undertaken by O'Neill and Gunning (1934) and later by Vermaak (1985a), and there is no need for reiteration here. The main production came from British Columbia, notably from the Tulameen river section of the Similkameen Division, the Quesnel river and its tributaries, the Frazer river, and streams of the Atlin Division and on Graham island. From 1948 to 1950, the Atkinson Dredging Co. Ltd. operated in the Similkameen river, but no reports of recent production are available.

The Far East and Oceania

In Borneo, platinum is known to occur in widely distributed gold- and diamond-bearing placers discovered in 1831. The best known deposits are in the Tanah-Laut, Martapura, and particularly the Gunong-Lawack region, where gold concentrates contain 10 per cent platinum. Small amounts of PGE are also found in India, Burma, Java, Sumatra, and the Philippines. Bachmann *et al.* (1987) and Bachmann (1988) have shown that in Papua New Guinea, the PGE are related to the well-defined Papuan and April ultramafic belts and the Marum ophiolite complex. The PGE are transported and concentrated by the Gira, Sepik and Tumin rivers. Placers at Milne Bay, Yodda-Kokoda, and Lakekamu produced a total of 7908 kg of gold in the past; where full production analyses are available for three of the deposits, the amount of Pt + Os/Ir amounted to 32 kg, together with 2618 kg of gold in concentrates. Placers also occur in New Zealand (Orepuki, Southland, and Nelson districts), China (Uryauchai district of Mongolia), and Japan (Rivers on the islands of Hokkaido, Hokushu, and Sado in Honshu province).

The Rest of Africa

PGE have been reported in placers in Algeria, the Congo, Egypt, and Madagascar. In Sierra Leone, placers in the Whale river and its York and Toke tributaries have been derived from a funnel-shaped intrusion of layered basic rocks (troctolites, gabbros, and anorthosites) of the Freetown Complex on the Freetown peninsula. PGE also occur in laterites related to that complex (Bowles, 1986). Separate placers occur in the Congo Dam, Guma Water, and Big Water rivers. From 1929 to 1969, 163 kg (5232 oz) of crude platinum was produced from Sierra Leone.

2.8.3. The PGE in Argillaceous Sediments

The best-documented example of a classic occurrence of the PGE in argillaceous sediments is the Kupferschiefer of Poland, which is described by Banas *et al.* (1982), Bogandov *et al.* (1982), and Osika (1986) among others. The mineralized Kupferschiefer ('copper slate') occurs at the juncture of the 300 m thick Lower Permian terrestrial red-bed (Rotliegender) and volcanic sequence with the Upper Permian Zechstein marine sediments and salt deposits. The copper slate, with an average thickness of 1 m (0,3 to 3,0 m), is a thin but complex black to dark grey or greenish-grey mudstone or marl, heavily enriched with organic (bituminous) matter and mineralized with a great variety of elements, including copper, zinc, lead, molybdenum, nickel, cobalt, vanadium, rhodium, gold, silver, platinum, palladium, mercury, selenium, and bismuth. Osika regards the deposit as volcanosedimentary in origin, since there is no evidence of epigenetic hydrothermal fluids. The deposit therefore appears to be linked to a low-temperature diagenetic cycle, in which the organic matter acted as scavenger for the heavy metals and other elements. The footwall is a grey-white sandstone that has been leached of its ferric iron, typical of the normal red-bed Rotliegende sandstone to which it belongs. The leaching (0,4 to 42,0 m) is commonly replaced by patchy, mostly sub-economic copper mineralization to a depth of 30 to 40 m below the contact, probably inherited from the copper slate above. The hangingwall Zechstein dolomites and limestones may also be infiltrated by copper solutions up to the salt beds, which consist of sylvite, halites, and anhydrites.

In a series of papers, Kucha (1981, 1982, 1984) described mainly the mineralogy of the PGE and related mineral phases identified in the Kupferschiefer of Poland. He did, however, postulate that auto-oxidation and desulphurization of the organic matter in the 'slates' were due to the transition metals acting as catalysts in the oxidizing reactions, which caused those metals to be concentrated near the oxidation-reduction boundary. The completely oxidized rocks and ores are termed the 'Rote Fäule', and the copper and the other elements (nickel, cobalt, vanadium, uranium, molybdenum, rhemium, arsenic, bismuth, selenium, PGE, and gold) are concentrated near their boundary. The ores further from the boundary are richer in zinc and lead plus cadmium. Careful study of the 0,5 m of ore-bearing rocks has caused Kucha to recognize an interesting microlithology in the layering. At the basal contact with the grey-white Rotliegende sandstone is a thin shale, followed by 12 cm of apparently barren boundary dolomite. This is followed sequentially upwards by a thin noble-metal-bearing shale, a thin thucolite shale, a thicker pitchy shale, a thinner clayey shale with digenite, a thin dolomitic shale, and finally a thick dolomite of the main Zechstein sequence. Each of the shales has its own unique metallic and elemental signature and bituminous content (which is only of academic interest in this review). The noble-metal-bearing shale is only a few centimetres in thickness. Here, concentration by the auto-oxidation process, assisted by gamma radiation from the thucolite-bearing shale and coagulation of the precious metals by phosphates and borates has increased the platinum content to 10 to 370 g/t, and that of palladium to 10 to 120 g/t (although this may locally be as high as 1000 ppm), with 3000 g/t gold).

Unfortunately, very few other economic data are available for the Kupferschiefer deposits but, according to Kuchu (*op cit.*), they are well developed only in the NW-SE-trending Fore-Sudetan monocline (south of Poznan), where the Lower Zechstein occurs at a depth of 700 m (dip 3 to 6° NW). Further north, the dip increases, and the sequence reaches depths of 6000 to 7000 m. Four mines are operating in this area and, by all accounts, the grade is about 0,5 per cent copper; however, no overall PGE grades are available. Drilling by these mines has established mineralized shale at 3200 m depth near Poznan. Crocket (1969) has provided analyses in the ppb range for two Kupferschiefer samples: platinum 67,66 per cent, palladium 27,06 per cent, ruthenium 4,06 per cent, rhodium 0,2 per cent, and iridium plus osmium 0,7 per cent. The richer, incompletely analysed sample (total PGE 1050 ppb) gave platinum 33,3 per cent, palladium 19,05 per cent, and iridium plus osmium 47,62 per cent, which resembles PGE analyses of coal ash. With the meagre information available, no tonnage assessment is possible.

2.9. PGE Resources of the World

In this publication, all available information has been used to calculate the amounts of the individual PGE that can be regarded as identified resources, contained in all the major deposits in the various countries of the world. The results are summarized in Table 2.27. In terms of the US Geological Survey's Circular No. 831 of 1980, identified resources are 'those whose location, grade, quality and quantity are known or estimated from specific geological evidence', and which 'include economic, marginally economic and subeconomic components'. In my estimation, Table 2.27 reflects such resources. It should be noted that, for the USA, the 'provisional resources' in Table 2.20 for the Duluth and Crillion-La Perouse complexes have not been included in Table 2.27. It would be questionable whether a single PGE grade for one small part of the Duluth complex can be applied to all the ores of that complex as a whole; for the Crillion complex, the limits of the orebody remain to be established, as has been indicated. The calculations may therefore not be acceptable in terms of the 'grade, quality, and quantity' constraints of the definition above. Naturally, if my readers disagree, they may add those 'resources' to the table.

The distribution of PGM resources among the world's major deposits is shown in Figure 2.22. The distribution of the individual PGM is shown in Figure 2.23.

Table 2.28 compares my resource data with those of modern resource estimates by other authors. Some qualification is required. The data of Loebenstein (1990) and Odendaal (1992) are virtually the same, except that Loebenstein has qualified his 'other' category as 'other Market Economy Countries' (which was pertinent at that time), while Odendaal regrettably provides no information on the location of his 'other' category. Moreover, he also gave no information on the Finnish deposits, although he had a full report on those deposits at the time (Vermaak, 1989). Neither author provides any insight into the grades, quality, thickness, and depth utilized in their information as specified in the definition of their resource category. Both authors have called their data a 'reserve base', which the USGS defines as: 'That part of an identified resource that meets specified minimum physical and chemical criteria related to current mining and production practices, including those for grade, quality, thickness, and depth. The reserve base is the in-place demonstrated (measured plus indicated) resource from which reserves are estimated. It may encompass those parts of the resources that have a reasonable potential for becoming economically available within planning horizons beyond those that assume proven technology and current economics'. On this basis, all of the identified resources that have been calculated in this report can be included as a resource base, in view of the latter part of the definition. This would include the total Zimbabwean resources, and possibly even justify those US resources discussed in Section 2.5.

Naldrett (1989) has admitted basing his estimate on published information from Buchanan (1979) and Jolly (1978). Reservations regarding Buchanan's resources, and especially his overestimation of Bushveld PGE grades, have already been stated. I have combined Naldrett's 'reserves' and 'other resources' to approximate comparison with the estimate in the present work and that of Loebenstein and Odendaal *(op. cit.)*, as shown in Table 2.28. Rather remarkably, there is virtually no discrepancy for the Bushveld resources, but that is where any similarity ends. There is better agreement between Naldrett's data and my own, than with those of Odendaal and Loebenstein. None of the other authors include any information on China. Finland, and Zimbabwe, although the data on China is admittedly very new. The Loebenstein and Odendaal estimates for Russia are much less than those of the other authors, and they do not regard Colombia as significant, although Odendaal may have included that country in his 'other' category. If I had included the Duluth and Crillion-La Perouse resources with my USA category, my agreement with Naldrett's data would have been much closer.

Much of the resource information in this publication is based on speculative grades, thicknesses etc. but, owing to the secrecy in the PGE industry which I have highlighted before, there was little choice in the matter. Criticsim of a positive nature, particularly if it is based on information that was not available to the author, will be welcome.