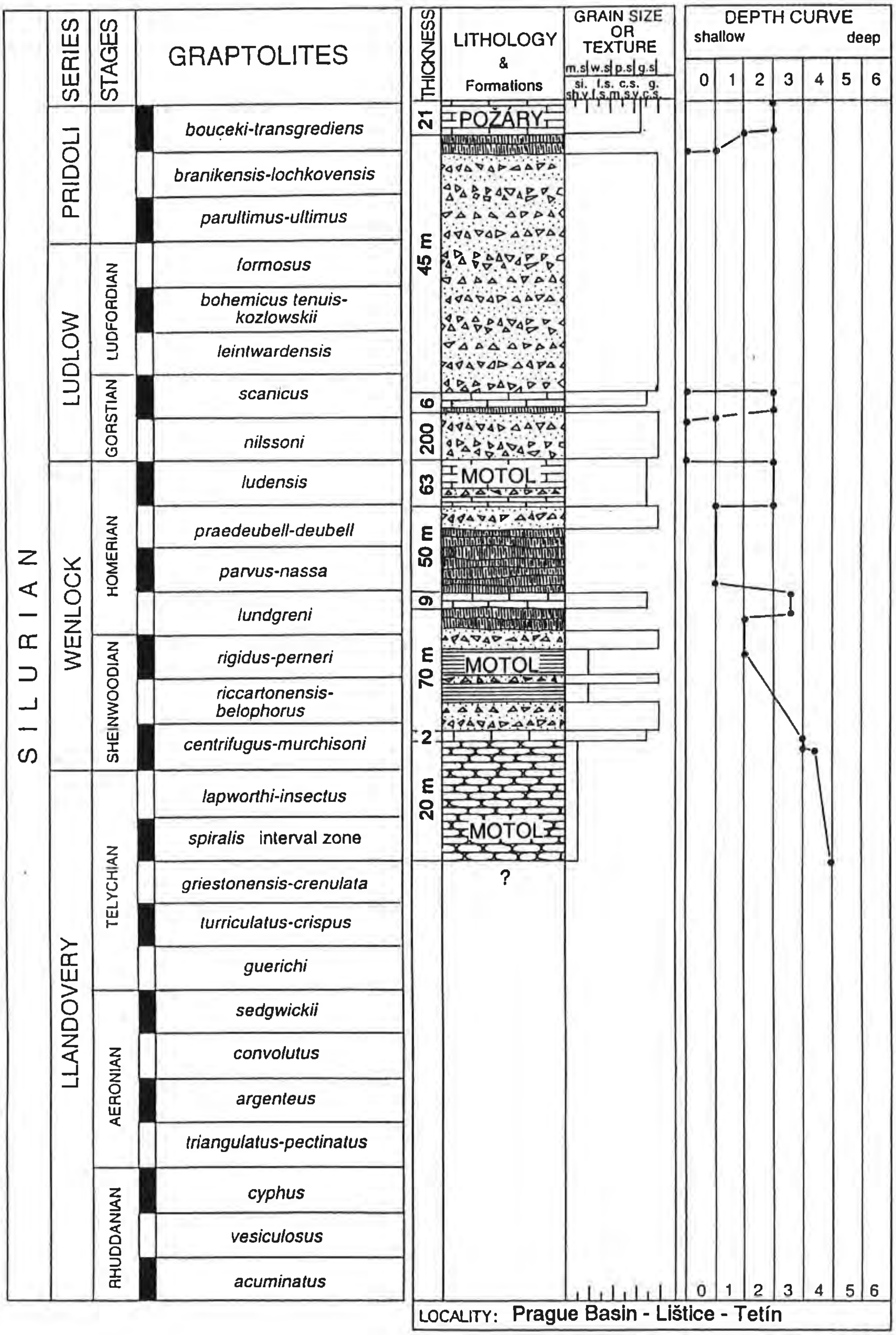

FIGURE 38 — Silurian of Svatý Jan volcanic center, central Prague Basin, Bohemia.

blage Zone appears in upper Wenlock tuffaceous shales and limestones close to the Svatý Jan volcanic center (Dufka, 1995a, 1995b).

In other parts of the Prague Basin, the Pridoli is characterized by laminated limestones and calcareous shales (Figs. 36, 37). In many Gondwanan basins, late Pridoli regression led to the production of shallow-water fossil hash limestones with abundant cephalopods or crinoids (e.g., in the Prague Basin, Carnic Alps, eastern Serbia, the Montagne Noire, Sardinia, and Morocco). In other parts of the world, this lowstand culminated in a transition from marine to non-marine facies.

The unusual facies diversity within the Prague Basin has been a major reason for defining lithostratigraphic units by biostratigraphic criteria. These rock units really represent chronostratigraphic units. The Lower Silurian corresponds to the Liteň Group (Kříž, 1975) and includes the Želkovice, Litohlavy, and Motol Formations (Fig. 36). The base of the Želkovice Formation correlates with the Ordovician–Silurian boundary and is characterized by the lowest dark shale of the *Akidograptus ascensus-Parakidograptus acuminatus* Zone. These dark shales are overlain by the Litohlavy Formation, with a base defined by a thick band of green calcareous shale to clayey limestone. Higher parts of the Lower Silurian correspond to the Motol Formation, mostly calcareous shale with its lower boundary defined at the base of the *Oktavites spiralis* Zone.

The Upper Silurian is represented by the Kopanina and Požáry Formations (Fig. 36). Considerable facies diversity has led to definition of the lower boundary of the Kopanina Formation at the base of the Colonograptus colonus (=*Neodiversograptus nilssoni*) Zone. The lower boundary of the Požáry Formation at its stratotype is defined at the top of the massive cephalopod limestones (Kříž et al., 1986). At some localities, this lithostratigraphic boundary is upper Ludlow, and at others it is lower Pridoli. The base of the Pridoli is defined at its international stratotype in the Požáry Quarries near Praha-Řeporyje, where it coincides with the base of the *Monograptus parultimus* Zone within bed no. 96 of the Požáry Formation (Kříž et al., 1986).

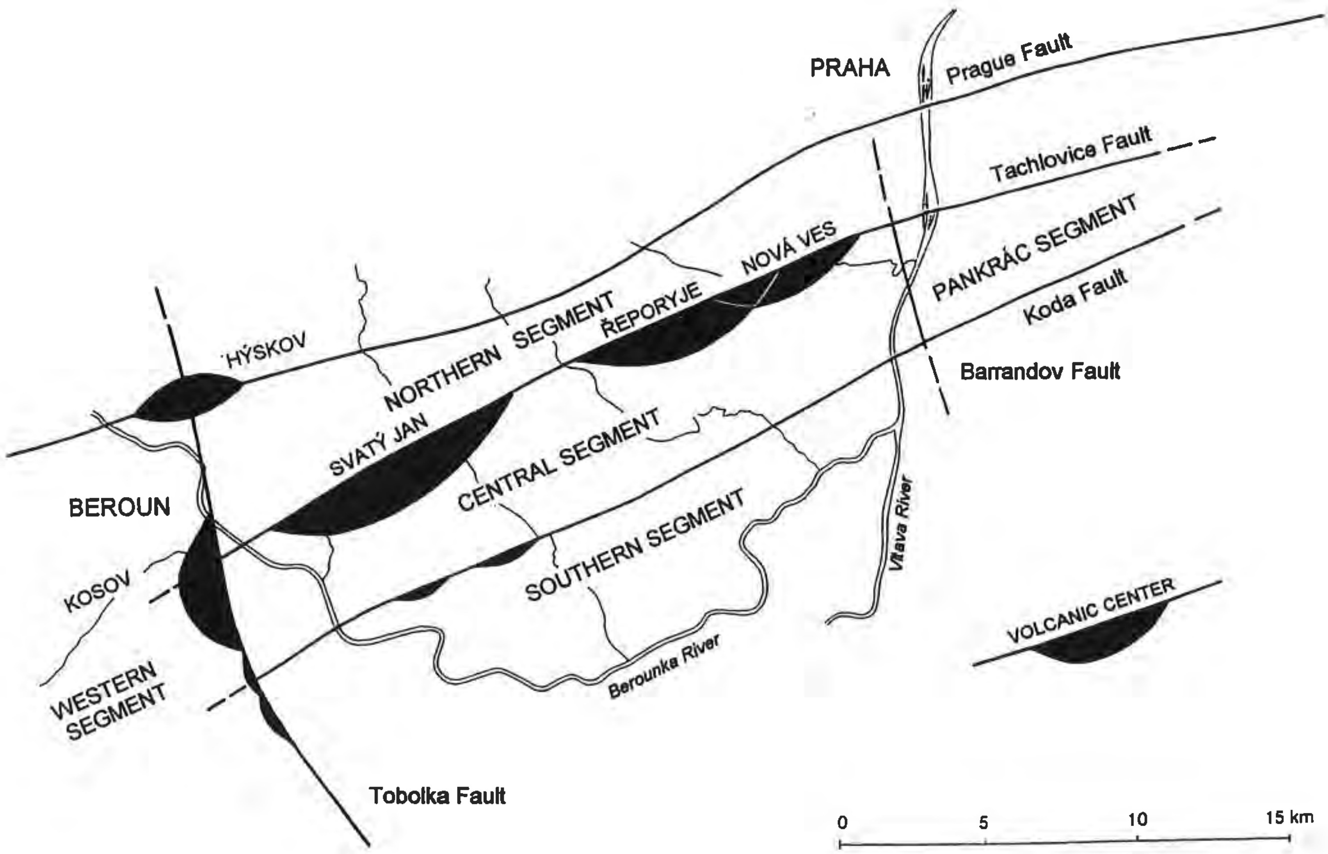

FIGURE 39 — Silurian synsedimentary tectonics, volcanic centers, and basin segments (sub-basins) in the Prague Basin, Bohemia (after Kříž, 1991).

The Prague Basin Silurian is more than 580 m thick in regions of igneous activity and maximum deposition of volcaniclastics (Kosov and Svatý Jan volcanic centers). In other areas, the dominant shale facies reach a maximum of 250–450 m in the southwestern Prague Basin (Fig. 39). Thicknesses are much less in the north- and southeastern basin.

The Silurian near Stínava in Drahany (Moravo–Silesian region) is similar to that of the Prague Basin. The lower part of the sequence is dominated by black graptolitic shale (upper Telychian) and the upper part by calcareous shale with limestone nodules that contain cephalopods, bivalves (*Cardiola*, *Patrocardia*, and *Dualina*), and crinoids in the lower Gorstian. The entire thickness is about 100 m (Bouček, 1935).

BIOSTRATIGRAPHY — The Bohemian Silurian is dated mostly by graptolites (Kříž, 1994). In the west Sudetes at Poniklá, northwest of Jilemnice, Horný (1964) described Wenlock graptolites from phosphatic concretions in graphitic phyllites. Ockerkalk Group limestones in the upper part of this sequence have columnals and stems of *Scyphocrinites* (Chlupáč, 1993). Graptolitic shales occur in the Telychian–Sheinwoodian boundary interval, the Homerian, and the lower Gorstian in the Rožmitál area in the Bohemian "Islet Zone" (Havlíček, 1977). In the Mirovice metamorphic "islet," the Homerian is dated by graptolites (Štorch et al., 1984). Two horizons in the Sedlčany–Krásná Hora metamorphic "islet" in the middle Llandovery and at the Llandovery–Wenlock boundary are dated by graptolites (Chlupáč, 1986). In the Železné Hory Mountains, Silurian phyllitic black shales have uppermost Telychian, Sheinwoodian, Homerian, and lowest Gorstian graptolites and *Scyphocrinites* in Pridoli black limestones (Svoboda and Prantl, 1950). In the Hlinsko region, Aeronian and Telychian graptolite zones are recognized (Horný, 1956).

The Prague Basin Silurian is well dated paleontologically (e.g., Horný, 1955, 1962, and Kříž, 1991, 1992). Štorch (1994) developed a zonal scheme for the Llandovery and Wenlock in the Prague Basin and recognized 27 graptolite zones. In the Ludlow, Štorch (1995) recognized eight graptolite zones, and H. Jaeger (*in* Kříž et al., 1986) recognized six in the Pridoli. The conodont biostratigraphy has been documented by Walliser (1964), who defined eleven successive zones in the carbonate facies. The Wenlock–Ludlow boundary interval was studied by H. P. Schönlaub (*in* Kříž et al., 1993). The lowest *Pristiograptus dubius parvus-Gothograptus nassa* Zone–*Colonograptus colonus* Zone is characterized by the acme of *Ozarkodina bohemica*, which has three morphotypes below and above the Wenlock–Ludlow boundary. Bed-by-bed conodont biostratigraphy has been done through the Ludlow–Pridoli boundary (H. P. Schönlaub *in* Kříž et al., 1986). In particular, the *Polygnathoides siluricus*, *Ozarkodina snajdri*, *O. crispa* and *O. eosteinhornensis* Zones are well documented. Chitinozoan biostratigraphy through the Ludlow–Pridoli boundary has been detailed by F. Paris (*in* Kříž et al., 1986). Dufka (1992, 1995; P. Dufka *in* Kříž et al., 1993; Dufka et al., 1995) applied the global Lower Silurian chitinozoan zonation to the Prague Basin (see Verniers et al., 1995). An ostracode biostratigraphy has been developed by Bouček and Přibyl (1955) and Hansch (1993b).

Other fossil groups allow correlation of the Prague Basin Silurian with that of other Gondwana basins. Bivalves allow correlations with western Macedonia (Bouček et al., 1968), the Moesian Platform of Romania (Kříž and Iordan, 1975), eastern Serbia (Kříž and Veselinovič, 1975), Sardinia (Kříž and Serpagli, 1993), the Taimyr Peninsula of Russia (Kříž and Bogolepova, 1995), the Montagne Noire and Mouthoumet Massif in France (Kříž, 1996), and the Carnic Alps (Kříž, 1999).

The Silurian near Stínava, in Drahany, (Moravo–Silesian region; Fig. 34) is correlated with the *Oktavites spiralis* and *Stomatograptus grandis* Zones (upper Telychian) and the *Cyrtograptus lundgreni* and *Pristiograptus ludensis* Zones (Homerian). Graptolites and bivalves (*Cardiola*, *Patrocardia*, and *Dualina*) allow correlation of the uppermost Silurian with the lower Gorstian *Colonograptus colonus* Zone (Bouček, 1935).

BOHEMIAN SILURIAN COMMUNITIES — Graptolite associations were studied through the Lower Silurian and into the upper Pridoli by H. Jaeger (*in* Kříž et al., 1986) and Štorch (1994, 1995) in the Prague Basin. Benthos-dominated communities are known in the Bohemian Massif only from the Prague Basin facies and from the shelly-fauna facies near Stínava, Drahany. In the Prague Basin, Chlupáč (1987) recognized one trilobite-dominated assemblage in the upper Aeronian, one in the middle Sheinwoodian, five in the Homerian, nine in the Ludlow, and three in the Pridoli. Kříž et al. (1993) revised the Wenlock–Ludlow boundary trilobites. These trilobite assemblages are lithofacies-related. Most assemblages occur in light-colored, fossiliferous limestones which were deposited in the shallow subtidal to intertidal zones (i.e., Boucot's [1975] Benthic Assemblages 2–3). Four assemblages occur in the dark grey and bituminous limestone facies (Benthic Assemblage 4), which was deposited in oxygen-deficient environments (Ludlow–Pridoli). Seven trilobite assemblages are associated with the Wenlock–Ludlow volcanic archipelago, and occur in tuffaceous, calcareous shales and carbonates (Benthic Assemblages 4–6).

Havlíček and Štorch (1990) analyzed the brachiopod-dominated benthic communities from the Prague Basin. One community was described from the Aeronian, three from the Sheinwoodian, six from the Homerian, two from the Gorstian, five from the Ludfordian, and four from the Pridoli. These communities are strictly related to lithofacies and depth. Most communities occur in shallow environments (Benthic Assemblages 2–4) around the Wenlock–Ludlow volcanic archipelago. Few communities occur in calcareous shale (Benthic Assemblages 5–6). Kříž et al. (1993) described two additional communities from the upper Homerian and Homerian–Gorstian boundary. Havlíček (1995) distinguished five brachiopod biofacies in the Homerian and lowermost Gorstian. Brachiopods are the dominant benthic elements in the non-strophic-brachiopod-dominated biofacies, the pyroclastic biofacies, and the crinoid-stromatoporoid-coral biofacies. They are uncommon in the deeper-water trilobite-dominated biofacies, and very rare in the graptolitic shale biofacies. In general, the brachiopods of the Homerian differ from those of the lower Gorstian, but they are not useful in defining the Wenlock–Ludlow boundary. Kříž et al. (1993) showed that several species cross this boundary without any change in shell morphology.

Silurian communities dominated by bivalves were grouped by Kříž (1997a, in press) into four community groups that are related to lithofacies and depth of deposition (Fig. 40). The shallow-water *Cardiola* Community Group is represented in the Prague Basin by six *Cardiola*- and one *Cardiolinka*-dominated community that characterize the episodically oxygenated cephalopod limestones (Benthic Assemblage 2–3). The *Cheiopteria* Community Group is represented by two recurrent *Cheiopte-*

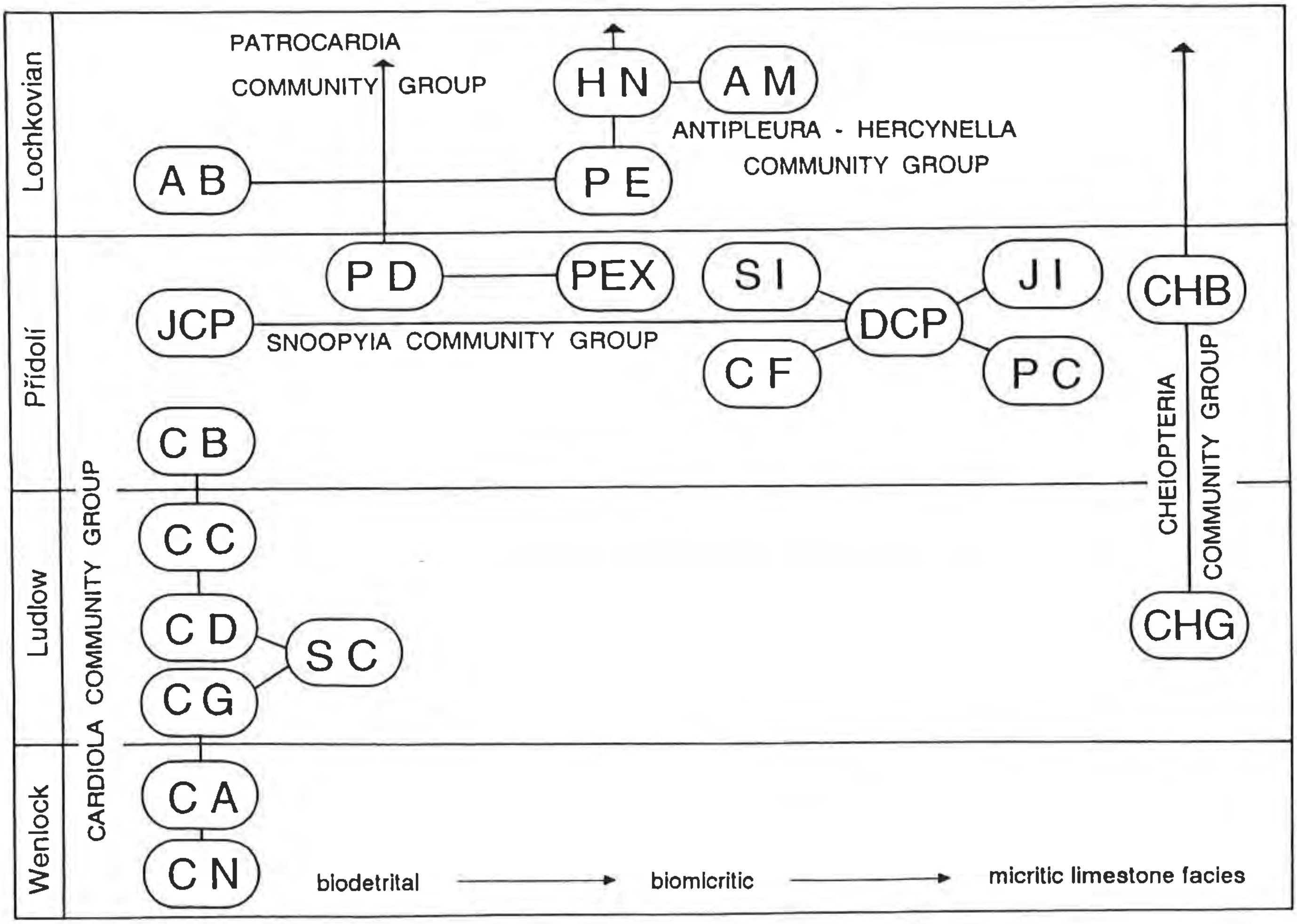

FIGURE 40 — Bivalve-dominated community succession and environmental framework for the Silurian and Lower Devonian carbonates of North African Gondwanan and Perunican facies. AB, *Antipleura bohemica* Community (=Cm.); AM, *Actinopteria migrans migrans* Cm.; CA, *Cardiola agna* Cm.; CB, *Cardiolinka bohemica* Cm.; CC, *Cardiola conformis* Cm.; CF, *Cardiolinka fortis* Cm.; CG, *Cardiola gibbosa* Cm.; CN, *Carnalpia nivosa* Cm.; CHB, *Cheiopteria bridgei* Cm.; CHG, *Cheiopteria glabra* Cm.; DCP, *Dualina-Cardiolinka-Paracardium* Cm.; HN, *Hercynella-Neklania* Cm.; JCP, *Joachymia-Cardiolinka-Pygolfia* Cm.; JI, *Joachymia impatiens* Cm.; PD, *Patrocardia-Dualina* Cm.; PE, *Patrocardia evolvens* Cm.; PEX, *Patrocardia excellens* Cm.; PC, *Pterinopecten (P.) cybele cybele* Cm.; SC, *Slava cubicula-Cardiola donigala* Cm.; SI, *Snoopyia insolita* Cm. (after Kříž, in press).

ria-dominated communities; it occurs in a micritic limestone facies that was less oxygenated and deeper than the cephalopod limestone biofacies (Benthic Assemblages 3–4). The *Snoopyia* Community Group is represented by six commonly monospecific communities; it occurs in the Pridoli in deeper water micritic limestones (Benthic Assemblages 3–4), where it occupied less favorable habitats with limited current activity and low oxygen. The *Patrocardia* Community Group is represented in the Silurian of the Prague Basin by three communities dominated by *Patrocardia;* it occurs in somewhat shallower, better-ventilated environments than the *Snoopyia* Community Group. Wacke- to packstones of the *Patrocardia* Community Group facies correspond to Benthic Assemblages 2–3.

The *Cardiola* Community Group is very closely related to the cephalopod limestone biofacies. Limestones with cephalopods occur in the Prague Basin Silurian at eleven horizons (Kříž 1997b, 1998, in press). Each horizon has characteristic cephalopods (Š. Manda, personal commun., 1997) and indicates a period when the sea floor below wave-base was ventilated by surface-water currents.

BOHEMIAN SILURIAN PALEOGEOGRAPHY — The Bohemian Massif (=Perunica microcontinent of Havlíček et al., 1994) drifted from high southern to low northern latitudes in the latest Paleozoic. Data for this supposition were summarized by Krs et al. (1986, 1987) from Bohemia. Lower Middle Cambrian graywacke from the Příbram–Jince Basin shows a paleolatitude of ca. 39° S, and Upper Cambrian andesite records a paleolatitude of ca. 29° S. Lower Ordovician chert and tuffaceous rock in the Prague Basin record a paleolatitude 28° S, and Lower Devonian micrites show a 5–9° S paleolatitude. The Upper Carboniferous in northern Bohemia was deposited approximately on the equator. Younger Permian rocks show a paleolatutude of 6–10° N, and the Triassic preserves a 14–18° N paleolatitude. The insular development of Perunica is suggested by its probable rotation, as shown by changes in paleomagnetic directions from ca. 65° in the Middle Cambrian, 90° in the Late Cambrian, and to 127–132° in the Early Ordovician (Krs et al., 1986). These data support Burrett's (1983) interpretation of apparent polar wander path and his suggestion that the Bohemian Massif moved independently of Armorica during the Early Paleozoic. Havlíček et al. (1994) supported the existence of an insular Perunica in the Ordovician by the analysis of microplate and plate separations based on brachiopod and trilobite assemblages.

Early Silurian sedimentation on the Bohemian Massif was influenced by Late Ordovician glaciation. Seawater temperature was probably relatively low in the post-glacial period. In the Early Silurian, the sea was anoxic or strongly dysaerobic, and black graptolitic shale was deposited in all Bohemian Massif basins. During the Telychian, the temperature slowly increased and better circulation commenced. In the Prague Basin, this is related to the deposition of calcareous shales. Wenlock and especially Homerian limestone facies in the Prague Basin indicate a further increase in temperature, which reached a maximum in the Pridoli. Climate in the latter interval corresponded to a 20–30° latitudinal separation of Perunica from the equator (Krs et al., 1986).

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