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PHOSPHATE IN SOUTHEASTERN BRITISH COLUMBIA (82G and 82J)

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A contribution to the Canada/British Columbia Mineral Development Agreement, 1985–1990

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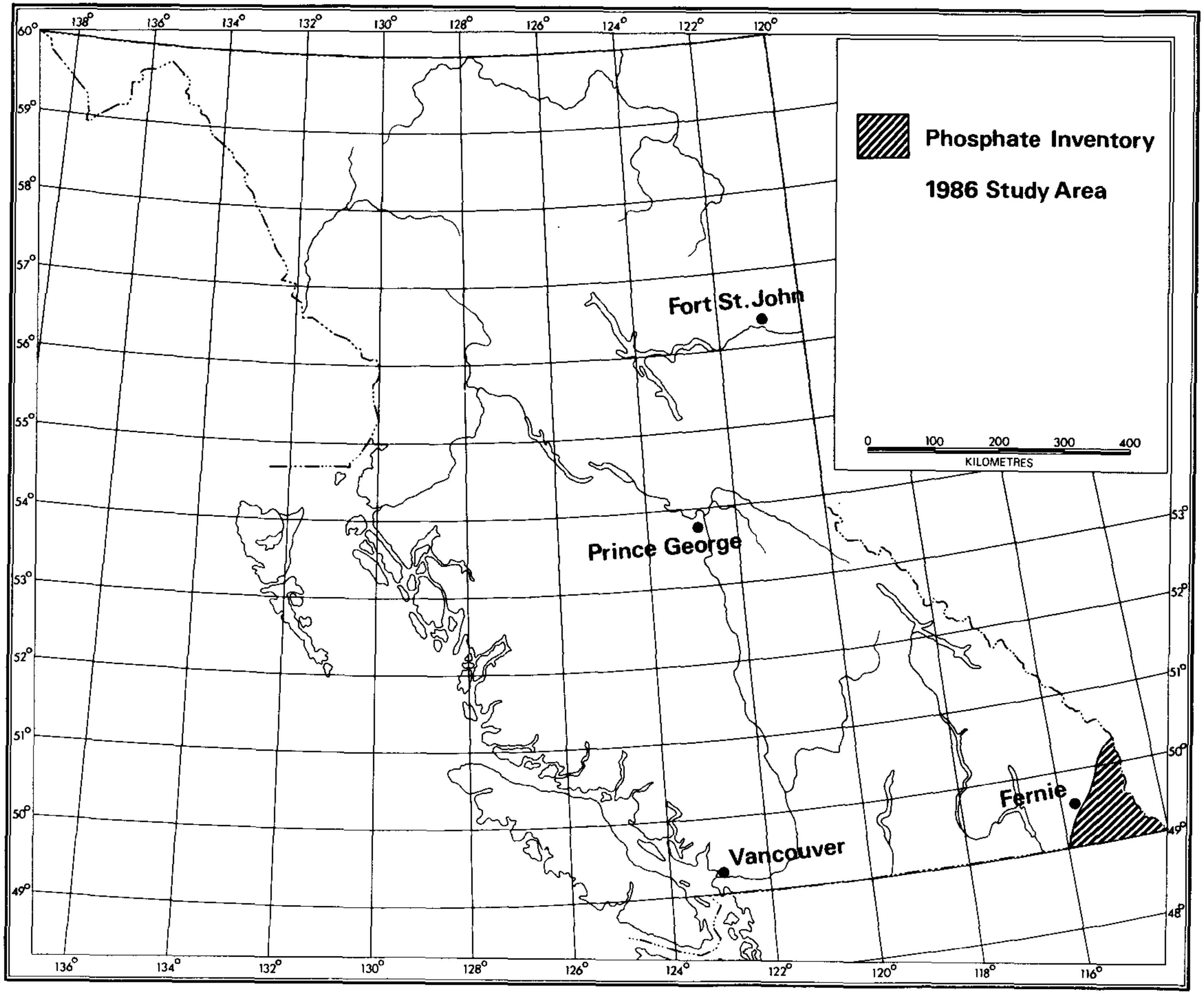

Figure 1. Location of study area.

INTRODUCTION

Although extensive phosphate deposits occur in British Columbia and other regions of Canada, at present all phosphate rock used in Canada is imported. The source of most of our phosphate rock is the United States; Florida supplies 45 to 50 per cent and the western United States 50 to 55 per cent. In 1985 Canada imported 2.64 million tonnes of phosphate rock (Barry, 1987). Imports are expected to decline through 1987. From 1988 onwards experts predict that there will be a steady growth in demand but prices will not rise substantially until at least 1990-92 (Barry, 1987). Energy, Mines and Resources Canada predicts that by 1990 Canada will require 4.6 to 5 million tonnes of phosphate rock annually (Werner, 1982). These additional requirements will probably not be available from current sources and Canada will have to look for new suppliers or produce phosphate rock within its own borders.

In 1983 the average cost paid by fertilizer plants in Canada per tonne of phosphate rock in Canada was $75 (Prud'homme and Francis, 1987). Christie (1981) estimated that it would cost approximately $73 per tonne to deliver phosphate rock from Baja California to Calgary. It is predicted that prices for phosphate rock will remain competitive until the end of the 1980s and then rise from the current price of US$27.50 f.o.b. vessel Tampa to US$45 per tonne in 1995 (basis 70 per cent bone phosphate of lime). Prices approaching $70 to $80 range could make deposits in Canada economic (Barry, 1987).

It is estimated that future annual growth rates of worldwide phosphate consumption will be 3 per cent in the fertilizer industry and 2 per cent in the non-fertilizer sector. Present trends are toward the mining of lower grade deposits resulting in increased interest in treating lower grade material at minimal cost (Lavers, 1986). The trend is for exporting countries to treat their own rock and export products with higher added value. Imports of phosphate rock will be increasingly limited to those countries that have a supply of sulphuric acid at competitive prices (Lavers, 1986). Canada has a more than adequate supply of both sulphuric acid and sulphur.

Phosphate is produced from three sources: marine sedimentary deposits, igneous apatite (carbonatites and related alkaline intrusions) and guano-derived deposits. Approximately 80 per cent of phosphate production is from bedded sedimentary rocks and most of the balance is from alkaline igneous rocks or carbonatites. Approximately 90 per cent of phosphate rock production is used in the fertilizer industry.

British Columbia is known to have extensive marine sedimentary phosphate deposits although none are considered economic at the present time. Recent studies have delineated several carbonatite bodies, some of which are reported to contain apatite.

In 1986 a program funded under the Canada/British Columbia Mineral Development Agreement (MDA) was initiated to study the phosphate resource in the province. The 1986 program studied phosphate deposits in southeastern British Columbia (Figure 1) and is the subject of this report. The program is designed to identify potentially economic deposits, and to study their chemical and mineralogical characteristics.

Potential beneficiation problems and economic byproducts (rare earths) will be identified. Carbonatites and the northern part of the province will be investigated in ongoing studies.

METHOD OF STUDY

Since the early work of Telfer (1933), several companies have explored for phosphate in southeastern British Columbia. This work has delineated the stratigraphic setting of phosphatic horizons and identified several significant phosphate occurrences. However, there has been no comprehensive review of these occurrences.

This study is an attempt to collect all available data on phosphate resources and compile a comprehensive province-wide inventory. The ultimate objective is to identify potentially economic deposits.

During the compilation stage of the project favourable stratigraphic horizons were identified and known phosphate occurrences were recorded for follow-up field examination. Fieldwork consisted of an evaluation of reported phosphate occurrences and examination of stratigraphic horizons known to contain phosphate deposits. Phosphate localities were chip sampled and, wherever possible, stratigraphic sections were measured. Samples were analysed for phosphate, copper, lead, zinc and arsenic. Further analyses will be done to determine their uranium, vanadium and rare earth content. Specimens were also collected for petrographic and X-ray diffraction studies, and whole rock and trace element analyses. These studies will help to determine potential beneficiation problems and to identify potential byproducts.

Analytical results are tabulated in Appendix 2 and sample locations are shown in Figure 2.

Seventeen samples were submitted for X-ray diffraction work and 15 samples for whole rock and trace element analyses.

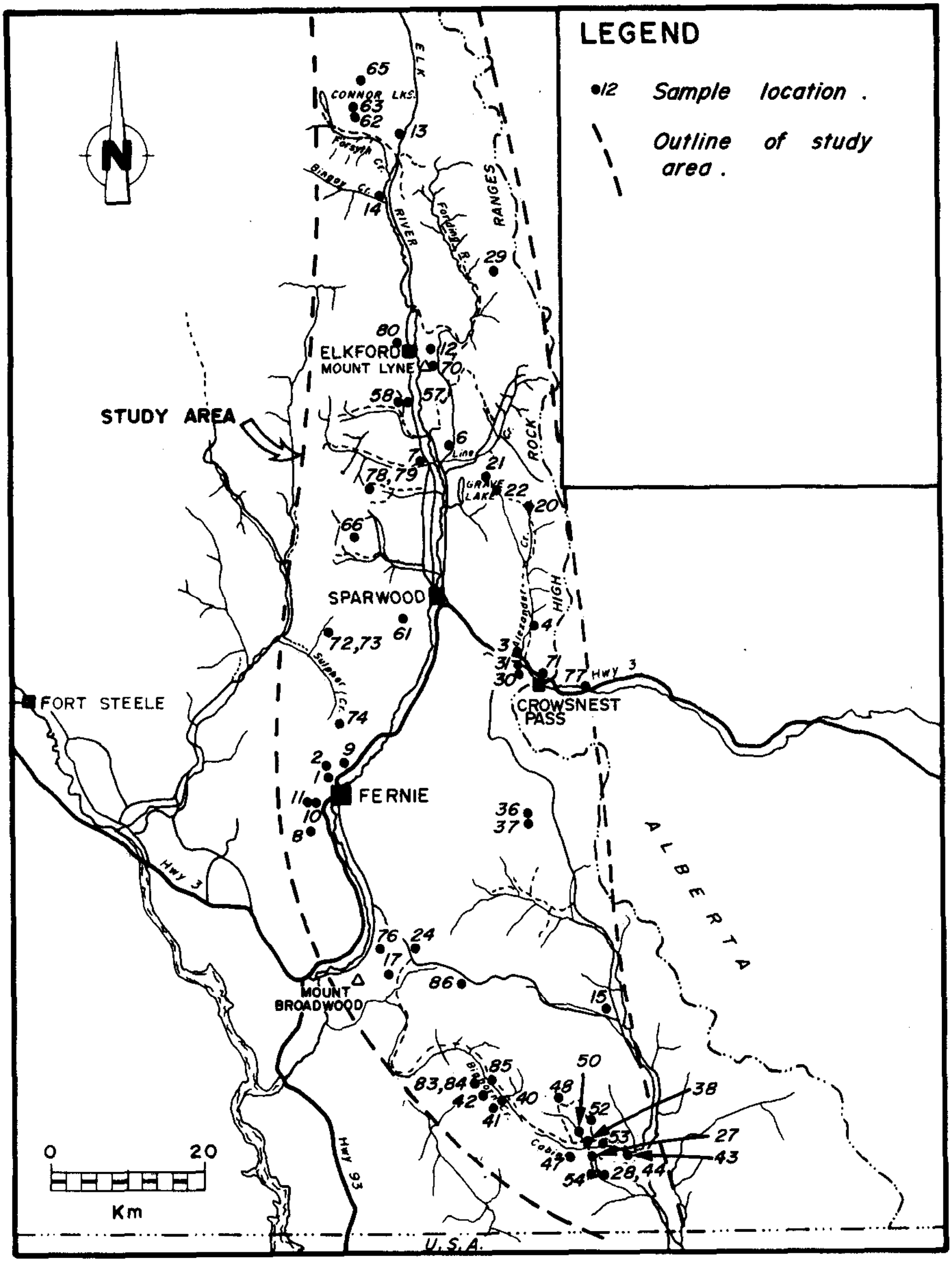

Figure 2. Sample location map.

REGIONAL GEOLOGY

Phosphate deposits in southeastern British Columbia occur in a sequence of marine strata ranging in age from Devonian to Jurassic (Figure 3). These strata lie within the thrust and fold belt of the Rocky Mountains and have generally been thrust eastward onto the craton. Prior to the deposition of the first phosphate beds a thick sequence of carbonate rocks of Middle Cambrian to Upper Devonian age was deposited in the Alberta Trough (Christie and Kenny, in preparation). Deposition of the first phosphate took place in the Upper Devonian-Lower Mississippian Exshaw Formation. Mississippian strata of the Rundle Group, consisting of crinoidal limestone, argillaceous and cherty limestone, shale and finely crystalline limestone and dolomite, were deposited in a shallow shelf environment. In the field these strata are conspicuous by their resistant cliff-forming appearance.

During the Pennsylvanian-Permian, deposition of shallow-marine fine clastic and carbonate strata took place under quiescent conditions (Douglas *et al.*, 1970). Pennsylvanian quartzitic sandstone and chert-bearing dolomite and limestone were deposited in a neritic to littoral environment. The Permian is characterized by low hinterland relief and low-energy, shoreline environments (MacRae and McGugan, 1977). During this time there were a number of marine transgressions and regressions resulting in a number of unconformities. In the waning stages of the Permian, sabkha conditions appear to have been present locally, resulting in the deposition of evaporites. Phosphate deposition occurred at several stratigraphic intervals and is frequently associated with unconformities. The end of the Permian is marked by a major unconformity.

Triassic sediments of the Sulphur Mountain Formation were laid down during minor marine transgressions and regressions in a deltaic type environment (Douglas *et al.*, 1970). Sediments of the overlying Whitehorse Formation were deposited in a more restricted shallow-marine, intertidal and/or lagoonal environment with an arid to semi-arid climate (Douglas *et al.*, 1970; Gibson, 1974). A major unconformity marks the end of the Triassic.

During the Jurassic, subsidence in the Alberta Trough was minimal. Moderately deep-water sedimentation was interrupted by only minor regressions. Deposition of widespread phosphorite and phosphatic shales began in Sinemurian time and phosphatic shales persist into the Toarcian. Sedimentation gradually became non-marine at the end of the Jurassic.

The phosphate-bearing sequence is overlain by non-marine Cretaceous strata containing extensive coal measures.

Thrust faults with displacements of up to 165 kilometres are important structural features in southeastern British Columbia (Benvenuto and Price, 1979; MacDonald, 1985). These thrusts extend for many kilometres in a north-south direction and have generally resulted in older rocks overriding younger rocks to the east. Notable examples of these faults are the Lewis thrust with a displacement of 72 kilometres (Christie and Kenny, in preparation), the Hosmer thrust west of Fernie and the Bourgeau thrust along the west side of the Elk River in the

Age	Group/Formation (Thickness, Metres)	Lithology	Phosphate	Thickness (metres)	Grade (% P_2O_5)
Cretaceous	Kootenay Fm.	— grey to black carbonaceous siltstone and sandstone; nonmarine; coal			
Jurassic	Fernie Fm. (±244)	— black, shale, siltstone, limestone; marine to nonmarine at top — glauconitic shale in upper section — belemnites; common fossil — rare calcareous sandstone — thin conglomerate may be present at base	— basal phosphate in Sinemurian strata; generally pelletal/oolitic; rarely nodular; 1-2 metres thick; locally two phosphate horizons; top of phosphate may be marked by a yellowish-orange weathering marker bed — approximately 60 metres above base low-grade phosphate bearing calcareous sandstone horizon or phosphatic shale	1-2	11-29
		regional unconformity			
Triassic	Spray River Group: Whitehorse Fm.	— dolomite, limestone, siltstone			
	Spray River Group: Sulphur Mtn. Fm. (100-496)	— grey to rusty-brown weathering sequence of siltstone, calcareous siltstone and sandstone, shale, silty dolomite and limestone	— nonphosphatic in southeastern British Columbia		
		regional unconformity			
Permian	Ishbel Group: Ranger Canyon Fm. (1-60)	— sequence of chert, sandstone and siltstone; minor dolomite and gypsum; conglomerate at base — shallow marine deposition	— basal conglomerate-chert with phosphate pebbles present (≤1 metre) — upper portion — brown, nodular phosphatic sandstone; also rare pelletal phosphatic sandstone (few centimetres to +4 metres)	0.5-1.0 0.6	13-18 9.5
	Ishbel Group: Ross Creek Fm. (90-150)	— sequence of siltstone, shale, chert, carbonate and phosphatic horizons areally restricted to Telford thrust sheet — west of Elk River, shallow marine deposition	— phosphate in a number of horizons as nodules and finely disseminated granules within the matrix — phosphatic coquinoid horizons present	0.4-1.0	1.7-6.0
		unconformity			
	Ishbel Group: Telford Fm. (210-225)	— sequence of sandy carbonate containing abundant brachiopod fauna; minor sandstone — shallow marine deposition	— rare, very thin beds or laminae of phosphate; rare phosphatized coquinoid horizon	0.3	11.4
	Ishbel Group: Johnson Canyon Fm. (1-60)	— thinly bedded, rhythmic sequence of siltstone, chert, shale, sandstone and minor carbonate; basal conglomerate — shallow marine deposition	— basal conglomerate (maximum 30 centimetres thick) contains chert and phosphate pebbles — phosphate generally present as black ovoid nodules in light-coloured siltstone; phosphatic interval ranges in thickness from 1-22 metres — locally present as a black phosphatic siltstone or pelletal phosphate	1-2 1-22 0.2-0.3	14.2-21.2 0.1-11.0 3.0-4.0
		regional unconformity			
Pennsylvanian	Kananaskis Fm. (±55)	— dolomite, silty, commonly contains chert nodules or beds	— locally, minor phosphatic siltstone in uppermost part of section		
	Tunnel Mountain Fm. (±500)	— dolomitic sandstone and siltstone			
Mississippian	Rundle Group (±700)	— limestone, dolomite, minor shale, sandstone and cherty limestone			
Mississippian	Banff Fm. (280-430)	— shale, dolomite, limestone			
Devonian-Mississippian	Exshaw Fm. (6-30)	— black shale, limestone — areally restricted in southeastern British Columbia	— basal phosphate less than 1 metre thick; pelletal — phosphatic shale and pelletal phosphate 2-3 metres above base — an upper nodular horizon		
Devonian	Palliser Fm.	— limestone			

Figure 3. Stratigraphy of phosphate-bearing formations in southeastern British Columbia (modified from Butrenchuk, 1987).

northern part of the study area. Folds formed in conjunction with the thrust faulting. Other faulting includes northeast-trending transverse faults and two ages of north-trending normal faults (Christie and Kenny, in preparation).

A second important structural feature is the Fernie synclinorium (basin). This double-plunging synclinal fold (which is delineated by the distribution of the Jurassic Fernie Formation) has been the focus of phosphate exploration for many years. Several west-side-down normal faults cut through the centre of the synclinorium, including the Erickson and Flathead faults.

An important factor in the evaluation of phosphate deposits is the structural style of the host lithologies. In southeastern British Columbia beds of Triassic or younger age generally have gentle to moderate dips. The Fernie Formation, being less competent, has absorbed much of the structural deformation and beds may have gentle to vertical dips. In many places beds of all ages are overturned and truncated by thrust faults. Elsewhere, especially in the Fernie Formation, thrusting has caused a repetition of beds, as at the Crow property (Telfer, 1933), resulting in a thickening of the phosphate section. Areas where phosphate beds have been thickened by repetitive thrust faulting are of particular economic significance, as are areas of overturning where competent strata of the Triassic Sulphur Mountain Formation overlie the basal phosphate and incompetent shale beds of the Jurassic Fernie Formation. Where beds are overturned, the more competent Triassic lithologies provide a better back for underground mining.

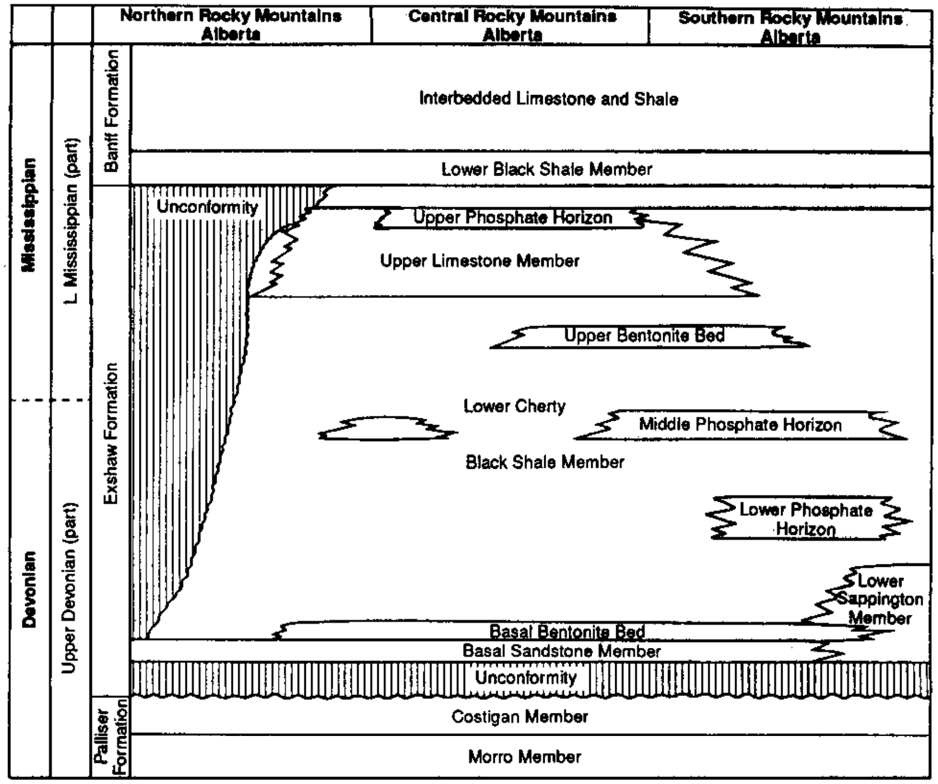

Figure 4. Age, nomenclature and stratigraphic relationships - Exshaw Formation (modified from MacDonald, 1985).

PHOSPHATE STRATIGRAPHY

EXSHAW FORMATION

The first deposition of phosphate took place in the Upper Devonian-Lower Mississippian Exshaw Formation (Figure 4). This is a distinctive, recessive black shale unit that forms an excellent marker (Plate 1). Exposures of Exshaw Formation are restricted to a narrow band in the High Rock Range, locally in the Flathead River area, and in the Morrissey Range south of Fernie. The best occurrences of phosphate occur north and south of Crowsnest Pass.

Investigation of the Exshaw Formation was limited to a single outcrop south of Highway 3, at the southwest end of Crowsnest Lake. Here, the formation is in fault contact with the underlying Palliser Formation (Figure 5). At this locality it is comprised of shale, fine siltstone, phosphatic shale and minor phosphate. A limestone band present within the unit may belong to the Banff Formation. The overlying shale may be a repetition of the Exshaw as a fault occurs at the top of the limestone. Phosphate at this locality is low grade (less than 4 per cent P_2O_5) with the highest grade (3.60 per cent P_2O_5) occurring above the central limestone band.

Phosphate occurs at four horizons within the Exshaw Formation (MacDonald, 1985). A basal phosphate is present in sandstone overlying the top of the Palliser Formation, but was not observed at the locality on Highway 3. Three other phosphate horizons occur in the middle and upper portions of the formation. They consist of pelletal and nodular phosphate and a fine-grained phosphorite that are best developed in the area between Phillipps Pass and Racehorse Pass north of Crowsnest Pass (Kenny, 1977; MacDonald, 1985).

A thin section of material taken from the phosphatic horizon midway between the base of the Exshaw and the middle limestone unit indicates that the phosphate occurs as dispersed pellets 1 millimetre or less in size. These pellets are subrounded and constitute approximately 10 per cent of the rock by volume. Most of the pellets are structureless although a few are nucleated. MacDonald (1985) observed that most of the phosphate in the lower and middle horizons is pelletal with nucleated and oolitic varieties predominant. Structureless nodules and intraclasts are also present. The basal phosphate consists of nodules up to 2 centimetres in size, bone fragments, intraclasts and nucleated and rimmed pellets; the uppermost phosphate horzion consists of a conglomeratic mixture of nodules, bone fragments and minor pellets and intraclasts (MacDonald, 1985).

BANFF FORMATION

The Banff Formation of Lower Mississippian age conformably overlies the Exshaw Formation. This sequence consisting of interbedded limestone, dolomite and shale varies in thickness from 280 to 430 metres. No phosphate is known to occur in this unit within the study area.

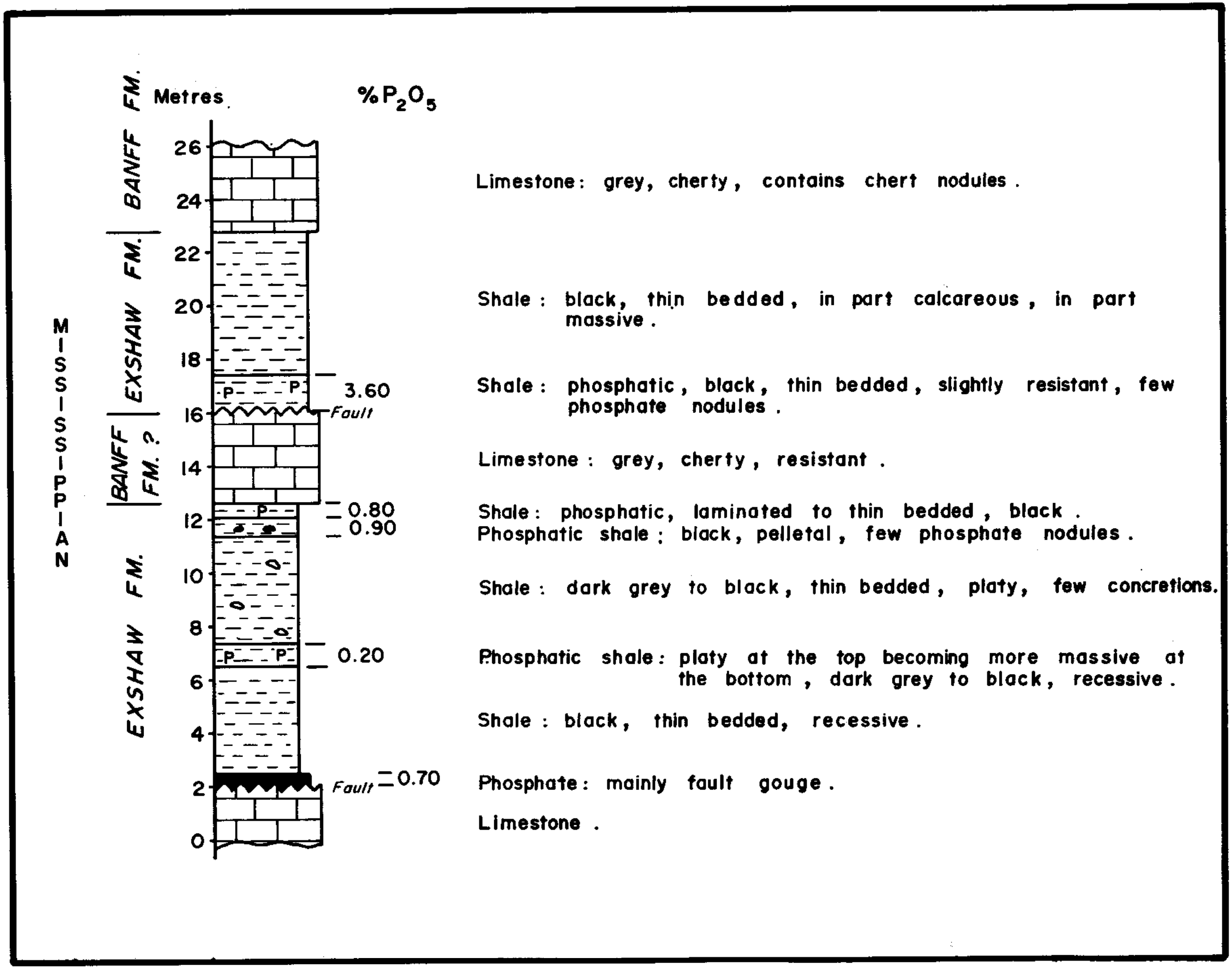

Figure 5. Stratigraphic section 77: Highway 3, Crowsnest Lake, Alberta.

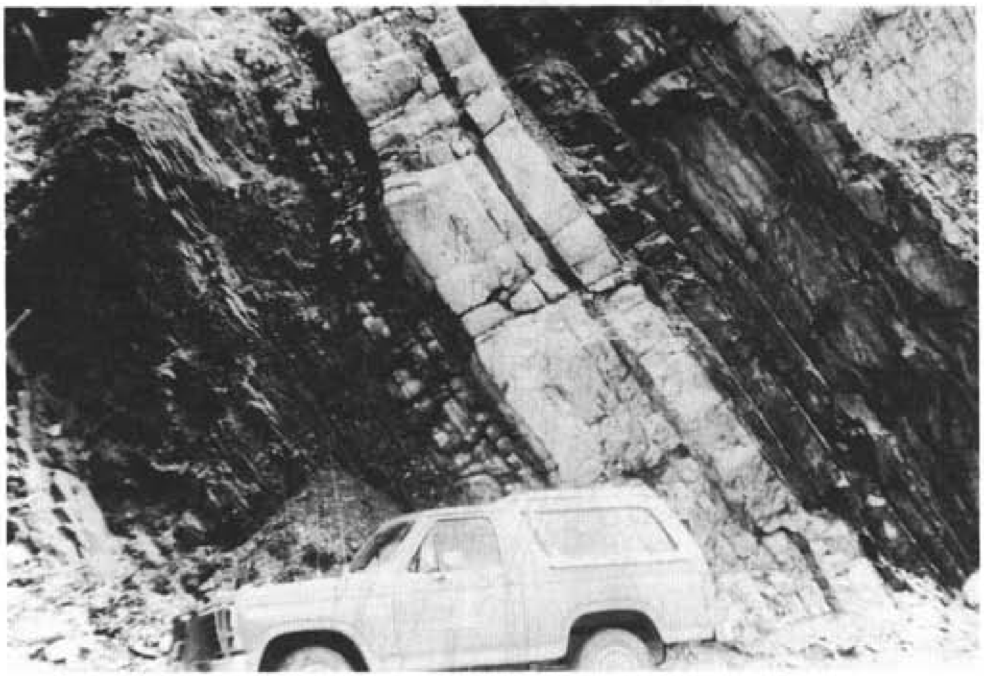

Plate 1. Outcrop of Exshaw Formation south of Highway 3, at the southwest end of Crowsnest Lake, Alberta.

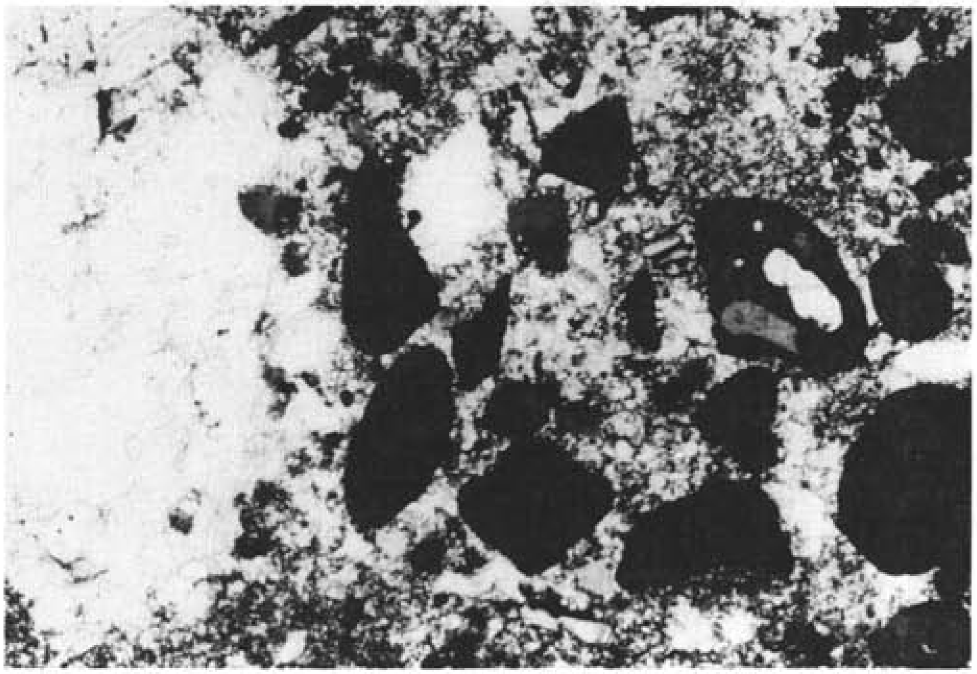

Plate 2. Photomicrograph (40x) of phosphate pellets (black) within a matrix of calcite and quartz. Large crystal on right of photograph is calcite. From Kananaskis Formation, Cabin Creek.

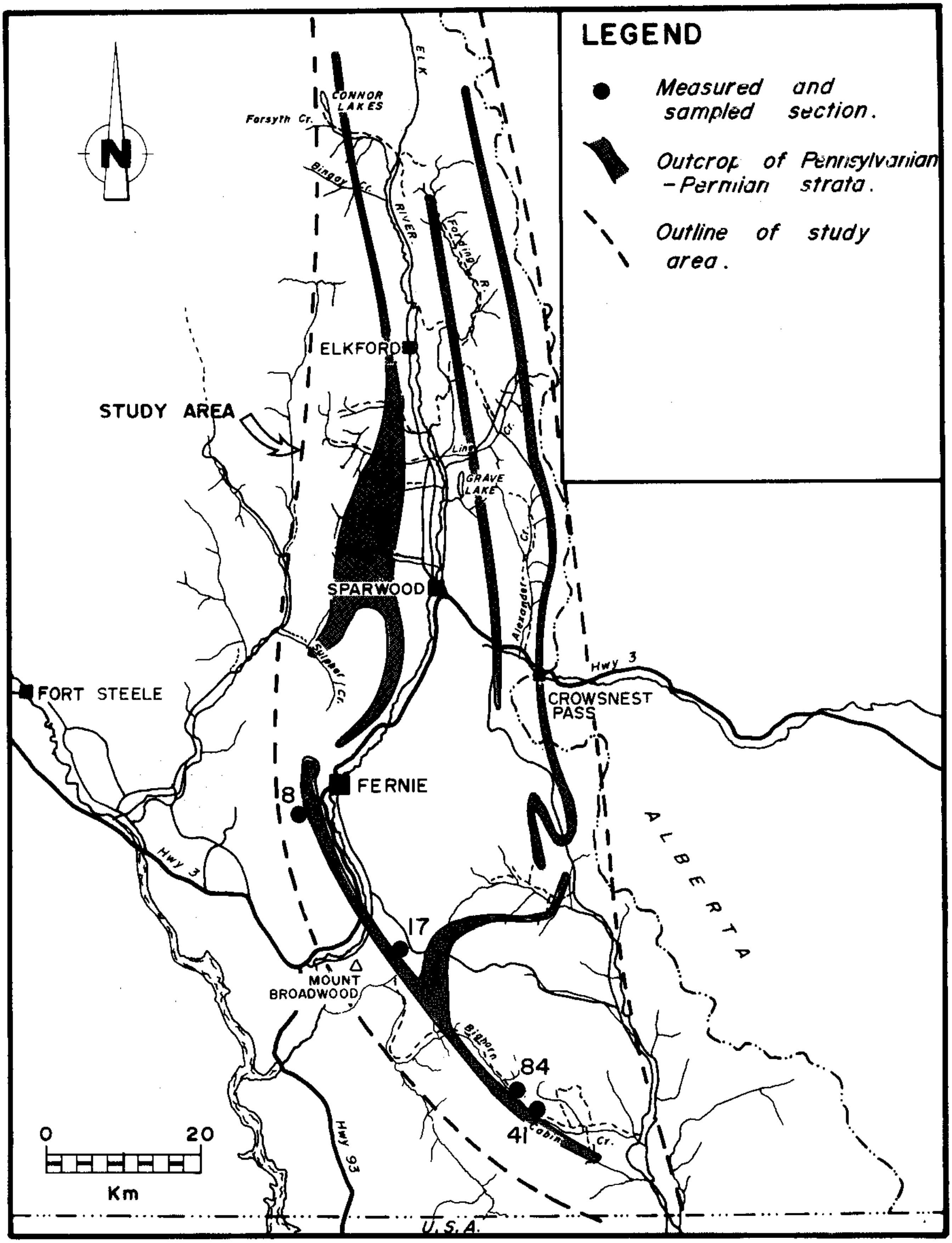

Figure 6. Distribution of Pennsylvanian-Permian strata in southeastern British Columbia (Butrenchuk, 1987).

RUNDLE GROUP

The Rundle Group of Mississippian age consists of a sequence of resistant, thick-bedded crinoidal limestone, fine crystalline limestone, argillaceous limestone and shale, which attains thicknesses of approximately 700 metres. Deposition is believed to have taken place in a carbonate shelf environment. These strata are non-phosphatic in the study area.

TUNNEL MOUNTAIN FORMATION

The Tunnel Mountain Formation of Lower Pennsylvanian age is described as a uniform, monotonous sequence of reddish brown-weathering dolomitic sandstone and siltstone (MacDonald, 1985). It is exposed as far west as the Elk River where it attains thicknesses in excess of 500 metres and thins eastward to a thickness of 18 metres in the Highwood Range. Minor phosphate is associated with intraformational conglomerate (1.22 per cent P_2O_5 across 10 centimetres) within this formation in Alberta (MacDonald, 1985).

KANANASKIS FORMATION

The Middle Pennsylvanian Kananaskis Formation conformably overlies the Tunnel Mountain Formation. It consists of a sequence of light grey, silty dolomite and dolomitic siltstone. Chert nodules and intraformational chert breccias are found in the upper part of the section. This unit attains its greatest thickness (approximately 70 metres) near Fernie and gradually thins eastward. Its contact with overlying Permian Ishbel Group strata is conformable. The contact is generally marked by a thin (30-centimetre) phosphatic chert-pebble conglomerate. Locally, as in the vicinity of the Fernie ski-hill, the contact zone consists of a series of concordant beds that are differentiated by a change to darker coloured Permian strata and a 1-centimetre-thick phosphatic conglomerate.

Phosphate is rare in the Kananaskis Formation, only being observed at one locality along the MacDonald thrust fault. Here, disseminated phosphate grains and rare nodules or intraclasts are present in a calcareous siltstone (Plate 2). Some phosphate also replaces shell fragments or sponge spicules. A grab sample of typical material from this locality contained 1.3 per cent P_2O_5.

ISHBEL GROUP

The Ishbel Group of Permian age (*see* Figure 6) is comprised of four formations containing a number of phosphatic horizons (Figure 7). Phosphate is present in the Johnson Canyon, Ross Creek and Ranger Canyon Formations. The Telford Formation is non-phosphatic except for phosphate laminae and rarely, a very thin phosphate bed.

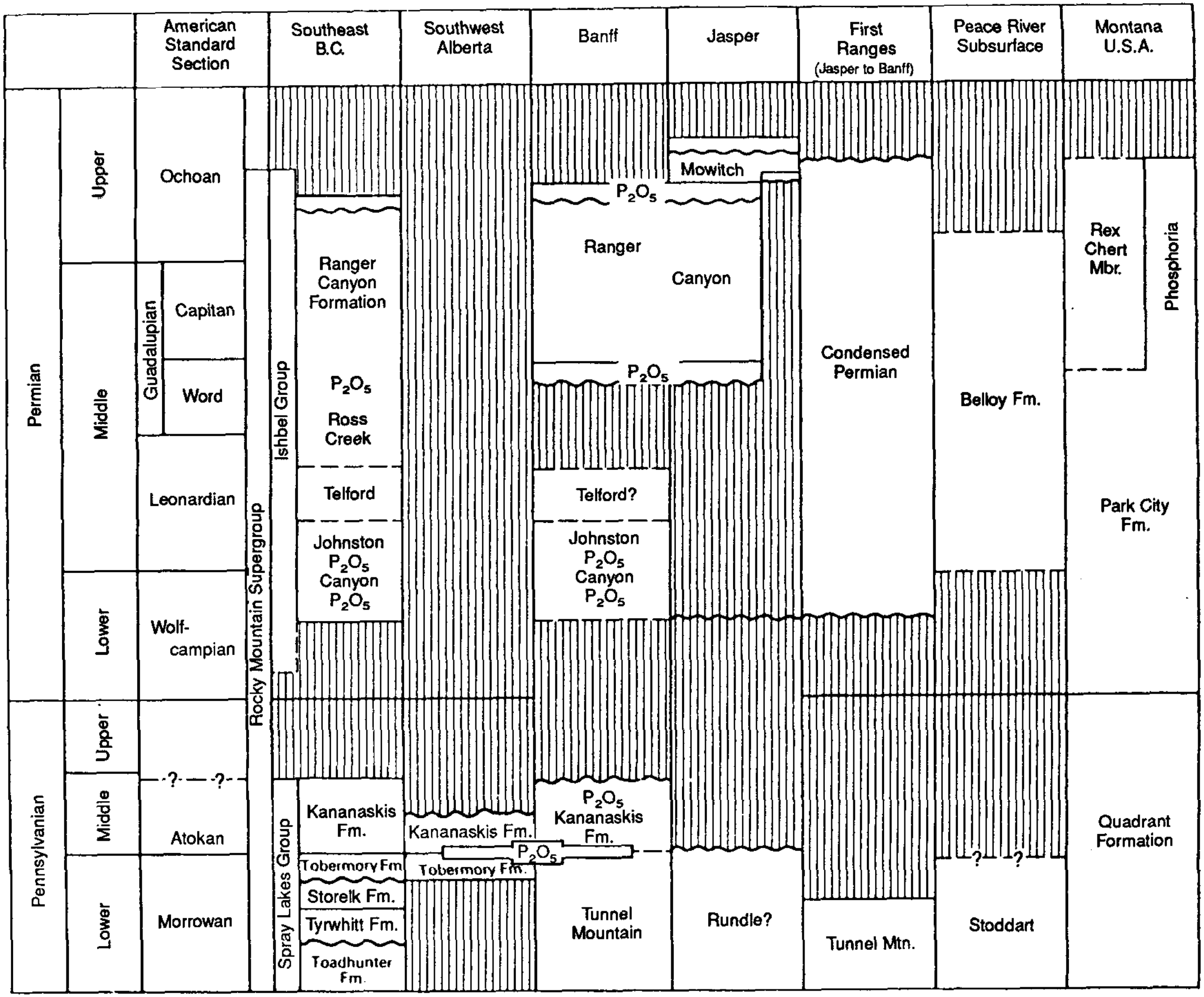

Figure 7. Nomenclature and stratigraphic correlation chart of the Rocky Mountain Supergroup, Alberta, British Columbia and Montana (MacDonald, 1985).

Johnson Canyon Formation

The Johnson Canyon Formation, which unconformably overlies Kananaskis or Tunnel Mountain strata, consists of a series of thin to medium-bedded siltstone and sandstone with minor shale and chert. Locally these strata are calcareous. A phosphatic chert-pebble conglomerate, a few centimetres thick, marks its base (MacRae and McGugan, 1977). Phosphate is present as black nodules in distinct horizons within sandstone, siltstone or calcareous siltstone beds at or near the base of the formation. It is also present as phosphate-cemented siltstone or as pelletal phosphorite. Phosphatic intervals range in thickness from less than 1 metre to a maximum of 22 metres near Mount Broadwood (Plate 3).

The nodular phosphatic horizons may contain true nodules formed *in situ* or intraclasts that have been transported a short distance. Intraclasts are distinguished from nodules by the fact that contained nuclei differ in size from that of the surrounding matrix. They may also be comprised of several pellets and/or bioclastic debris.

Pelletal phosphorite was observed north of Weigert Creek. Phosphate pellets 0.1 to 0.5 millimetre in size comprise 50 to 60 per cent of the rock by volume. The pellets, which are subrounded, ovoid, structureless and chestnut-brown to dark brown in colour, occur in a matrix consisting mainly of quartz and calcite. This phosphorite is interpreted to occur on the limbs of an anticline.

Phosphate as cement in sedimentary rocks was observed near the headwaters of Nordstrum Creek, where phosphate cement, probably fluorapatite, encloses quartz grains. Phosphate pellets are also present. The bed containing this phosphate is 1 metre thick and contains 21.2 per cent P_2O_5.

Telford Formation

The Telford Formation comprises a thick sequence of carbonates and sandy carbonates. Much of this carbonate sequence is thick bedded and fossiliferous. These strata are resistant cliff-forming units that are preserved only in the Telford thrust plate (MacRae and McGugan, 1977).

Prior to this study, phosphate was thought to be absent in the Telford Formation. Although rare, some phosphate does occur in the middle part of the section. Our observations indicate the presence of a single nodular phosphate bed, 30 centimetres thick; a sandstone bed containing fine phosphate laminae (Plate 4); and a phosphatic coquinoid bed, 5 centimetres thick (Plate 5). Although thin, these beds appear to have been deposited over a wide area under conditions of very quiescent sedimentation.

Ross Creek Formation

The Ross Creek Formation, preserved only in the Telford thrust plate, consists of a sequence of recessive thin-bedded siltstone, argillaceous siltstone, minor carbonate and chert (MacRae and McGugan,

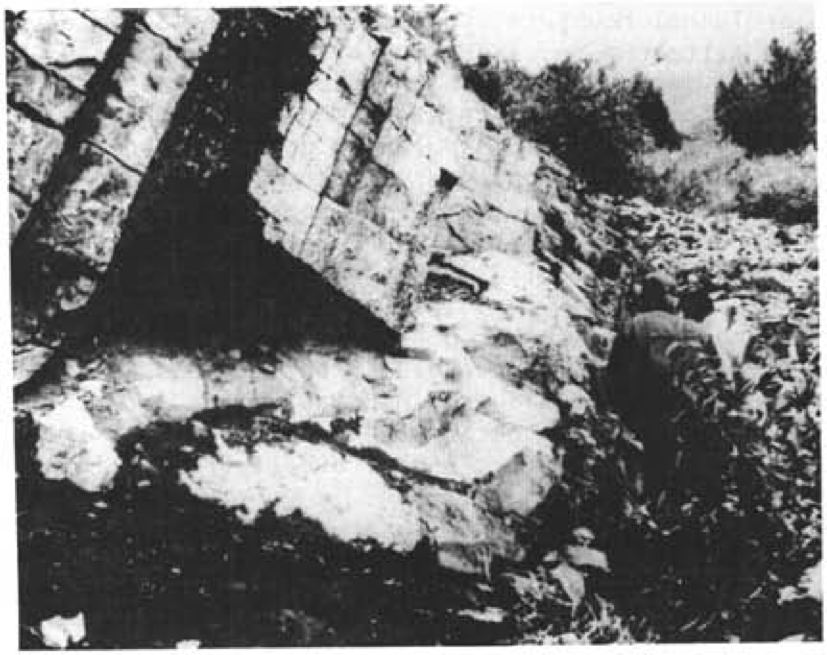

Plate 3. Phosphatic section of Johnson Canyon Formation, Mount Broadwood.

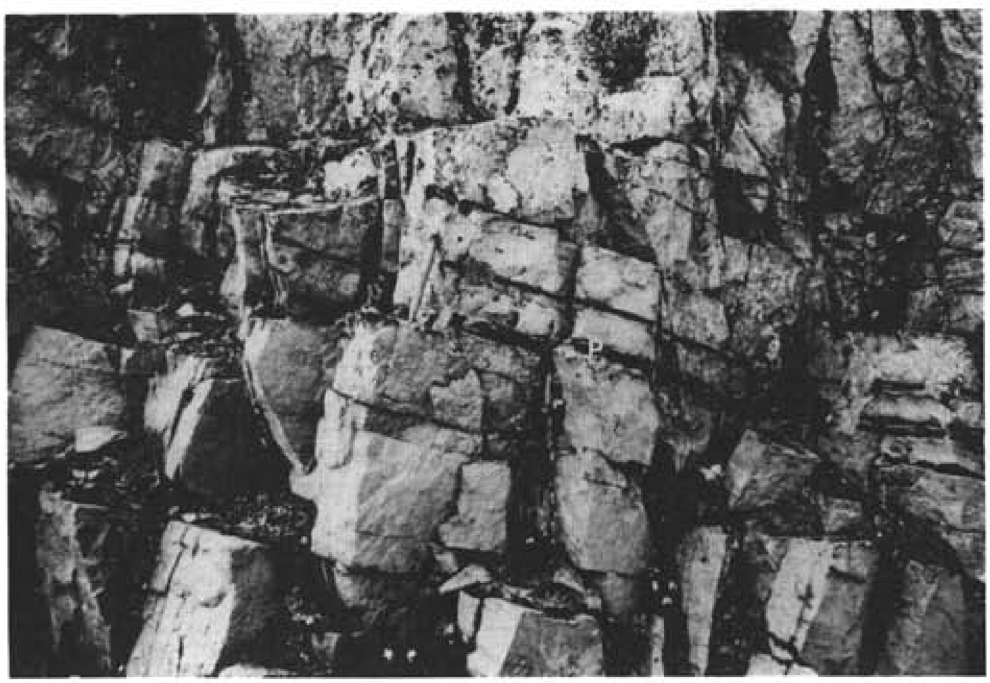

Plate 4. Phosphate laminae (P) in a sandstone bed, Telford Formation, Telford Creek.

Plate 5. Phosphatic coquinoid bed (P) in Telford Formation, Telford Creek area.

Plate 6. Phosphate nodules (N) within a coquinoid bed of Ross Creek Formation, north of Sulphur Creek.

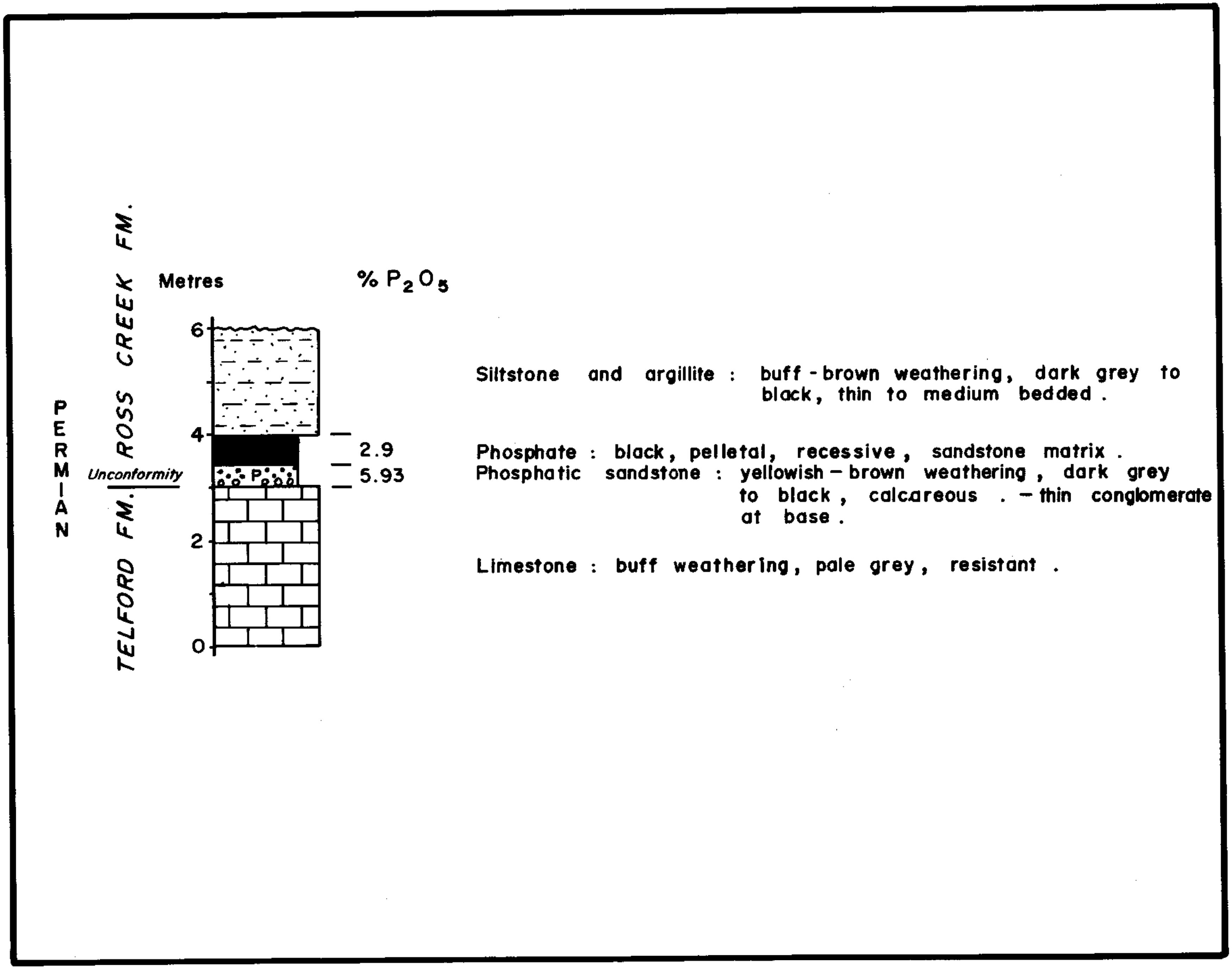

Figure 8. Stratigraphic section 80: Elkford ski-hill.

1977). Nodular phosphate occurs in the upper portion together with relatively thin coquinoid horizons. The matrix in the coquinoid horizons contains some phosphatic material (Plate 6). Locally, as at the Elkford ski-hill, pelletal phosphate is also present (Figure 8). Unlike the other occurrences in the Ross Creek Formation, the phosphate at this locality occurs at the stratigraphic base of the formation, in an overturned sequence.

Ranger Canyon Formation

The Ranger Canyon Formation, which unconformably overlies the Ross Creek Formation, consists of cliff-forming chert, cherty sandstone, siltstone, fine sandstone and conglomerate. Minor gypsum, as a primary cement in sandstone, and dolomite are also present (Rapson-McGugan, 1970; MacRae and McGugan, 1977). Rapson-McGugan (1970) postulated that these strata were deposited in two environments: (1) a shallow marine shelf starved of terrigenous material but able to produce clastic and authigenic phosphate; or (2) a shoreline constructed of quartzose and phosphatic detritus. The depositional environment of the Ranger Canyon Formation is interpreted to be similar to that of Baja California, where shelf phosphate, with associated lag gravels, is forming offshore at the present time (Rapson-McGugan, 1970).

The base of the Ranger Canyon Formation is marked by a phosphate-cemented chert-pebble conglomerate containing massive phosphate intraclasts. This conglomerate was only observed beneath the MacDonald thrust fault in the Cabin Creek area.

Phosphate also occurs in sandstone beds in the upper part of the formation where it is most commonly present as nodules. Phosphatic material is also present as detrital apatite, amorphous and crystallized fragments of bone material, pellets, rods, spheres and oolites (Rapson-McGugan, 1970). Rapson-McGugan (1970) also noted that phosphate, after quartz, was the most frequent clastic component, generally comprising 5 to 6 per cent of the rock.

Phosphate is also present as phosphatic chert. Rapson-McGugan (1970) suggests that much of the chert is a replacement of pelletal phosphorite resulting from solution of phosphate under acidic conditions. If the solution becomes slightly alkaline, some relict phosphate will remain in the chert (Rapson-McGugan, 1970). The cherts were not studied in detail, and no petrographic work was done on them in the course of the current study.

Phosphate horizons in the upper part of the Ranger Canyon Formation range in thickness from a few centimetres at Mutz Creek to 4 metres at Fairy Creek, north of Fernie. With the exception of a phosphate bed in the vicinity of the Fernie ski-hill, most of the phosphatic horizons were low grade.

Series	Formation and Thickness (metres)	Member and Thickness (metres)	Lithology
Jurassic	Fernie Formation		
		Unconformity	
Middle or Upper Triassic	Whitehorse Formation (0 to 53)	Undivided	Calcareous to dolomitic sandstone and siltstone: minor sandy, quartzose dolomite, limestone, and collapse breccia
Middle Triassic	Sulphur Mountain Formation (87 to 512)	Llama Member (0 to 64)	Well-indurated dolomitic, quartz siltstone, and very fine-grained sandstone
		Whistler Member (0 to 14)	Shaly- to flaggy-weathering, dolomitic, quartz siltstone
Lower Triassic		Vega Siltstone Member (55 to 364)	Dolomitic to calcareous quartz siltstone, silty limestone, and shale; locally dolomitic sandstone, sandy to silty quartzose dolomite
		Phroso Siltstone Member (30 to 244)	Calcareous and dolomitic siltstone, silty shale, and minor quartz sandstone
		Unconformity	
Permian	Ishbel Group		

Figure 9. Age and nomenclature of Triassic Sulphur Mountain and Whitehorse Formations (modified from Gibson, 1969).

Plate 7. Basal phosphate horizon (P) in Fernie Formation shale (Jf) overlying siltstone of the Sulphur Mountain Formation (Tsr), Mount Lyne; top of the phosphate marked by yellow-orange limestone bed (Y).

SULPHUR MOUNTAIN FORMATION

The Sulphur Mountain Formation unconformably overlies the Ishbel Group (Figure 9) and typically consists of a rusty brown-weathering sequence of medium-bedded siltstones, calcareous and dolomitic siltstones, silty dolomite and limestone, and minor shale. This formation, which attains thicknesses of 100 to 496 metres, exhibits a general thickening northward. Sediments of the Sulphur Mountain Formation are postulated to have been deposited in a shallow-water, deltaic environment (Gibson, 1974). The formation is non-phosphatic in southeastern British Columbia, but northwest of Jasper phosphate occurs in the Whistler Member (Heffernan, 1980; Legun and Elkins, 1986) extending from the British Columbia - Alberta boundary to northwest of Wapiti Lake. Further to the north phosphate is present in the Toad Formation which is stratigraphically correlated with the Sulphur Mountain Formation.

WHITEHORSE FORMATION

The Whitehorse Formation in southeastern British Columbia is restricted to the areas west of the Elk River north of Elkford; north of Grave Lake; and in the Flathead River area south of Fernie (Gibson, 1969). It varies in thickness from 6 to 418 metres and consists of an assemblage of pale-weathering, variegated dolomite, limestone, sandstone and intraformational breccias (Gibson, 1974). Its contact with the underlying Sulphur Mountain Formation is gradational and its contact with the overlying Fernie Formation is disconformable. It is non-phosphatic in the study area.

FERNIE FORMATION

Triassic strata are unconformably overlain by dark grey to black shales, phosphate and minor limestone, siltstone and sandstone of the Jurassic Fernie Formation (Figure 10) (Freebold, 1957, 1969). In southeastern British Columbia this formation (*see* Figure 11) attains thicknesses of 70 and 376 metres with a general thickening westward. A persistent pelletal phosphorite bed, 1 to 2 metres thick and generally containing greater than 15 per cent P_2O_5, occurs at the base of the Fernie in strata of Sinemurian age. It rests either directly on Triassic strata or is separated from the underlying rocks by a thin phosphatic conglomerate. The phosphate interval may also be represented by two phosphate beds separated by phosphatic shale. Thicknesses in excess of 2 metres are attained locally, as at Mount Lyne where 3 metres of phosphate rock are present (Plate 7). Phosphatic shales of variable thickness, generally less than 3 metres, overlie the phosphate. The top of this sequence may be marked by a yellowish-orange calcareous bed 2 to 5 centimetres thick and thin marcasite beds may also be present locally within the phosphatic interval.

A second phosphate horizon lies approximately 60 metres above the base of the Fernie. It is low grade (less than 1 per cent P_2O_5) and may be associated with a belemnite-bearing calcareous sandstone horizon. This horizon was only observed above the railroad tracks south of the

Highway 3 roadcut at Alexander Creek and in a poorly exposed outcrop north of Mount Lyne, where it occurs in shale rather than sandstone.

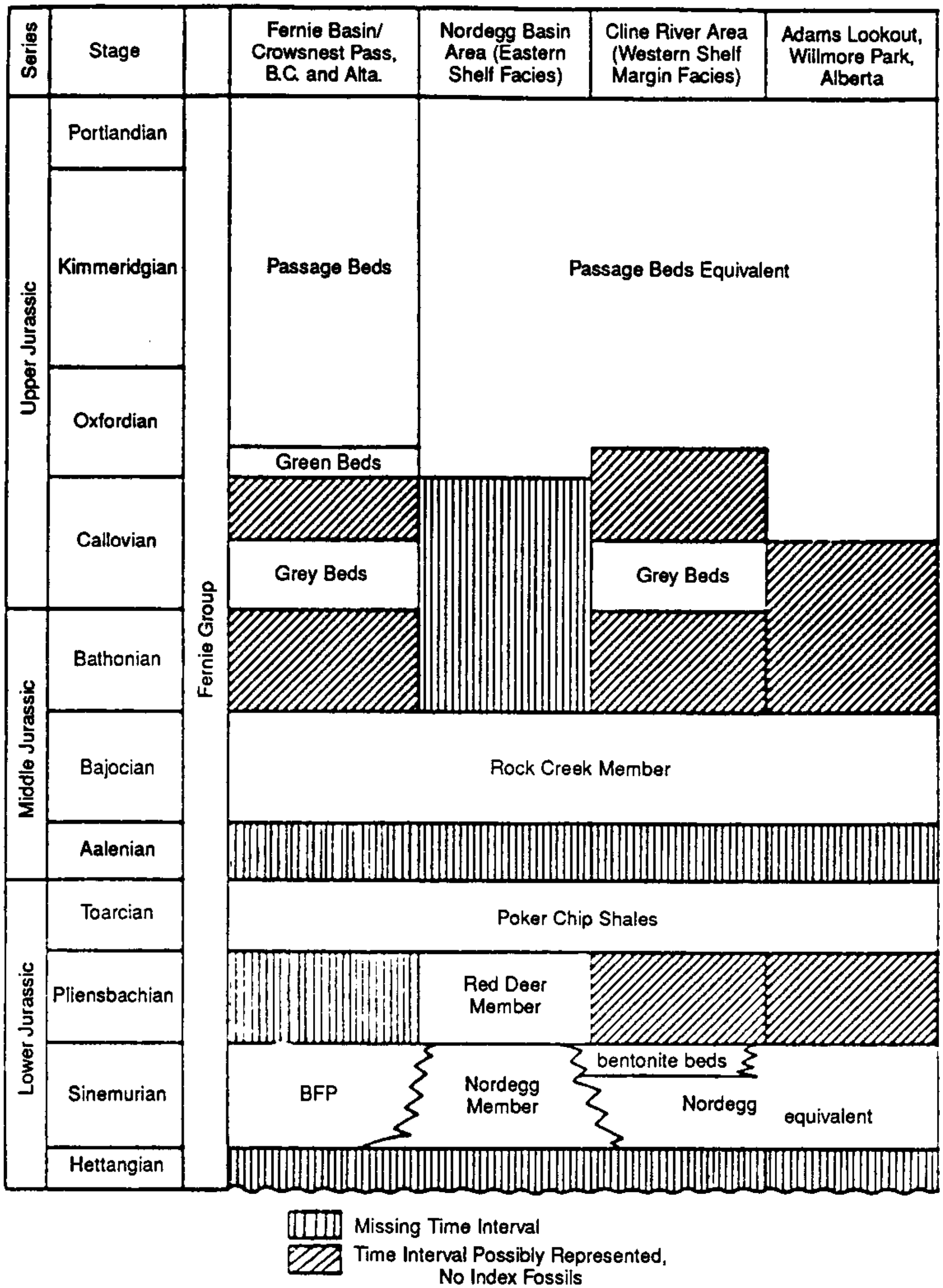

Figure 10. Age and nomenclature of Fernie Group, Alberta and southeastern British Columbia (modified from Freebold, 1957).

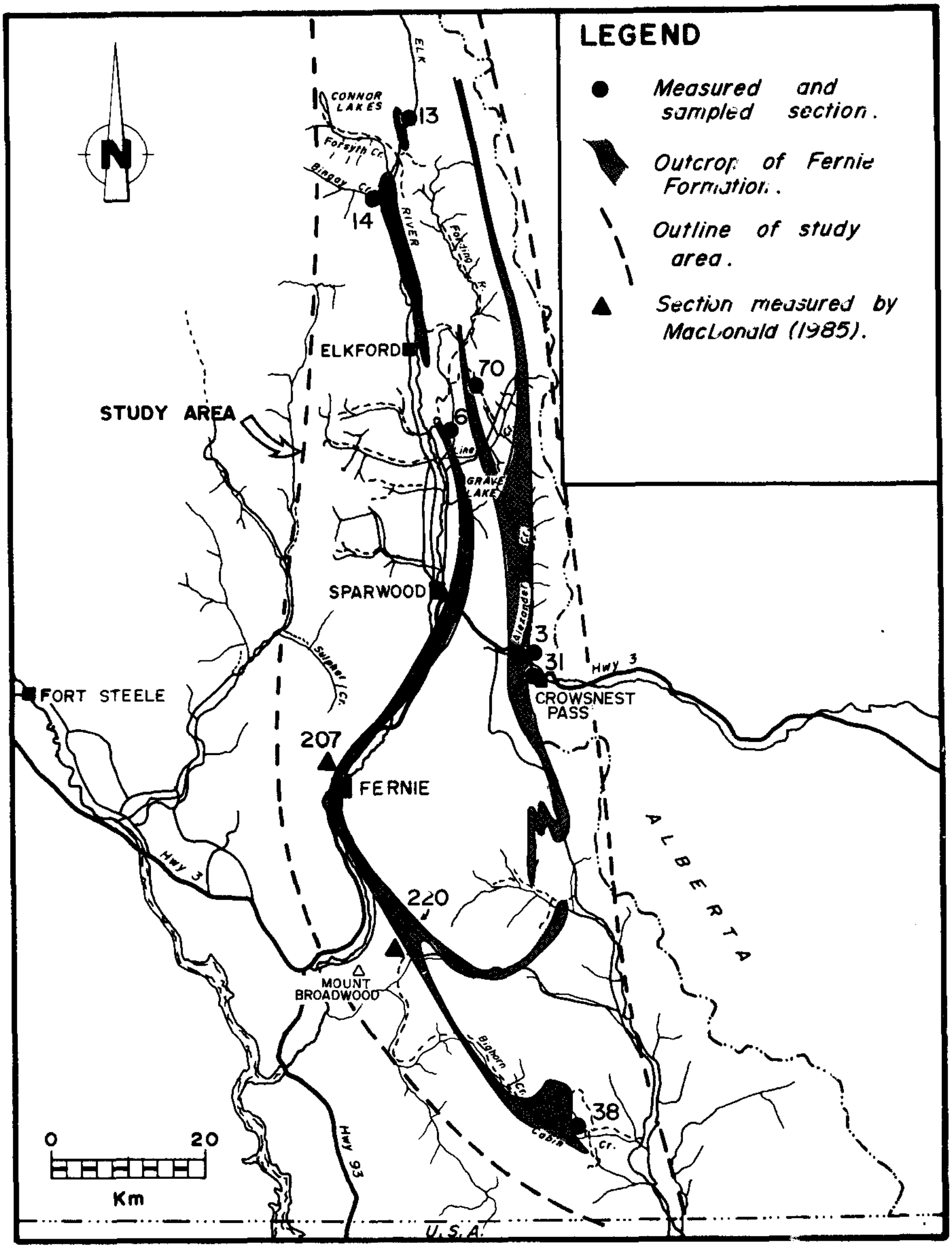

Figure 11. Distribution of the Jurassic Fernie Formation in southeastern British Columbia (Butrenchuk, 1987).

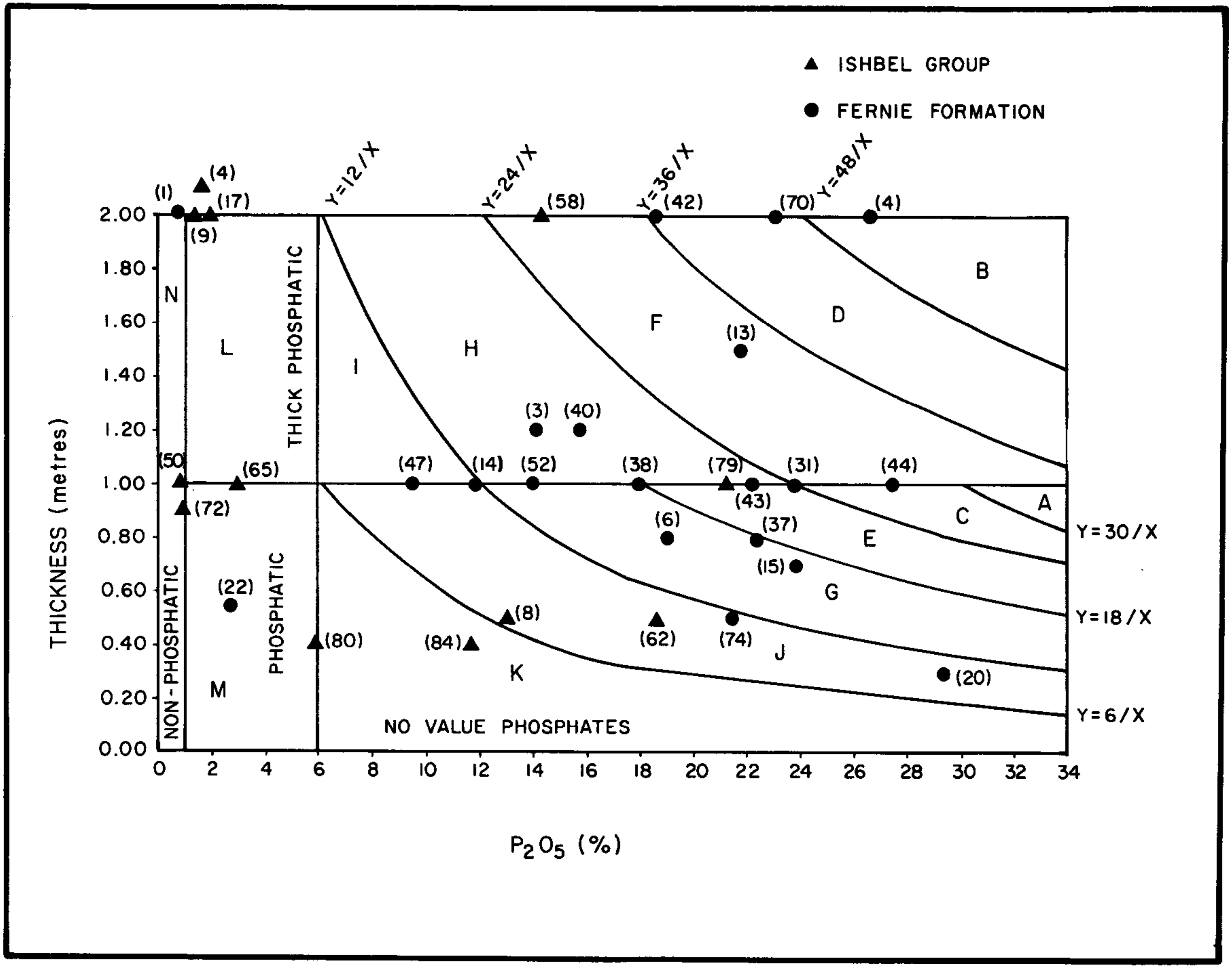

Figure 12. Economic classification of phosphate rocks (MacDonald, 1985).

PHOSPHATE DEPOSITS

Early this century Telfer (1933), while working for the Consolidated Mining and Smelting Company of Canada, Limited (now Cominco Ltd.), recognized a number of distinct stratigraphic intervals containing phosphate. Since this early work a number of authors have recorded the presence of phosphate in southeastern British Columbia. MacDonald (1985) also completed a cursory evaluation of the phosphate potential of the region. Several companies, including Cominco Ltd., Imperial Oil Ltd. (now Esso Minerals Canada), Crows Nest Resources Ltd. and First Nuclear Corp. Ltd. have conducted extensive surface exploration for phosphate.

Phosphate deposition in southeastern British Columbia occurred principally in the Exshaw Formation, Ishbel Group and Fernie Formation (*see* map in pocket). MacDonald (1985) reports some deposition during Late Pennsylvanian time and Telfer (1933) suggests that some phosphate was deposited during the Triassic. Only the Jurassic Fernie Formation and the Permian Ishbel Group contain phosphate deposits of some economic significance while the remaining phosphatic units are of interest as marker horizons or as mineralogical curiosities.

Figure 12 is a diagrammatic representation of an economic classification of phosphate rocks developed by MacDonald (1985); thickness and grade are used to determine the economic significance for any phosphate occurrence. The curves and domains are arbitrary based on 1 and 2 metres as alternative mimimum mining widths for a phosphate orebody. The potential economic importance of a deposit can be quickly determined and comparisons made between phosphate occurrences at different stratigraphic horizons. This diagram does not take into account other economic factors such as mining method and cost, impurities that may affect the beneficiation (calcite, dolomite) or transportation and infrastructure costs.

With the exception of a few localities, phosphate occurrences in the Ishbel Group appear to have little economic potential. While thicknesses at many localities are in excess of 2 metres, phosphate content rarely exceeds 1 or 2 per cent P_2O_5. Only occurrences at Weigert Creek (58) and Nordstrum Creek (79) may be of possible interest. Most thicker sections contain several nodular phosphatic beds. While the nodules themselves may contain in excess of 25 per cent P_2O_5, this is not reflected in the rock as a whole.

The Fernie Formation has a wide range of values from very high to sub-economic. The most significant occurrences are at Mount Lyne (70) and the Crow deposit (4). The Cabin Creek area (represented by samples 42, 43 and 44) and the Abby Ridge area (sample 13) may also have some economic significance. A sample taken from the headwaters of Alexander Creek (20) is misleading in that the thickness shown on the diagram represents a minimum thickness. It represents a new phosphate showing and is one of the rare dip-slope occurrences that may have open-pit potential.

EXSHAW FORMATION

The Exshaw Formation, although phosphate bearing, does not represent a significant phosphate resource in southeastern British Columbia. The best phosphate exposures are restricted to the High Rock Range immediately north and south of Crowsnest Pass. Many of the better occurrences are in Alberta.

Grades of 1 to 9 per cent P_2O_5 across 10 to 30 centimetres have been reported from the basal sandstone between Phillipps Pass and Racehorse Pass (MacDonald, 1985), while the middle phosphate horizons have recorded grades of 6 to 10 per cent P_2O_5 across widths of 1 metre (MacDonald, 1985). Grades of 15 per cent P_2O_5 or more across widths of 10 centimetres or less (MacDonald, 1985) have been recorded from the uppermost phosphate horizon.

In the Flathead River area and Morrissey Ridge, Exshaw exposures are restricted and were not examined. MacDonald (1985) recorded values of 0.28 per cent P_2O_5 across a width of 1.5 metres and 0.16 per cent P_2O_5 across 0.8 metre at Mount Broadwood. West of the Elk Valley the Exshaw Formation is not exposed.

ISHBEL GROUP

Phosphate deposits within the Permian Ishbel Group have been known since 1916 (de Schmid, 1917). These strata occur extensively throughout southeastern British Columbia, with their maximum development in the Telford thrust plate west of the Elk River and north of Sparwood (MacRae and McGugan, 1977). The Ishbel Group has been correlated with the Phosphoria Formation of the western United States where extensive phosphate deposits are mined.

The Phosphoria Formation covers an area of approximately 130 000 square miles and underlies parts of Montana, Idaho, Utah, Wyoming and Nevada. Facies variations indicate deposition in a basin that was deepest in central Idaho and shallower to the north, west and east. It is estimated to have a resource potential of 22.5 billion tonnes of which 1.5 billion tonnes are considered economic reserves. The phosphate content varies between 18 and 36 per cent P_2O_5 averaging approximately 25 per cent. Phosphate is typically pelletal and consists of fluorapatite, quartz, minor muscovite and illite, and lesser organic material, carbonate and iron oxide.

The Permian phosphate deposits in southeastern British Columbia occur at several stratigraphic intervals. The Johnson Canyon and Ranger Canyon Formations are the most significant units with respect to phosphate resource potential, because of their widespread distribution. Phosphate is also present in the Ross Creek Formation but its distribution is restricted and good exposures are rare. Deposition was in a shallow shelf environment, with the eastern sequence being deposited close to a hingeline parallel to a shoreline trend (MacRae and McGugan, 1977). Host lithologies vary from conglomerate to fine-grained sandstone, siltstone and shale. Phosphatic intervals vary considerably in thickness and grade.

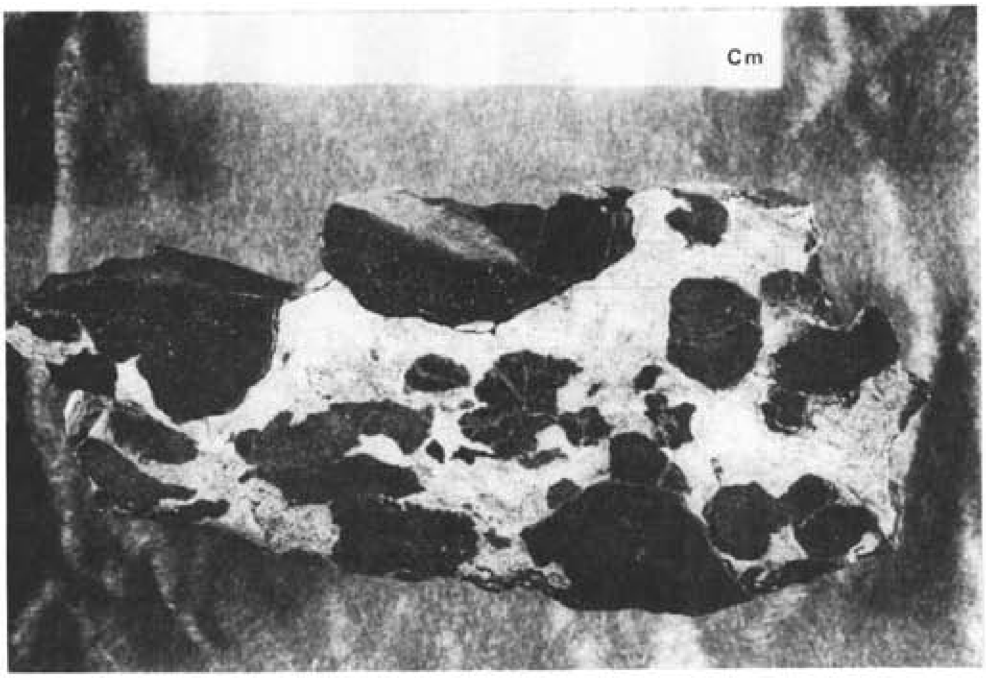

Plate 8. Phosphate nodules and intraclasts in quartzose sandstone from Permian Ishbel Group, Crowsnest Pass area.

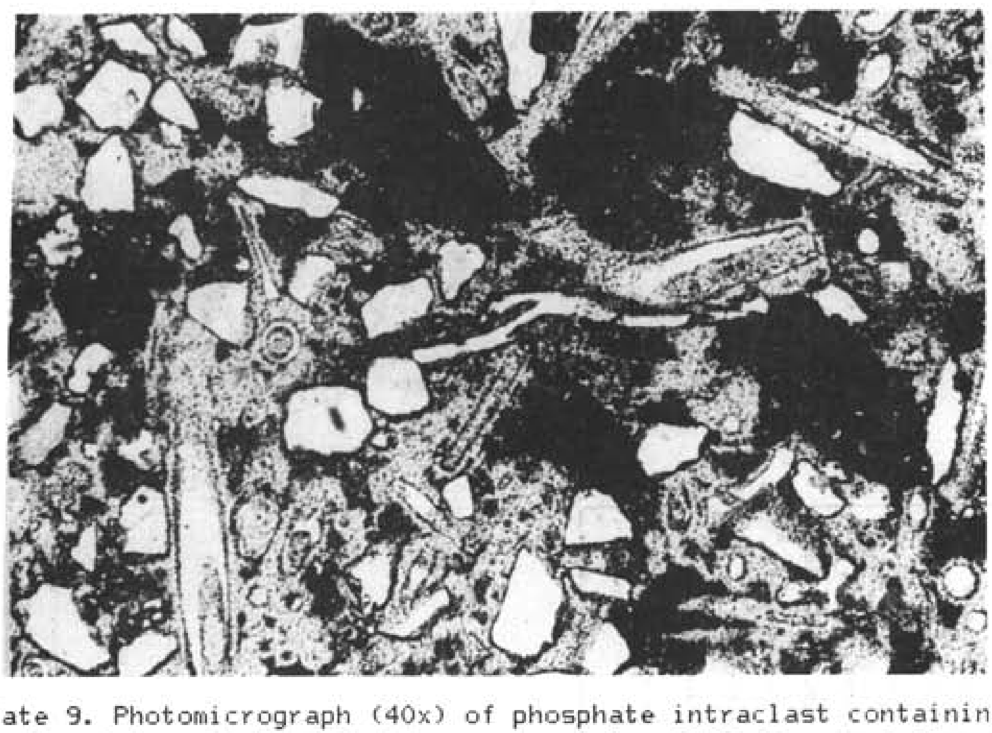

Plate 9. Photomicrograph (40x) of phosphate intraclast containing phosphate pellets (black), quartz grains (white) and shell material from Permian Ishbel Group, Crowsnest Pass area.

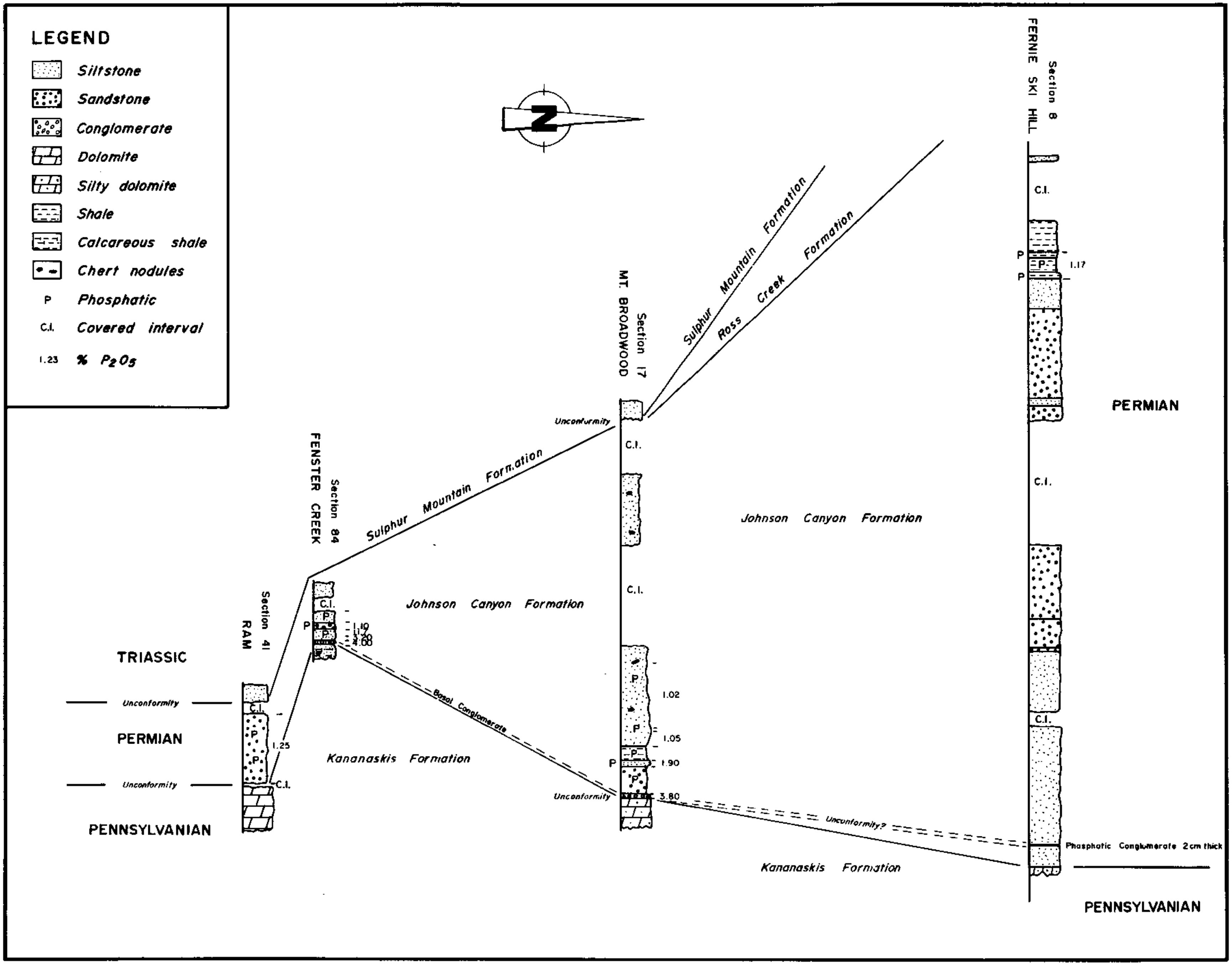

Figure 13. Stratigraphic correlation of phosphate-bearing strata, Johnson Canyon Formation, Fernie - Cabin Creek area.

Phosphate occurs in a number of forms but nodular varieties are the most common. Phosphate nodules may comprise anywhere from 5 per cent of the rock by volume to almost the entire rock (Telfer, 1933). While the nodules themselves may contain 25 to 32 per cent P_2O_5, the rock as a whole rarely exceeds 2 per cent P_2O_5. The best exposures of nodular phosphate lie along the MacDonald thrust fault, particularly near Mount Broadwood and in the Connor Lakes area, north of Forsyth Creek.

Johnson Canyon Formation

Probably the best potential for Permian phosphate in southeastern British Columbia is in the Johnson Canyon Formation. De Schmid (1917) suggests that a continuous phosphate sheet may have been deposited at the base of the Johnson Canyon Formation and although much of it has been removed by erosion, much phosphate is still present.

Along the MacDonald thrust fault in the Bighorn - Cabin Creek area at the southeastern limit of deposition of the Johnson Canyon Formation, phosphate occurs almost continuously. Phosphatic intervals vary considerably, ranging in thickness from less than 5 metres in the southeast to 22 metres at Mount Broadwood (Figure 13). Northwesterly along the same trend, in the vicinity of the Fernie ski-hill, phosphate horizons vary from 1 centimetre to 1 metre thick. Along this trend, a basal conglomerate 25 to 30 centimetres thick contains chert and phosphate pebbles and has a phosphate content averaging 4.29 per cent P_2O_5. At the Fernie ski-hill this conglomerate is only 1 to 2 centimetres thick.

Pelletal phosphorite in the Johnson Canyon Formation was recognized only in the Nordstrum - Brûlé - Weigert Creeks area. Work by the author and MacDonald (1985) indicates the presence of at least one pelletal phosphorite bed, ranging in thickness from 0.48 to 2 metres with the phosphate content ranging from 12.7 to 22.7 per cent P_2O_5.

Along the eastern margin of Permian exposures phosphate occurs primarily as nodules in a sandstone matrix (Plates 8 and 9). This section is only a few metres thick and is tentatively assigned to the Johnson Canyon Formation. A sample of nodules from an outcrop in the Crowsnest area assayed 24.0 per cent P_2O_5. A sample of sandstone from the same locality had a phosphate content of 12.3 per cent P_2O_5. This phosphate horizon, which is approximately 1 metre thick, can be traced as far south as Flathead Pass and as far north as Banff, where grades of 27.63 per cent P_2O_5 have been reported (de Schmid, 1917).

The best phosphate potential in the Johnson Canyon Formation appears to be in the Nordstrum - Weigert Creek area and along the MacDonald thrust, but estimating of tonnage and grade is difficult.

Telford Formation

The Telford Formation has little or no phosphate resource potential.

Ross Creek Formation

Phosphate in the Ross Creek Formation was only observed at a few localities. Both nodular and pelletal varieties are present. As already indicated, the Ross Creek Formation is restricted in its distribution. Phosphate horizons tend to be low grade (less than 5 per cent P_2O_5) and are generally less than 1 metre thick. The potential for economic deposits is poor.

Ranger Canyon Formation

The Ranger Canyon Formation is widely distributed. It is estimated to outcrop over an area of 150 000 square kilometres (Rapson-McGugan, 1970). In southeastern British Columbia exposures are thickest along the western and southwestern margins of the Fernie basin.

Phosphate is present in a basal conglomerate and in the upper part of the section where it is typically nodular, although other forms are also present. Samples from the basal conglomerate in the Cabin Creek area returned assays of 9.58 per cent P_2O_5 across a thickness of 0.6 metre. The phosphate occurs as both clasts and primary cement.

A phosphate horizon varying in thickness from 0.4 metre to 4 metres outcrops in the Mutz Creek - Fairy Creek area north of Fernie. Phosphate content is low and is not considered economically significant. This horizon is believed to extend into the Hartley Creek area. To the west, near the Fernie ski-hill, a phosphate bed assays 13.3 per cent P_2O_5 across 0.5 metre and is the best occurrence in this area.

A well-defined phosphate bed is present in the upper part of the Ranger Canyon Formation in the Connor Lakes area. A sandstone bed, 1 metre thick and containing phosphate nodules averaging 6 centimetres in diameter, occurs on the limbs of a series of anticlinal and synclinal folds. Although this bed has an extensive strike length and the phosphate nodules contain in excess of 25.0 per cent P_2O_5, the bed as a whole (including the nodules) averages less than 5 per cent P_2O_5.

The phosphate resource potential for the Ranger Canyon Formation in southeastern British Columbia appears to be limited. Most of the areas examined contain extensive occurrences of low-grade phosphate (less than 2 per cent P_2O_5 across thicknesses of 1 to 10 metres).

FERNIE FORMATION

The Fernie Formation occupies a broad canoe-shaped synclinal structure known as the Fernie basin covering an area of approximately 2000 square kilometres in southeastern British Columbia. Pelletal phosphorite and phosphatic shale and sandstone occur at the base of the formation in strata that unconformably overlie fine clastic or carbonate strata of the Triassic Sulphur Mountain or Whitehorse Formations. This contact can be traced for approximately 300 kilometres.

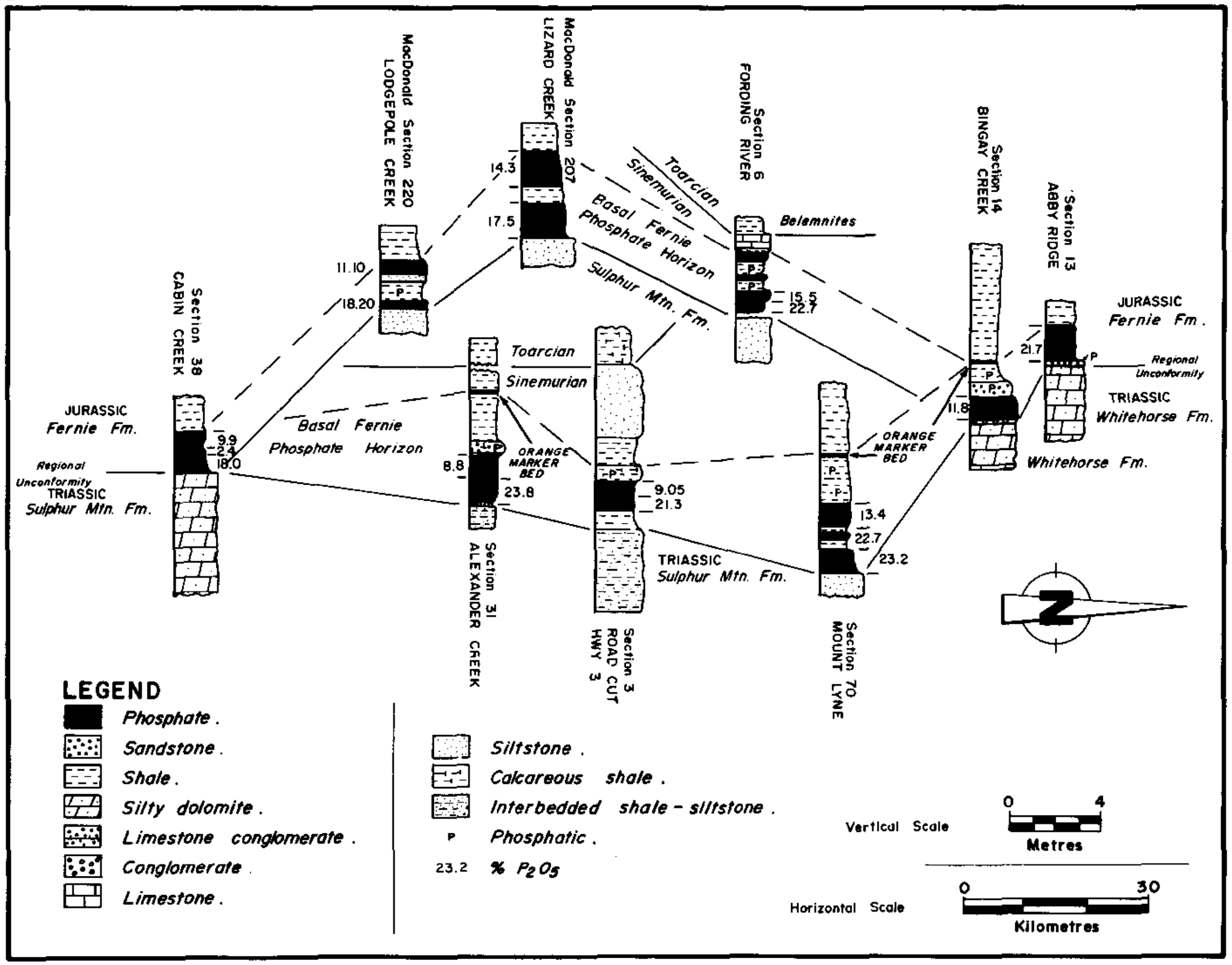

Figure 14. Stratigraphic correlation of the basal Fernie phosphate in southeastern British Columbia.

During Sinemurian time there was a rapid marine transgression. Phosphate was deposited as a single bed, or as two beds separated by phosphatic shale, during a period of slow clastic sedimentation. The environment, although reducing, was not toxic. This phosphatic unit extends throughout the basin and is consistently at least 1 to 2 metres thick (Figure 14) and reaching thicknesses of 2 to 3 metres locally. As much as 8.4 billion tonnes of phosphate rock may have been deposited, but less than 5 per cent of this can be considered a potential resource. The resource potential is estimated to be 400 million tonnes with a grade between 11 and 29 per cent P_2O_5 and averaging approximately 20 per cent P_2O_5. A down-dip extension of 300 metres has been used as a practical mining depth in this calculation.

Surface exposures are invariably weathered and may be enriched in phosphate as a result of leaching of carbonates. Weathering of surface phosphate has been cited as the reason for differences in grade between surface and drill core samples in the Line Creek area (Hannah, 1980) and in the Barnes Lake area (Dales, 1978). The presence of blebs of limonite replacing pyrite grains indicates that some weathering has taken place. It is most pronounced in the Barnes Lake area and at the Lodge phosphate occurrence. In thin section there is no indication that weathering has affected the phosphate pellets. Only surface exposures were sampled in this study and the depth to which the phosphate has been weathered, or how much the grade has been affected, was not determined.

The amount of quartz, calcite and dolomite present is an important factor in the processing of phosphate rock. Both calcite and dolomite are detrimental minerals. The relative proportions of these minerals are summarized in Table 1. Petrographic and X-ray diffraction studies suggest that there is a crude zonal distribution of carbonate in the basal Fernie phosphate. In the Iron Creek area, and at the Lizard deposit, calcite is the dominant accessory mineral, while quartz is rare. This trend of abundant carbonate appears to continue into the Fording River area and southeasterly into the Mount Broadwood area. Along the southeastern and eastern margins of the Fernie basin quartz is dominant and calcite is only a minor constituent, becoming virtually absent at the Mount Lyne locality. Dolomite is rare to absent throughout the Fernie phosphate.

Southeastern and eastern exposures of the basal phosphate appear to offer the best economic potential.

The southeasternmost exposures of the basal phosphate occur in the Cabin Creek area. Exploration by First Nuclear Corp. Ltd. (Hartley, 1982), Imperial Oil Ltd. (Van Fraassen, 1978) and the author has demonstrated that a phosphate bed averaging 1.5 metres in thickness occurs along a strike length of 27 kilometres. Phosphate is present in a broad synclinal structure modified by thrust faults and smaller folds. Thrust faulting has thickened the phosphate bed at some localities and at others, the phosphate has been remobilized into the axial portions of folds (Hartley, 1982). Phosphate content is in the range of 13 to 20 per cent P_2O_5. Less silty varieties contain more than 20 per cent P_2O_5 (Hartley, 1982).

TABLE 1
MEAN VALUES FOR SELECTED BASE METALS OF PHOSPHATE HORIZONS IN SOUTHEASTERN BRITISH COLUMBIA AND THEIR COMPARISON TO SOME WORLD PRODUCERS

Phosphate Unit	Mean Value (parts per million)*			
	Copper	Lead	Zinc	Arsenic
Johnson Canyon Formation	17.5	17	180	<40
Ranger Canyon Formation	11	10	99	<40
Fernie Formation	42	18	167	<40
Phosphoria Formation[1]	100	<10	300	40
Moroccan Phosphate[2]	22		144	
Phosphorite (average)[3]	4-40		4-200	5-35

*Mean values calculated from values in Appendix 2.

[1]From Gulbrandsen (1966).
[2]From Slansky (1986).
[3]From Krauskopf (1955).

The Cabin Creek area is estimated to have a resource potential of 34 million tonnes, calculated to a depth of 300 metres, with an average grade of approximately 20 per cent P_2O_5. There is some untested potential immediately west of the Flathead River in the vicinity of Cabin Creek.

North of Crowsnest Pass, the Crow deposit has been the subject of extensive underground work and metallurgical testing by Cominco Ltd. The Crow deposit has an estimated resource potential in excess of 2 million tonnes with an average grade of approximately 25 per cent P_2O_5.

In the west Line Creek area the basal phosphate can be traced for a strike length of 15 kilometres, in strata that dip 40 to 75 degrees easterly. It varies in thickness from less than 1 metre south of west Line Creek, to more than 3 metres at Mount Lyne. Phosphate content ranges from a low of 3.7 per cent P_2O_5 in a diamond-drill hole to a high of 23.7 per cent P_2O_5 across 1.6 metres in a backhoe trench (Hannah, 1980). At Mount Lyne the phosphorite averages 22.95 per cent P_2O_5 across 2 metres or 19.77 per cent P_2O_5 across 3 metres.

Crows Nest Resources Ltd. has calculated a reserve of 972 800 tonnes to a depth of 30 metres in the west Line Creek area, based on a strike length of 5850 metres and an average thickness of 2 metres. The resource potential of the Line Creek area is estimated to be in excess of 25.2 million tonnes with a grade of approximately 20 per cent P_2O_5, assuming a strike length of 15 kilometres, an average thickness of 2 metres and a depth of 300 metres. The estimated grade is based on surface samples and therefore could be lower, depending on how much weathering of the phosphate has taken place.

The phosphate resource potential for the Fernie Formation in the Barnes Lake area is estimated to be 7 million tonnes to a depth of 100

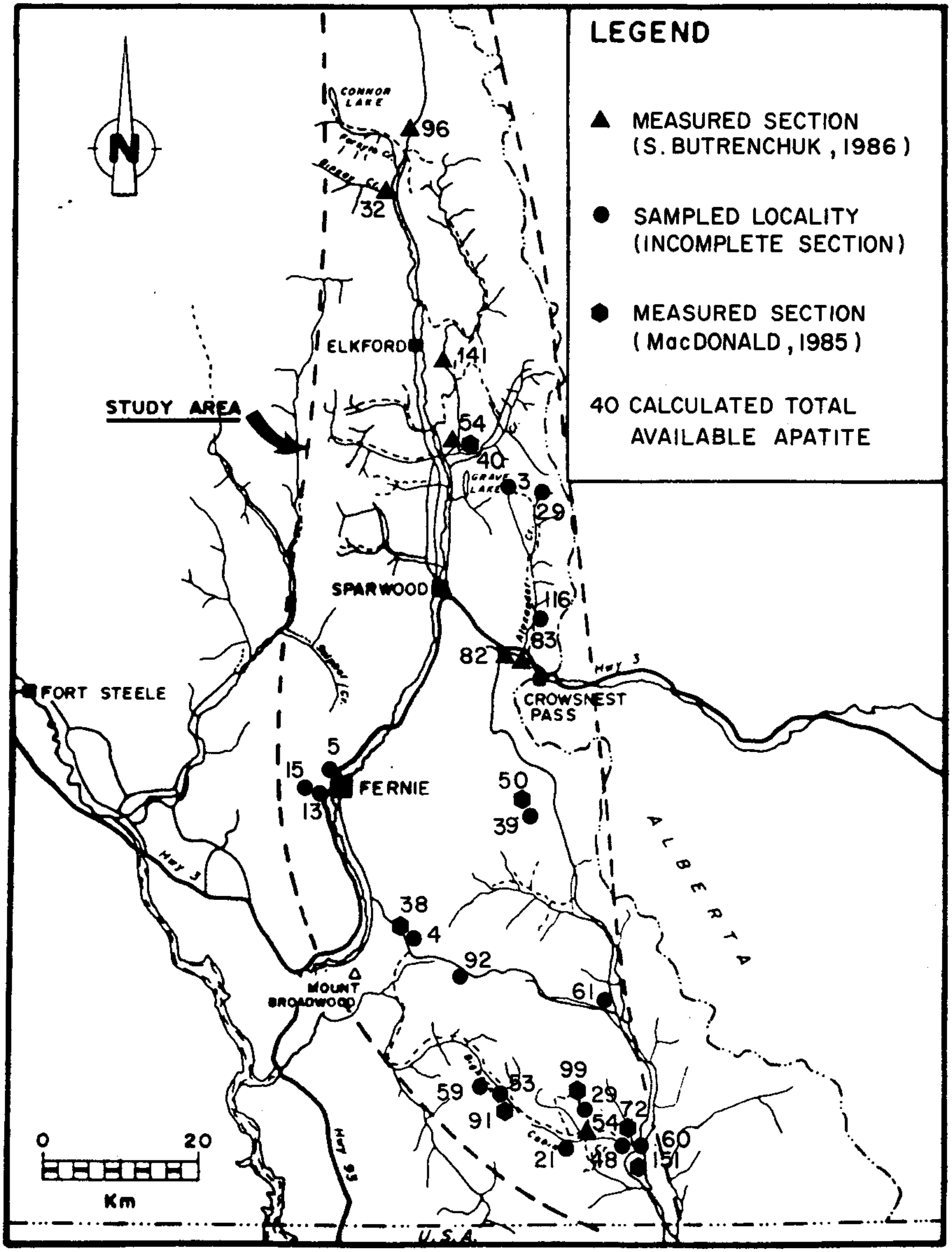

Figure 15. Total formational apatite, basal phosphate horizon, Fernie Formation.

metres, based on a 25.5-kilometre strike length and an average thickness of 1 metre. An additional 4.2 million tonnes may be available to the east of the Corbin logging road.

Christie (1981, *in preparation*) has suggested that "normative apatite" or "bone phosphate of lime" could be called "total formational apatite" (TFA) and expressed in centimetres by the formula:

$$TFA = \text{thickness (metres)} \times \text{assay } (\% \ P_2O_5) \times 2.18.$$

Under ideal conditions, "total formational apatite" can be used to *indicate where apatite formed, that is, which parts of the basin are most* phosphogenic. This procedure, although it will not show where the phosphate is economic, can be useful in locating target areas within a phosphogenic region that may contain economic phosphate.

Total formational apatite (TFA) has been calculated for several localities in the Fernie basin, the results for which are shown in Figure 15. Their distribution suggests that the eastern margin of the basin is the most phosphogenic, and that there are two centres of more intense phosphogenesis. These are the Cabin Creek and Crowsnest Pass areas. A single value at Mount Lyne southeast of Elkford suggests that phosphogenesis was also active in this area. It should be noted that for those localities where the section is incomplete, the calculated value is a minimum value. These results tend to confirm the hypothesis that the eastern margin of the Fernie basin offers the best potential for economic phosphate deposits.

GEOCHEMISTRY

All routine phosphate analyses (Appendix 2) were originally done using X-ray fluorescence (XRF) techniques. However results were low compared with those of others from the same locality. Wet chemical techniques confirmed the inaccuracy of XRF analyses and samples with values greater than 5 per cent P_2O_5 were re-analysed using the classical volumetric method. Emigh (1983) also found the X-ray fluorescence method may give inaccurate results. The Geological Survey of Canada has found that classical analytical methods are required for phosphate values greater than 2 per cent P_2O_5 (D. Bell, oral communication, 1987). Titration is recommended as the best method for exploration and development assays.

Analytical results for routinely collected chip samples indicate that phosphates in southeastern British Columbia, independent of their age, show no appreciable enrichment in copper, lead, zinc or arsenic. Mean values for each of these elements are given in Table 1. The mean value for copper in the Fernie phosphate is substantially higher than phosphate in the Permian. Lead is low throughout. Both the Johnson Canyon and Fernie Formations show local enrichment in zinc, especially in the Cabin Creek area. Mean values for copper, lead, zinc and arsenic are lower than in the Phosphoria Formation but generally higher than for deposits elsewhere in the world. This is particularly true of zinc in the Fernie and Johnson Canyon Formations. These same patterns are also exhibited by specimens submitted for whole rock and comprehensive trace element analyses.

According to Krauskopf (1955) and Gulbrandsen (1966) the abundance of trace elements is due to their association with organic matter or to integration into the apatite lattice. High concentrations of arsenic, copper, lead and zinc are principally due to organic matter.

Fifteen samples were submitted for whole rock and comprehensive trace element analyses, six from the Fernie Formation and the remainder from various phosphatic horizons within the Ishbel Group. Results of these analyses are given in Appendix 3.

The magnesium content is an important consideration in the appraisal of phosphate rocks as it seriously affects the acidulation process. Fertilizer processing plants require an MgO content of less than 1 per cent. The Highway 3 locality and Crow deposit have a magnesium content that exceeds this standard. These high magnesium values would have to be addressed during the concentration phase.

$CaO:P_2O_5$ ratios for the Fernie Formation range from a low of 1.35 to a maximum of 2.92, compared to acceptable values in the range 1.32 to 1.60. The optimum value for the $R_2O_3:P_2O_5$ ratio is 0.1 (R_2O_3 equivalent to Al_2O_3 + Fe_2O_3 + MgO). With the exception of the Lizard deposit, values for both the Fernie Formation and the Ishbel Group exceed this value.

Marine sedimentary phosphate deposits generally contain uranium in the range 50 to 300 parts per million, with most containing less than 100 parts per million (Slansky, 1986). It is believed to replace calcium in the apatite lattice (Altschuler *et al.*, 1958) and varies directly with phosphate content.

The uranium content of seven samples from the Fernie Formation ranged from 27 to 42 parts per million and averages 33 parts per million. Eight samples from phosphatic rocks in the Ishbel Group returned analyses of 4 to 103 parts per million, with a mean of 36 parts per million. In comparison, the average uranium content of the Phosphoria Formation is 90 parts per million (Slansky, 1986).

Thorium content in marine phosphates is generally low, averaging 6 to 7 parts per million (Altschuler, 1980). The thorium content of British Columbia deposits approximates the average, as compared to a mean of 11 parts per million in the Phosphoria Formation.

Selenium generally shows some enrichment in phosphorites as compared to the average shale. It is believed to correlate with the amount of organic material present. Selenium in phosphorites of the Fernie Formation and Ishbel Group varies from 1 to 6 parts per million with slightly higher values in the Ishbel Group.

Arsenic in phosphate deposits in southeastern British Columbia averages less than 9 parts per million as compared to a mean of 23 parts per million for phosphorites in general (Altschuler, 1980).

The Fernie Formation contains above average values for strontium and barium as compared to the average phosphorite as determined by Altschuler (1980). Strontium averages 954 parts per million compared to a value of 750 parts per million for the average phosphorite. Barium averages 522 parts per million compared to 350 parts per million for the average phosphorite and 100 parts per million for the Phosphoria Formation.

PETROGRAPHY

Depending upon its chemical and mineralogical composition phosphate rock can occur in a variety of forms. Figure 16 shows a classification of phosphates based on their composition, developed by Mabie and Hess (1976) while studying the Phosphoria Formation. This classification is based on the abundances of three end-members: fluorapatite representing the phosphate component, muscovite-sericite-clay representing the argillaceous component and quartz-chert representing the sand or silt-sized component. This classification can be expanded by using the terms "calcareous" and "ferruginous" to describe phosphate rock containing more than 10 per cent carbonate and 1 to 2 per cent iron respectively.

Most Fernie phosphates can be described as quartzitic. A sample from the Lizard deposit (Liz) is calcareous and one sample from the Cabin Creek area (40) is ferruginous. The sample from the Line Creek deposit (70) indicates a greater argillaceous component not seen elsewhere in the Fernie Formation. Comparing the Fernie and Phosphoria Formations one can see that the Fernie Formation is slightly more siliceous. In general, phosphates from these two formations appear to be similar.

For the Ishbel Group most of the phosphate-bearing rocks can be classified as phosphatic sandstones or siltstones. The samples from Weigert Creek (57) are calcareous. Both the samples from Weigert Creek and Nordstrum Creek (79) can be classified as phosphorites. They, too, are slightly more siliceous than phosphorite from the Phosphoria Formation.

ISHBEL GROUP

Phosphate, as fluorapatite, is present in the Ishbel Group as nodules, pellets, cement, intraclasts and as replacement of bioclastic debris that include brachiopod shells, sponge spicules and possibly foraminifera.

The most common form is the nodular variety with nodules occurring throughout the Permian section. They appear to be most prominent in the Johnson Canyon and Ranger Canyon Formations. Nodules commonly occur as ovoid structures that vary from 1 centimetre to greater than 7 centimetres in diameter. Locally they have irregular shapes and may be elongated parallel to the bedding. Internally they may contain one or more quartz nuclei as well as bioclastic material. Some nodules exhibit etching of their external surfaces.

Pelletal phosphorite was observed only in the Johnson Canyon and Ross Creek Formations. Pellets are generally structureless although oolitic pellets, and the occasional pellet having a radial structure, were also observed. Less than 15 per cent of the pellets are nucleated or encased. Quartz, and to a lesser degree carbonate, form these nuclei. Grain size of the pellets varies from 0.1 to 0.5 millimetre. These pelletal varieties have semidispersed to dispersed textures.

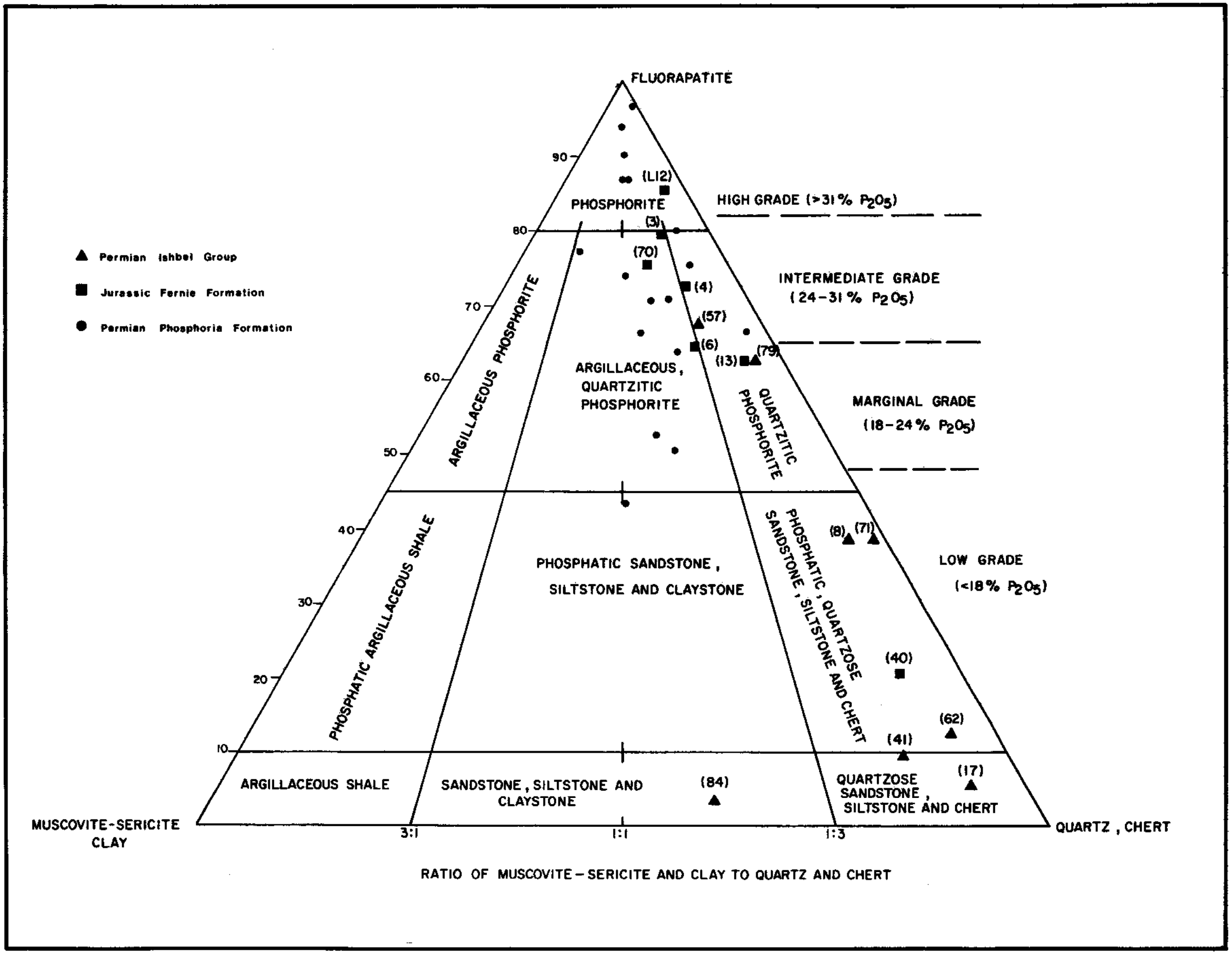

Figure 16. Compositional classification of phosphate ores (Mabie and Hess, 1976).

Phosphate is present as cement throughout the Ishbel Group. Primary cement was observed in the basal conglomerate of the Ranger Canyon Formation as well as in fine clastics of the Johnson Canyon and Ross Creek Formations. Rapson-McGugan (1970) also reports the presence of primary phosphate cement in the Ranger Canyon Formation. In thin section phosphate cement generally appears as a brown colour.

Replacement of bioclastic debris, in whole or in part, by phosphate was also observed. It is most prominent in the Ross Creek and Johnson Canyon Formations. Intraclasts are not abundant; where observed, they may contain quartz nuclei that are different in grain size from the surrounding matrix or contain several phosphate pellets.

Host lithologies in the Ishbel Group are quartz-rich siltstones and fine-grained sandstones (*see* Figure 16). The quartz is subangular to subrounded and generally well sorted. Feldspar with varying amounts of calcite are also present in the matrix. Dolomite, albite and illite may be present in minor amounts.

FERNIE FORMATION

The basal phosphate of the Jurassic Fernie Formation is essentially all pelletal phosphorite, although some nodular is present locally at the Crow deposit and Lodge occurrence. Pellets are brown to dark brown, occasionally black, well sorted, subrounded to subangular with a grain size varying from 0.1 to 0.3 millimetre. Approximately 95 per cent of the pellets are structureless and up to 50 per cent may be nucleated. Occasionally, the pellets may have an oolitic structure. Pellets are composed of fluorapatite and organic material that gives them their colour. The matrix is generally finer grained than the pellets. A general molding of pellets is seen suggesting that deposition may have been as plastic or gel-like material.

The phosphorite has a compact to semidispersed texture and contains 50 to 85 per cent pellets by volume. Quartz is the principal component of the matrix except in the Lizard Range - Iron Creek area. Here, calcite is dominant and quartz is virtually absent. At the Line Creek deposit calcite is virtually absent. In general, there appears to be a decrease in carbonate content eastward. Also present in minor amounts are feldspar and albite. Illite and sericite are present in trace to minor amounts. Dolomite, montmorillonite or mixed clay are generally absent but do occur locally in trace amounts. Limonite, probably after pyrite, is usually present in amounts of 1 to 2 per cent. The semi-qualitative abundance of minerals present in the basal Fernie phosphate is summarized for 11 samples in Table 2. These minerals were determined by X-ray diffraction work.

TABLE 2
RELATIVE ABUNDANCE OF MINERALS PRESENT IN BASAL FERNIE PHOSPHATE
(obtained by X-ray diffraction)

Sample No.	Mineralogy
Liz	Calcite > fluorapatite >> quartz > albite ± montmorillonite, mixed clay
SBB86-3	Fluorapatite ≥ calcite ≥ quartz > dolomite, albite, K-feldspar, illite/sericite
SBB86-4F	Fluorapatite > quartz >> K-feldspar, calcite, illite, albite
SBB86-11	Calcite ≥ quartz > fluorapatite >> albite > K-feldspar, illite
SBB86-14	Quartz > K-feldspar > fluorapatite >> albite > illite
SBB86-15	Fluorapatite >> quartz > K-feldspar, illite, mixed clay
SBB86-31	Fluorapatite > quartz >> dolomite, calcite > albite, illite, K-feldspar
SBB86-37	Fluorapatite >> quartz >> K-feldspar, albite, illite
SBB86-38	Fluorapatite > quartz >> calcite, K-feldspar > illite, albite ± dolomite
SBB86-42	Quartz >> fluorapatite >> K-feldspar, illite
SBB86-70	Fluorapatite >> quartz > K-feldspar, albite, illite

BENEFICIATION AND PROCESSING OF PHOSPHATE ROCK

Most commercial fertilizer plants use a wet acidulation method in the initial stage of fertilizer production. Phosphate rock is treated with sulphuric acid to produce phosphoric acid and gypsum ($CaSO_4$) as a waste product. A high calcium carbonate content in the phosphate rock increases the consumption of sulphuric acid while magnesium renders the phosphoric acid unacceptably viscous.

The purpose of beneficiation is to raise the P_2O_5 level to commercial standards (30 to 37 per cent P_2O_5) and to reduce the proportion of carbonate, iron and alumina oxides, organic matter or trace elements. Most phosphate rock requires some beneficiation prior to shipment to processing plants and the mineralogical and chemical characteristics of the deposits are therefore important. Processing plant specifications for major impurities are as follows:

- P_2O_5 content: 27 to 42 per cent
- $CaO:P_2O_5$ ratio: 1.32 to 1.60 for apatite
- $\frac{Al_2O_3 + Fe_2O_3 + MgO}{P_2O_5} < 0.1$ (optimum value)
- MgO tolerance is approximately 1.0 per cent
- BPL[1]:MgO ratio: 170 or higher
- BPL:Al_2O_3 + Fe_2O_3 ratio: ≥ 20
- BPL:CaO ratio: ≥ 1.5

[1] Bone phosphate of lime (2.1852 x per cent P_2O_5)

In 1974 the Department of Energy, Mines and Resources Canada carried out a beneficiation test on a sample of Fernie phosphate from the Lodgepole Creek area south of Fernie. The sample was from a surface trench and averaged 10 to 11 per cent P_2O_5. It also contained approximately 20 per cent calcite with minor amounts of quartz, feldspar and traces of mica and mafic minerals (Hartman and Wyman, 1974). The results indicated recovery of 31.5 per cent with a maximum grade of 28.5 per cent P_2O_5 by attrition methods and recovery of 49 per cent with a maximum grade of 28.5 per cent P_2O_5 by hot conditioning and flotation with soda ash and oleic acid.

The authors also report: "The highest grade product was achieved using a mechanical treatment: attrition and ultrasonics. This grade occurred in the 65- and 100-mesh fractions. Flotation results using hot conditioning with soda ash and oleic acid show the importance of screening and grinding to free and clean surfaces. Results are even better when ultrasonics are included. The approach to beneficiation using hot conditioning, although a costly step, appears promising. The results suggest that concentration by attrition and/or other mechanical means followed by heavy liquid separation should be considered". This investigation was not carried through to completion because of the low grade of the sample.

To the author's knowledge, Cominco Ltd. is the only company that has done beneficiation testing of phosphate from southeastern British Columbia. Cominco has tested samples from the Lizard, Crow and Mount Lyne deposits. Work to date has been unsatisfactory as the basal phosphate of the Fernie Formation has a strong hydrophyllic character and cannot be floated effectively with fatty acid or anionic collectors. A process of careful grinding, attrition-scrubbing and elutriation produced the best results (J.M. Hamilton, personal communication, 1986; Christie and Kenny, in preparation).

The basal Fernie phosphate has many lithological similarities to the Phosphoria Formation. Research on the beneficiation of the phosphorite from the Phosphoria Formation is ongoing. Recent work by Judd *et al.* (1986) has achieved 98 per cent recovery of phosphate by leaching of unbeneficiated phosphate ores, but did not evaluate the cost effectiveness of the procedure. Rule *et al.* (1982) also completed a study of flotation techniques on the Phosphoria phosphates. Their work involved a process of depression of the phosphate minerals with fluosilicic acid and anionic flotation of carbonate minerals, followed immediately by cationic flotation of silica. Results demonstrated a potential for an increase of 12 to 15 per cent in total phosphate recovery if the flotation process is incorporated into an existing washing-sizing plant. Pilot plant tests achieved recoveries from flotation feed in the range of 73 to 96 per cent.

Studies on the beneficiation of Brazilian phosphate ores at The University of British Columbia (de Araujo *et al.*, 1986) have indicated that selective desliming, using selective flocculation followed by a conventional single stage anionic flotation of phosphate, gave the best results.

For the basal Fernie phosphate to be economic a suitable means of beneficiation that will produce a concentrate grade of 30 per cent P_2O_5, with acceptable recoveries, is required. All test work done to date is over 10 years old. New methods being developed may be more effective for phosphate extraction in southeastern British Columbia. Processes that have recently been tried or seriously considered include dense medium cyclone preconcentration, high-intensity magnetic separation and selective leaching of dolomite from high-grade phosphorites (Hollick and Wright, 1986).

SUMMARY AND CONCLUSIONS

The best potential for phosphate in southeastern British Columbia occurs at the base of the Fernie Formation. The phosphate content averages 18 to 20 per cent P_2O_5 across a thickness of 1 to 2 metres. Locally there has been some thickening of the phosphatic unit. Acceptable grades of phosphate vary with mining, beneficiation and transportation costs. Mining grade in Florida is as low as 10 per cent P_2O_5 or even less. From an exploration perspective the eastern margin of the Fernie basin offers the best potential. However, at present this phosphate cannot compete with production in the western United States where beds grading 30 per cent P_2O_5 are selectively mined (Cook, 1976).

Phosphate deposits in southeastern British Columbia are generally low to medium grade (18 to 24 per cent P_2O_5). At present commercial plants require a grade of approximately 30 per cent P_2O_5 for processing, Fernie phosphate would therefore require beneficiation. Research work to date has been unsatisfactory but recent studies on methods to upgrade phosphate rock may offer some encouragement for the future recovery of phosphate from the Fernie Formation.

In addition to the metallurgical problems, mining of phosphate in southeastern British Columbia presents other practical difficulties. Phosphate beds are narrow and their attitude precludes open-pit mining in most locations. However, new developments in hydraulic borehole mining of phosphates (Savanick, 1983) suggest that this provides an alternative to conventional underground mining techniques.

The basal phosphate of the Fernie Formation has a significant resource potential. Once the problems of mining and beneficiation are overcome, these deposits could provide a valuable source of phosphate for the fertilizer industry in western Canada.

The phosphate potential of the Ishbel Group is more difficult to access. While phosphate intervals at several localities exceed 5 metres in thickness, grades are generally less than 5 per cent P_2O_5. Most of this phosphate occurs as nodules. While the nodules themselves contain in excess of 25 per cent P_2O_5, the host beds have phosphate values of generally less than 2 per cent. These nodular varieties may represent a potential phosphate resource if an inexpensive method can be found to separate the nodules from the fine clastic matrix.

Two areas offer some exploration potential for Permian phosphate deposits. These are located along the MacDonald thrust fault and in the Nordstrum - Weigert Creeks area west of the Elk River. Pelletal phosphorite with grades approaching those of the Fernie Formation were recorded in the second of these localities.

At present phosphate is in oversupply. While reserves are sufficient for several years our traditional sources of imports to western Canada will begin to decline in the near future. Due to declining ore grades the trend in exporting countries is towards more downstream processing and sale of higher value-added phosphate products. Canada phosphate fertilized plants are dependent on imports for feedstock supply and therefore vulnerable to changing trade patterns or a tightening of export markets. The phosphate deposits of southeastern British Columbia could provide an alternative source of supply, provided beneficiation difficulties can be overcome and suitable mining methods can be found.

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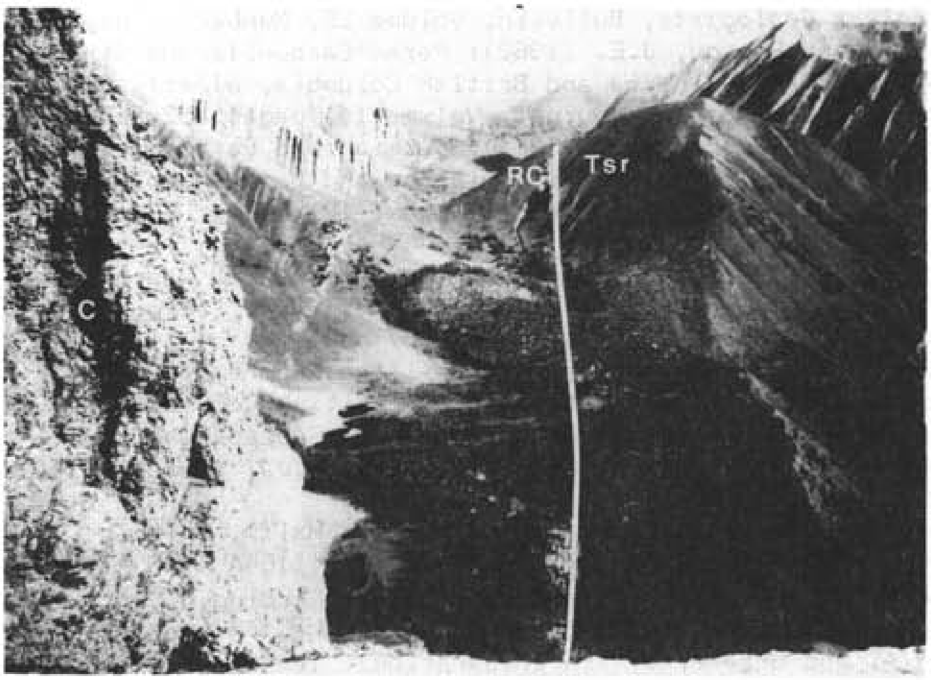

Plate 10. Resistant chert bed (C) of Ranger Canyon Formation (RC) north of Forsyth Creek, in contact with Sulphur Mountain Formation (Tsr).

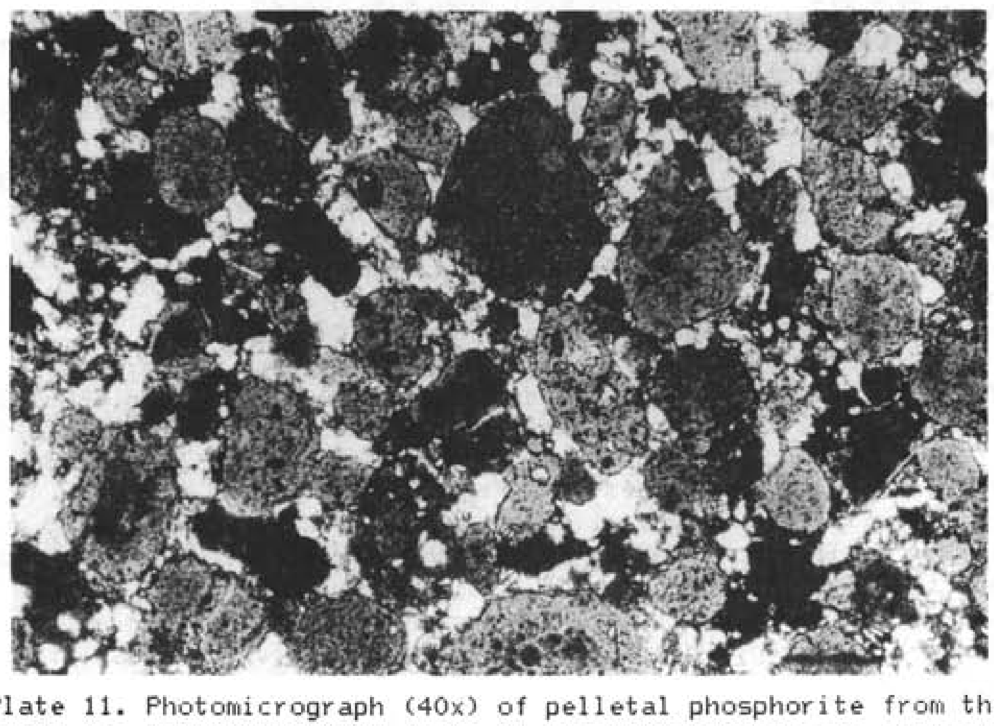

Plate 11. Photomicrograph (40x) of pelletal phosphorite from the Johnson Canyon Formation, Weigert Creek.

APPENDIX 1

PHOSPHATE LOCALITIES IN THE FERNIE BASIN

PERMIAN: ISHBEL GROUP

Forsyth Creek - Connor Lakes (1)

Latitude: 50°17'50"   Longitude: 115°02'45"   NTS: 82J/2

Several exposures of phosphate in the Ross Creek and Ranger Canyon Formations lie north of Forsyth Creek, in the Connor Lakes area. These strata are unconformably overlain by siltstone of the Triassic Sulphur Mountain Formation (Plate 10). Two sections were measured in this area (Figures 17 and 18). The Ranger Canyon Formation consists primarily of a thick, resistant chert horizon that is overlain by a sandstone bed 1 metre thick containing 10 to 15 per cent phosphate nodules by volume. These nodules are black, subrounded and average 5 centimetres in diameter. They contain 25.8 to 28 per cent P_2O_5 but a sample collected across the sandstone bed assayed only 1.6 per cent P_2O_5. A massive to nodular phosphate bed, 0.5 metre thick, underlies the chert bed in the more northerly section (Figure 18). It contains 18.6 per cent P_2O_5. A phosphatic interval, 10 metres thick, lies below the chert horizon. With the exception of the uppermost bed, the phosphate content was less than 5 per cent P_2O_5 throughout the section.

The geology of this area is complicated by a number of steeply dipping normal faults which have caused a thickening of the section, particularly in the more northerly section. Several fault repetitions can be seen in outcrop, especially in beds beneath the chert horizon. Along strike to the north faulting becomes less prevalent and the phosphatic interval thins dramatically.

A number of sandstone beds containing phosphate nodules are present in the Ross Creek Formation. The nodules are a minor component of the rock and the phosphate grade is low, averaging approximately 0.9 per cent P_2O_5.

MacDonald Thrust Fault (2)

Latitude: 49°10'30" to 49°18'00"   Longitude: 115°49'05" to 114°56'55"   NTS: 82G/2

Several exposures of phosphate were examined along the MacDonald thrust fault at the southern margin of the Fernie basin. Stratigraphic sections were measured at Mount Broadwood (Figure 19), north of Fenster Creek (Figure 20) and at a locality approximately 4 kilometres northwest of Cabin Pass (Figure 21).

A phosphate horizon in the basal portion of the Johnson Canyon Formation can be traced almost continuously from Mount Broadwood in the northwest to Burnham Creek in the southwest. It varies in thickness from

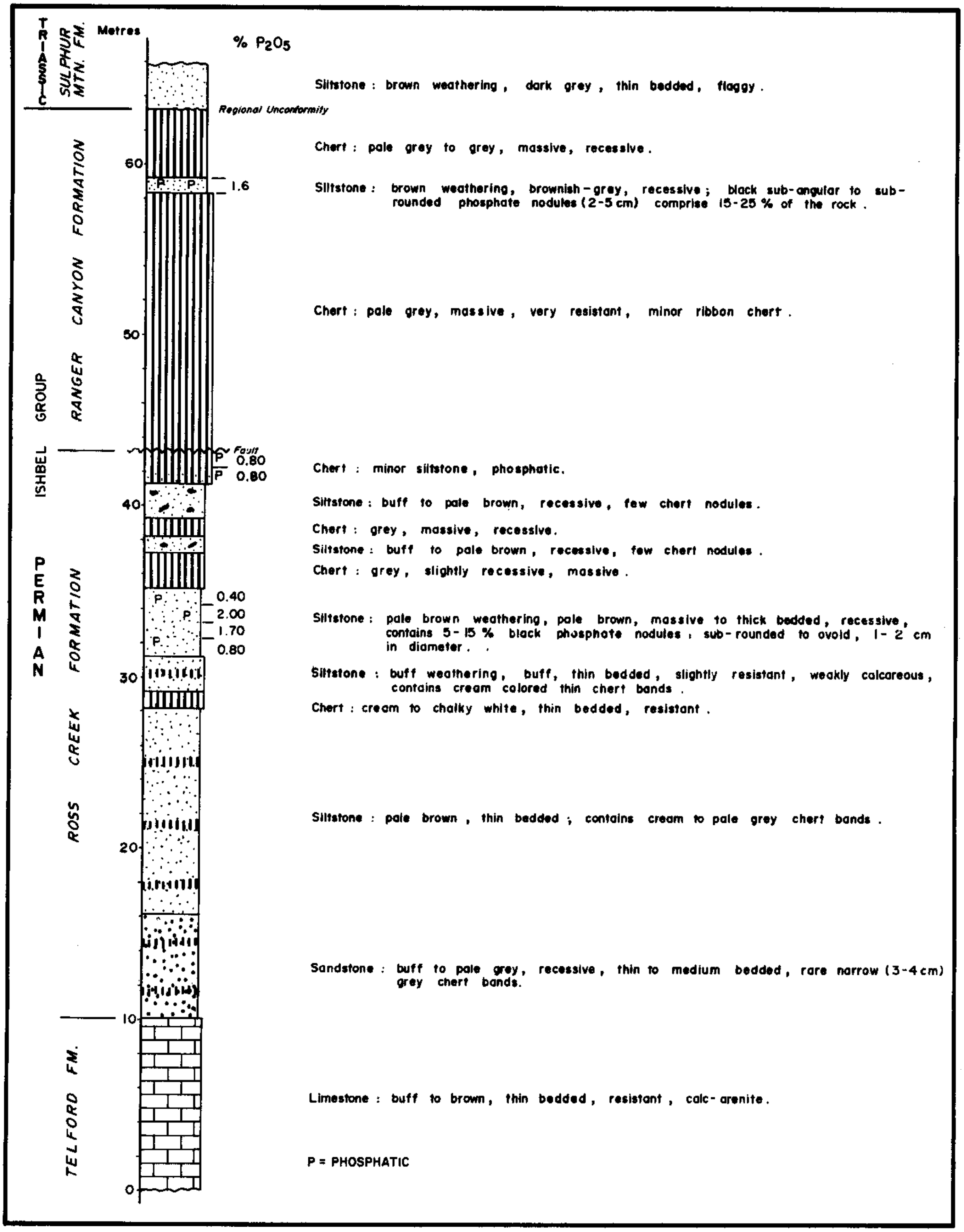

Figure 17. Stratigraphic section 62, Forsyth Creek.

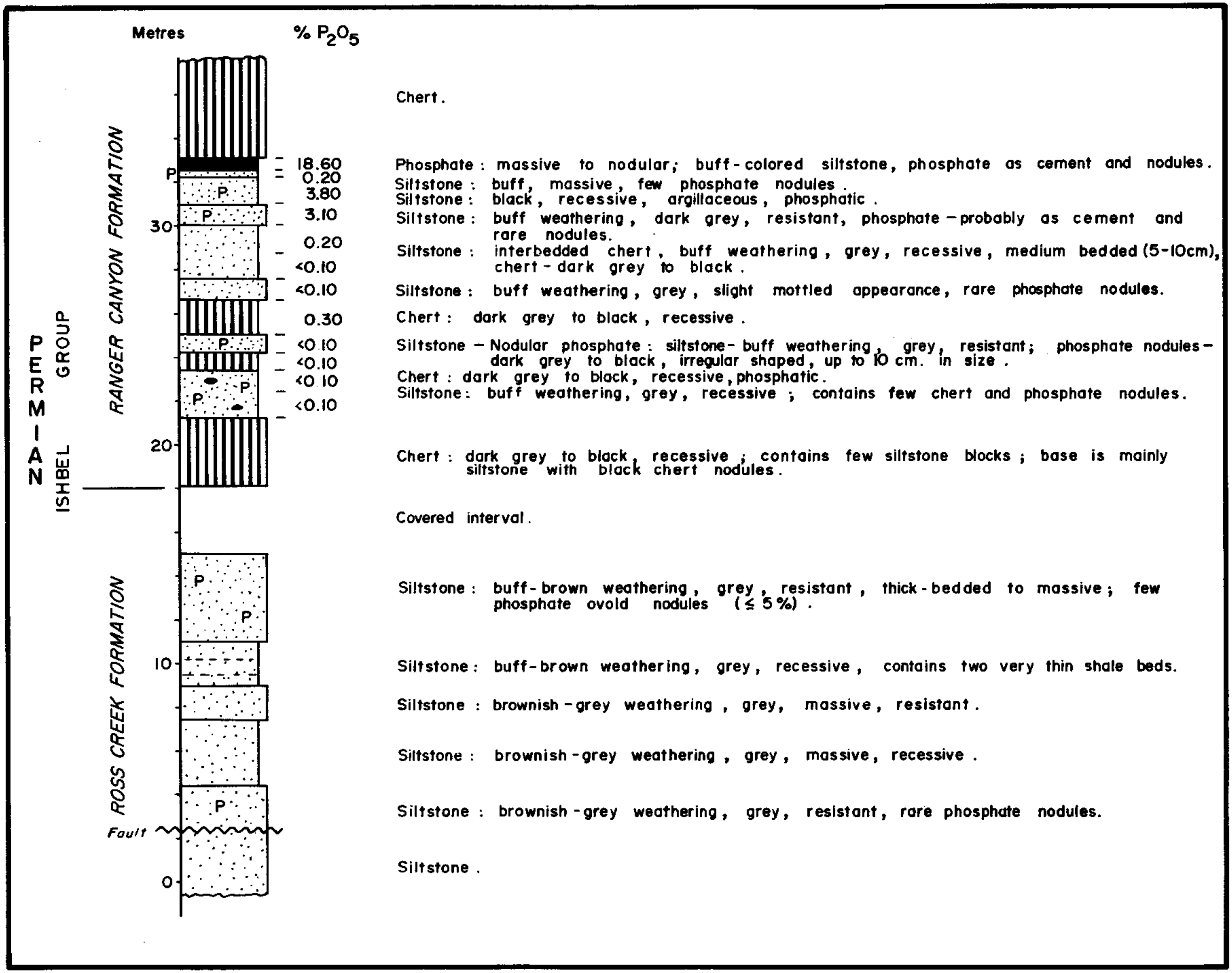

Figure 18. Stratigraphic section 63, Forsyth Creek north.

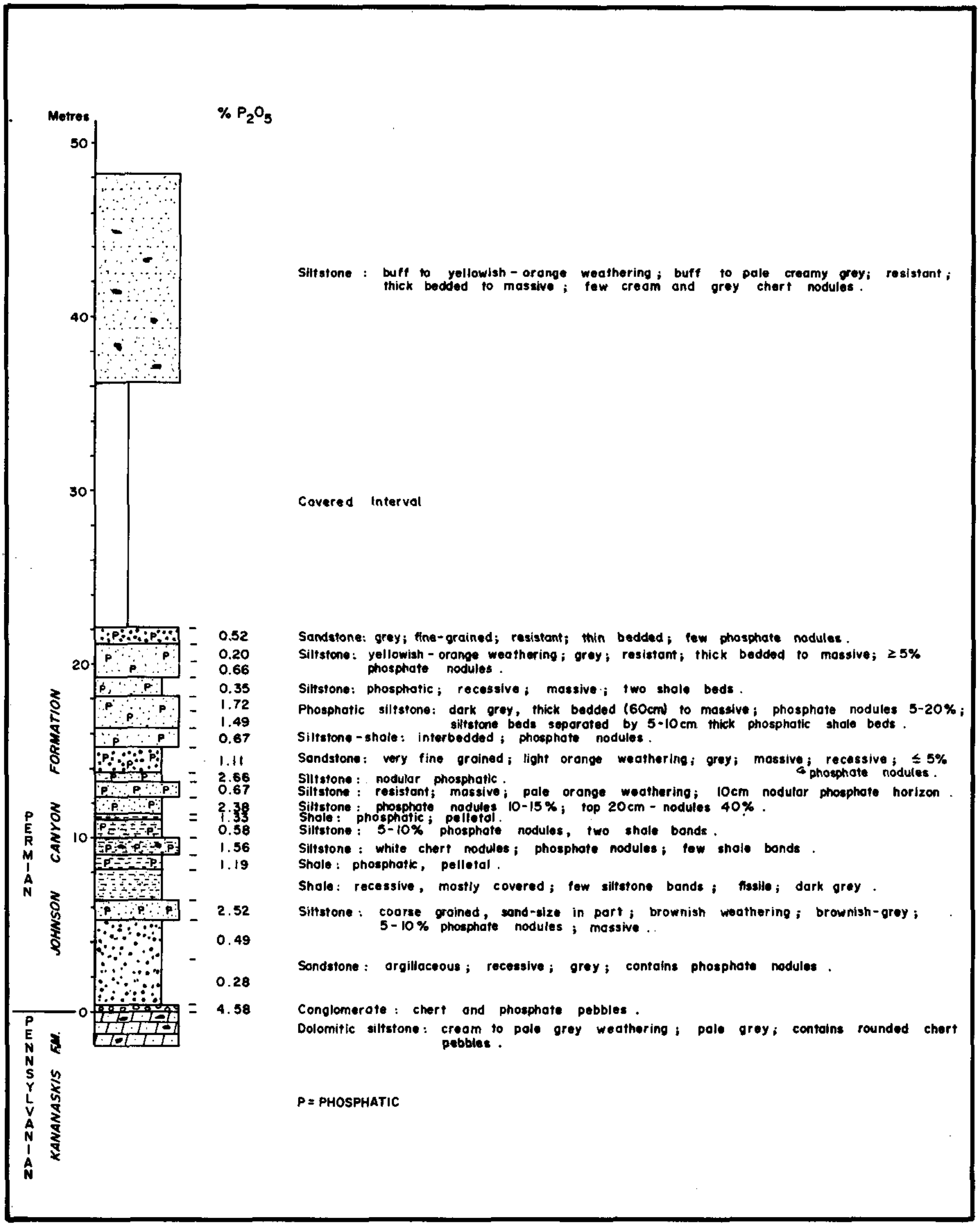

Figure 19. Stratigraphic section 17, Mount Broadwood.

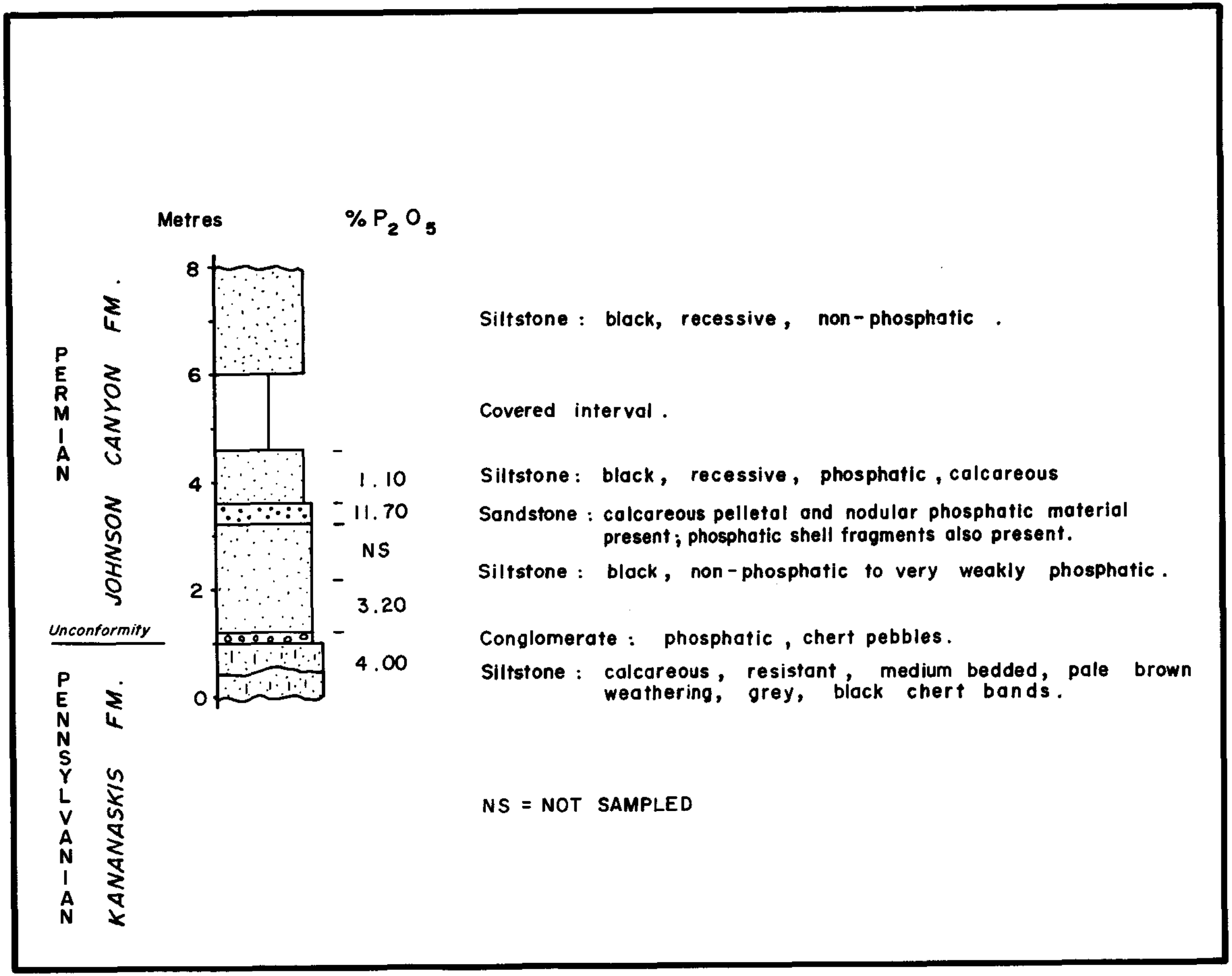

Figure 20. Stratigraphic section 84, MacDonald thrust fault at Fenster Creek.

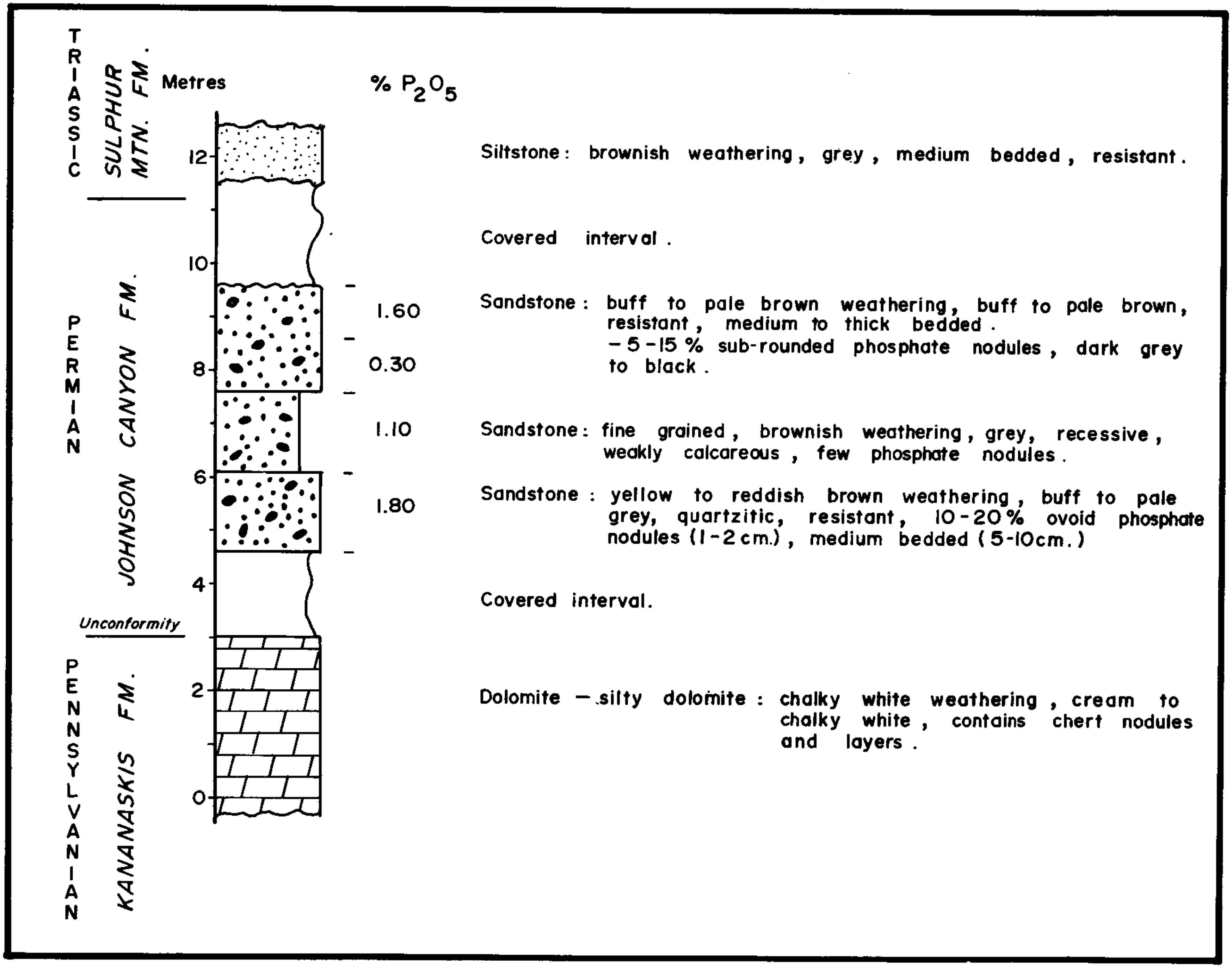

Figure 21. Stratigraphic section 41, MacDonald thrust fault, Ram.

less than 1 metre in the Burnham Creek area to 22 metres near Mount Broadwood.

Phosphate is most commonly present as nodules, but also as phosphate cement, phosphatic replacement of shell material and rarely, as intraclasts. It also occurs as clasts and cement in a thin basal conglomerate that appears to extend along the entire length of the fault. Host lithologies are typically siltstones and fine-grained sandstones with minor shale. Locally these clastic strata are calcareous.

At Mount Broadwood, where the thickest phosphatic interval was observed, individual phosphate beds contain 0.2 to 1.72 per cent P_2O_5. Phosphate is typically nodular although it is also present as cement. The basal conglomerate, which is 30 centimetres thick, contains 3.20 per cent P_2O_5.

At the Fenster Creek locality, clastic beds are more calcareous and contain relatively abundant bioclastic debris. A calcareous sandstone bed 0.5 metre thick contains 11.70 per cent P_2O_5. The basal conglomerate contains 4.0 per cent P_2O_5.

Near Cabin Pass only nodular phosphate is present and individual beds contain less than 2 per cent P_2O_5.

Nodular phosphatic beds of the Ranger Canyon Formation may also be present locally.

Weigert Creek (3)

Latitute: 49°57'45" Longitude: 114°56'25" NTS: 82G/15

Phosphate is exposed at two localities along a four-wheel-drive road that extends northward from the main Weigert Creek logging road. It is interpreted to occur along the limbs of a north-trending anticlinal fold in the Johnson Canyon Formation. Lithologies include sandstone, shale, dolomitic siltstone and conglomerate.

The western exposure consists of a 2-metre-thick phosphorite bed averaging 14.25 per cent P_2O_5 and comprised of semidispersed, subrounded, generally structureless pellets. Approximately 5 per cent of the pellets are nucleated and the occasional pellet is oolitic. Some phosphate cement is also present. The pellets, which comprise 40 to 50 per cent of the rock by volume, occur primarily in a quartz matrix with some feldspar.

The eastern exposure consists of a 1-metre-thick phosphorite bed containing 15.8 per cent P_2O_5 (Plate 11). The phosphorite is pelletal, with the pellets comprising 50 to 60 per cent of the rock by volume. They are subrounded, brown to dark brown, with a grain size of 0.1 to 0.5 millimetre. Less than 5 per cent of the pellets are nucleated or encased. Rare oolitic radial structures may also be present. The matrix is comprised mainly of calcite with minor quartz and clay minerals.

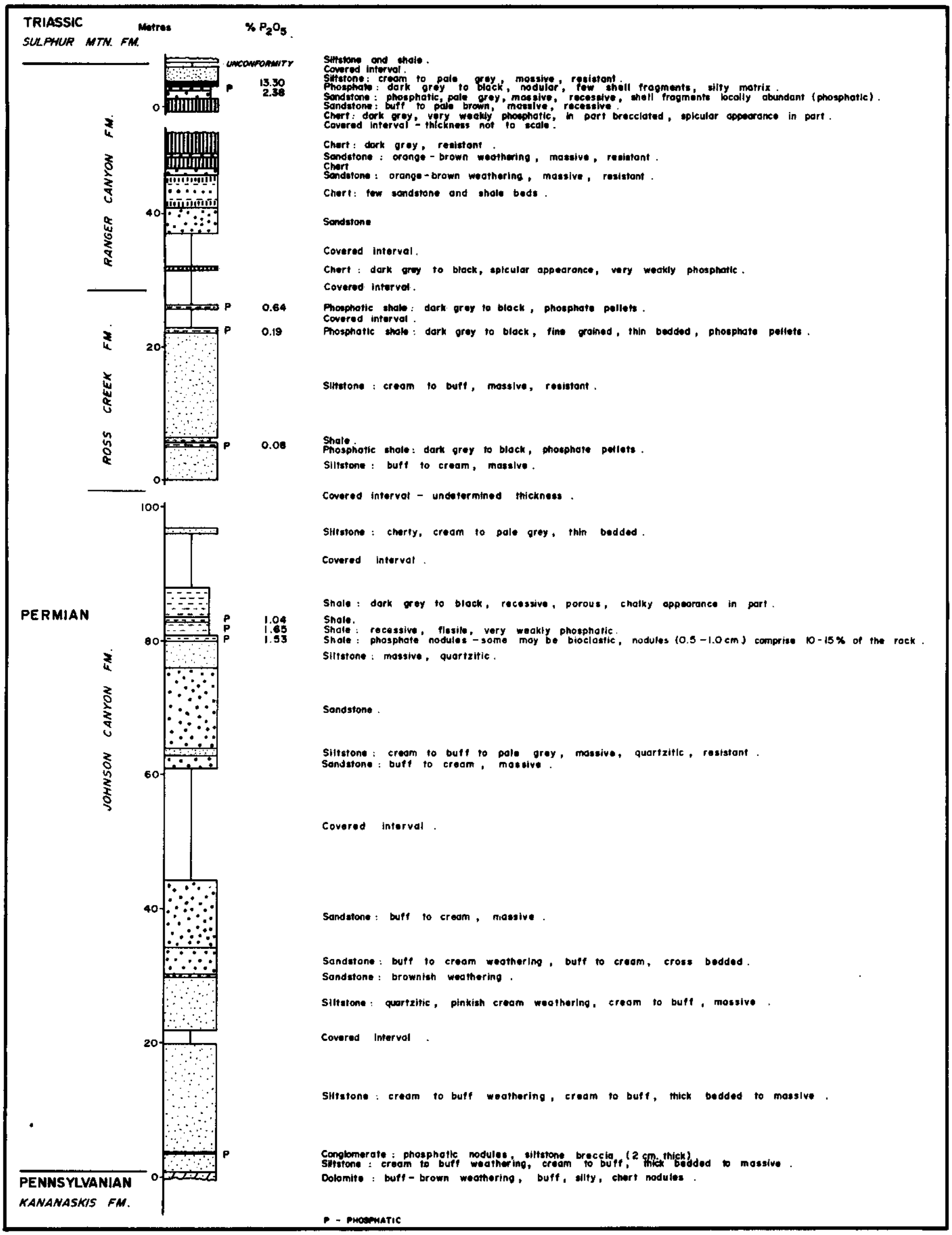

Figure 22. Stratigraphic section 8, Fernie ski-hill.

Nordstrum Creek (4)

Latitude: 49°51'50" Longitude: 114°59'55" NTS: 82G/15

Near the headwaters of Nordstrum Creek, at the end of a seismic road, three phosphate beds are poorly exposed over a 60-metre width. The area between the phosphate beds is covered by overburden. The host rocks are buff-brown-weathering sandstone and pale grey quartzitic siltstone of the Johnson Canyon Formation.

Phosphate occurs as nodules, pellets and as cement in the most westerly exposed bed. This phosphorite bed has an exposed thickness of 1 metre and contains 21.20 per cent P_2O_5. The matrix consists of quartz, bioclastic debris and minor feldspar.

The two easterly beds contain approximately 5 per cent phosphate nodules by volume and less than 2 per cent P_2O_5. The nodules are composed of fluorapatite, quartz, and minor dolomite and potash feldspar. Both of the beds are 1 metre or less thick.

Fernie Ski-hill (5)

Latitude: 49°27'40" Longitude: 115°06'30" NTS: 82G/6

In the Lizard Range, and specifically at the Fernie ski-hill, Permian strata are overturned. This locality provided the rare opportunity to measure a section across the entire Permian sequence (Figure 22). The Johnson Canyon Formation is approximately 100 metres thick and contains a few very thin phosphatic shale beds. The basal conglomerate, which occurs throughout the region, is represented by only a 2-centimetre-thick bed.

The Ross Creek Formation is approximately 25 metres thick and contains only a rare very low-grade phosphatic shale bed. Although the author has placed these strata in the Ross Creek Formation, they could also be assigned to the Johnson Canyon Formation or Ranger Canyon Formation.

The Ranger Canyon Formation is approximately 50 metres thick and consists of chert and sandstone. Close to the top there is a 0.5-metre-thick phosphate bed containing 13.30 per cent P_2O_5 (Plate 12). Phosphate is present as nodules (Plate 13), pellets and cement. The nodules may contain quartz grains and chert spicules or may be devoid of any extraneous material. The phosphate bed itself is composed of quartz, potash feldspar, minor illite, sericite, calcite and albite. Phosphatic sandstone and chert beds underlie the phosphate bed.

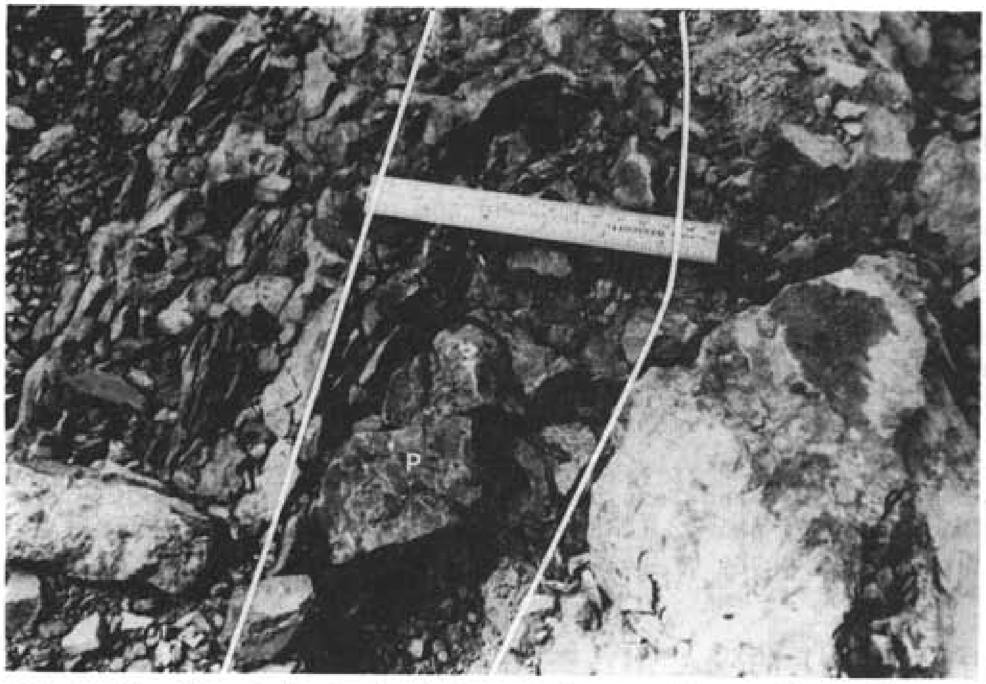

Plate 12. Phosphate bed at top of Ranger Canyon Formation, Fernie ski-hill.

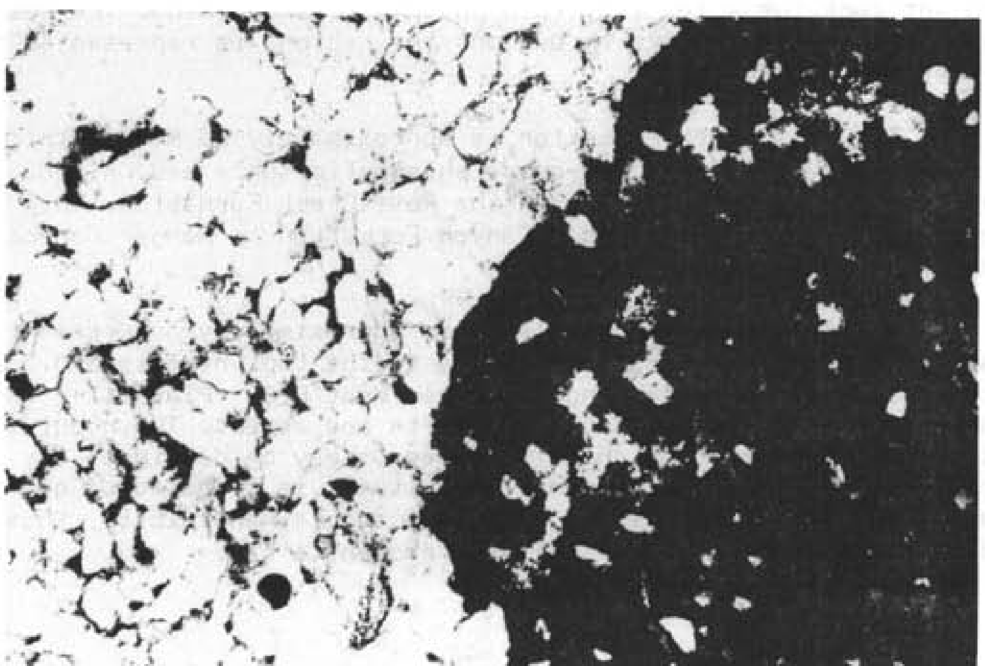

Plate 13. Photomicrograph (40x) of phosphate nodule (black) in a quartz-rich matrix, Ranger Canyon Formation, Fernie ski-hill.

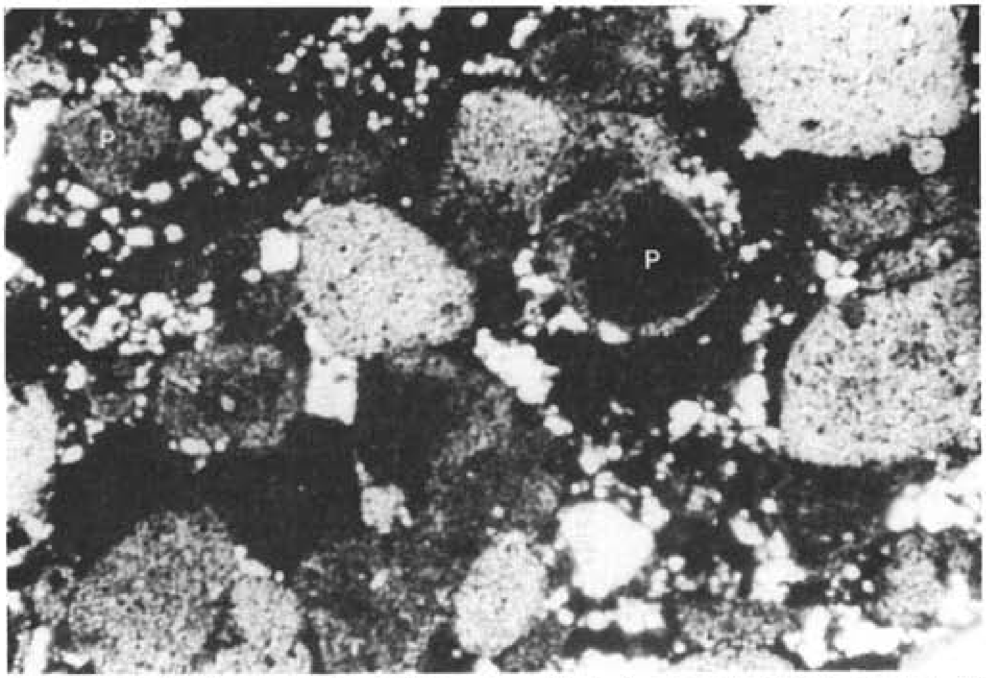

Plate 14. Photomicrograph (40x) of pelletal phosphorite, Mount Lyne. Phosphate pellets (P) with a compact texture occur in a quartz matrix.

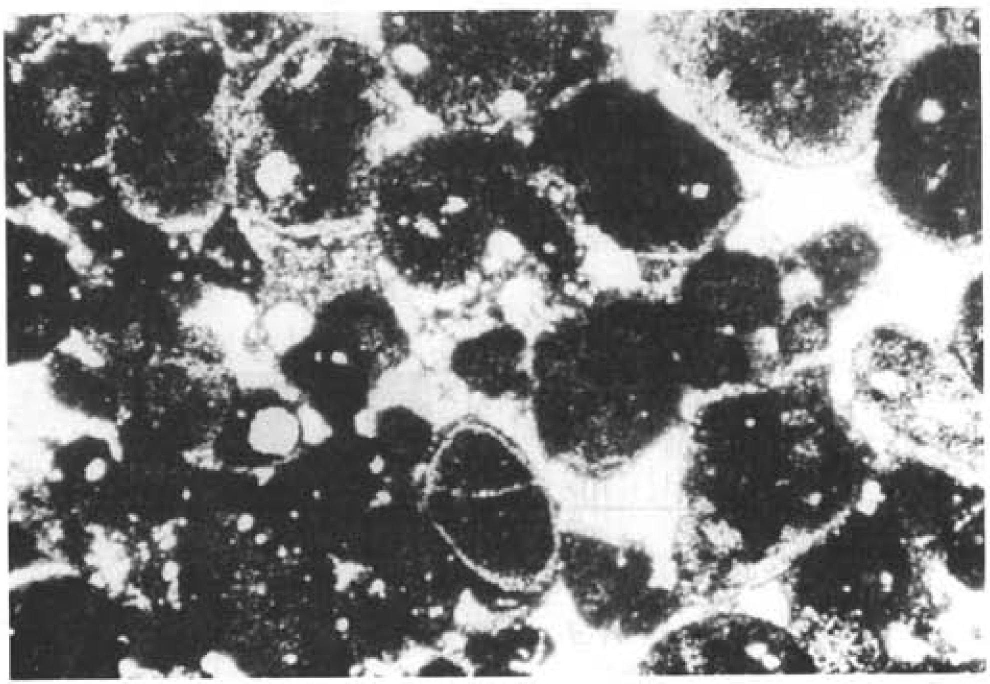

Plate 15. Photomicrograph (40x) of pelletal phosphorite from the Crow deposit. Pellets of fluorapatite occur in a matrix of quartz with minor calcite and lesser feldspar, illite and albite.

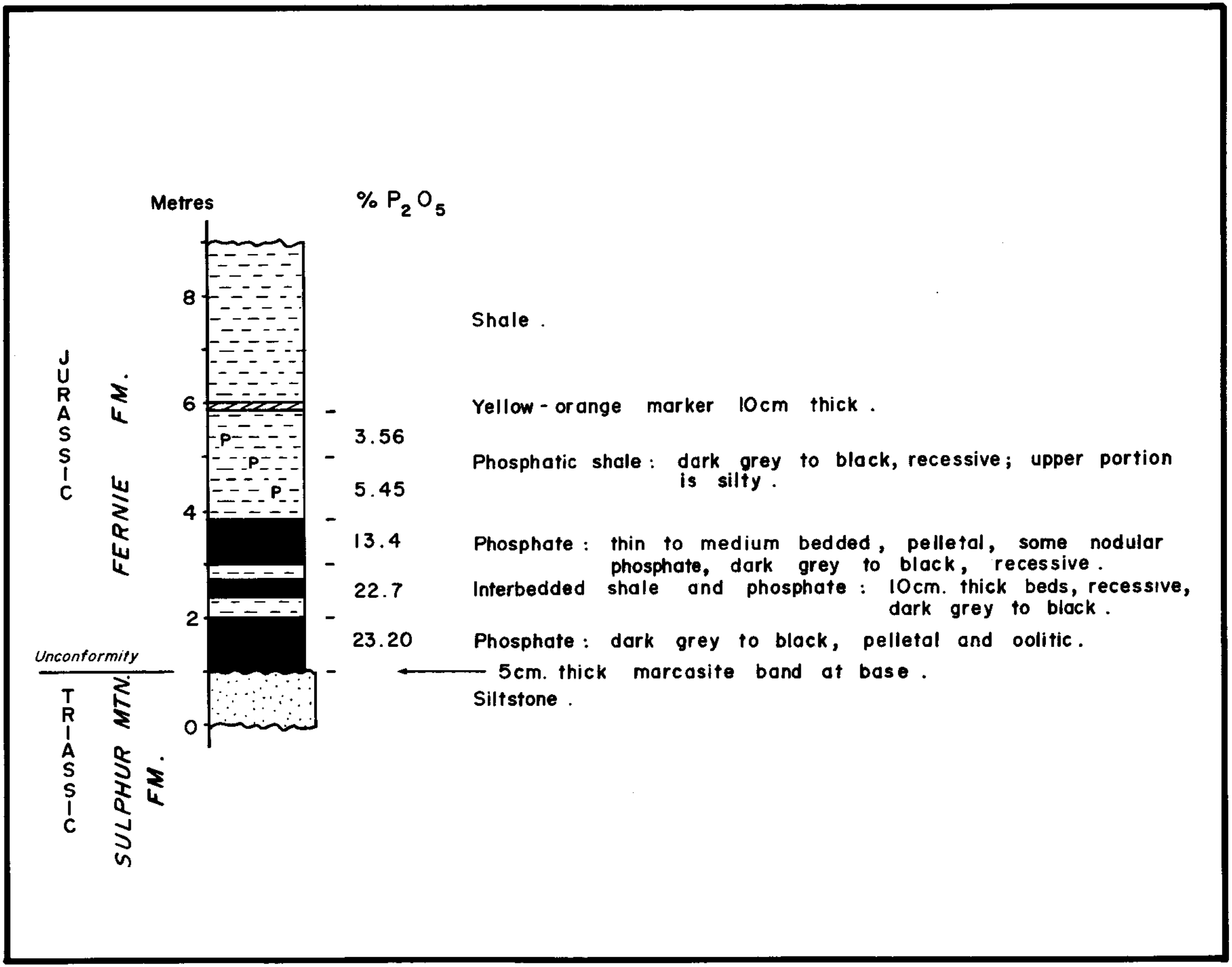

Figure 23. Stratigraphic section 70, Mount Lyne.

JURASSIC: FERNIE FORMATION

Line Creek (6)

Latitude: 49°58'00"   Longitude: 114°48'00"   NTS: 82G/15W

Cominco Ltd. owns six phosphate leases in the West Line Creek area east of the Elk River. A phosphate horizon varying in thickness from less than 1 metre to in excess of 3 metres occurs at the base of the Fernie Formation. It can be traced along strike for 15 kilometres; 8 kilometres of strike length are covered by the Cominco leases.

At Mount Lyne, site of Cominco's bulk sample (G.L. Webber, personal communication, 1986), a 4.9-metre-thick, steep, easterly dipping phosphate sequence is present (Figure 23). The base of this sequence is marked by a marcasite band 5 centimetres thick and the top by a 10-centimetre-thick yellow-orange cherty limestone marker horizon. The basal 2 metres of the phosphate averages 23.0 per cent P_2O_5. These strata are in turn overlain by a bed of lower grade phosphate, 90 centimetres thick, containing 13.4 per cent P_2O_5, and capped by 2 metres of phosphatic shale with a phosphate content averaging less than 5 per cent P_2O_5.

The phosphorite at Mount Lyne is typically pelletal with a compact (Plate 14) to semidispersed texture. The pellets are chestnut-brown to dark brown, ovoid, moderately well sorted and generally structureless. Less than 5 per cent are nucleated. The matrix is comprised almost entirely of quartz, with trace amounts of sericite and illite. Neither petrographic nor X-ray diffraction work reveals the presence of any carbonate.

Along strike to the south, near Harriet Lake, this phosphate interval has thinned to 0.55 metre and contains 13.8 per cent P_2O_5. Work by Crows Nest Resources Ltd., between the Line Creek access road and Mount Lyne, obtained values of 3.7 per cent P_2O_5 in a diamond-drill hole and 23.7 per cent P_2O_5 across 1.6 metres in a backhoe trench (Hannah, 1980). The phosphate bed dips between 45 to 70 degrees easterly throughout its strike length (*see* Figures 24 and 25).

Crow (7)

Latitude: 49°39'45"   Longitude: 114°42'30"   NTS: 82G/10

The Crow property, consisting of seven phosphate leases held by Cominco Ltd., is located in the Crowsnest Pass area, 2.5 kilometres north of the pumping station on Highway 3. This deposit, discovered by Telfer in the early 1900s, was explored sporadically until the mid-1970s. Cominco has completed 600 metres of underground work and shipped a 1800-tonne sample to Trail for metallurgical testing in 1931. Further testing was done in the mid-1960s. Beneficiation work by Cominco has yielded acceptable concentrate grades with recoveries of approximately 75 per cent (Kenny, 1977).

The adit and underground workings are now inaccessible. Only one old trench and a few surface exposures south of the underground workings

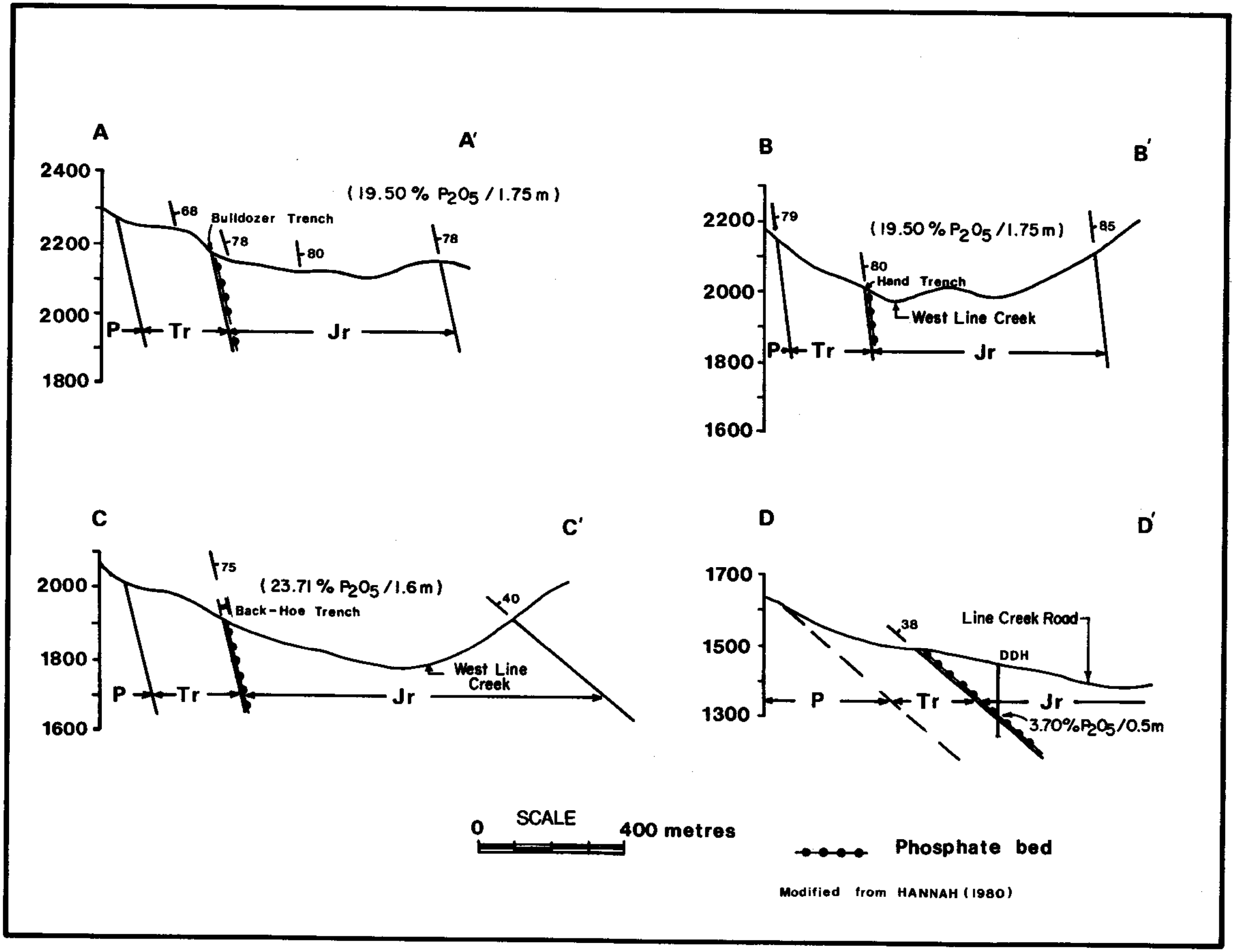

Figure 24. Cross-sections through basal Fernie phosphate, west Line Creek.

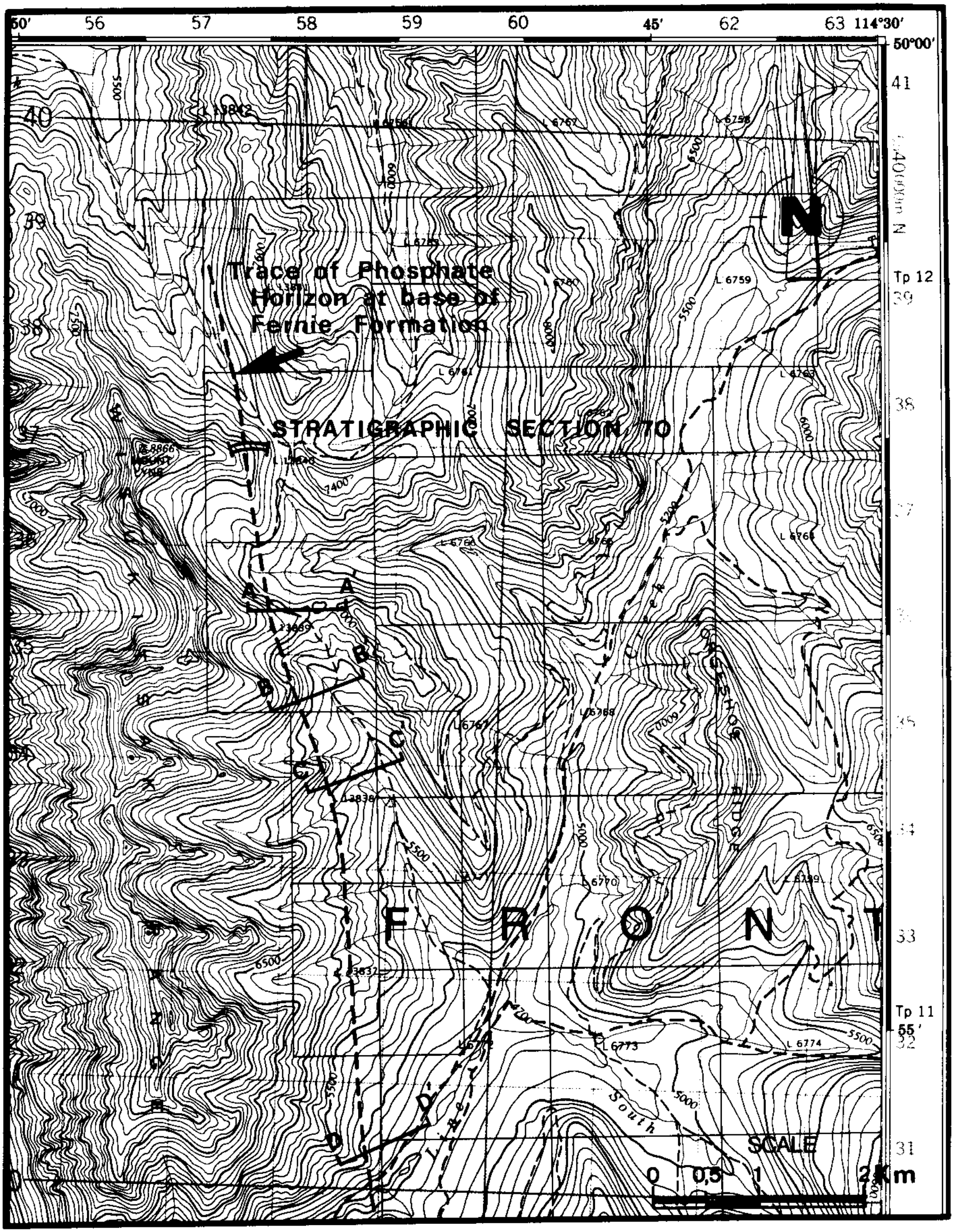

Figure 25. Location of cross-sections, west Line Creek.

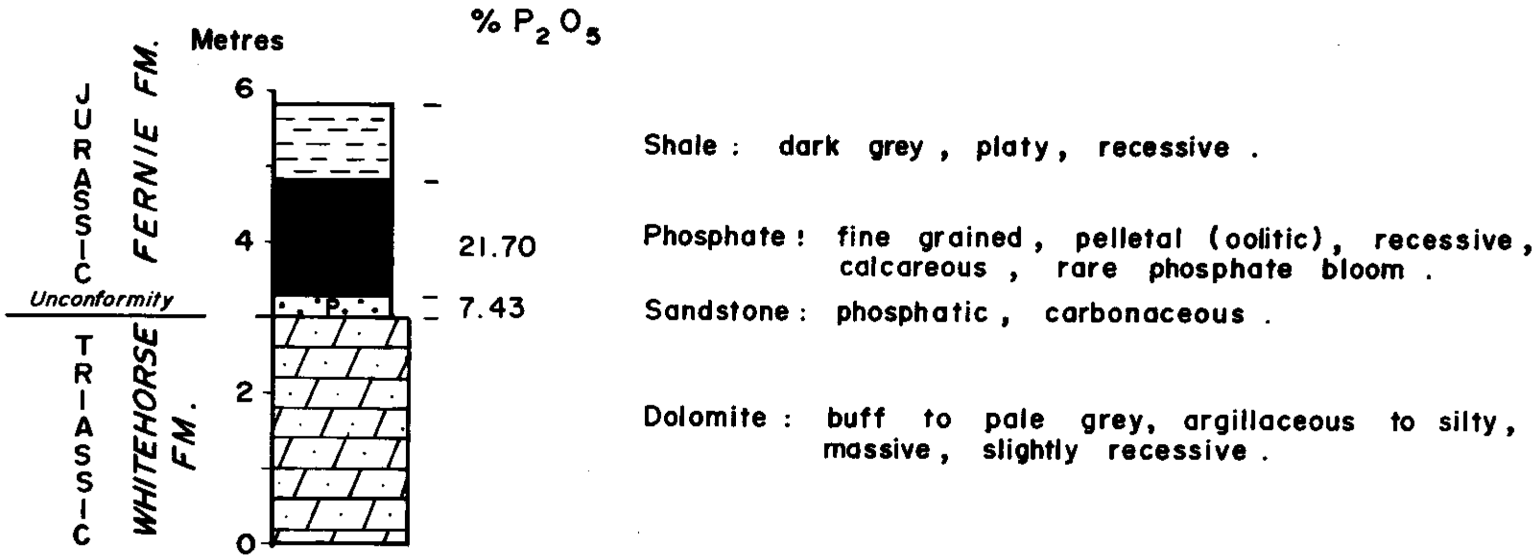

Figure 26. Stratigraphic section 13, Abby Ridge.

are available for examination. Telfer (1933) describes the phosphate horizon as consisting of three beds: a lower oolitic high-grade phosphorite, a shale parting and an upper nodular phosphorite with a yellow marker bed at the top. The high-grade phosphorite bed consists of structureless pellets with only a rare pellet having an oolitic texture (Plate 15). The beds average approximately 1 metre in thickness, but are repeated as many as four or five times by thrusting in an easterly direction (Telfer, 1933). In the trench the phosphate horizon occurs over an interval of 19 metres within which a phosphorite bed 1 metre thick is repeated four times. Sampling indicates an average phosphate content of 26.20 per cent P_2O_5.

This phosphate horizon, although not seen in outcrop, is believed to be continuous into the headwaters of Alexander Creek where it is exposed in two roadcuts. The top and bottom of the phosphorite were not observed, but it has a minimum thickness of 0.3 metre. The phosphate content in these localities ranges from 27.4 to 29.4 per cent P_2O_5. Bedding in this area dips westerly at approximately 25 degrees.

Lizard (8)

Latitude: 49°29'22" Longitude: 115°07'40" NTS: 82G/11E

The Lizard property, consisting of two phosphate leases retained by Cominco Ltd., is located on Lizard Creek 5 kilometres southwest of Fernie. Only two caved adits and a dump are available for inspection. The area is overgrown by dense alder and thick underbrush with almost no outcrop.

Work by Cominco has indicated the presence of a phosphorite bed averaging 12.90 per cent P_2O_5 across 3.4 metres (Taplin, 1967). In thin section (Plate 16) the phosphorite is seen to consist of brown to dark brown pellets averaging 0.2 to 0.3 millimetre in diameter. They are generally well rounded and structureless, with approximately 50 per cent having a quartz nucleus. The matrix, which comprises 20 per cent of the rock, is dominantly carbonate with lesser quartz and minor amounts of mica and clay minerals. Deposition of phosphate as a gel is evidenced by molding of pellets around each other. In thin section there is no evidence that the phosphorite has been subjected to any significant weathering, and therefore no upgrading of the phosphate content.

Abby (9)

Latitude: 50°18'25" Longitude: 114°56'05" NTS: 82J/7

The Abby occurrence is located along the Elk River forestry road 31.5 kilometres north of Elkford. It was exposed in a reclaimed trench put in by Cominco Ltd. while exploring for phosphate in the mid-1970s.

Clastic rocks of the Fernie Formation unconformably overlie dolomite and dolomitic siltstone of the Whitehorse Formation. The base of the Fernie consists of a thin bed of phosphatic sandstone, overlain by a phosphorite bed 1.5 metres thick (Figure 26). The phosphorite is pelletal

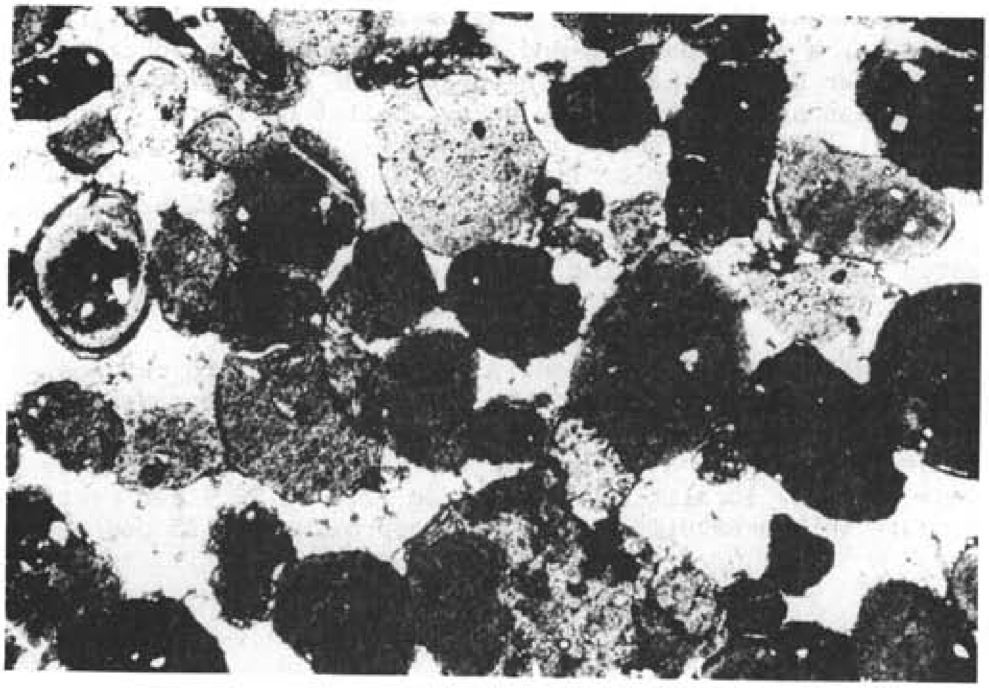

Plate 16. Photomicrograph (40x) of pelletal phosphorite from the base of the Fernie Formation, Lizard property.

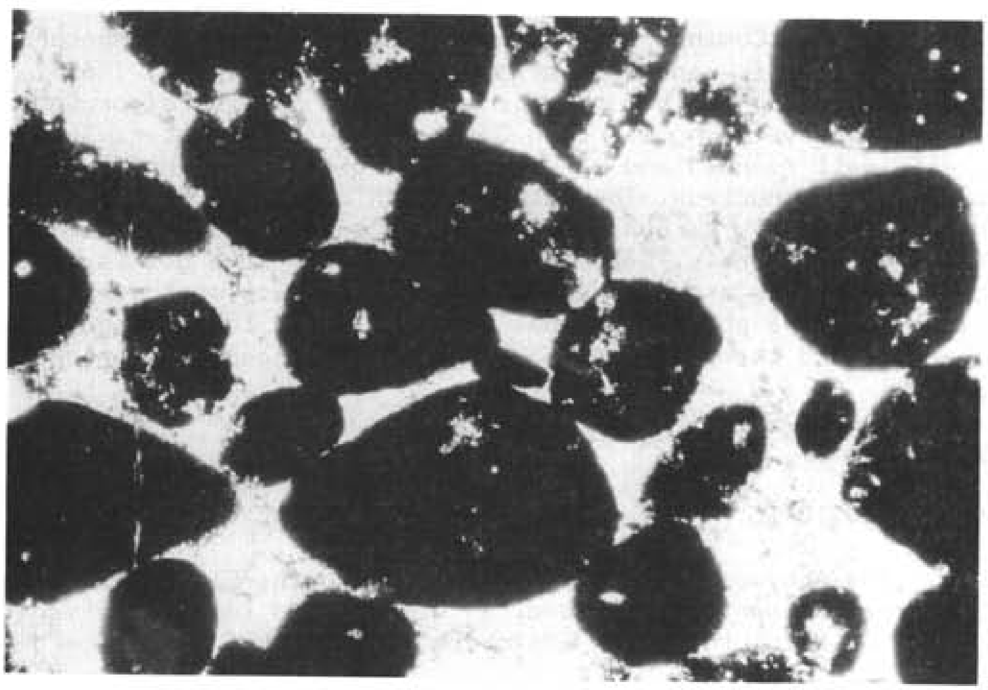

Plate 17. Photomicrograph (40x) of pelletal phosphorite with semidispersed texture, Abby Ridge.

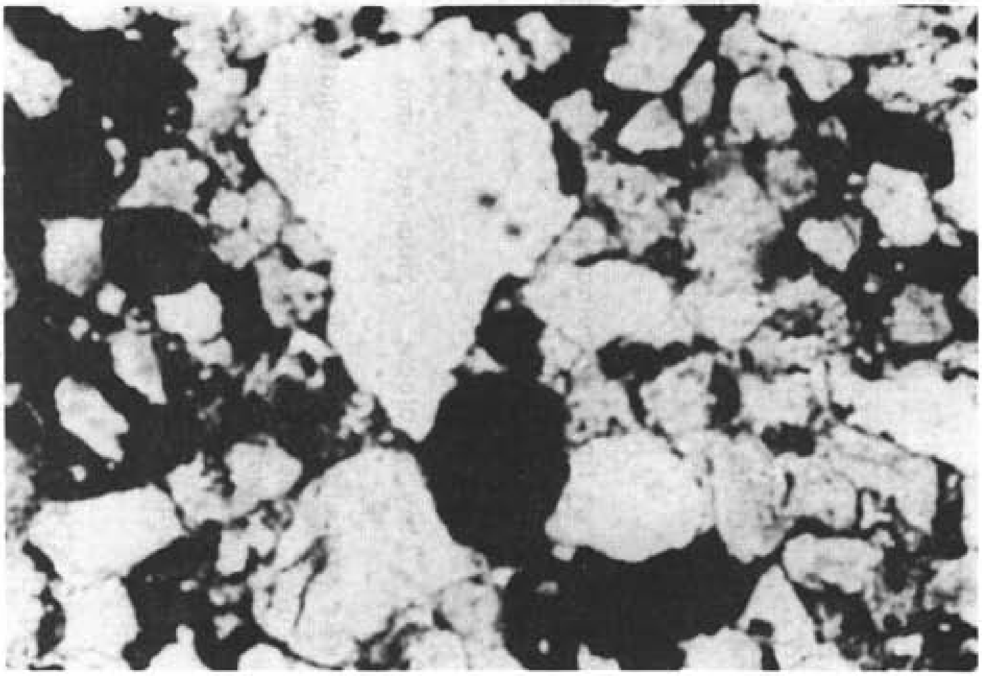

Plate 18. Photomicrograph (40x) of phosphate pellets (black) in a quartz (white) sandstone, Abby Ridge.

Plate 19. Basal phosphorite bed (P) in Fernie Formation shale (Jf) overlying siltstone of the Sulphur Mountain Formation (Tsr), Highway 3 roadcut at Alexander Creek.

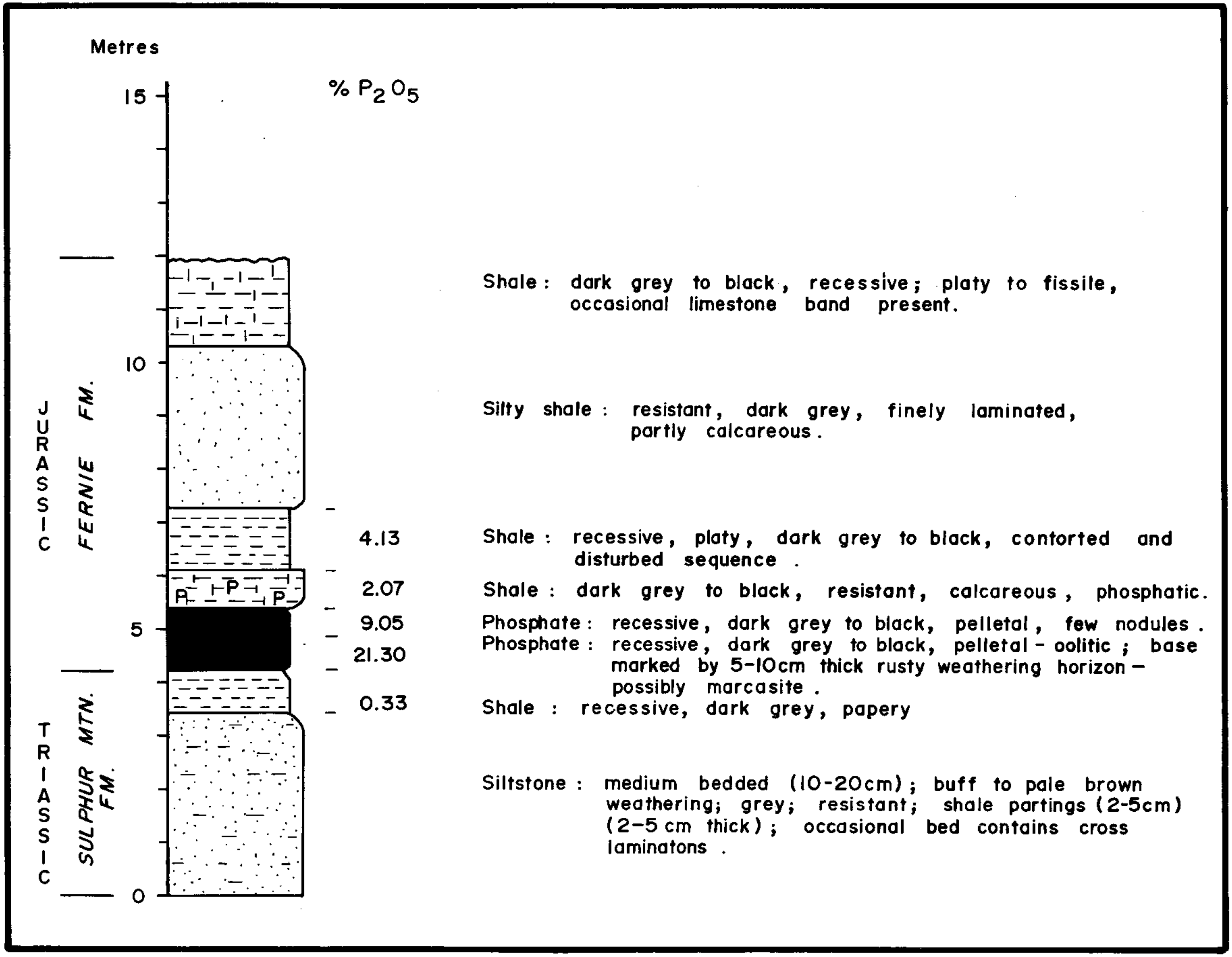

Figure 27. Stratigraphic section 3, Highway 3 roadcut, approximately 8 kilometres east of Michel.

with an average grain size of 0.1 millimetre. Phosphate content is 21.7 per cent P_2O_5; phosphate content of the sandstone is 7.43 per cent P_2O_5. Phosphatic shale and shale overlie the phosphorite.

In thin section the phosphorite can be seen to consist of light to dark brown, generally structureless, subangular to subrounded pellets 0.1 to 0.2 millimetre in size (Plate 17). Less than 5 per cent of the pellets are nucleated (generally quartz grains). The occasional pellet is oolitic. The matrix is comprised of subangular quartz grains with trace to minor amounts of potash feldspar, sericite and carbonate. The pellets comprise 50 to 60 per cent of the rock by volume and are semicompact to dispersed.

The phosphatic sandstone (Plate 18) contains 10 to 15 per cent fluorapatite pellets. The pellets are subrounded, brown and dispersed. Quartz with minor carbonate and trace feldspar, sericite and carbonate comprise the sandstone matrix. Quartz grains are subangular and moderately well sorted.

Highway 3 - Alexander Creek (10)

Latitude: 49°39'15" Longitude: 114°44'10" NTS: 82G/10

Two outcrops of phosphate are located on provincial Highway 3 near Alexander Creek. A phosphorite bed 1.2 metres thick is exposed in a roadcut (Plate 19) unconformably overlying shale and siltstone of the Sulphur Mountain Formation. The phosphorite is overlain in turn by phosphatic shale, minor limestone and shale (Figure 27).

The phosphorite consists of brown to dark brown, subangular to subrounded, structureless pellets that are 0.1 to 0.3 millimetre in diameter. Approximately 5 per cent of the pellets have nuclei of either quartz or calcite. The pellets are compact to semicompact and sometimes molded around previously formed pellets, suggesting that they were in a gel-like state when deposited. The matrix consists of quartz and calcite in equal amounts, with minor dolomite, albite, potassium feldspar and trace illite and sericite.

A second phosphate occurrence outcrops along Alexander Creek south of the highway. Here, a phosphorite bed 1 metre thick containing 23.8 per cent P_2O_5 overlies a basal phosphatic conglomerate 5 centimetres thick. This conglomerate overlies siltstone and minor shale of the Sulphur Mountain Formation (Figure 28). The phosphatic section is 5.5 metres thick, the upper limit of the phosphatic sequence corresponding to a yellowish-orange-weathering limestone bed 3 centimetres thick. Shale cut by numerous minor faults overlies the phosphatic sequence.

Lodge (11)

Latitude: 49°16'50" Longitude: 114°47'40" NTS: 82G/7

The Lodge phosphate occurrence is located immediately south of the Lodgepole forestry road, 31 kilometres southeast of Fernie. Previous

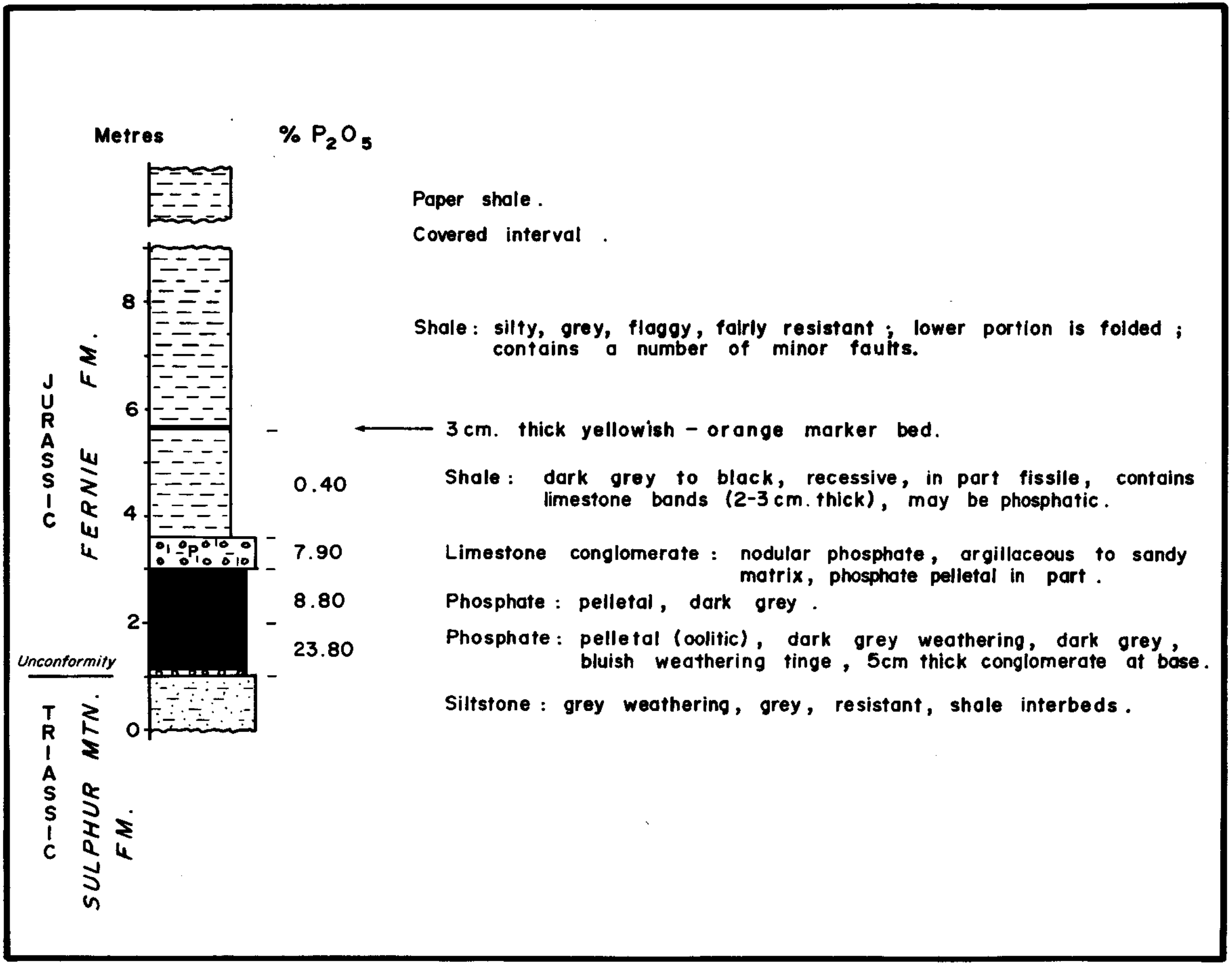

Figure 28. Stratigraphic section 31, Alexander Creek at Highway 3.

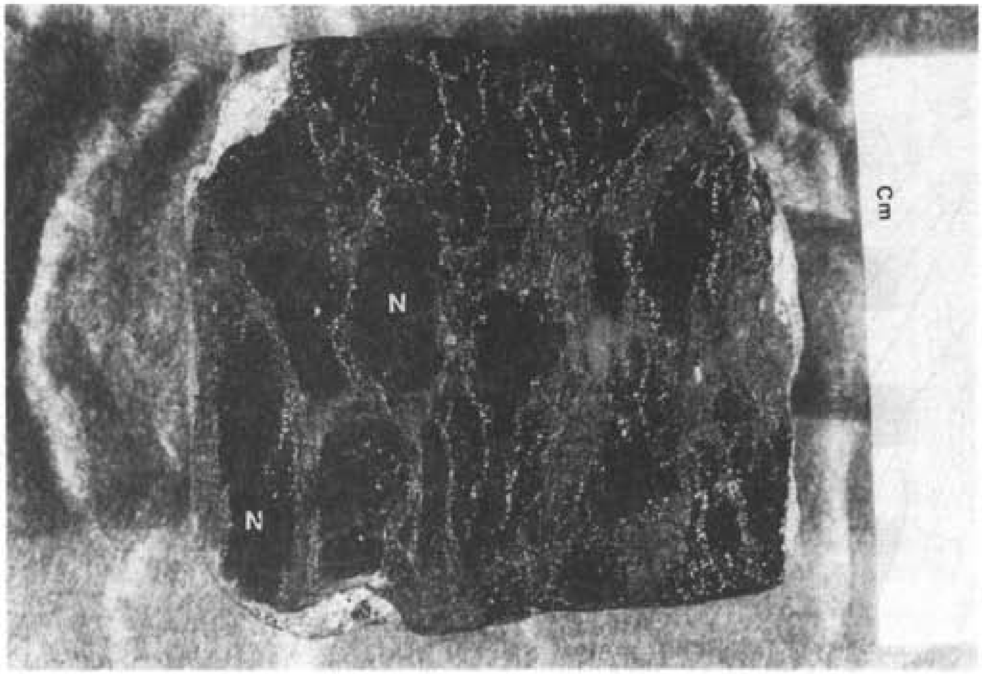

Plate 20. Hand specimen of basal phosphorite of the Fernie Formation, Lodge phosphate occurrence. Note the presence of phosphate nodules (N) in a pelletal matrix.

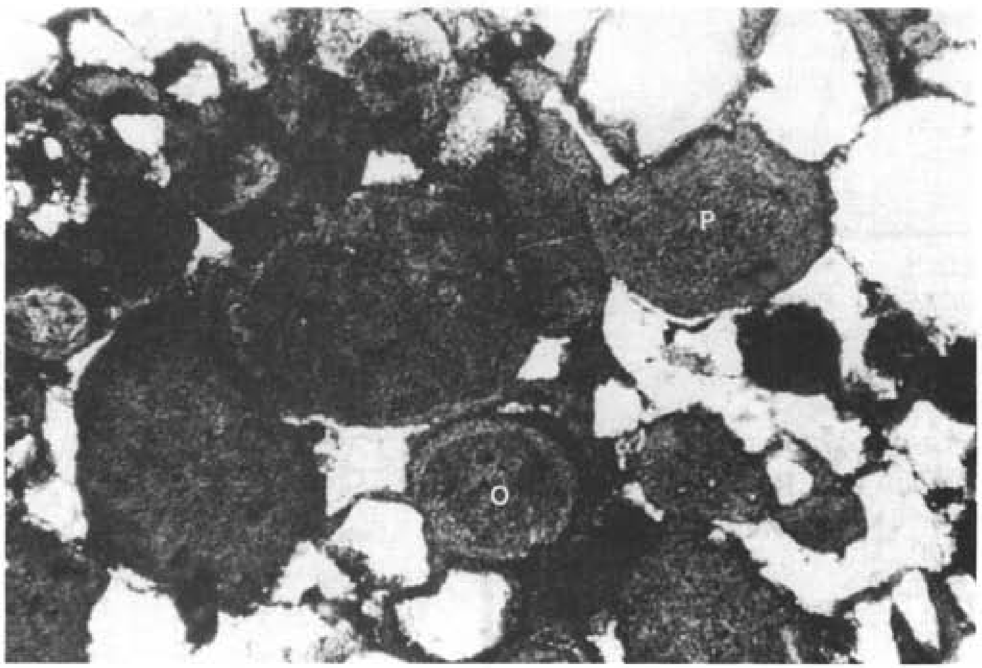

Plate 21. Photomicrograph (40x) of pelletal phosphorite, Fording River. Structureless pellets (P) and rare oolite (O) occur in a matrix of calcite and quartz.

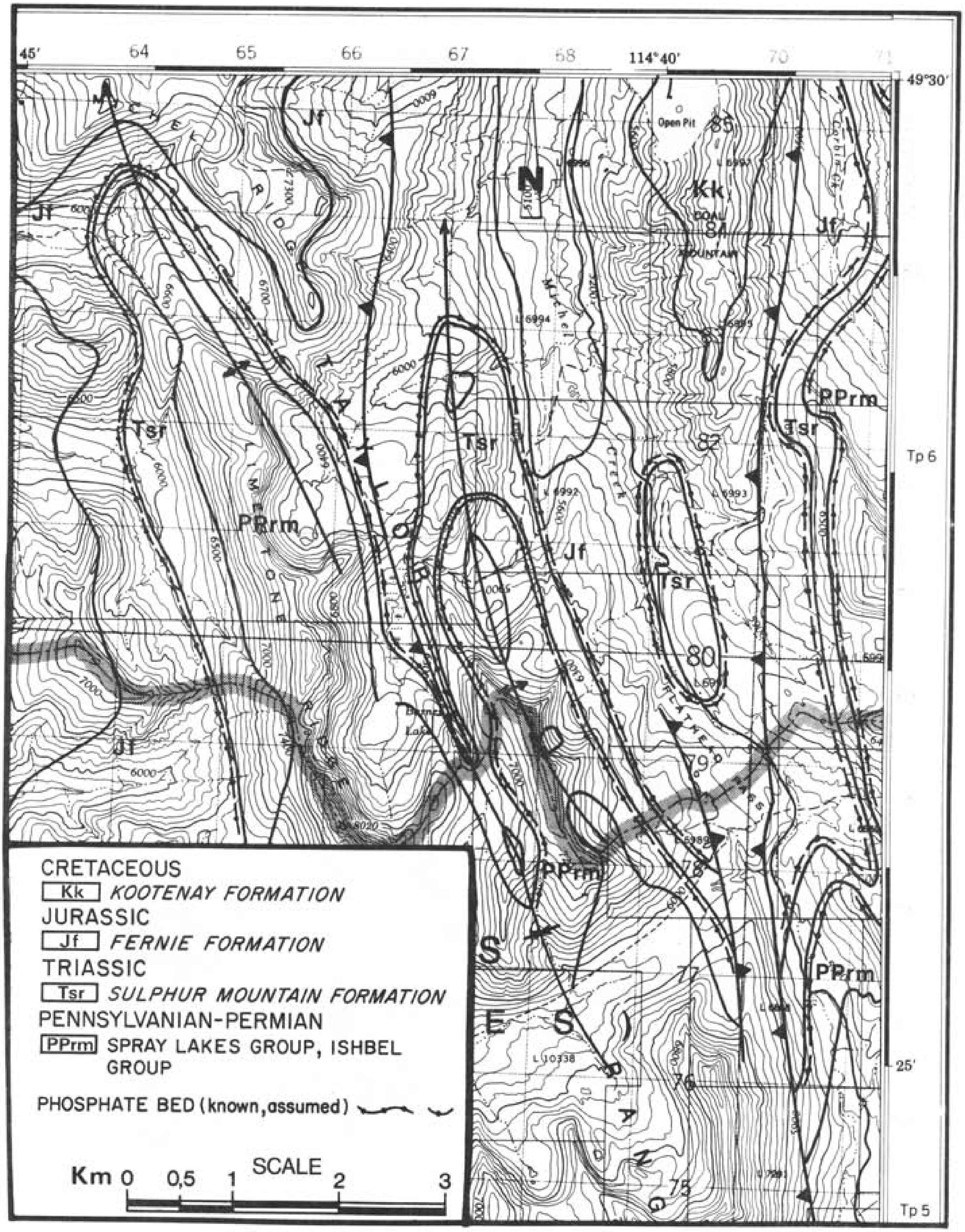

Figure 29. Phosphate distribution in the Barnes Lake area (geology after Price, 1964).

exploration for phosphate in this area was done by Imperial Oil Ltd. A phosphorite bed occurs in brown and black shale and siltstone at the base of the Fernie Formation. These strata unconformably overlie fine siltstone of the Sulphur Mountain Formation. The only outcrop of phosphate is strongly weathered and the thickness of the phosphorite was not determined. A large grab sample from this locality contained 29.5 per cent P_2O_5. In hand specimen the phosphate is both pelletal and nodular (Plate 20). Drilling intersected 2.44 metres of phosphate averaging 17.33 per cent P_2O_5 (Heffernan, 1978).

Iron Creek (12)

Latitude: 49°31'30"   Longitude: 115°10'40"   NTS: 82G/11

Two phosphate occurrences in partially slumped trenches were briefly examined along the powerline in the Iron Creek area, west of Fernie. These trenches are believed to have been put in by Crows Nest Resources. At both localities a phosphorite bed 1 metre thick with phosphate values ranging from 13.2 to 15.4 per cent P_2O_5 occurs at the base of the Fernie Formation. The phosphorite is pelletal with a matrix of by calcite with lesser quartz. Minor albite and trace amounts of potash feldspar and illite are also present.

Barnes Lake (13)

Latitude: 49°27'10"   Longitude: 114°40'50"   NTS: 82G/7

A phosphorite bed 0.8 to 1.2 metres thick is exposed at the base of the Fernie Formation on the limbs of a series of northerly plunging folds in the Barnes Lakes area (Figure 29). It unconformably overlies siltstone of the Sulphur Mountain Formation and is overlain by paper shales of the middle Fernie Formation. Exploration work by Western Warner Oils Ltd. and Medesto Exploration Ltd. consisted of geological mapping, trenching, seismic surveys and drilling (Dorian, 1975; Pelzer, 1977; Dales, 1978) and outlined 262 000 tonnes of phosphate to a depth of 18 metres (60 feet). Phosphate grades in surface trenches were reported as 27.0 to 33.0 per cent P_2O_5. Sampling by the author gave a value of 22.7 per cent P_2O_5 across 0.80 metre.

In the same area nodular phosphate is present in sandstone in the Johnson Canyon Formation. This phosphate-bearing sandstone bed is 30 to 40 centimetres thick with a phosphate content of 1.7 per cent P_2O_5. There appears to be very little economic potential for phosphate in the Permian in the Barnes Lake area.

Fording River (14)

Latitude: 49°54'20"   Longitude: 114°50'55"   NTS: 82G/15

The Fording River phosphate occurrence, which has been known for a number of years, has been explored by both Crows Nest Resources and

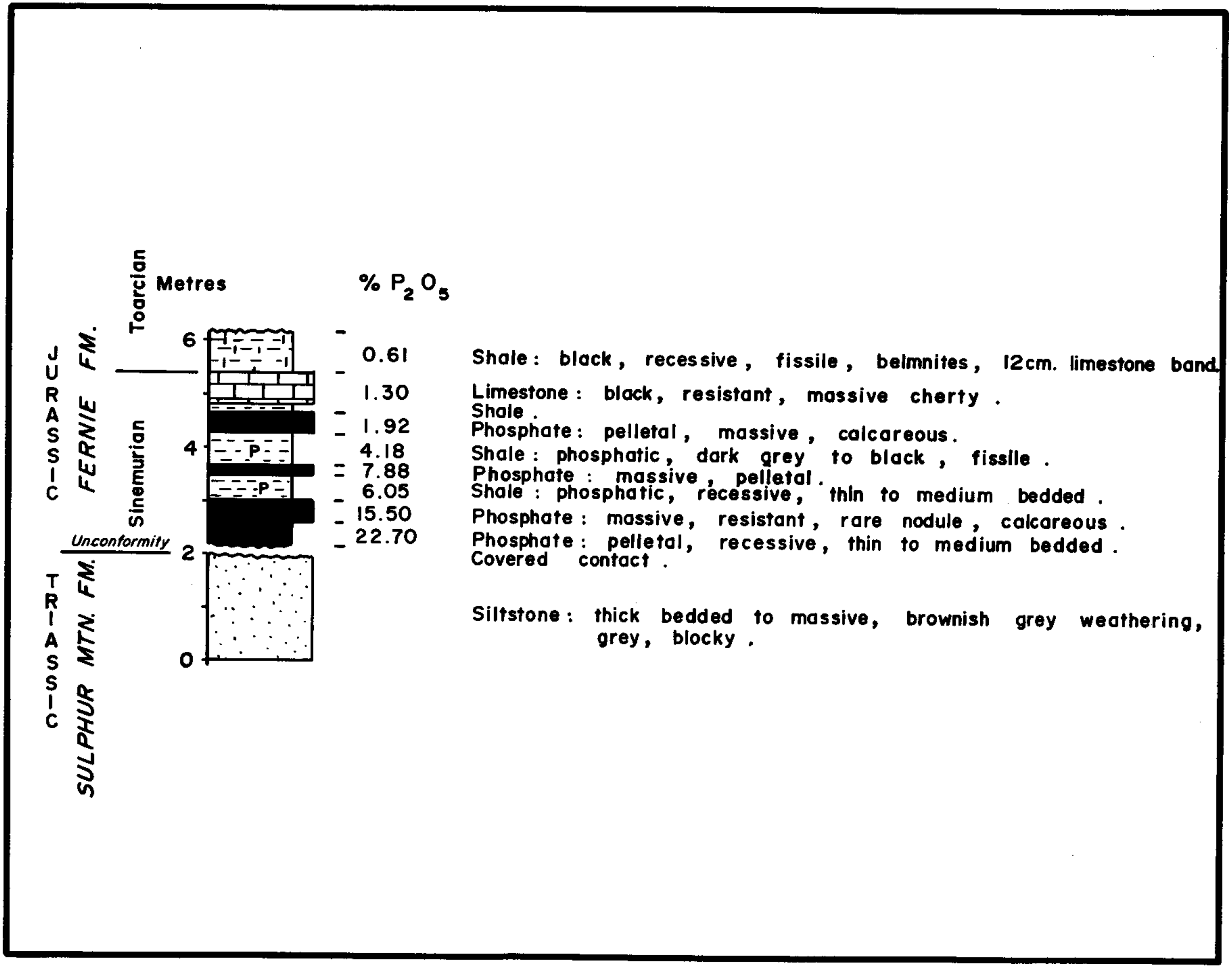

Figure 30. Stratigraphic section 6, Fording River.

Cominco Ltd. Work by Cominco included mapping, trenching and a 12-metre adit.

A shallow southwest-dipping pelletal phosphorite bed occurs at the base of the Fernie Formation and is overlain by phosphatic shale and limestone. These strata are of Sinemurian age. The phosphate sequence is conformably overlain by belemnitic shales of Toarcian age and underlain by siltstone and minor shale of the Sulphur Mountain Formation (Figure 30).

In outcrop the phosphorite bed is 80 centimetres thick and contains 19.10 per cent P_2O_5. It is overlain by 74 centimetres of phosphatic shale containing 6.64 P_2O_5. Similar results were obtained by Cominco in the adit where a pelletal phosphorite bed 1.2 metres thick containing 21.3 per cent P_2O_5 is overlain by 51 centimetres of phosphatic shale containing 6.5 per cent P_2O_5 (Webber, 1975). The phosphorite is typically pelletal with pellets of fluorapatite present in a matrix of calcite and lesser quartz (Plate 21).

A diamond-drill hole completed by Cominco to the northwest, intersected 1.76 metres of phosphate containing 18.57 per cent P_2O_5 at a depth of 49.4 metres (Webber, 1976). This phosphate horizon is believed to continue into the Grave Creek area where drilling (Figure 31) intersected 1.5 metres of phosphate containing 16.93 per cent P_2O_5 (Webber, 1976).

Bingay Creek (15)

Latitude: 50°12'00" Longitude: 115°00'00" NTS: 82J/2

This phosphate occurrence is located on Bingay Creek, 2.4 kilometres upstream from the Elk River forestry road, 19 kilometres north of Elkford. Vertical-dipping conglomerate, phosphorite, sandstone and shale of the Fernie Formation unconformably overlie silty dolomite of the Whitehorse Formation (Figure 32). The phosphatic sequence consists of a phosphorite bed 1.04 metres thick containing 11.80 per cent P_2O_5, phosphatic sandstone and shale. The phosphatic sequence is marked by conglomerate (4 centimetres thick) at its base and is capped by an orange-weathering calcareous bed, 2 centimetres thick. The phosphorite is pelletal and contains a few shell fragments.

Cabin Creek (16)

Latitude: 49°06'40" Longitude: 114°40'45" NTS: 82G/2

Exploration for phosphate in the Cabin Creek area began in 1978 when Imperial Oil Ltd. completed a program of geological mapping and drilling (Van Fraassen, 1978). In 1982 First Nuclear Corp. Ltd. reassessed the potential in this area, completing radiometric surveys, geological mapping and trenching (Hartley, 1982).

The Cabin Creek area represents the southernmost exposures of phosphate in both Permian and Jurassic strata in southeastern British

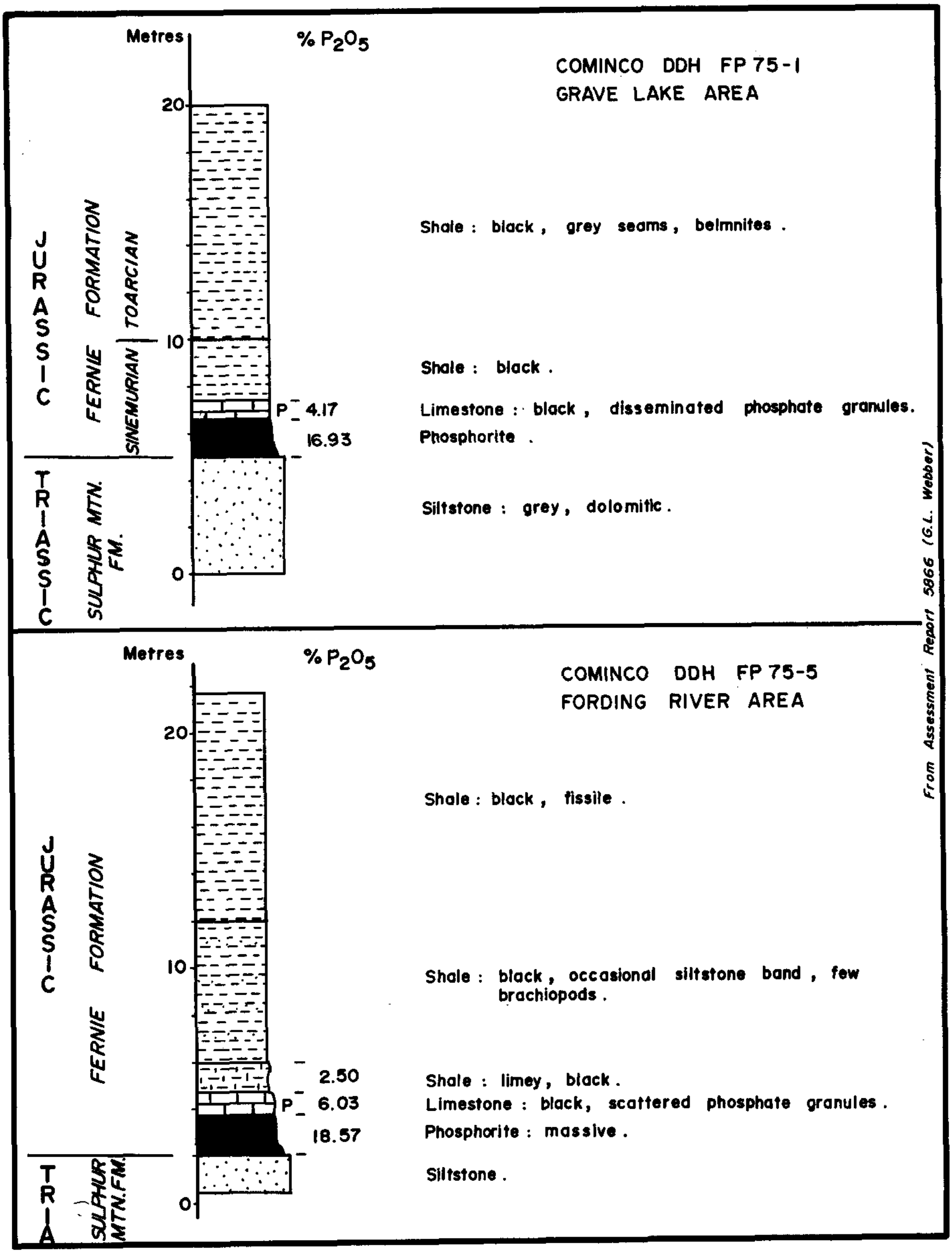

Figure 31. Diamond-drill hole sections, Fording River - Grave Lake area.

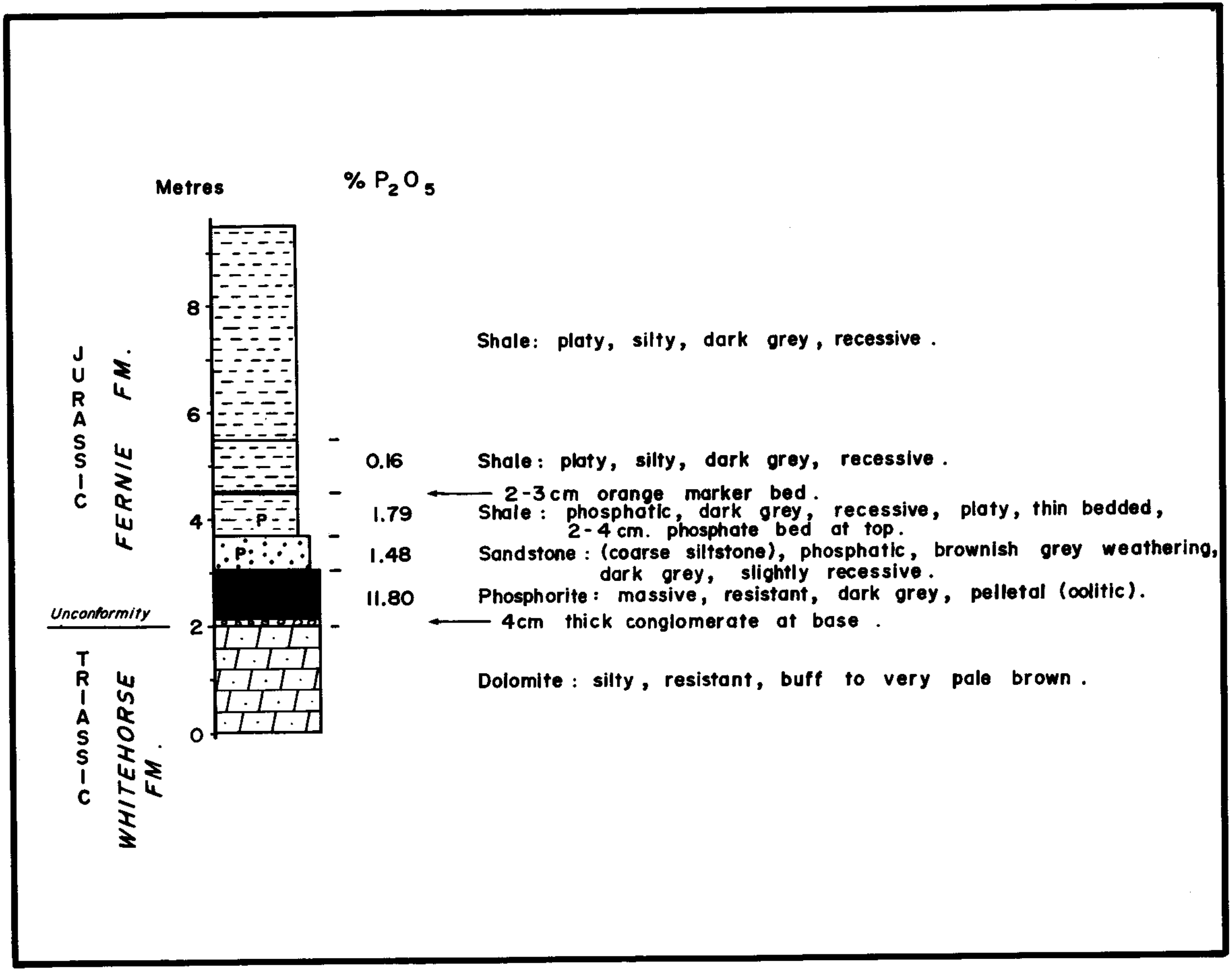

Figure 32. Stratigraphic section 14, Bingay Creek.

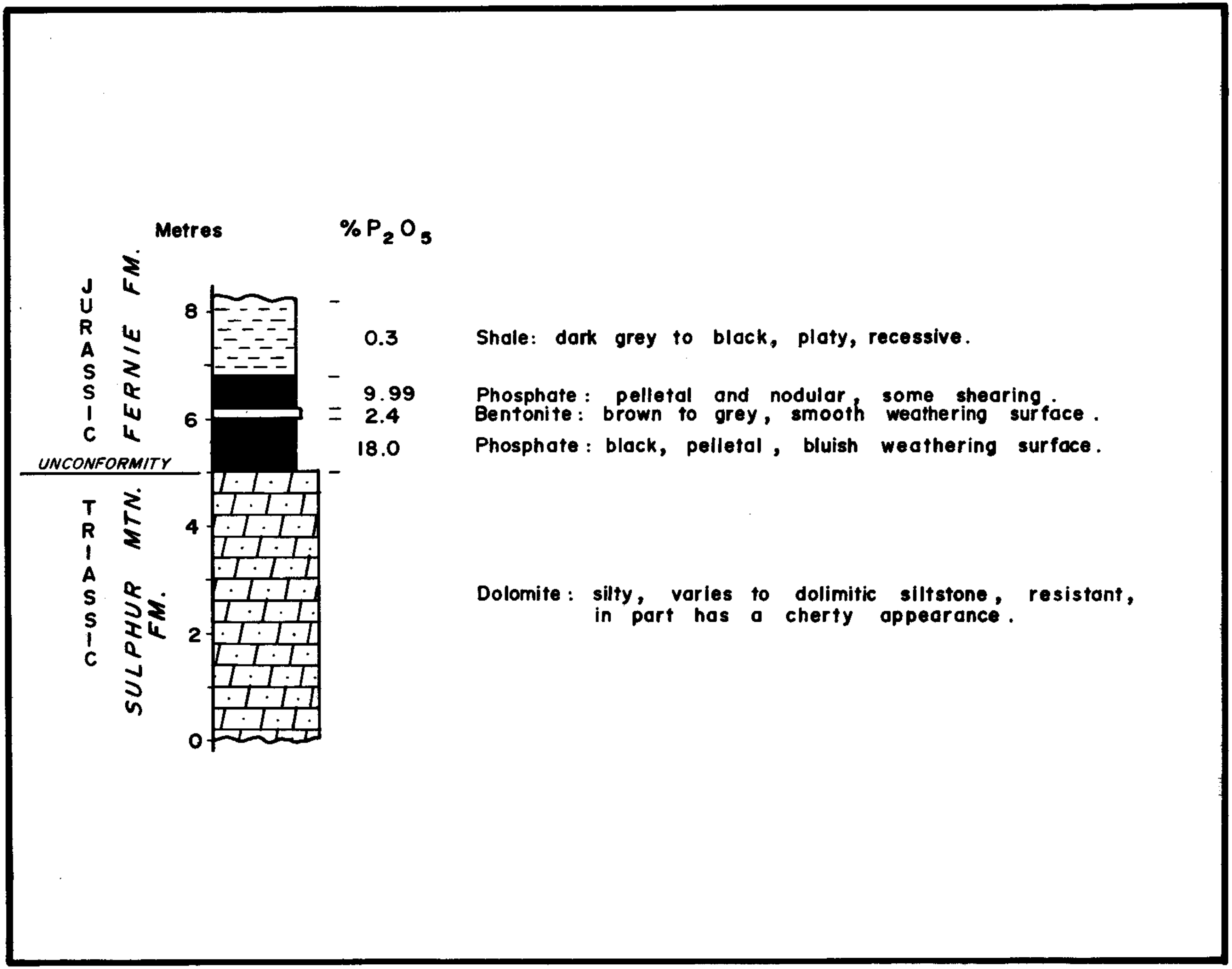

Figure 34. Stratigraphic section 38, Cabin Creek.

Columbia. These occurrences correspond to the southern limit of the Fernie basin. A total of 18 phosphatic sections were measured by First Nuclear Corp. Ltd., some of which were re-examined in the course of this study.

Permian strata are represented by the Ranger Canyon Formation above and below the MacDonald thrust fault and the Johnson Canyon Formation above the fault. Phosphate in the Johnson Canyon Formation is typically nodular with occasional pelletal phosphate present in a lower, dark grey to black, calcareous siltstone unit. The pelletal phosphate consists of dispersed pellets, 0.3 to 0.5 millimetre in diameter, in a matrix of calcite and quartz. Phosphatized shell material is also present. A thin phosphatic conglomerate occurs at the base of the Johnson Canyon Formation.

Phosphate is present in the Ranger Canyon Formation in a basal chert-pebble to cobble conglomerate (Plate 22) and as pellets or nodules in the upper part of the section. Within the conglomerate phosphate occurs both as phosphate pebbles and as cement. The conglomerate, at the one locality observed, is in excess of 2 metres thick and contains a 60-centimetre-thick horizon at the top containing 9.58 per cent P_2O_5. Only minor phosphate is present in the upper portion of the Ranger Canyon Formation.

In the same area, the phosphate horizon in the basal portion of the Fernie Formation is exposed at several localities (Figure 33). A phosphorite bed averaging 1.5 metres thick, and consisting of compact to semicompact pellets, occurs along a strike length of approximately 27 kilometres. The pellets are typically subrounded to subangular, structureless, well sorted and 0.1 to 0.3 millimetre in grain size. Less than 2 per cent of the pellets are nucleated. There has been some molding of pellets, suggesting deposition in a gel or plastic state. The matrix consists of quartz, calcite, minor potash feldspar, and trace amounts of albite, dolomite and illite. Although subordinate to quartz, calcite may be abundant locally.

In the measured section (Figure 34) two phosphorite beds are separated by a thin brownish coloured shale that may have a substantial bentonite component. The presence of bentonite in the Fernie Formation has been reported at a number of localities throughout the Fernie basin (Newmarch, 1953; MacDonald, 1985). To the north of this locality, in the Storm Creek area, the phosphorite bed thins to 1 metre with a phosphate content of only 14.0 per cent P_2O_5. Here, the phosphorite is badly weathered and contains 2 to 3 per cent limonite. Further to the north, west of Hunger Lake, the phosphorite is at least 1 metre thick, but the grade is approximately 29 per cent P_2O_5.

Phosphate is located both above and below the MacDonald thrust fault. Below the fault the phosphorite varies in thickness between 1 and 2 metres and contains phosphate values from 18.4 to 27.5 per cent P_2O_5. Above the fault the phosphorite is 1 metre thick with a grade of 9.51 per cent P_2O_5.

Work by First Nuclear Corp. Ltd. in the Burnham Creek area indicated the presence of phosphorite with grades in excess of 29 per

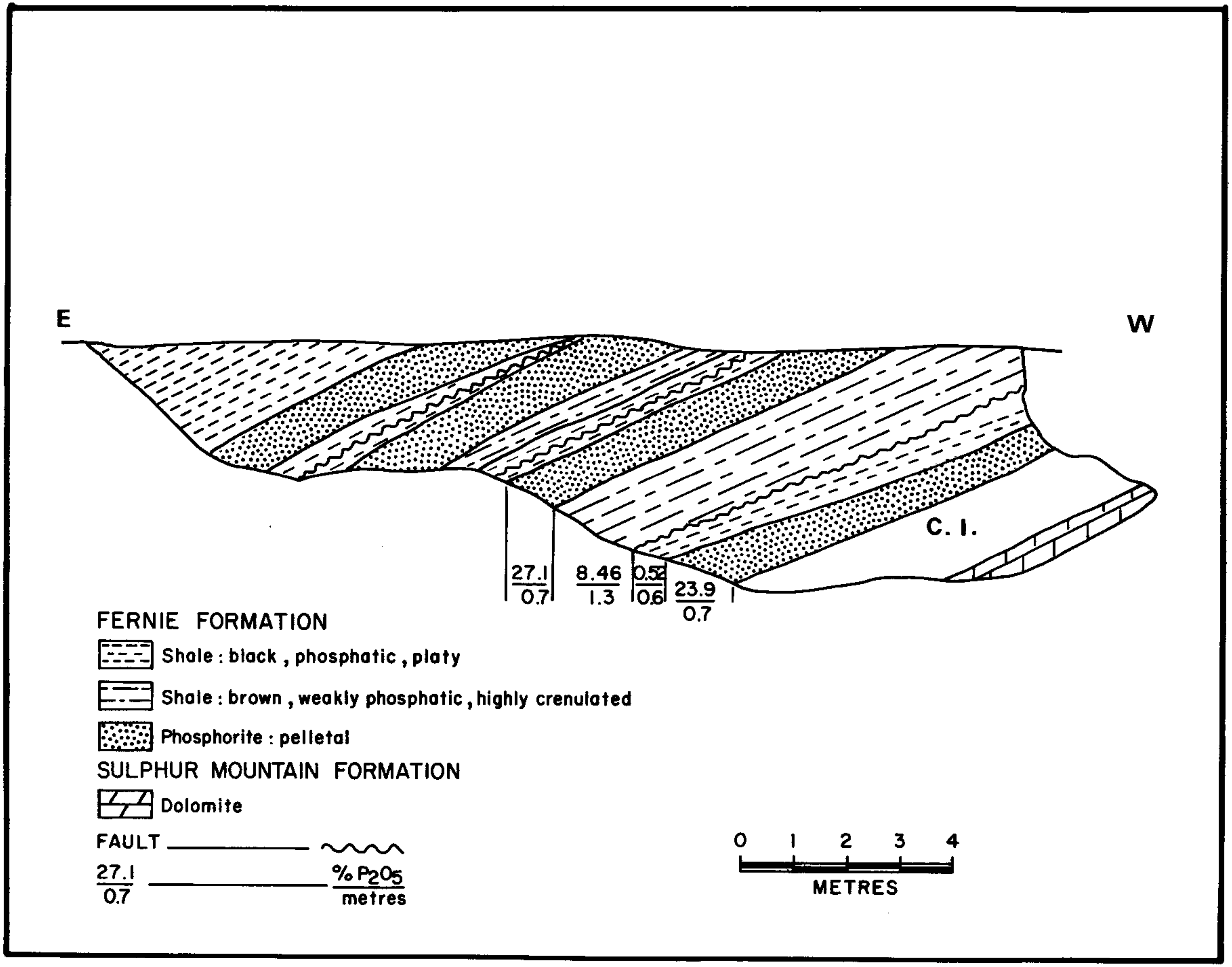

Figure 35. Cross-section through trench on Zip property.

cent P_2O_5 (Hartley, 1982). MacDonald (1985) also obtained grades in excess of 29 per cent P_2O_5 in this area as well as in the Storm Creek area. These localities were not examined by the author.

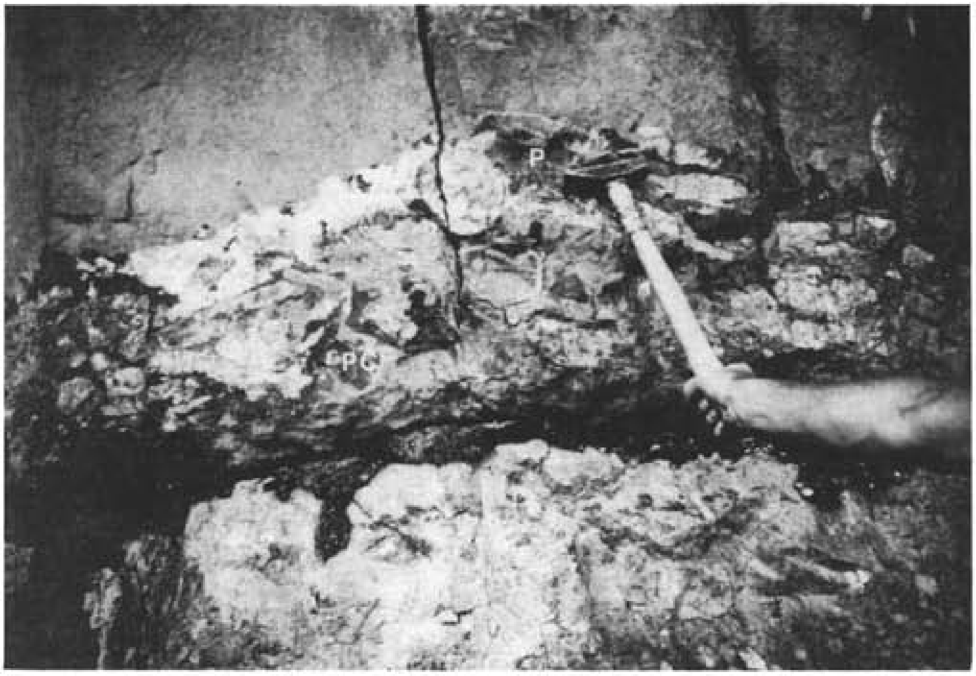

Plate 22. Basal conglomerate with phosphate cement (PC) and phosphate pebbles (P) in the Ranger Canyon Formation, Cabin Creek area.

Zip (17)

Latitude: 49°16'05" Longitude: 114°36'00" NTS: 82G/7

The Zip phosphate occurrence is located on Morris Creek northwest of the junction of the Harvey Creek and Corbin logging roads. This locality was explored by First Nuclear Corp. Ltd. in 1980; work consisted of geological mapping and trenching (Hartley, 1981, 1982).

A phosphorite bed, 0.7 metre thick, occurs at the base of the Fernie Formation and unconformably overlies dolomite and silty dolomite of the Sulphur Mountain Formation. It has been repeated several times by thrust faulting (Figure 35). Vanadium-rich shales overlie the phosphate (Hartley, 1981).

The phosphate at this locality has a very limited strike length, primarily because the Fernie Formation has been truncated by a trachytic syenite. Phosphate grades are in the range 23.9 to 27.1 per cent P_2O_5 across a thickness of 0.7 metre.

Sample Number	Latitude (N)	Longitude (W)	Age	Formation	Width (metres)	P_2O_5 (%)	Cu (ppm)	Pb (ppm)	Zn (ppm)
SBB86-8A	49°27'40"	115°06'30"	Permian	Johnson Canyon	0.90	1.53	6	12	159
SBB86-8B	49°27'40"	115°06'30"	Permian	Johnson Canyon	0.50	1.65	13	25	300
SBB86-8C	49°27'40"	115°06'30"	Permian	Johnson Canyon	0.60	1.04	11	64	330
SBB86-8E	49°27'40"	115°06'30"	Permian	Ranger Canyon	0.50	0.64	43	14	366
SBB86-8F	49°27'40"	115°06'30"	Permian	Ranger Canyon	0.50	0.19	17	14	186
SBB86-8H	49°27'40"	115°06'30"	Permian	Ranger Canyon	0.30	0.08	6	12	133
SBB86-8K	49°27'40"	115°06'30"	Permian	Ranger Canyon	0.50	13.3	12	11	24
SBB86-8L	49°27'40"	115°06'30"	Permian	Ranger Canyon	0.70	2.38	5	8	24
SBB86-9A	49°32'02"	115°04'55"	Permian	Ranger Canyon	1.00	1.77	9	24	59
SBB86-9B	49°32'02"	115°04'55"	Permian	Ranger Canyon	1.00	0.92	6	11	54
SBB86-9C	49°32'02"	115°04'55"	Permian	Ranger Canyon	1.00	0.29	11	13	108
SBB86-9D	49°32'02"	115°04'55"	Permian	Ranger Canyon	1.00	0.35	10	9	120
SBB86-10A	49°31'40"	115°10'40"	Jurassic	Fernie	grab	13.2	28	17	117
SBB86-11A	49°31'50"	115°10"45"	Jurassic	Fernie	grab	15.4	25	20	69
SBB86-12	49°58'50"	114°48'40"	Jurassic	Fernie	grab	0.10	36	20	24
SBB86-13A	50°18'25"	114°56'05"	Jurassic	Fernie	0.35	7.43	26	14	39
SBB86-13B	50°18'25"	114°56'05"	Jurassic	Fernie	1.50	21.7	46	19	60
SBB86-13C	50°18'25"	114°56'05"	Jurassic	Fernie	1.00	29.4	35	20	72
SBB86-14A	50°12'00"	115°00'00"	Jurassic	Fernie	1.04	11.8	31	14	77
SBB86-14B	50°12'00"	115°00'00"	Jurassic	Fernie	0.65	1.48	28	15	66
SBB86-14C	50°12'00"	115°00'00"	Jurassic	Fernie	0.85	1.79	28	10	60
SBB86-14D	50°12'00"	115°00'00"	Jurassic	Fernie	1.00	0.16	54	17	78
SBB86-15A	49°16'05"	114°36'00"	Jurassic	Fernie	0.70	23.9	43	23	108
SBB86-15B	49°16'05"	114°36'00"	Jurassic	Fernie	0.60	0.52	87	21	132
SBB86-15C	49°16'05"	114°36'00"	Jurassic	Fernie	1.30	8.46	31	13	103
SBB86-15D	49°16'05"	114°36'00"	Jurassic	Fernie	0.70	27.1	40	27	121

* Analyses done by XRF
Error ± 1% Absolute for values

Remaining samples analyzed by volumetric method

Sample Number	Latitude (N)	Longitude (W)	Age	Formation	Width (metres)	P_2O_5 (%)	Cu (ppm)	Pb (ppm)	Zn (ppm)
SBB86-27A	49°06'20"	114°40'45"	Permian	Ranger Canyon	1.00	1.1 *	10	8	18
SBB86-27B	49°06'20"	114°40'45"	Permian	Ranger Canyon	1.00	1.3 *	14	7	33
SBB86-28	49°05'03"	114°39'30"	Jurassic	Fernie	2.00	13.7	64	22	195
SBB86-29A	50°07'00"	114°45'30"	Permian	?	grab	2.1 *	7	15	24
SBB86-30	49°39'05"	114°44'00"	Jurassic	Fernie	grab	0.4 *	13	31	525
SBB86-31A	49°39'10"	114°44'00"	Jurassic	Fernie	1.00	23.8	38	20	714
SBB86-31B	49°39'10"	114°44'00"	Jurassic	Fernie	1.00	8.8	35	15	140
SBB86-31C	49°39'10"	114°44'00"	Jurassic	Fernie	0.60	7.9	32	20	80
SBB86-31D	49°39'10"	114°44'00"	Jurassic	Fernie	2.00	0.4 *	46	26	246
SBB86-36A	49°27'30"	114°41'40"	Permian	Johnson Canyon	grab	1.7 *	5	8	24
SBB86-37A	49°27'10"	114°41'50"	Jurassic	Fernie	0.80	22.4	45	22	144
SBB86-38A	49°06'40"	114°40'45"	Jurassic	Fernie	1.00	18.0	37	25	204
SBB86-38B	49°06'40"	114°40'45"	Jurassic	Fernie	0.20	2.4 *	65	20	585
SBB86-38C	49°06'40"	114°40'45"	Jurassic	Fernie	0.60	9.99	250	41	1500
SBB86-38D	49°06'40"	114°40'45"	Jurassic	Fernie	1.50	0.3 *	73	23	204
SBB86-40A	49°09'30"	114°46'00"	Jurassic	Fernie	1.20	15.7	28	13	134
SBB86-41A	49°09'00"	114°46'20"	Permian	Johnson Canyon	1.00	1.6 *	4	10	47
SBB86-41B	49°09'00"	114°46'20"	Permian	Johnson Canyon	1.00	0.3 *	5	109	65
SBB86-41C	49°09'00"	114°46'20"	Permian	Johnson Canyon	1.50	1.1 *	6	9	114
SBB86-41D	49°09'00"	114°46'20"	Permian	Johnson Canyon	1.50	1.8 *	4	10	140
SBB86-42A	49°09'30"	114°46'15"	Jurassic	Fernie	1.00	18.4	28	11	91
SBB86-42B	49°09'30"	114°46'15"	Jurassic	Fernie	1.00	18.6	25	23	62
SBB86-43A	49°05'20"	114°36'05"	Jurassic	Fernie	1.00	22.2	40	20	175
SBB86-44A	49°05'05"	114°39'20"	Jurassic	Fernie	1.00	27.5	31	16	110
SBB86-47A	49°06'20"	114°42'45"	Jurassic	Fernie	1.00	9.51	46	14	141
SBB86-47B	49°06'20"	114°42'45"	Jurassic	Fernie	1.00	0.4 *	61	16	91
SBB86-47C	49°06'20"	114°42'45"	Jurassic	Fernie	1.00	0.4 *	62	34	167
SBB86-47D	49°06'20"	114°42'45"	Jurassic	Fernie	1.00	0.2 *	54	16	189
SBB86-47E	49°06'20"	114°42'45"	Jurassic	Fernie	1.00	0.4 *	59	14	257

* Analyses done by XRF
Error ± Absolute for values

Remaining samples analyzed by volumetric method

Sample Number	Latitude (N)	Longitude (W)	Age	Formation	Width (metres)	P_2O_5 (%)	Cu (ppm)	Pb (ppm)	Zn (ppm)
SBB86-65A	50°19'20"	115°02'50"	Permian	Ranger Canyon	1.00	3.0 *	8	9	55
SBB86-66A	49°48'05"	115°03'00"	Permian	Telford	grab	11.4	6	9	19
SBB86-70A	49°58'00"	114°48'10"	Jurassic	Fernie	1.00	23.2	73	16	272
SBB86-70B	49°58'00"	114°48'10"	Jurassic	Fernie	1.00	22.7	50	17	165
SBB86-70C	49°58'00"	114°48'10"	Jurassic	Fernie	0.90	13.4	53	11	137
SBB86-70D	49°58'00"	114°48'10"	Jurassic	Fernie	1.00	5.45	61	14	141
SBB86-70E	49°58°00"	114°48'10"	Jurassic	Fernie	1.00	3.56	38	8	144
SBB86-71A	49°39'10"	114°42'30"	Permian		grab	14.5	6	7	54
SBB86-71B	49°39'10"	114°42'30"	Permian		grab	25.7	5	11	132
SBB86-72A	49°44'25"	115°02'50"	Permian	Ross Creek	0.90	0.9 *	16	10	195
SBB86-73A	49°44'20"	115°03'00"	Permian	Ross Creek	grab	0.5 *	34	11	428
SBB86-74A	49°36'05"	115°04'30"	Jurassic	Fernie	0.50	21.5	40	11	136
SBB86-76A	49°19'50"	114°57'00"	Jurassic	Fernie	1.00	<0.1 *	10	20	58
SBB86-76B	49°19'50"	114°57'00"	Jurassic	Fernie	1.00	<0.1 *	10	20	56
SBB86-76C	49°19'50"	114°57'00"	Jurassic	Fernie	0.30	<0.1 *	14	22	59
SBB86-76D	49°19'50"	114°57'00"	Jurassic	Fernie	1.00	<0.1 *	13	22	60
SBB86-76E	49°19'50"	114°57'00"	Jurassic	Fernie	1.00	<0.1 *	11	20	60
SBB86-76F	49°19'50"	114°57'00"	Jurassic	Fernie	0.80	0.5 *	9	20	55
SBB86-77A	49°37'20"	114°39'30"	Mississippian	Exshaw	0.50	0.7 *	85	22	533
SBB86-77B	49°37'20"	114°39'30	Mississippian	Exshaw	0.90	0.2 *	50	18	340
SBB86-77C	49°37'20"	114°39'30"	Mississippian	Exshaw	0.70	0.9 *	24	10	59
SBB86-77D	49°37'20"	114°39'30"	Mississippian	Exshaw	0.50	0.8 *	30	10	78
SBB86-77E	49°37'20"	114°39'30"	Mississippian	Exshaw	1.50	3.6 *	58	12	236
SBB86-78A	49°51'45"	114°59'50"	Permian	Ross Creek	grab	0.1 *	24	12	43
SBB86-79A	49°51'50"	114°59'55"	Permian	Johnson Canyon	1.00	21.2	9	12	54
SBB86-79B	49°51'50"	114°59'55"	Permian	Johnson Canyon	0.50	1.5 *	6	12	31

* Analyses done by XRF
Error ± 1% Absolute for values

Remaining samples analyzed by volumetric method

APPENDIX 3. WHOLE ROCK AND TRACE ELEMENT ANALYSES

Sample No.	Stratigraphic Unit	Location	SiO_2 %	CaO %	P_2O_5 %	Al_2O_3 %	Fe_2O_3 %	Na_2O %	MgO %	K_2O %	TiO_2 %	MnO %	$\frac{CaO}{P_2O_5}$	$\frac{R_2O_3}{P_2O_5}$	H_2O %	LOI %
Liz	Fernie	Lizard	10.16	47.78	24.71	1.04	0.25	0.62	0.65	0.05	0.04	0.02	1.93	0.08	0.29	14.09
SBB86-3	Fernie	Highway 3	16.49	43.13	27.28	1.91	0.29	0.43	1.38	0.34	0.09	0.02	1.58	0.13	0.29	8.68
SBB86-4	Fernie	Crow	19.64	41.07	22.33	1.90	0.34	0.40	1.47	0.33	0.09	0.03	1.83	0.17	0.44	11.97
SBB86-6	Fernie	Fording River	16.66	39.29	13.41	1.99	0.44	0.44	0.94	0.20	0.08	0.03	2.92	0.25	0.30	21.15
SBB86-8J	Ishbel	Fernie Ski Hill	59.59	20.47	14.63	1.62	0.31	0.15	0.27	0.57	0.13	0.01	1.40	0.15	0.25	1.69
SBB86-13D	Fernie	Abby Ridge	35.06	34.11	23.19	1.69	0.42	0.39	0.43	0.38	0.07	0.02	1.47	0.11	0.42	4.71
SBB86-17	Ishbel	Mt. Broadwood	79.14	5.57	1.65	1.99	0.55	0.17	2.63	0.70	0.18	0.02	3.38	3.13	0.23	6.70
SBB86-40	Fernie	Cabin Creek	74.65	10.22	7.29	2.49	1.18	0.22	0.32	0.87	0.41	0.03	1.40	0.55	0.20	2.04
SBB86-41	Ishbel	Cabin Creek	66.16	8.95	2.70	3.64	0.72	0.06	4.44	1.47	0.31	0.04	3.31	3.26	0.19	10.38
SBB86-57	Ishbel	Weigert Creek	16.88	43.65	14.71	1.57	0.25	0.31	0.66	0.15	0.06	0.04	2.96	0.17	0.24	21.26
SBB86-62	Ishbel	Forsyth Creek	61.92	12.85	3.21	1.48	0.69	0.05	5.83	0.47	0.11	0.13	4.00	2.49	0.32	13.07
SBB86-70	Fernie	Line Creek	20.51	38.33	28.43	3.59	0.88	0.31	0.58	1.30	0.19	0.02	1.35	0.18	0.80	5.37
SBB86-71	Ishbel	Crowsnest Pass	64.18	20.49	14.41	0.66	0.33	0.14	0.23	0.19	0.07	0.02	1.42	0.08	0.17	1.44
SBB86-79(1)	Ishbel	Nordstrum Creek	37.41	33.90	24.59	1.50	0.76	0.35	0.34	0.48	0.11	0.01	1.38	0.11	0.21	1.77
SBB86-84	Ishbel	MacDonald Fault	30.83	28.48	0.44	4.80	1.41	0.45	1.16	0.84	0.18	0.03	64.72	6.14	0.39	26.13

APPENDIX 4

DEFINITION OF PETROLOGICAL TERMINOLOGY USED IN THIS REPORT

Pellet:	Phosphate grain less than or equal to 2.0 millimetres in size.
Nodule:	Phosphate grain greater than or equal to 2.0 centimetres in size.
Oolite:	Pellets that contain concentric structures.
Nucleated pellet:	Pellet that has centre of non-phosphatic material with a diameter of less than one-half the minimum diameter of the pellet.
Encased pellet:	Pellet with core-diameter equal to or greater than one-half of the minimum diameter of the pellet.
Intraclast:	Reworked fragment of a contemporary sediment of the same depositional basin.
Compacted texture:	Texture in which more than one-half of the fluorapatite occurs as pellets that are mostly adjoining.
Semidispersed texture:	Texture in which one-half of the fluorapatite occurs as pellets that are only partially adjoining.
Dispersed texture:	Texture in which gangue is dominant or where greater than one-half of the fluorapatite occurs interstitially as pellets.
Phosphate rock:	Term applied to phosphate-bearing rock that is mined or mined and beneficiated and used as a raw material for the next stage of manufacturing.
Phosphorite:	A deposit of phosphate rock of sedimentary origin, which is of economic interest. It is generally assumed that the rock contains a minimum of 18 per cent P_2O_5 or 50 per cent apatite by volume. For purposes of this report ther term phosphorite is applied to those rocks having a pelletal texture and containing greater than 7 per cent P_2O_5.
Bone Phosphate of Lime (BPL):	Expression of the calcium phosphate content of phosphate rock.
Phosphatic sandstone:	Rock with arenite grain size that contains less than 5 per cent P_2O_5.
Phosphatic shale:	Rock with rudite grain size that contains less than 5 per cent P_2O_5.

TO ACCOMPANY OPEN FILE 1987-16
1
PHOSPHATE DEPOSITS IN THE FERNIE BASIN
COMPILATION BY S.B. BUTRENCHUK (1987)
GEOLOGY COMPILED FROM: BENVENUTO, G.L. AND PRICE, R.A. (1979); LEECH, (1960 AND 1979); PRICE, R.A. (1961 AND 1964); PRICE, R.A. AND GRIEVE, D. (IN PREPARATION)
Kilometres 5 0 5 10 Kilometres
Scale 1:250 000
LEGEND
JURASSIC
Jf
FERNIE FORMATION: shale, siltstone, limestone, phosphate, phosphatic shale
TRIASSIC
Tsr
SULPHUR MOUNTAIN FORMATION: siltstone, shale, dolomitic siltstone, silty dolomite, includes whitehorse formation
PENNSYLVANIAN-PERMIAN
PPrm
TUNNEL MOUNTAIN FORMATION, KANANASKIS FORMATION, ISHBEL GROUP: dolomite, sandstone, siltstone, limestone, shale, chert, conglomerate, phosphate, phosphatic siltstone
DEVONIAN-MISSISSIPPIAN
Mbe
EXSHAW FORMATION: shale, siltstone, limestone phosphate
SYMBOLS
Bedding (inclined, vertical, overturned)
Thrust fault
Normal fault
Fault
Measured stratigraphic section (number refers to section number in text)
38
Measured stratigraphic section (MacDonald, 1985)
M207
Phosphate bed or horizon (known, probable)
Syncline
Anticline
Diamond drill hole
DDH
PHOSPHATE LOCALITY DESCRIBED IN REPORT
1. Forsyth Creek — Connor Lakes
2. MacDonald Thrust Fault
3. Weigert Creek
4. Nordstrum Creek
5. Fernie Ski-Hill
6. Line Creek
7. Crow
8. Lizard
9. Abby
10. Highway Three — Alexander Creek
11. Lodge
12. Iron Creek
13. Barnes Lake
14. Fording River
15. Bingay Creek
16. Cabin Creek
17. Zip
CONTINENTAL RANGES
FRONT RANGES
(ROCKY MOUNTAINS)
PROVINCIAL
FOREST
BRITISH COLUMBIA
MONTANA
UNITED STATES OF AMERICA
CANADA
116°00'
114°00'
51°00'
50°00'
49°00'
580000m E.
690000m E.
710000m E.
5530000m N
5430000m N
FIFTH MERIDIAN
Province of British Columbia
BC
Ministry of Energy, Mines and Petroleum Resources
Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada
THIS PROJECT IS A CONTRIBUTION TO THE CANADA–BRITISH COLUMBIA MINERAL DEVELOPMENT AGREEMENT, 1985 – 1990

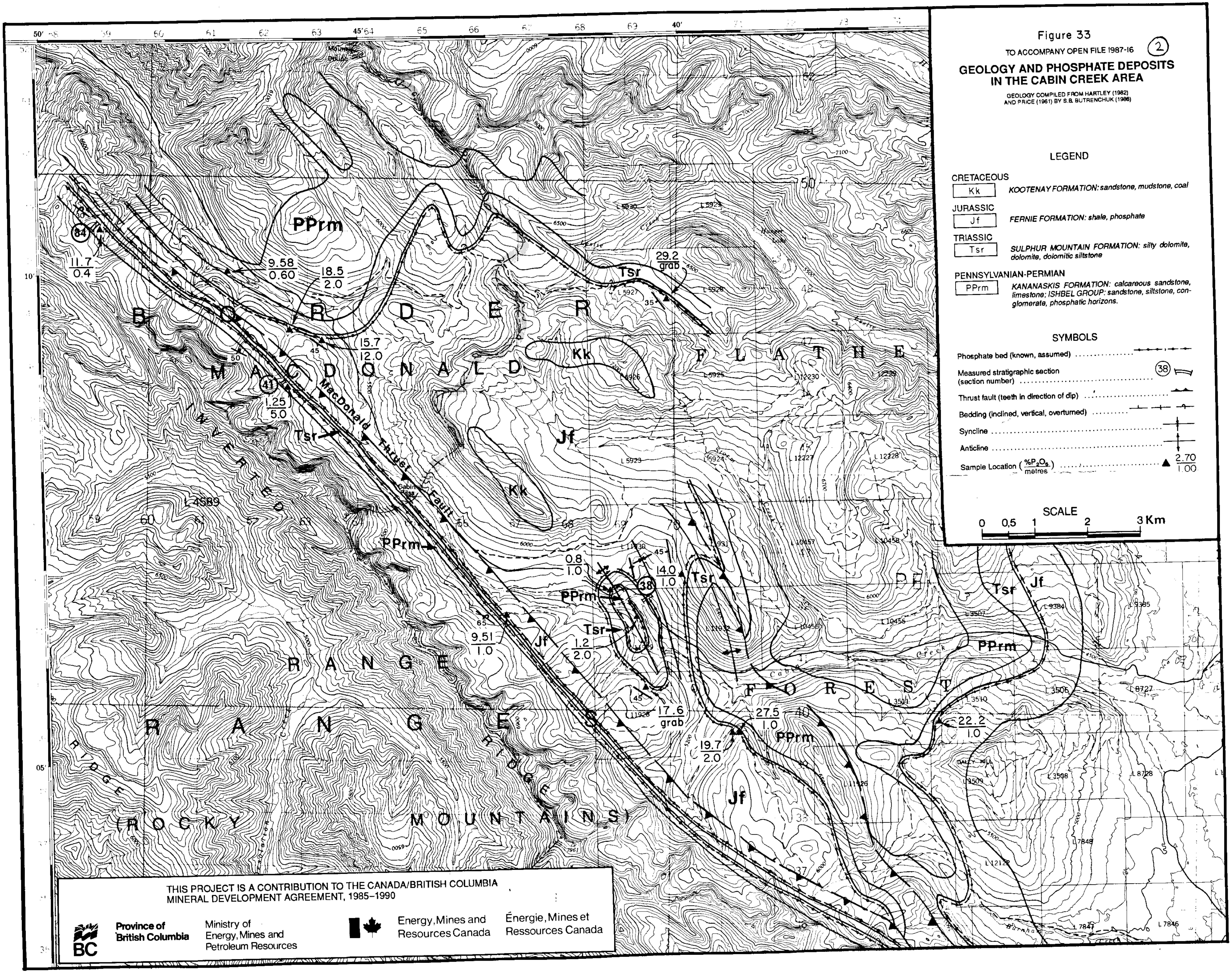
Figure 33
TO ACCOMPANY OPEN FILE 1987-16
2
GEOLOGY AND PHOSPHATE DEPOSITS IN THE CABIN CREEK AREA
GEOLOGY COMPILED FROM HARTLEY (1982) AND PRICE (1961) BY S.B. BUTRENCHUK (1986)
LEGEND
CRETACEOUS
Kk
KOOTENAY FORMATION: sandstone, mudstone, coal
JURASSIC
Jf
FERNIE FORMATION: shale, phosphate
TRIASSIC
Tsr
SULPHUR MOUNTAIN FORMATION: silty dolomite, dolomite, dolomitic siltstone
PENNSYLVANIAN-PERMIAN
PPrm
KANANASKIS FORMATION: calcareous sandstone, limestone; ISHBEL GROUP: sandstone, siltstone, conglomerate, phosphatic horizons.
SYMBOLS
Phosphate bed (known, assumed)
Measured stratigraphic section (section number)
38
Thrust fault (teeth in direction of dip)
Bedding (inclined, vertical, overturned)
Syncline
Anticline
Sample Location ($\frac{\%P_2O_5}{metres}$)
$\frac{2.70}{1.00}$
SCALE
0 0.5 1 2 3 Km
BORDER
FLATHEAD
MACDONALD
INVERTED
RANGE
RANGE
RIDGE
RIDGE
(ROCKY MOUNTAINS)
FOREST
MacDonald Thrust Fault
Cabin Pass
Mount Doupe
PPrm
Tsr
Jf
Kk
84
41
38
$\frac{11.7}{0.4}$
$\frac{9.58}{0.60}$
$\frac{18.5}{2.0}$
$\frac{15.7}{12.0}$
$\frac{1.25}{5.0}$
$\frac{29.2}{grab}$
$\frac{0.8}{1.0}$
$\frac{14.0}{1.0}$
$\frac{9.51}{1.0}$
$\frac{1.2}{2.0}$
$\frac{17.6}{grab}$
$\frac{27.5}{1.0}$
$\frac{19.7}{2.0}$
$\frac{22.2}{1.0}$
THIS PROJECT IS A CONTRIBUTION TO THE CANADA/BRITISH COLUMBIA MINERAL DEVELOPMENT AGREEMENT, 1985–1990
Province of British Columbia
Ministry of Energy, Mines and Petroleum Resources
Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada