eras, and especially in current times, only about one per cent of the world's PGE are supplied from placers. Placers occur throughout geological time, and consist of rock boulders, gravels, sands, muds, or related materials that contain base or precious metals in payable and exploitable quantities. Most placers are riverine deposits; lacustine and marine placers are rare. The tracing of heavy metals or minerals from their source to their final repository is a highly complex subject, but the main pointers are provided below.

A primary requisite for heavy-metal or mineral (HMM) placers is naturally a source of metals or minerals in the catchment area being drained by creeks, streams, or rivers. Gold occurs in a wider variety of rocks than the PGE, which are restricted to the rocks and environments noted in the introduction to this chapter. Placers originate from enormous volumes of rock. The primary releasing agent of HMM is weathering — mechanical weathering is more prevalent in colder climates, chemical weathering in hotter climates. The PGE would survive mechanical transport better in cold climates, but glaciers are not conducive to the formation of placers, owing to the diluting effect of the enormous volumes of material that glacial erosion produces. Generally, unglaciated areas produce more favourable placers than glaciated areas. In hot climates, PGE survive in so-called *in situ* alluvial or residual placers and laterites. These form on top of the source rock, thus involving a minimum of transport and attrition, the HMM being concentrated by an intricate interplay of localized mechanical and chemical agencies. For most cold-climate placers, gravity and flowing water in streams are the main transporting and winnowing agencies for the HMM, but wave action on the shores of lakes or seas can assist in the winnowing process. By these means, placers are concentrated in streams or rivers (alluvial placers), or as beach, deltaic, or wind-blown (eolian) placers. The HMM in placers commonly offer great resistance to mechanical abrasion or comminution, as well as to solution by surficial waters, and their mineral grains have an equidimensional form. Placers of many ages may exist in a single river — the older gravels occur in higher-level terraces than the younger ones. The most favourable placers occur in youthful creeks or streams, situated in the area intermediate between the catchment divide and the mature river into which they eventually drain. Gravels may occur adjacent to present-day streams on floodplains. Gravel-plain placers are formed in broad, flat-bottomed valleys, and contain gravels that have been repeatedly reworked by braided streams. Gravels slow the flow of water, causing streams to drop any HMM being transported. Placer porosity determines the relative amounts of heavy black sands and fine argillaceous material retained in the placer. The fresh HMM are preserved mostly at the base of the placer, and become oxidized upwards. As the streams mature away from their source, continuous mechanical abrasion causes all the material in placers to become finer, and by the time the mature river is reached, only silt with few HMM as fine flour-like particles remain, the rest having been skimmed or floated off by the flowing water.

It was initially recorded by Mertie (1969) that PGE residing in alluvial or alluvial placers consist essentially of two alloy types — either platinum alloys with varying amounts of iron, or alloys consisting essentially of osmium and iridium. It is also interesting to note that Cabri and Harris (1975) considered that placers containing platinum-iron alloy (isoferroplatinum) as the major mineral originate from Alaskan-type complexes, whereas osmium–iridium–ruthenium alloys are the principal components of placers originating from Alpine-type ophiolitic complexes. To test this contention, Vermaak (1985a) calculated the average worldwide PGE distributions in Alaskan and Alpine complexes, based on large numbers of available analyses to be as follows.

Type	Pt, %	Pd, %	Ru, %	Rh, %	Ir, %	Os, %
Alaskan	76,73	8,86	7,85	0,83	1,67	4,07
Alpine	41,20	15,87	7,38	9,34	8,12	18,09

These data appear to confirm the Cabri and Harris hypothesis.

Experiments by Shaw (1921), however, showed that the PGE are very prone to solution in the presence of chloride ions. Ferric and cupric chlorides in aqueous solution easily dissolve platinum at ordinary temperatures, but more so at elevated temperatures. This contention was confirmed by F.C. Chittenden (personal communication with Cousins and Kinloch, 1971). Later studies and theoretical considerations (Fuchs and Rose, 1974; Westland, 1981; Hodge *et al.*, 1985, and Bowles 1986) have shown that the PGE can enter into solution and be mobile in laterites and soils under very acid, chloride-rich conditions with a high Eh value.

Cousins (1973 a and b) and Cousins and Vermaak (1976) gave consideration to the PGE in the fossil placers of the Witwatersrand, and Cousins and Kinloch (1976) examined large numbers of PGE grains from younger worldwide placers. From this work, the following factors emerged.

(a) Leaching of PGE during weathering of their primary host rocks is caused by their oxidation, hydration, biochemical breakdown by humic and other organic acids, as well as by acids generated by the dissolution of magmatic base-metal sulphides. Cousins postulated that the PGE show decreasing leachability during weathering, in the order Pd>Pt>Rh>Ru>Ir>Os.

(b) During the initial stages of weathering, a marked increase of the Pt:Pd ratio occurs in the host rocks as palladium is leached preferentially. There is also a marked increase of the leachability of the PGE in acid solutions in the weathered rocks compared to the PGE in the fresh host rocks.

(c) Whereas primary PGE deposits contain minute grains of a complex PGE mineral assemblage in low concentration, the relatively simple PGE grains in the eluvial or alluvial material derived from the

primary deposit occur as a higher concentration of relatively large, nugget-like rounded alloy grains.

(d) The nuggety rounded PGE alloy grains grow virtually *in situ* on top of the primary deposit in lateritic regoliths during and after the dissolution process, in what has been termed an intermediate accretion stage of placer development. The grains exhibit a characteristic zonal onion-skin-type growth, with a zonal order of osmium, iridium, ruthenium, rhodium, platinum, and possibly palladium; that is, the reverse order of their dissolution during leaching.

(e) Cousins suggested that a low or high Os + Ir/Pt ratio is respectively a measure of the youth or maturity of any placer. He postulated a link between placer maturity and saline conditions in the depositional lacustrine or marine environment, calling on the leachability of platinum under high chloride concentrations to bring about the occurrence and separation of either the platinum-rich or Os + Ir-rich placers. Thus, in contrast to the Cabri and Harris (*op. cit.*) theory of differing primary host origins of placers, Cousins envisaged that the differing PGE content of placers was a late-stage depositional consequence of leachability under saline wave action.

(f) With increasing placer maturity (i.e. with greater osmium and iridium, and lower platinum contents), a progressive diminution of grain size is evident, as well as an unexpected degree of complexity in the composition and microtexture of the grains. These phenomena are fully documented by Cousins and Kinloch (1976).

It is therefore clear that there may be two stages of PGE and gold concentration in nature. Laterites and gossans are apparently preferentially formed under conditions of chemical weathering in hot desert or tropical rainforest areas, while soil regoliths are formed residually on the host-rock outcrops in colder climates. Both these residual deposits are necessary to allow the PGM and gold alloys to separate and grow *in situ* as an intermediate step before the residual deposits are eroded (if ever) by flowing water in high rainfall areas. In dry areas, the laterites or gossans may simply remain in place. Bowles (1986) provided some interesting data concerning the PGM and gold in laterites, but his data (and some of my own thoughts) which follow, may also be applicable to placers and the geochemistry of the entire sedimentary cycle.

(a) High chloride concentrations in residual soils or catchment areas may be caused by onshore winds from the sea. As we have seen, the chloride ion plays a significant role in the forming of complexes with the PGM and gold. The chloride ion thus provides a mechanism for the solution and transport of these metals, either within the residual soils and laterite soils or in the waters of creeks, streams, or rivers draining them.

(b) Complexing reactions may occur between the PGE and gold with free carboxylic or humic acids, or with any other ligand ions or colloids of soil organic matter, which are also known to be excellent adsorbers of heavy metals. This also provides a mechanism for the solution and transport of the metals in question.

(c) During the weathering process, easily soluble components (magnesium, silicon etc.) are removed, leaving a residue of iron and alumina, but the latter may also be removed at low pH values. Platinum, iridium, and gold show relationships with the hydrous iron oxides (which are excellent collectors of other heavy metals), while palladium correlates with highly mobile manganese and copper.

(d) It is evident that the PGE and gold are concentrated by several orders of magnitude in residual soils or laterites, and that their alloys show considerable growth before (if ever) they are removed by groundwater flow.

(e) PGM or gold may be deposited from solution as a result of chemical changes in the solvent, such as reduction by ferrous iron, changes in pH value, oxidation by manganese dioxide, or change of the concentration of chloride ions or other ligands due to dilution. All of these reduce the pH/Eh stability fields of the metals and cause their precipitation, or (in the case of colloids, flocculation). It is also possible that an electrical field is created by solutions flowing through porous media, causing an electrochemical cathodic reaction and precipitation of the metals (Veronin and Goldberg, 1972), particularly platinum and gold with their high electrode potentials.

Changing conditions and differing responses of the individual PGE and gold would therefore allow preferential growth of some phases and resorption of others, conditions which would undoubtedly apply to all the deposits in which these metals find themselves in the sedimentary cycle.

2.8.2. Major Placers of the World

There are literally hundreds of PGE-bearing placers in the world, and therefore only the most important of these can be reviewed. Some attention will be given to those of lesser importance. Some of the available analyses of the PGE from placers world-wide are provided in Table 2.25, and their average production record from 1916 up to 1934 is shown in Table 2.26. Most publication of placer production ceased about that time.

The Urals

The Ural mountains are a typical Palaeozoic (Hercynian) but highly mineralized geosynclinal belt extending over 3500 km southward from Novaya Zelmga to the Aral sea in Russia. The source rocks are chromite-bearing domelike plugs of dunite (typically 1200 to 10 584 m long by 1000 to 5250 m wide, or 100 to 5500 ha in extent). The surrounding pyroxenites and gabbros, which contain magmatic titanomagnetite deposits, extend over some 560 km, and are part of a 10 km thick, pre-Permian basalt-rhyolite volcanic and sedimentary geosynclinal suite. The main platinum sources are chromite schlieren, lenses, pockets, or veins controlled by jointing in the