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PAPER 68-30

CARDIUM FORMATION, EDSON AREA, ALBERTA

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R. N. Sinha

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ABSTRACT

The Cardium Formation of the Edson area includes an oil-producing sandstone body which extends along a northwesterly trend for 12.5 miles. The sandstone has a maximum width of one mile and a maximum thickness of 15 feet. It is interpreted as an offshore bar with a flat base and a convex top.

The Cardium Formation consists mainly of marine sediments, including silty and sandy shales, conglomeratic sandstones, and granule conglomerates. The sediments were deposited in shallow marine to brackish lagoonal environments associated with progradation of the shoreline.

Megafauna recovered from upper beds are referable to the Turonian zone of *Scaphites preventricosus* and *Inoceramus deformis*.

At least two thrust faults occur within the Edson area. These were traced through the First White Specks, Bad Heart, and Second White Specks markers, as well as through the top of the Cardium Formation. The regional strike of both faults is about northwest-southeast.

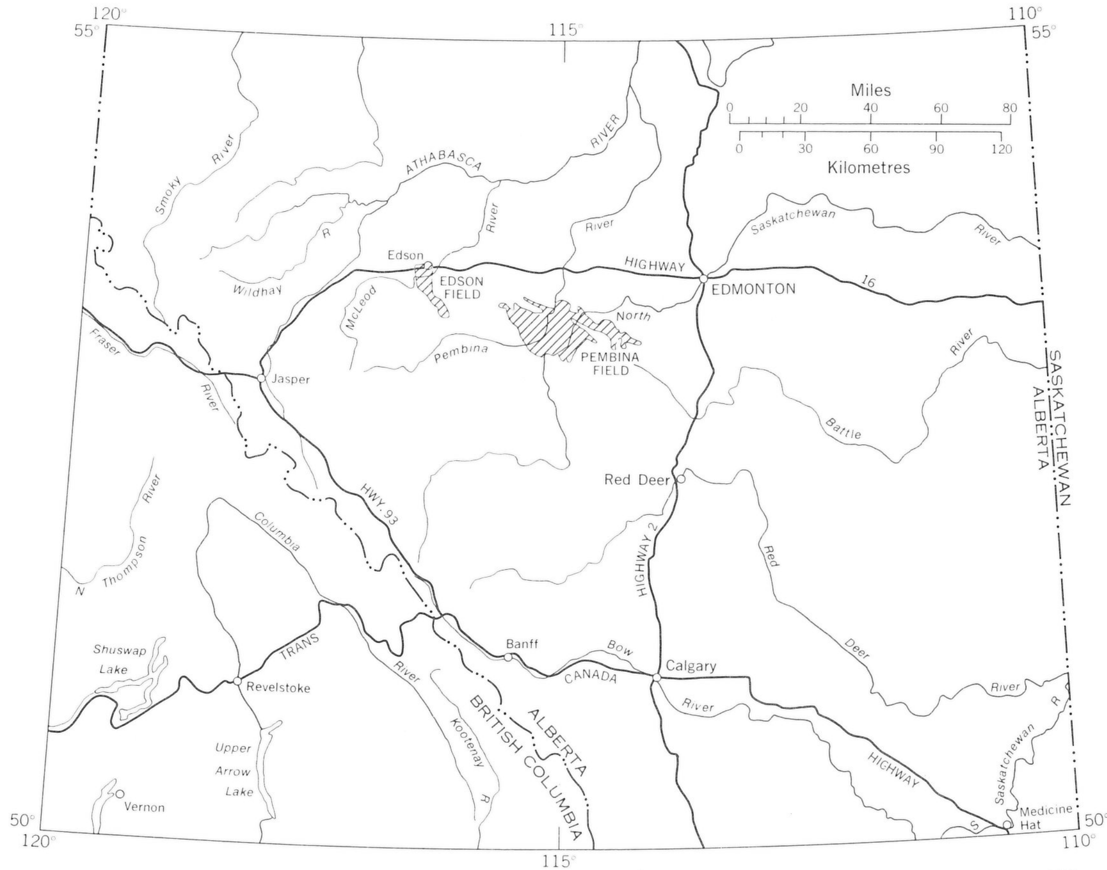

Figure 1. Index map showing location of study-area

CARDIUM FORMATION, EDSON AREA, ALBERTA

INTRODUCTION

This report describes the results of a study of the petrography and depositional environments of the Upper Cretaceous Cardium Formation as well as the geometry of the associated oil-producing sandstone of the Edson area. Oil was discovered in the Cardium sandstone in 1963 (Skiber, 1967) during development of the Edson gas field, a large gas pool in the Mississippian Elkton Formation (Young, 1967). The Edson area is located approximately 120 miles west of the city of Edmonton and 200 miles north-northwest of Calgary, Alberta (Fig. 1). The report-area, lying within Townships 52 to 54 and Ranges 15 to 18, west of the fifth meridian, includes about 450 square miles.

A total of sixty-four wells were selected for study, giving an average density of control points for the area of about five wells per township (Fig. 2). Thirty wells delineate the producing body. Twenty-six additional wells in the western sector of the area were drilled to obtain gas from Mississippian rocks. Only eight wells are available for study in the eastern sector.

Stratigraphic studies were based mainly on electric-log correlation of four marker horizons; First White Specks, Bad Heart, top of Cardium Formation, and Second White Specks (Fig. 3A; and Burk, 1963). Sandstone and minor amounts of conglomerate occurring between the Second and First White Specks markers were identified easily by means of the spontaneous potential curve of the electric-log (Fig. 3A). Whenever necessary, other logs were employed for more accurate identification, especially of the sandstones of the Cardium Formation. Structure contour maps (Figs. 4-7), isopach maps (Figs. 8, 9), and cross-sections (Figs. 3A, 3B, 10-13) were used for the determination of structural elements and geometry. Structure sections (Figs. 14, 15) illustrate the general trend of the various markers and thrust faults.

A total of one hundred and thirty-one thin sections representing shales, arenites, wackes, conglomerates, and siderite encountered in twenty-three cored wells were examined. Lithologic associations, sedimentary structures, petrographic characters, faunal and floral assemblages, as well as the geometry of the producing sand bodies, were employed to interpret the environment of deposition of the Cardium sediments.

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STRATIGRAPHY

The Cardium Formation occurs within a widespread succession of Upper Cretaceous, dark marine shales, commonly assigned in the subsurface to the Colorado Group (Williams and Burk, 1964). The sandstones of the Cardium Formation form some of the most distinctive lithologic units within the group although variations are present in the major shale sequences. Several electric-log marker horizons associated with more or less distinctive lithologic units, including the First and Second Specks and Bad Heart markers (Burk, 1963; Williams and Burk, 1964), have been used to establish relationships on a regional scale. Additional subsurface stratigraphic control for the Cardium Formation in the general region of the report-area has been given by Harding (1955), Nielsen (1957), Michaelis (1957), MacDonald (1957), and Berven (1966).

The term "Cardium Shales" was introduced by Hector (in Whiteaves, 1895, p. 110) for Cretaceous marine shales that occur in the Rocky Mountain Foothills. Later, the name Cardium was restricted to the sandstone member within the shales and used informally in southern Alberta (see Cairnes, 1907, p. 27) until Rutherford (1927, p. 25) applied it in a formational sense to the succession on Bow River. The later history of the development of nomenclature is outlined by Stott (1963, p. 3) in a report on the regional stratigraphy of the Cardium Formation in surface outcrop. The distribution of the Cardium Formation in the Foothills west of the Edson area is shown by Irish (1965). In the subsurface, an informal subdivision of the Cardium has developed and, for the Edson area, Skiber (1967) has recognized two main sandstone

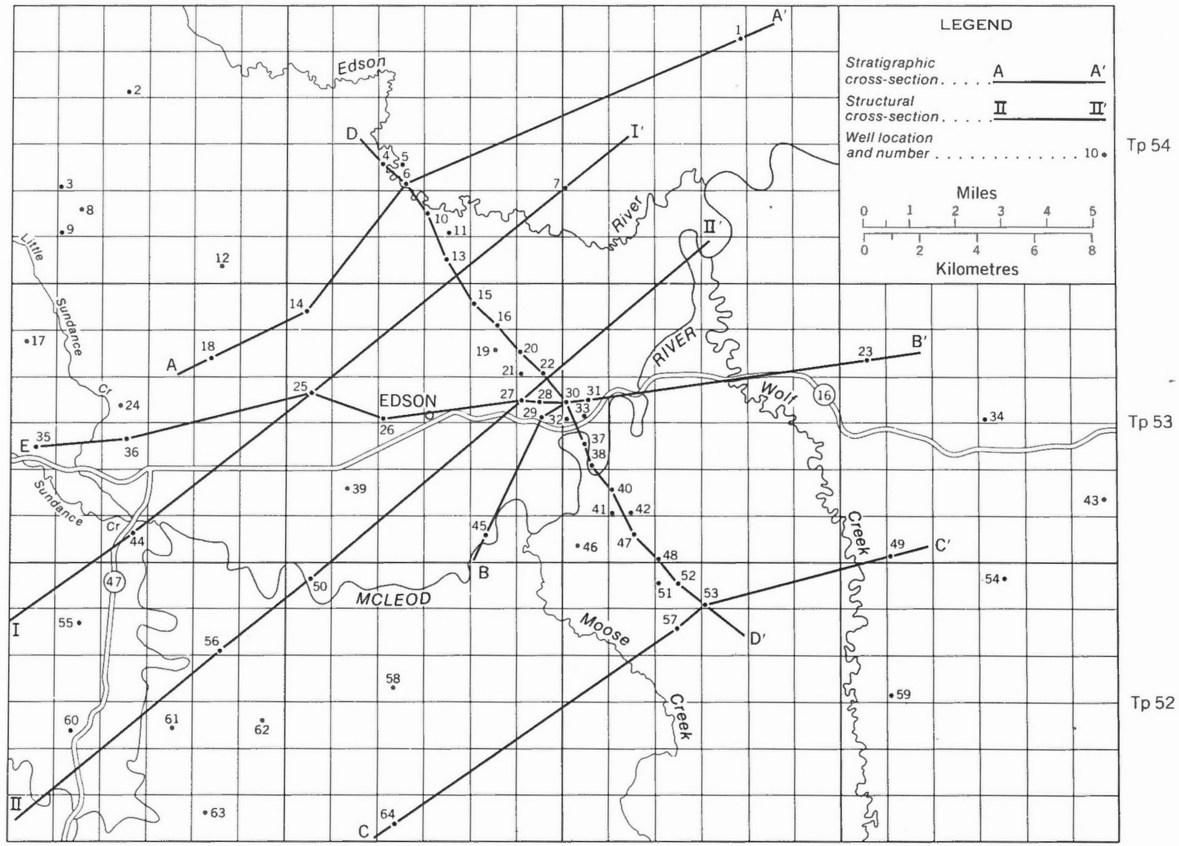

Figure 2. Index map showing location of wells and cross-sections; Edson area, Alberta

units: the Cardium "A" sandstone which occurs near the middle of the formation, and the lower Cardium "B" sandstone, which occurs near the base. This terminology has been accepted by the writer for the purposes of this report and no attempt was made to relate these units to those used in other areas, such as the Pembina Field (Nielson, 1957), the Crossfield-Garrington area (Bervan, 1966), or the Foothills, (Stott, 1963).

MARKER HORIZONS

Electric-log marker horizons associated with distinctive lithologic zones were used by Burk (1963) in his regional study of the Upper Cretaceous marine succession. The First and Second White Specks markers occur, respectively, above and below the Cardium Formation. Each marker lies near the top of a calcareous, marine shale sequence of relatively high electrical resistance. A third marker horizon in the Edson area is related to strata equivalent to the Bad Heart sandstone (see Stott, 1963), as noted by Harding (1955, p. 21, 22). This zone, present in a central position between the First White Specks marker and the Cardium Formation, lies within dark, silty, non-calcareous shales.

CARDIUM FORMATION

The stratigraphic limits of the Cardium Formation shown in the accompanying cross-sections (Figs. 3A, 3B, 10-12) are based on electric-log characteristics and correspond to those used in previous studies (e.g. Nielsen, 1957, Figs. 4, 5) of the Pembina field, 25 miles to the southeast. In the Edson area, both the upper and lower boundaries are marked by abrupt changes in the resistivity curves. The thickness of the Cardium Formation in wells shown on the cross-sections varies from 218 feet (well 26) to 275 feet (well 45) (Fig. 3A), and increases generally from east to west. No attempt is made here to re-define the upper and lower limits of the formation. The boundaries used for the purpose of this report are different, however, from those used by Burk (1963, Figs. 1, 4), who defined the formation by the apparent limits of sandstone development.

The basal strata of the Cardium Formation, including the Cardium "B" unit, consist of alternating sequences of cross-stratified sandstone, siltstone, and dark grey, hard, silty shale. The lower Cardium sandstones are mainly arenites, and are best developed in the northwestern part of the producing body. The arenites become argillaceous east and southeast of the producing body and, in the eastern sector, grade laterally into silty shales. A prominent body of conglomeratic sandstone and granule conglomerate forms much of the producing zone (Cardium "B" sandstone), but those beds do not appear to be developed on either side of the producing body except for a thin deposit in the extreme northwestern part of the area. This thin conglomeratic zone contains some oil in three wells, HB Edson 4-17-54-18 (well 3), HB Edson 10-8-54-18 (well 8), and HB Edson 4-8-54-18 (well 9)[1]. The conglomeratic sandstones

[1] Descriptions of these three wells are given in Appendix I. Well 9, although containing beds similar to the Cardium "B" unit, is representative of the wells in the western sector; well 30, of the producing zone; and well 49, of the eastern sector.

and granule conglomerates exhibit marked variations in grain size, being coarser grained in the northwestern part of the area and finer grained toward the southeast where pebbles are absent. Similarly, the shales lose much of their arenaceous content and become only sporadically silty southeastward.

The beds overlying the lower sandstones and conglomerates comprise a sequence of intercalated dark grey, pyritic, in part carbonaceous, moderately silty shale and grey to light grey, fine-grained, argillaceous sandstone. In these strata worm burrows are common and bedding is obscure, although lenticular laminations and cross-stratification were observed.

The sand grains and pebbles are moderately well sorted and are rounded to well rounded. The amount of matrix present is generally very small and is absent in a few places. The dominant constituents of the conglomerates are chert, quartzite, and very small amounts of quartz; those of the sandstones consist mainly of quartz and chert. Carbonaceous material, oil staining, and bituminous material are conspicuous in all rocks and secondary siderite occurs in some of the conglomerates.

The Cardium "A" sand, which includes some interbedded dark shale and siltstone, occurs near the middle of the formation. The top of this unit (Figs. 3A, 3B, 10-12) is marked by the occurrence of chert and quartzite pebbles in dark grey shale (Pl. I, figs. 4, 5, 11). Sandstone is more abundant and coarser grained in the northern part of the western sector and grades to silty shale toward the eastern sector. Both sandstone and siltstone are light grey to grey, hard, moderately well-sorted, argillaceous, medium- to fine-grained rocks that are commonly cross-stratified (Pl. II, figs, 2, 3). In some wells, the sandstones are intensely cross-stratified (Pl. II, fig. 8). "Scour and fill" structures (Pl. II, fig. 10) are not common but lenticular and wavy laminations (Pl. I, figs. 12, 13; Pl. II, figs. 5, 6) are abundant. Worm burrows occur throughout (Pl. I, fig. 12). The shales are grey to dark grey, carbonaceous, silty, and contain abundant pyritized organic material as well as pyritic nodules (Pl. IV, figs. 1 and 3).

The conglomerate at the top of the unit consists of pebbles of chert and quartzite in a dark grey, hard, silty shale matrix (Pl. I, figs. 4, 5, 11). In a few cases, thin pebble-beds are intercalated with shale. The pebbles have an imbricate pattern with, in most cases, their longer diameter oriented parallel to the horizontal. They average 0.6 inches in diameter and have a roundness of 0.7 to 0.9. The shale matrix contains abundant plant remains.

This unit displays complexly shaped sandstone bodies in shale (Pl. II, figs. 11, 12), sandstone dykes cutting across the shale laminae, and vertical fractures in shales (Pl. II, fig. 9). Such features are thought to be formed by compaction.

Generally, the sandstone has a sharp and, in places, erosional contact with the overlying shales; a few quartzite and chert pebbles are present at the contact (Pl. I, fig. 10). In rare cases, the sandstone appears to grade into the shale. In a few cores, the conglomerates are in direct contact with the underlying arenites. There, the presence of an irregular and erosional contact and absence of any disturbance in the internal planar laminations of the underlying sandstone (Pl. IV, fig. 2) may indicate that the conglomerate was deposited on a partly scoured and semi-consolidated upper surface of the sandstone.

The upper beds of the Cardium Formation consist of grey to dark grey, silty, pyritic and fissile shale. The top is marked by a consistent resistivity character that can be recognized on the electric-logs and traced throughout the area (Figs. 3A, 3B, 10-12). Lenses, pods, stringers, and thin laminae of grey to light grey, fine- to medium-grained, well-sorted sandstone, and grey siltstone are normally present. Worm burrows (Pl. I, figs. 1 and 2) were observed near the base of this unit. Pyritized plant remains (Pl. II, fig. 1), as well as sideritic and pyritic nodules occur but are not abundant. The basal part of this unit contains chert and quartzite pebbles having a maximum diameter of 0.4 inches.

Geometry of Cardium "B" sandstone body

Conglomeratic sandstones and granule conglomerates lying above basal fine-grained sandstones and siltstones (Figs. 3B, 10-12) form the main reservoir for oil in the Edson area. The "B" sandstone is a long, narrow, linear body aligned approximately northwest-southeast; it is about 12.5 miles long and one mile wide at the middle (Fig. 16) with tapering extremities. Both sides have almost the same slope although, in some parts, the western side appears to be steeper. The western edge is relatively straight whereas the eastern edge is slightly sinuous. The maximun thickness is 15 feet in Champlin *et al*. Edson R 2-16-54-17 (well 6) (Fig. 10) and Champlin *et al*. Edson 10-3-52-16 (well 52)(Fig. 13); the average is 8 feet.

There is a similar, second sandstone body in the extreme northwestern corner of the area that is penetrated by H.B. Edson 4-17-54-18 (well 3) (Fig. 13), H.B. Edson 10-8-54-18 (well 8), and H.B. Edson 4-8-54-18 (well 9). Its extent is not known. It is absent in H.B. Hamilton Edson 6-26-53-18 (well 18) (Figs. 10, 13) about 4.5 miles southeast of wells 3 and 8, and there is no control northwest of well 3. This second sandstone, in which the granule conglomerate is 5 feet thick in well 3 and 3 feet thick in well 8, may be aligned almost parallel to the main producing body.

The cross-sectional shape of the Cardium "B" sandstone body is shown by stratigraphic sections (Figs. 3B, 10-12). The top of the Cardium Formation was chosen as the datum plane to ensure least distortion of shape. Isopach values for the interval between the top of the Cardium Formation and the top of the Cardium "B" sandstone are less where the body is thickest and greater where the sandstone is thinnest. On the other hand, the isopach values for the interval between the top of the formation and the base of the sandstone are more uniform. Hence, the sandstone body appears to have an almost flat bottom and a convex top.

Fauna, age, and correlation

The megafaunal assemblage (Pl. III, figs. 6-10), identified by J.A. Jeletzky (pers. comm., 1968) consists of *Actinocamax* n. sp., *Scaphites* ex gr. *S. impendicostatus-preventricosus* Cobban, *Inoceramus* cf. *I. deformis* Meek, *Inoceramus* cf. *I. labiatus* var. *latus* Mantell, *Modiolus* sp. indet., and an indeterminate true belmenite[1]. According to Jeletzky (pers. comm., 1968), the Scaphites and Inoceramus cf. I. deformis (GSC loc. 82033; see Appendix II) are referable to some part of the latest Turonian Scaphites preventricosus and Inoceramus deformis zone. Inoceramus cf. I. labiatus var. latus (GSC loc. 82230) was presumed by Jeletzky to represent either that zone or his Ostrea lugubris zone (Jeletzky, 1968). The upper Cardium beds from which the fauna was recovered may be equivalent to the upper Cardium members, Leyland and Sturrock, of the southern and central Foothills which lie within the Scaphites preventricosus and Inoceramus deformis zone (Stott, 1963).

Microfossils are most common in silty shales but also occur in sandstones and in conglomerates that have a shale matrix.

The microfaunal assemblage, observed in thin sections, was identified by T.P. Chamney (pers. comm., 1968) and includes Trochammina sp., Haplophragmoides sp., Gaudryina sp., Reophax sp., Miliammina sp., Bathysiphon sp., Haplophragmoides cf. H. crickmayi Stelck and Wall, ?Saccammina sp., ?Verneuilinoides sp., and Globigerina sp. Other fossils include ostracods, algal encrustations, sponge spicules, and holothuroidean sclerite. The thin sections also contain bone (? fish remains), comminuted plant remains, megaspores, and wood fragments (Pl. VI, figs. 4, 5).

The microfauna provides some indication of the sedimentary environments. According to Chamney (pers. comm., 1968), the ostracods with abundant comminuted plant fragments occurring in Cardium "B" sediments (GSC locs. C-421, C-422), represent brackish to fresh-water environments. Cardium "B" sediments also include species of Trochammina, Gaudryina, Verneuilinoides, Haplophragmoides, Reophax, Miliammina, and Bathysiphon (GSC locs. C-417, C-419, C-420, C-424A), which Chamney considers to be indicative of restricted marine conditions. Similar conditions apparently occurred during deposition of sediments immediately above the Cardium "A" sandstone, as a similar assemblage occurs there (GSC locs. C-414, C-415).

PETROGRAPHY

In the present study the classification and nomenclature of sandstones is that proposed by Gilbert (1954). Shales, arenites, quartz-wackes, and conglomerates are the main lithotypes of the cored intervals. The abundance of the various rock components and the roundness of the grains were estimated visually with the aid of diagrams by Shvestov (Terry and Chilingar, 1955) and Krumbein and Sloss (1963) respectively.

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[1] Fossil lists are given in Appendix II.

SHALES

The shales are dark grey and hard. They consist dominantly of clay minerals, carbonaceous and bituminous matter, silt and sand, and appreciable quantities of authigenic pyrite and secondary carbonates.

The clays occur as evenly oriented shred-like and, in places, poorly crystalline micaceous minerals (Pl. IV, fig. 4) conforming to the outlines of sand and silt grains.

The amount of silt varies throughout the area and appears to be greatest toward the northwest and west. Shales and siltstones are interlaminated (Pl. II, fig. 5) with both sharp and gradational contacts. In places, they are irregularly intermixed with one another and lenticular laminations of silt in a shaly framework are common (Pl. II, figs. 5, 6). Where the siltstone has sharp contacts, it is commonly clean and consists of angular to subangular quartz grains and is similar in composition to the finer grained arenites. In cases where the contacts are gradational, the siltstone is argillaceous and grades into mudstone. The intermixed types are most characteristic of the beds between the two main sandstones. The ultimate product of intermixing is a silty shale containing ill-defined patches of cleaner silt characterized by an abundance of diagenetic pyrite in the form of nodules (Pl. III, fig. 5).

The most abundant authigenic minerals, other than the micas, are pyrite and carbonates. Pyrite occurs mainly as single, euhedral crystals dispersed evenly throughout the shale fabric. Carbonate grains, generally siderite or dolomite, are disseminated through the shale fabric but also occur as small patches. Authigenic glauconite is very rare and generally absent in shales containing diagenetic pyrite and carbonates.

ARENITES

The arenites are dominantly fine- to medium-grained and fairly well sorted. Coarse-grained arenites, although not abundant, commonly contain well-rounded chert and quartzite pebbles and are strongly bimodal (Pl. IV, fig. 9).

There is some relationship between roundness, grain size, and matrix. In general, the detrital fraction is rounded; the coarser sand grains have a roundness varying from 0.5 to 0.7, and finer grained arenites, a roundness of 0.3 to 0.5. From 3 to 7 per cent of the coarser sandstone is matrix, and this increases to about 12 per cent in finer grained arenites.

The arenites (Pl. IV, fig. 8) occur as thin laminae, stringers, lenticles, and thin beds in a dominantly shale sequence. They are best developed in the oil-producing zone. Laminae thicker than one-half inch are often cross-stratified (Pl. II, figs. 2, 3, 7). Worm burrows (Pl. I, fig. 3) although present, are rare.

Detrital quartz comprises 40 to 60 per cent of the finer grained arenites. It is less abundant, 45 per cent or less, in the coarser grained arenites where the percentage of chert increases to as much as 50 per cent. The detrital quartz consists of the following types: unstrained, slightly strained with a few inclusions, considerably strained with minute opaque, liquid and gaseous inclusions, vein quartz, quartzitic aggregates, and polycrystalline quartz. Strained quartz containing rutile needles forms the bulk of the arenites. Authigenic growths defined by dust rings and dissolution-replacement by carbonates are commonly observed.

Feldspars were identified only when twinned. They are extremely rare, only two or three grains at most occurring per square inch of rock slice. The grains display lamellar twinning and a small extinction angle and probably belong in the albite-oligoclase range. A few grains of microcline exhibiting polysynthetic twinning were observed. The feldspars are moderately altered.

Detrital chert is most abundant in the coarse-grained arenites where it ranges from 30 to 50 percent and comprises three types. The most common type is an aggregate of interlocking silica grains, each grain measuring less than 20 microns in size. Such grains display characteristic pinhead extinction. The second type is a dark brown to reddish brown ferruginous chert which, in some grains, exhibits spherulitic structures. This chert usually contains secondary silica veins which, in a few cases, are faulted. The third type consists of chert grains displaying silicified organic remains. It is present in coarser grained sandstone and pebbly arenites (Pl. IV, fig. 10) but is generally absent in finer grained rocks. All chert grains seem susceptible to replacement by secondary carbonate and pyrite.

Rock fragments, exclusive of chert, are the third most abundant constituent. The total content of these is small in fine-grained arenites but is greater in medium- and coarse-grained arenites. The rock types present are fragments of argillites (Pl. IV, fig. 11), quartz schists, quartz-mica schists, agate, siliceous and non-siliceous ironstones, meta-quartzites and orthoquartzites.

The accessory detrital minerals include micas, chlorites, and heavy minerals. Biotite is the most common mica but some light green to pale green chlorites are present. Glauconite is extremely rare. Heavy minerals include well-rounded grains of bluish, pale yellow to brown, and green tourmaline, colourless and reddish brown zircon, colourless and pink garnets, and reddish brown rutile.

The non-detrital constituents include such secondary minerals as silica, carbonate, pyrite, micaceous clay minerals, and glauconite. The dominant cements include silica, ferruginous matter, and carbonates. Cementation by pyrite and clay minerals was also observed.

WACKES

The wackes of the Cardium Formation contain abundant quartz and are, therefore, designated as quartz-wackes. They are most common in the middle or Cardium "A" unit and are transitional between the arenites and shales. This rock type is present in both the western and eastern sectors, but is more abundant in the latter.

The dominant detrital elements are typically angular to subangular, having an average roundness of 0.3. They are poorly sorted and generally fine- to very fine-grained.

The matrix content ranges from 12 to 20 per cent and consists of a pale brownish, ferruginous, clay-like mass containing very fine quartz, chert, quartzite and argillite grains, as well as carbonaceous matter. There is a relationship between the textural parameters and the abundance of matrix content. With a decrease in the grain size, there is a definite increase in total matrix content and angularity. Similar observations were made in the arenites.

The detrital fraction displays point contacts and, less frequently, concavo-convex contacts. Floating grains are rare and were observed only where the matrix exceeded 20 per cent of the rock.

Quartz grains, most of which contain liquid and gaseous inclusions, constitute approximately 60 to 70 per cent of the rock. Vein, quartzitic, and polycrystalline quartz grains are comparatively rare. Authigenic growths occur on a few quartz grains.

Chert forms 10 to 15 per cent of the rock and is generally pale yellow to pale yellowish brown and marked by characteristic pinhead extinction. Ferruginous chert and chert containing silicified organic remains are also present.

Feldspars are generally absent. Only a few grains of altered plagioclase feldspars and microcline were observed. Rock fragments, exclusive of chert, are fairly common. These form a maximum of 10 per cent of the rock and include argillite, quartz schist and quartzite. The accessory detrital minerals include micas, chlorites, and a few heavy minerals such as well-rounded tourmaline and zircon.

The quartz-wackes are poorly cemented. Ferruginous matter is the most abundant cementing material, but silica cement was observed in quartz-wackes containing the smallest amounts of matrix. Cementation by carbonates also occurs and appears to be a result of secondary enrichment by siderite. Diagenetic pyrite occurs as individual euhedral crystals, irregular masses, veins, and nodules.

CONGLOMERATES

There are two main conglomerate units and these are differerent both texturally and compositionally.

The upper, occurring at the top of the Cardium "A" sandstone, has a widespread distribution, being observed in almost all the cored wells of both the eastern and western sectors. This unit has a maximum thickness of 1.5 feet but is commonly about 6 inches thick. It consists of pebbles that average one-half inch in diameter but reach a maximum of one inch, in a dark grey, ferruginous, pyritic shale matrix (Pl. I, figs. 4, 5, 10, 11).

The lower conglomerate unit, occurring in the main producing body, is locally developed. It reaches a maximum of 18 feet but averages 8 feet in thickness, and is composed of granule size pebbles (Pl. I, figs. 6-9) with very little matrix. Secondary siderite is common (Pl. III, fig. 1).

Conglomerates with shale matrix

The pebbles vary in size from 0.25 inch to 1.00 inch, most of them being in the size range 0.4 to 0.75 inches. They are moderately well sorted and well rounded (0.7 to 0.9). The roundness varies directly with the size, the larger pebbles being more rounded.

The pebble contacts range from "point" to "floating" type (Pl. I, figs. 4, 10; Pl. V, fig. 2). Sutured or microstylolytic contacts (Pl. V, fig. 3) are rare.

The cement is mainly a brownish ferruginous clay which occurs between the pebbles as thin films (Pl. V, fig. 4). Siliceous cement was also observed and, where present, the shaly matrix has been silicified.

The matrix consists of dark grey to greyish brown clay containing some grains of medium- to fine-grained, strained quartz and rock fragments of chert, argillite, and quartzite. Generally, matrix is abundant and in some places forms 30 per cent of the total rock. The clay content consists of moderately crystalline, micaceous minerals that conform to the grain boundaries of the pebbles (Pl. V, fig. 5) owing to compaction.

The pebbles consist mainly of clear to light brown to reddish brown, turbid chert. Some chert pebbles contain a net-work of secondary siliceous veinlets (Pl. V, fig. 6), and others contain silicified organic remains of crinoids, bryozoa and shells (Pl. V, fig. 7). Pebbles of phyllite, argillite, quartzite, quartz-schist, quartz-mica schist, and considerably strained quartz are common and usually constitute 15 to 20 per cent of the total pebble content.

The accessory detrital constituents include zircon, tourmaline, and rutile. Diagenetic pyrite is associated mainly with the matrix, but it also occurs in a few chert pebbles, where it appears to be replacing the chert. Secondary carbonates, megaspores, and fragments of plant material are rare.

Granule conglomerates and conglomeratic sandstones

The granule conglomerates are better sorted than those described above. The sizes of the constituent rock fragments range from 0.05 to 0.2 inch. They are very well rounded, the roundness ranging from 0.7 to 0.9. Imbrication, with the long diameter of the granules oriented parallel to the bedding, was observed, and reverse graded bedding is a characteristic feature (Pl. I, figs. 7-9).

The matrix, normally less than 10 per cent, is composed of sub-rounded to rounded, strained quartz and rock fragments of chert, quartzite, and argillite.

Cementation is poor, differential, and rarely complete. The granule conglomerates are commonly cemented by pale brown to dark reddish brown ironstone which, in a few places, constitutes 5 to 10 per cent of the rock. Cementation by silica and carbonate is very subordinate.

The granule conglomerates and the associated conglomeratic sandstones are porous and permeable owing to the incomplete filling of intergranular pore spaces by the sideritic and other cements. The textural parameters together with the lack of matrix and cement have been instrumental in promoting the porosity and permeability.

Chert constitutes 75 to 80 per cent of the total granule content of the conglomerates. The amount becomes less in the conglomeratic sandstones where there is a corresponding increase in the amount of strained quartz. The chert is light brown, reddish brown, and white. Some is ferruginous and some contains silicified organic remains similar to those occurring in the shaly conglomerates. The remainder of the granules include orthoquartzite, agate, siltstone, siderite, phyllite, argillite, and quartz-mica schist.

The accessory detrital constituents include well-rounded zircon and tourmaline and a few plant fragments. The non-detrital constituents include diagenetic pyrite, siderite, and very rarely, glauconite.

DIAGENESIS

Compaction

The megascopic evidence of compaction is best displayed by sequences of alternating sandstones and shales. In some places, the two are squeezed into one another, forming irregular bodies (Pl. II, fig. 11) whereas, in other cases, their contacts are curved (Pl. II, fig. 12), the curvature being related to the varing amounts of silt fraction in the interlaminated shales and the argillaceous content of the sandstones. In a few examples, differential compaction produced sandstone dykes (Pl. II, fig. 5; Pl. VI, fig. 8).

Compaction and packing, both of which control porosity, are indicated by the nature of the detrital grain contacts (Gilbert, 1949, Taylor, 1950; Thompson, 1959; Siever, 1959). The grains may posses floating contacts during the initial stages but, with progressively increasing compaction and packing, they are re-oriented and acquire a tangential, linear, concavo-convex, or sutured contact. Floating contacts are rarely observed in arenites, but they are present in a few rocks containing abundant silica cement. The contacts in the arenites vary from tangential to concavo-convex (Pl. IV, fig. 8), the latter being more common. These concavo-convex contacts appear to have formed by interpenetration assisted by pressure solution at points of contact. Sutured contacts have formed owing to the interfering of authigenic growths on quartz grains. When present, these are marked by ferruginous-argillaceous coatings (Pl. V, fig. 3). Heterogeneity in size distribution seems to bear some relationship to interpenetration. Larger quartz and chert grains are invariably penetrated by smaller ones that occur around their peripheries. The contact between them is not fused but is marked by a ferruginous-argillaceous film (Pl. VII, figs. 1, 2).

Compaction has brought about re-organization, both physical and diagenetic, of the argillaceous material. Generally, micaceous minerals have developed and, owing to compaction, wrap around the detrital grains. Futhermore, in rare cases, these micaceous minerals act as a cement.

Cementation

The Cardium sandstones and conglomerates are cemented by silica, carbonates, pyrite, and clay.

Cementation by silica

Cementation by silica is most common and best displayed in arenites containing abundant detrital quartz. The silica cement occurs as thin films between detrital grains, as anhedral interstitial fillings, and as interfering authigenic growths. The films are most commonly observed in finer grained arenites, where it occurs between grains possessing concavo-convex contacts.

Interfering authigenic growths that have caused an interlocking texture are more common in coarser grained arenites. There is some relationship between the size of the quartz grains and the overgrowths because the larger grains invariably exhibit the growths, whereas, the smaller ones are generally devoid of them. In some grains, the shapes of the growths correspond to the shapes of the cores and all the irregularities of the latter are reproduced. The original detrital grain boundaries are, is most cases, defined by "dust rings" (Pl. VI, figs. 9, 10) formed of minute fluid inclusions, either liquid or gaseous. In many cases these rings are broken or only partly developed (Pl. VI, fig. 9), whereas in others they are absent and it becomes difficult to ascertain the extent of the authigenic growths.

The development of authigenic growths seems to have been partly controlled by the clay content because the intensity of growth and the percentage of clay present vary inversely. The growths are more extensive in arenites containing less than 5 per cent argillaceous matrix and are less well developed with an increase in total clay content. Detrital quartz grains that have a coating of clay are devoid of authigenic grows; those grains that are partly coated with clay have overgrowths in areas free of clay.

Cementation by carbonates

Cementation by carbonate occurs in both conglomerates and arenites. It is commonly patchy and generally more intense along the bedding planes of arenites and, therefore, appears to have been controlled by textural inhomogeneities. Dolomite and calcite are the principal carbonate cements, the former possibly being a diagenetic replacement of the latter. The carbonate cement occurs as thin films surrounding the detrital grains and also fills, partly or wholly, the intergranular voids. The carbonates in the voids are well crystallized, display characteristic cleavages and, in some cases, are twinned. The carbonate cement, as a rule, has replaced silica cement.

Quartz and chert grains, in contact with carbonate, are invariably replaced (Pl. VII, figs. 3-6) and are generally marked by a rim (Pl. VII, fig. 7) presumably produced by a quartz-carbonate reaction. Various stages of peripheral dissolution were observed. Deep embayments along fractures, grain contacts and dust rings are common. Intense or nearly complete replacement of detrital grains, resulting in skeletal remains and ghosts, were observed in places. Quartz grains floating in carbonate cement occur in a few arenites. This relationship may be caused by corrosion and replacement of a large percentage of the detrital fraction. Some evidence of such replacement by carbonate was seen where quartzite fragments were dissolved and dissociated along their interlocking seams. Generally the detrital quartz fraction of the arenites is well sorted and well rounded but, in some sandstones containing carbonate cement, it has lost both those characters owing to differential dissolution-replacement. As a result the grains are now angular and of different sizes.

Cementation by clays

In some of the arenites micaceous clay minerals bring about cementation by diagenetic encroachments into detrital quartz grains. In a few cases, very fine clay fills the spaces between grains and, as a result of compaction and partial recrystallization, has become coherent enough to act as cement. In others, the clays are intimately associated with carbonates and act as cement.

Cementation by ferruginous matter

Ferruginous cement occurs in wackes and arenites but is most common in the granule conglomerates and coarse-grained arenites of the producing body. It appears to contain argillaceous material and occurs between grains as a thin film and, fills the pore spaces. In some granule conglomerates and arenites the ferruginous matter appears to have been partly leached out, leaving a slightly porous and poorly cemented rock.

Sideritic enrichment

Enrichment by siderite occurs in grey to dark grey shales, quartz-wackes, arenites, and conglomerates. It is best developed in the granule conglomerate of the producing body. The siderite is light brown to dark reddish brown and is distributed throughout the rock as stringers, small patches, irregular masses, and thick beds (Pl. III, figs. 2, 3). Most of the siderite is hard, brittle, and crypto- to microcrystalline.

Various stages of siderite enrichment were seen. The siderite occurring in shales is commonly cryptocrystalline and thoroughly interwoven into the argillaceous framework. It largely replaces the detrital fraction including clay minerals and, therfore, its contact with the shale is always gradational. The dark shales enriched by siderite are lacking diagenetic pyrite, therefore, the occurrence of siderite or pyrite may be indicative of different depositional or diagenetic conditions. The least enriched granule conglomerates commonly contain brown to dark brown siderite which is, in places, oolitic (Pl. VIII, fig. 2) and spherulitic (Pl. VII, fig. 1). The siderite fills the intergranular voids and partly acts as cement (Pl. VI, figs. 2, 7). Partial replacement of the detrital fraction is evident and widespread (Pl. V, fig. 10; Pl. VI, figs. 1-7), and most of the quartz and chert grains are surrounded by a rim of well-crystallized siderite. In moderately enriched conglomerates, the siderite is granular, microcrystalline, pink to brown, and contains many ghosts of the detrital fraction. In addition, most of the detrital grains exhibit floating contacts and are widely separated from one another (Pl. VI, fig. 7; Pl. VIII, figs. 3, 4). With an increase in enrichment and dissolution-replacement of the detrital fraction, the siderite becomes dense, cryptocrystalline, and abundant enough to form beds containing disseminated grains of chert and quartz (Pl. VIII, fig. 4).

Pyritization

Diagenetic pyrite is common in all rocks, but is most abundant in silty shales. It occurs as evenly distributed, individual euhedral crystals and less frequently as streaks, veins, and irregular masses. Nodules of diagenetic pyrite are normally oblong and ovoid, and rarely lenticular (Pl. IV, fig. 1) or irregular (Pl. III, fig. 5; Pl. IV, fig. 3). The nodules are formed of an aggregrate of crystals and include 20 to 35 per cent silt. The core consists almost entirely of pyrite with little or no silt but, away from the core, the amount of pyrite decreases with a corresponding increase in the amount of silt. The diagenetic nature of the nodules is confirmed by the preservation within them of primary sedimentary structures such as bedding and worm burrows (Pl. IV, fig. 1).

Replacement of detrital grains by pyrite occurs along cracks and marginal areas (Pl. VII, figs. 9, 10). All stages from initial replacement to complete replacement were observed, the final stages being marked by skeletal remains, ghosts, and large patches of pyrite.

A few silty shales contain rod-like masses, 1/2 to 3/4 inch long and 1/8 inch in diameter, that cut across bedding planes, taper toward the lower end, display sharp contacts with surrounding shale and include considerable silt (Pl. IV, fig. 6). They may represent worm burrows filled by diagenetic pyrite. Pyritized plant fragments (Pl. VI, fig. 5) and Inoceramus shells (Pl. IV, fig. 5; Pl. V, fig. 1) as well as detrital chert grains (Pl. VII, figs. 9, 10) are common.

STRUCTURE

The structural geology is illustrated by two isopach maps (Figs. 8, 9) and by structure contour maps of four marker horizons (Figs. 4-7).

The strike of the marker horizons is generally northwest-southeast (Figs. 4-7) with a somewhat more northerly trend in the southwestern part of the area. The strata generally dip uniformly to the southwest at about 7 to 8 degrees except near the two faults that occur in the southwestern quadrant. Between these faults (Fig. 14, Sec. 1-18), the dip is as much as 11 degrees but decreases again southwest of the faults. In Section II-II' (Fig. 15) the block between the faults shows variable attitudes and the dip of the strata progressively steepens from 4 to 5 degrees for the Second White Specks to an average of 16 degrees in the higher First White Specks. Southwest of fault F1 the regional dip is again about 7 or 8 degrees to the southwest.

The two faults occurring in the southwestern quadrant were identified in electric logs of various wells (Fig. 13). These faults seem to parallel the general tectonic strike observed in the Foothills to the west (Irish, 1965). Movement on fault F1 has increased the thickness of the stratigraphic sequence between the First White Specks and Bad Heart Markers in Hamilton Edson 7-18-53-18 (well 35), HB Hamilton Edson 10-4-53-18 (well 44), Hamilton et al. Edson 10-31-52-17 (well 50), and HB Triad Edson 6-21-52-17 (well 58). Similarly, fault F2 has increased the stratigraphic sequence between the Bad Heart marker horizon and Cardium Formation in HB Edson 4-17-54-18 (well 3), HB Edson 10-8-54-18 (well 8), Home Mobil Peers 4-22-53-18 (well 35), Triad Royalite Edson 2-26-52-18 (well 56), and HB Triad Edson 6-21-52-17 (well 58). The general trace of fault F1 on the Second White Specks marker (Fig. 7) is northwest-southeast, whereas that of fault F2 is north-northwest south-southeast. Thus, the faults possibly merge to the south and southeast. The dips of these faults are variable (Figs. 14, 15), being steep near the top of the First White Specks and flattening at depth. Their geometry between the First and Second White Specks suggests that they may coalesce at depth west and south of the study-area. The displacement on fault F1 is greater than on F2. In general, displacement is greatest near the First White Specks, where the faults are almost vertical, and decreases progressively with depth (Figs. 14, 15). The maximum stratigraphic repetition occurs on fault F1 and is of the order of 190 and 78 feet between the First White Specks and Bad Heart Marker horizon in Hamilton et al. Edson 10-31-52-17 (well 50) and between the Bad Heart Marker horizon and Cardium Formation in HB Triad Edson 6-21-52-17 (well 58) respectively.

Isopach maps (Figs. 8, 9) were drawn for two stratigraphic intervals which indicate, in general, increasing thicknesses toward the west and southwest. The thickness between the First White Specks and Bad Heart marker horizons increases gradually by 80 feet across the study-area from northeast to southwest (Fig. 8). The isopachs for the sequence between the Bad Heart marker horizon and Cardium Formation display a similar pattern and show a thickening of approximately 80 feet from northeast to southwest (Fig. 9). Some thinning (approximately 40 feet) of this sequence is present in the extreme southwestern part of the area in the vicinity of Hamilton et al. Edson 11-2-52-18 (well 63). This decrease is local, as shown by increased thickness (60 feet) farther west.

SEDIMENTARY ENVIRONMENT

The Late Cretaceous seaway extended from the present day Rocky Mountains in the west to Manitoba in the east (see Williams and Burk, 1964). The western part of the area received almost all its sediments from the rising Cordilleran geanticline to the west.

Maximum transgressions during early Turonian and Santonian (Stott, 1963; Williams and Burk, 1964) are recorded in the succession containing the Second and First White Specks calcareous shales, respectively. During middle and late Turonian time, positive movements of the Cordilleran geanticline resulted in a greater influx of detritus and resultant shoreline retreat. This regressive episode is recorded in the arenaceous rocks of the Cardium Formation (Stott, 1963).

The dispersal of Cardium sediments was attributed to turbidity currents by Beach (1955; 1956), de Wit (1957) and Passega (1957). That theory was disputed by DeWiel (1956), Hunt (1957), Michaelis (1957), Nielson (1957), Mountjoy (1957) and Stott (1963) who regard the Cardium Formation to be of shallow-water origin and to represent lagoonal, swampy, and shallow-marine environments. The present study further supports the conclusion that the Cardium sediments lack the characteristic features attributed to and considered to be diagnostic of turbidites (Kuenen, 1950; Walker, 1965).

The basal Cardium beds, which comprise dark silty shale with intercalated siltstone and which contain diagenetic pyrite, are thought to have been deposited in a quiet-water, euxinic and marine environment. Shallow-water deposition followed, as is indicated by the presence of worm burrows, the increase in abundance and grain size of the arenaceous fractions, the increase in plant remains and by the sporadic occurrence of glauconite.

The conglomeratic sandstone and granule conglomerates of the Cardium "B" unit display many characteristic features of a sand bar. It has a long, linear trend with its length many times greater than its width (Fig. 17); its base is flat and its top, convex (Figs. 3B, 10-12). The sandstone of the main body grades vertically downward into the underlying siltstones and silty shales, whereas the upper contact is sharp with overlying beds. The sandstone has a uniform mineral composition and contains diagenetic glauconite. There is an upward increase in grain size in the granule conglomerates which contain carbonized plant debris as well as a marine microfauna. Worm burrows are present in the silty shales occurring below the sand body. These features are similar to those described and interpreted as characteristic of other sand bars (Potter, 1967; Shelton, 1965, 1967).

Sediments in which shales are dominant, and in which arenites, quartz-wackes, and conglomerates with shale matrix are subordinate, appear to have been deposited in a shallow-marine, brackish (at times deltaic and lagoonal), partly reducing, restricted environment. The Cardium rocks show such features as the dark grey colour, abundance of silt and sand, plant remains, diagenetic pyrite in shales, reverse graded bedding in conglomerates, occurrence of conglomerates with shale matrix, quartz-wackes, alternating sequences of shale and siltstone, abundant wavy and lenticular laminations of sandstone in shale, worm burrows, and scour and fill structures; all of which have been attributed to such an environment (Scruton, 1960; Coleman and Gagliano, 1965). The formation of arenites may be attributed to agitation in the epineritic environment which resulted in winnowing of the sand and the removal of finer clastics. Sediments of the eastern sector were probably deposited in deeper water lying farther offshore. These shales contain fewer laminations of sandstone and rarely display worm burrows. Also, well-developed arenites and conglomerates are not present and there is a general decrease in grain size toward the east and southeast. It is concluded that the shoreline was prograding eastward and that the detritus was fed into the basin from the west.

PROVENANCE

The detrital constituents forming the arenites and wackes consist mainly of vari-coloured chert and strained quartz; feldspars are generally absent. The rock fragment content is subordinate and consists of orthoquartzite, metaquartzite, argillite, phyllite, and schist. The pebbles of the conglomerates are well rounded. The heavy minerals, consisting mainly of well-rounded grains of zircon, tourmaline, and rutile, represent the more stable suite. The mineral composition, together with the great preponderance of shales and siltstones, indicates that the detritus was derived mainly from a sedimentary and low-grade metamorphic terrain.

The general increase in the arenaceous content, increasing thickness (Figs. 3A, 8, 9) and replacement of marine with brackish water and lagoonal conditions toward the west indicates that the source area for the sediments was to the west. The sediments of the Cardium Formation of the Foothills were considered by Stott (1963) to be derived from a western source consisting mainly of sedimentary rocks including Paleozoic cherty limestones and, possibly, igneous as well as metamorphic rocks. Berven (1966) also concluded that the lower Cardium sandstones of the Crossfield-Garrington area were mainly derived from a sedimentary terrain, probably including Precambrian and Paleozoic quartzites, argillites, and limestones. The Cordilleran geanticline to the west was probably the main source.

RESERVOIR PROPERTIES

The various reservoir parameters of the Cardium sandstone of the Edson field were reported by Skiber (1967). According to him, the Cardium sandstone has an average porosity of 9.75 per cent and an average permeability of 53.7 millidarcies. The average thickness of the oil zone is 6.3 feet and its maximum thickness is 13.6 feet. The initial reservoir drive was gas but water flooding is necessary for pressure maintenance and secondary recovery. Skiber stated that the total oil in place is estimated to be 18,700,000 barrels; the amount recoverable by primary methods to be 1,411,000 barrels (recovery factor - 7.55 per cent); and that recoverable by secondary methods to be 4,488,000 barrels (recovery factor - 24.0 per cent).

The Alberta Oil and Conservation Board reports that a total of 274,178 barrels of oil and 343,662 million cubic feet of gas were produced from the Cardium "B" sandstone during 1967 and the cumulative production to December 31, 1967 amounted to 1,909,318 barrels of oil and 898,898 million cubic feet of gas. During the same year, 7,372 million cubic feet of gas and 3,961 barrels of oil were produced from the Cardium "A" sandstone, giving a cumulative production to December 31 of 49, 025 barrels of oil and 38,789 million cubic feet of gas. As of May, 1968, only one well was producing from the Cardium "A" sandstone and, although 22 wells were capable of producing from the Cardium "B" sandstone, only 14 were in operation.

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Table I

Figures 4 - 16

Well Numbers	Fault F1 - F1			Fault F2 - F2		
	First White Specks to Bad Heart Marker Horizon			Bad Heart Marker Horizon to Cardium Formation		
	Gross thickness	Corrected thickness	Total Repetition	Gross thickness	Corrected thickness	Total Repetition
3	-	-	-	275	240	32
8	-	-	-	298	247	51
35	403	385	18	297	263	34
44	477	377	100	-	-	-
50	560	370	190	-	-	-
56	-	-	-	309	257	52
58	484	365	119	318	240	78

GSC

Table I. Showing thickness (in feet) of repeated sequences; Edson area, Alberta

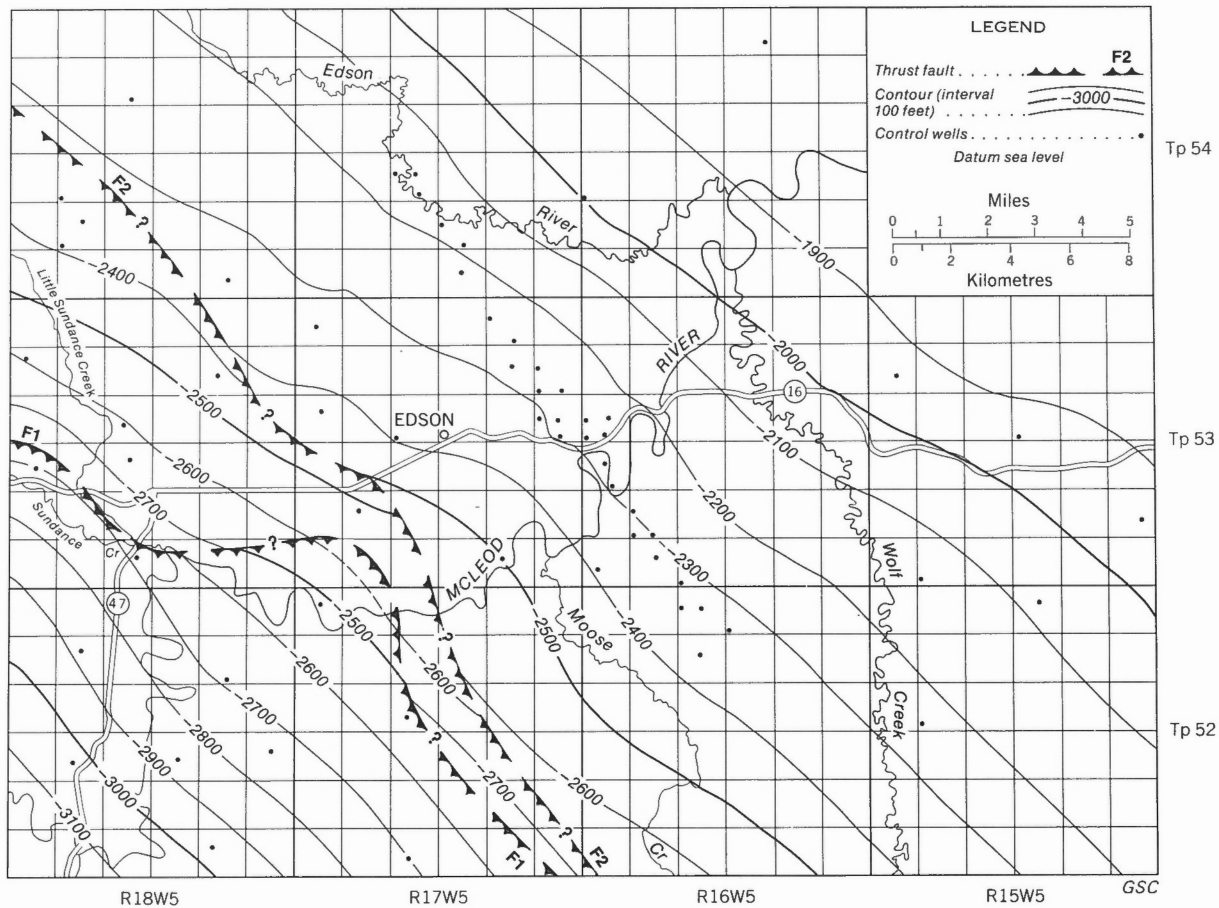


Figure 4. Structure contour map of top of First White Specks marker; Edson area, Alberta

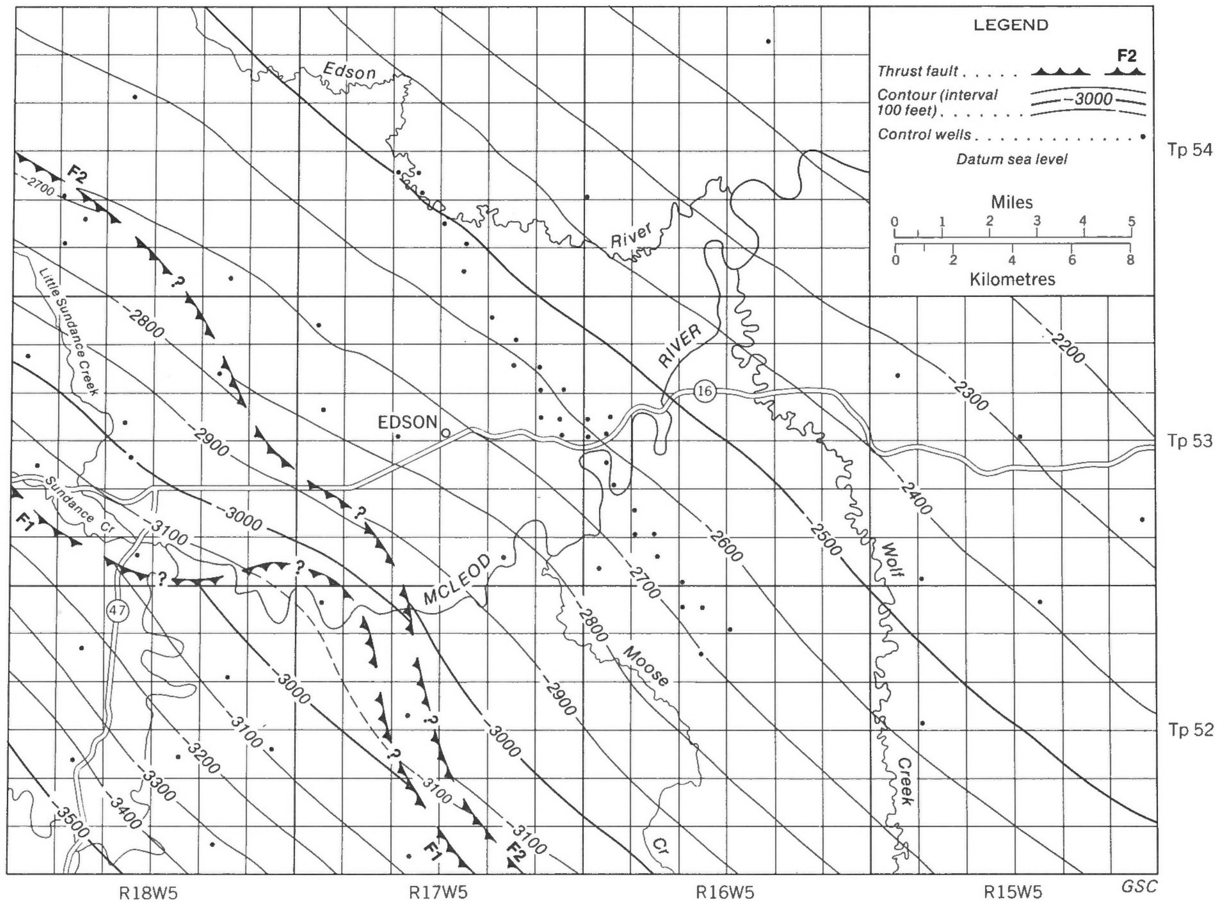


Figure 5. Structure contour map of top of Bad Heart marker; Edson area, Alberta

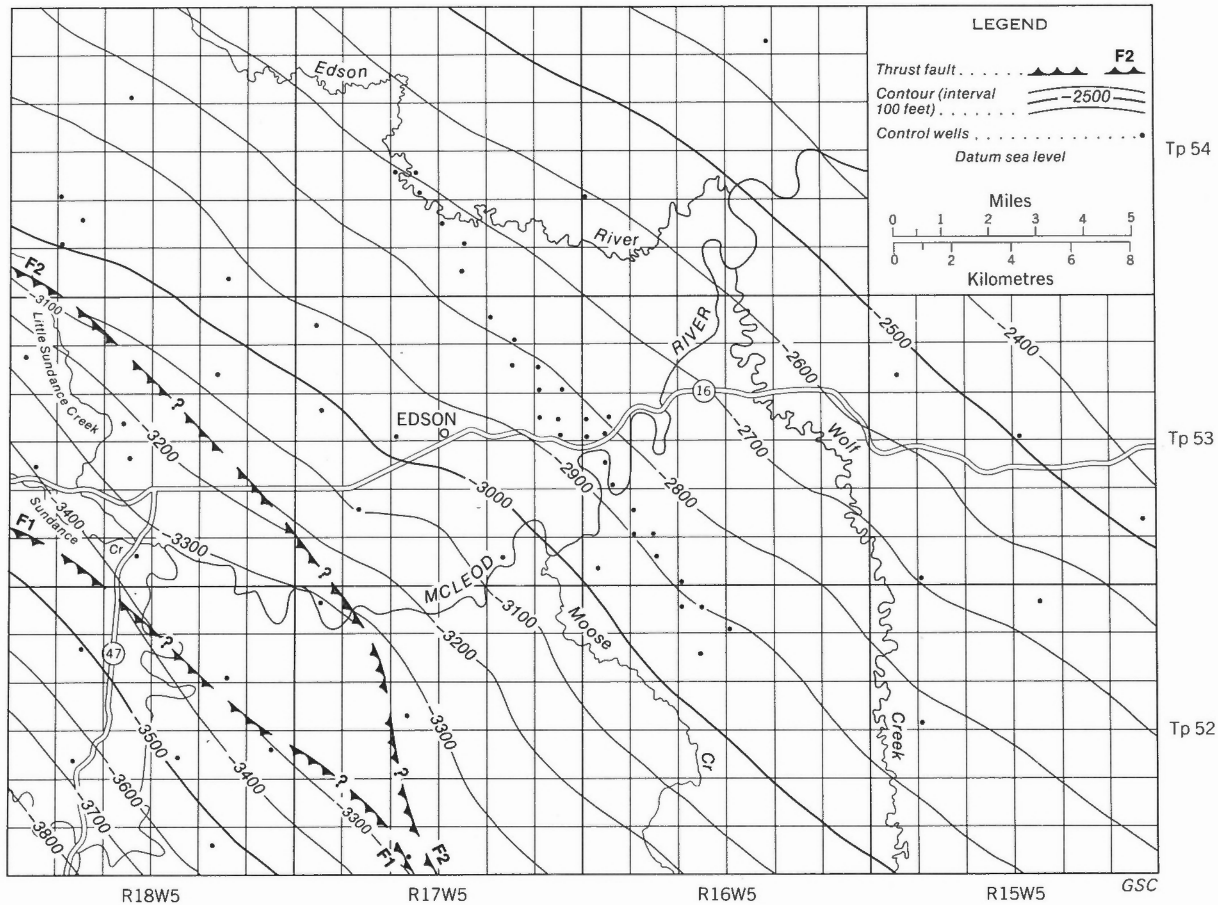


Figure 6. Structure contour map of top of Cardium Formation; Edson area, Alberta

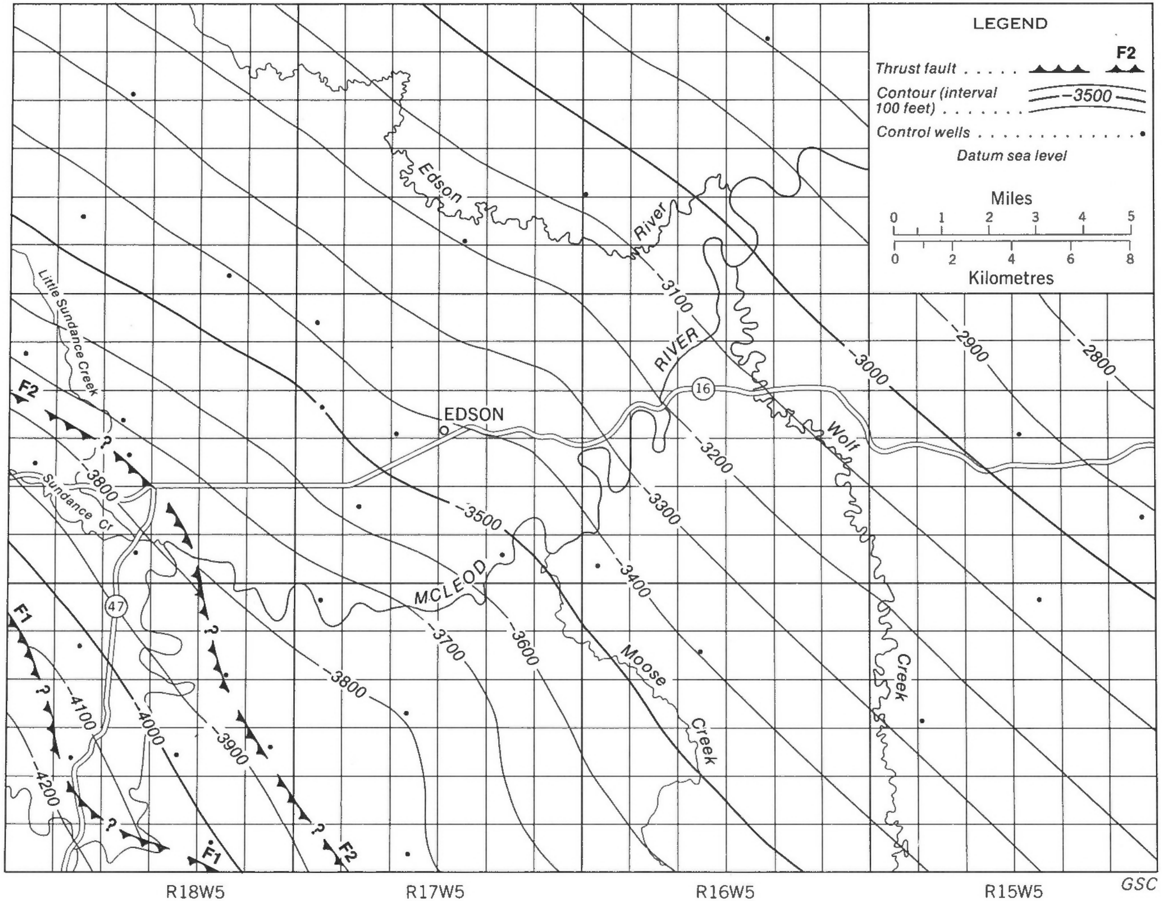


Figure 7. Structure contour map of top of Second White Specks marker; Edson area, Alberta

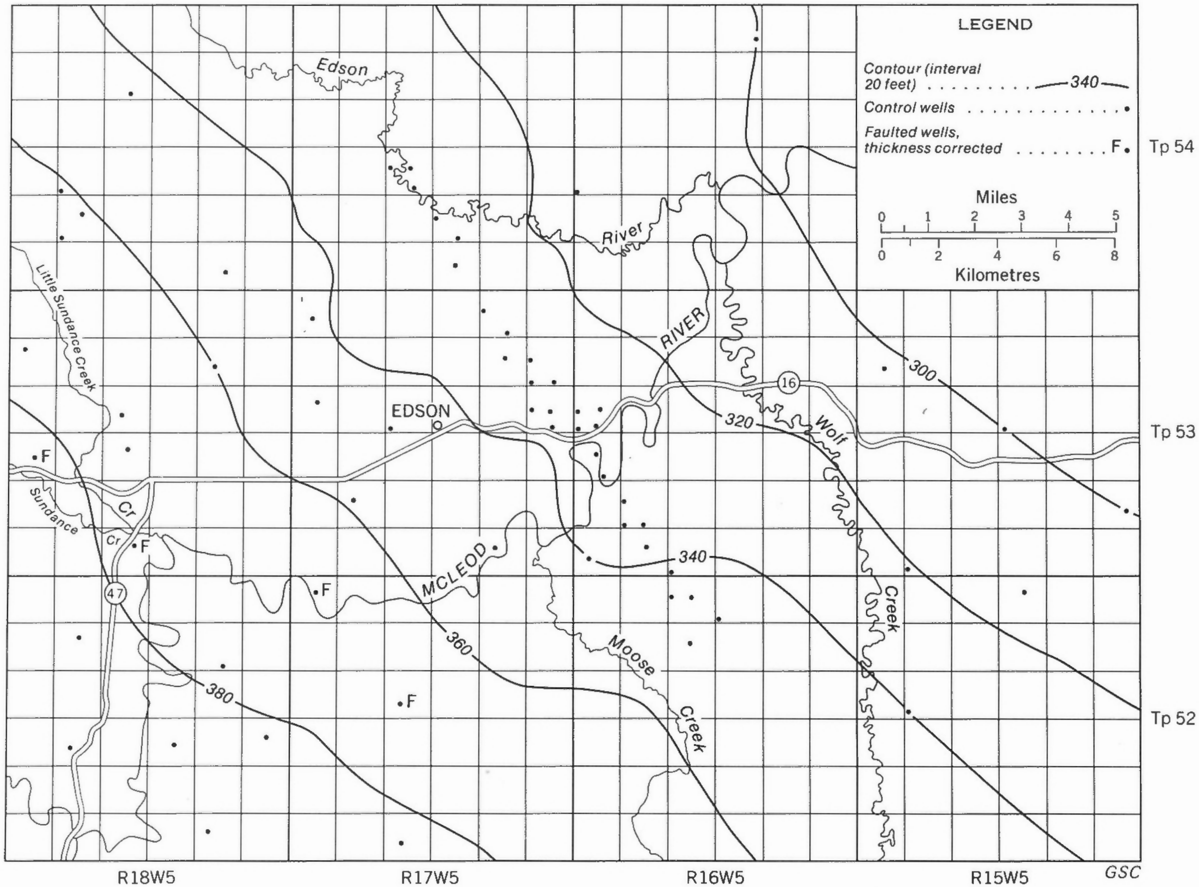


Figure 8. Isopach map of strata between First White Specks and Bad Heart markers; Edson area, Alberta

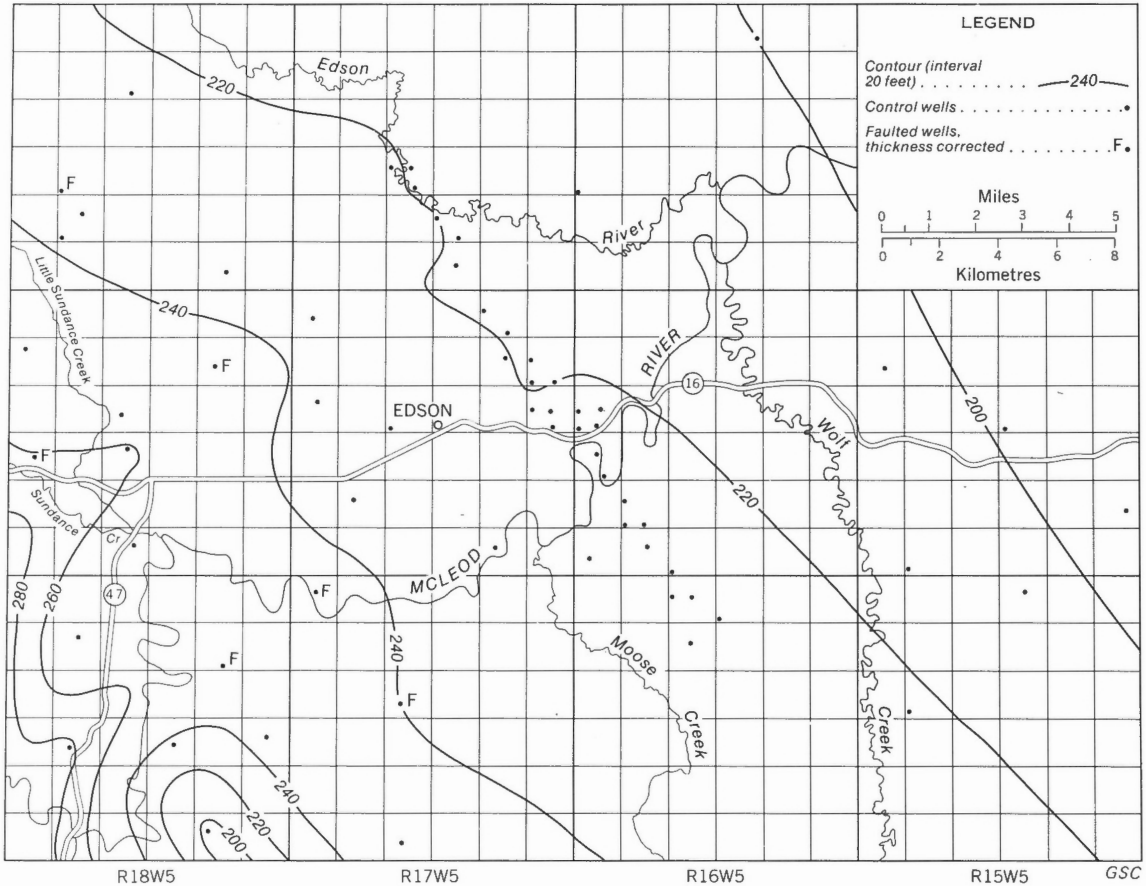


Figure 9. Isopach map of strata between the Bad Heart marker and top of the Cardium Formation; Edson area, Alberta

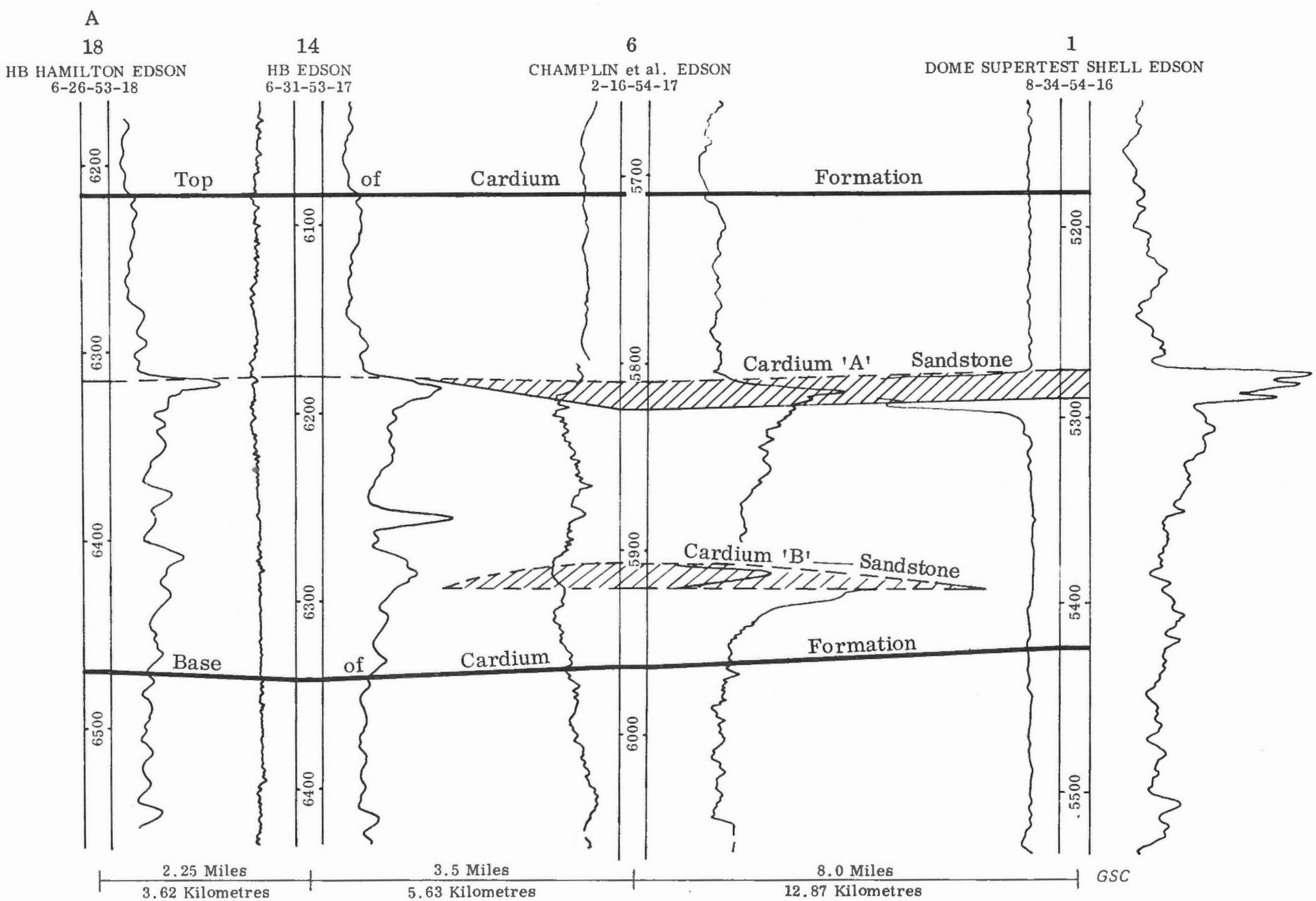


Figure 10. Stratigraphic cross-section of the Cardium Formation along line A-A'; Edson area, Alberta

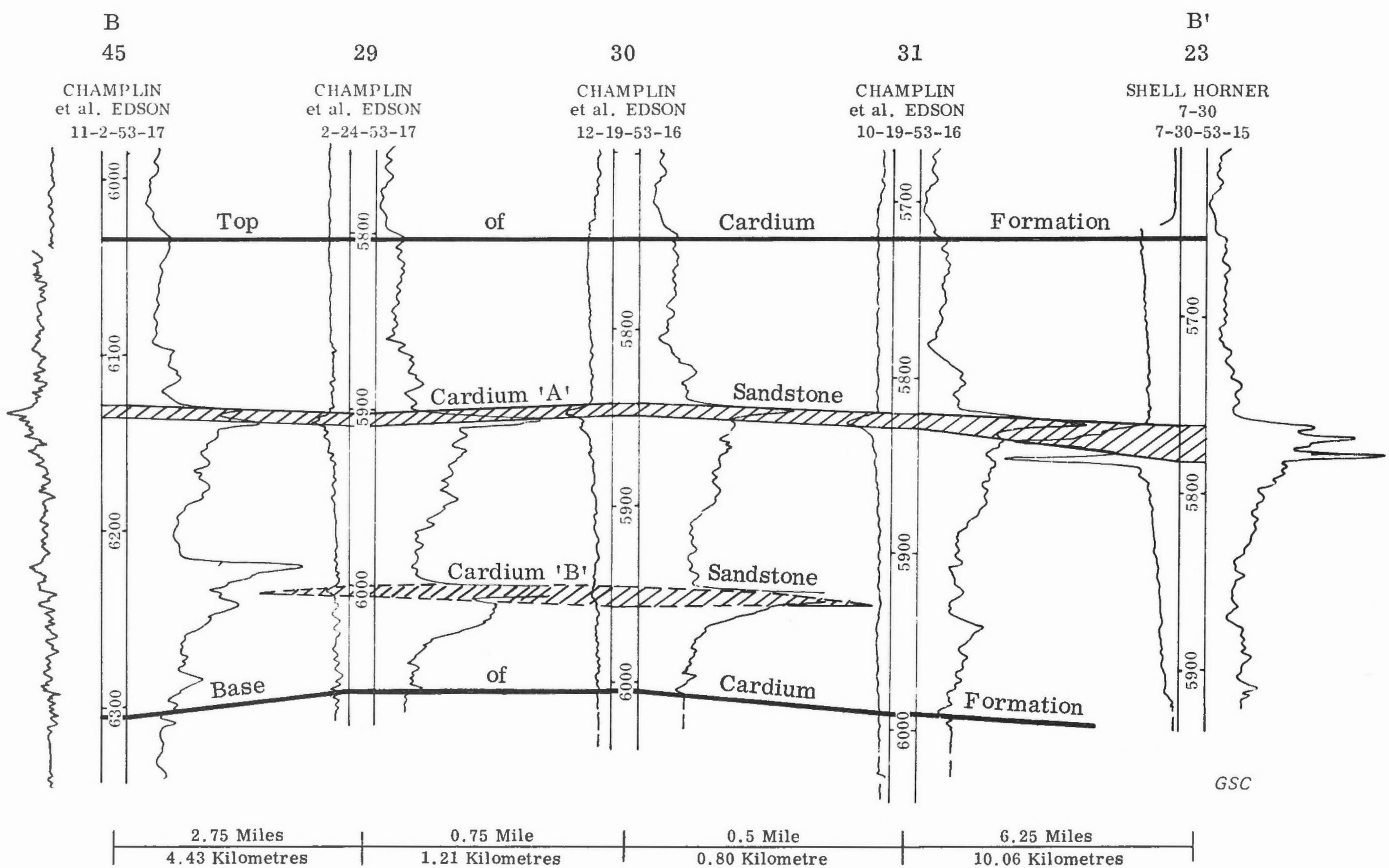


Figure 11. Stratigraphic cross-section of the Cardium Formation along line B-B'; Edson area, Alberta

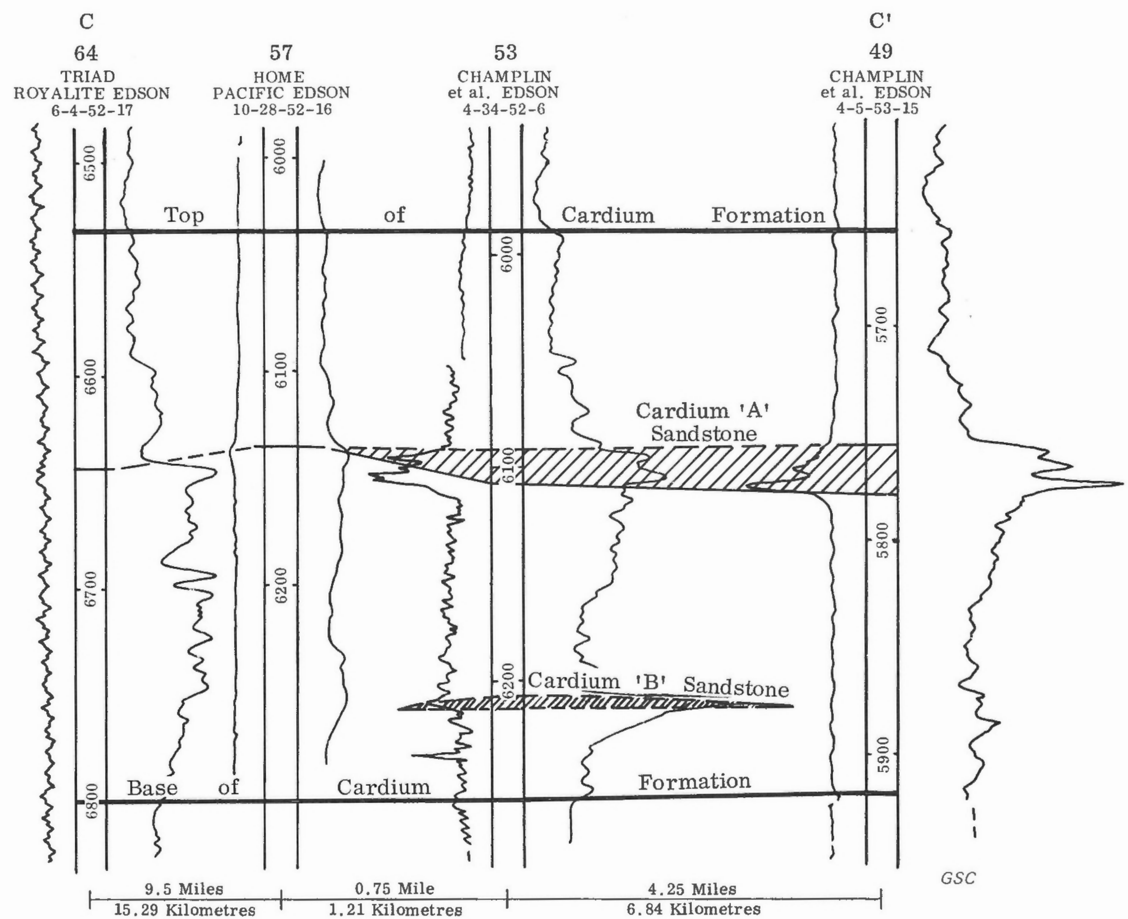


Figure 12. Stratigraphic cross-section of the Cardium Formation along line C-C'; Edson area, Alberta

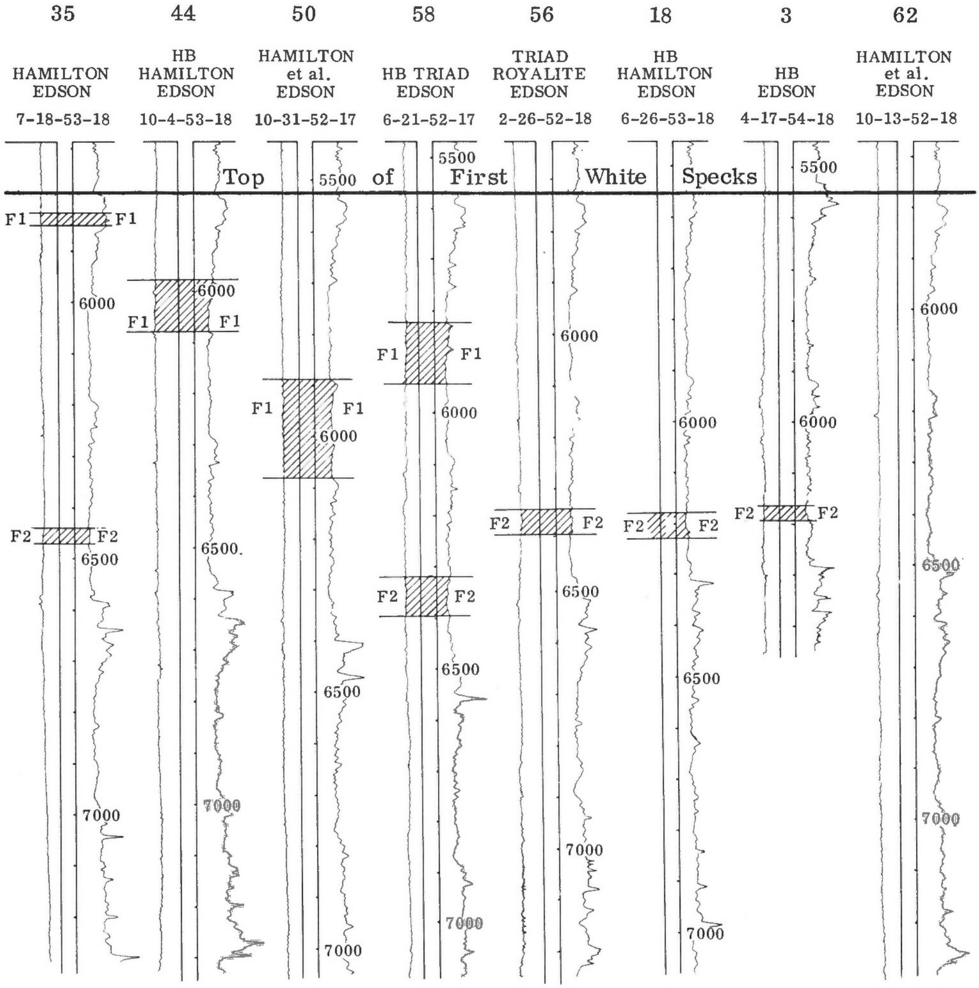


Figure 13. Electric logs of wells showing repeated sequences attributed to thrust faults (shaded areas); Edson area, Alberta. (Well number 62 is not faulted and is shown for comparison only. F1 and F2 refer to two separate faults).

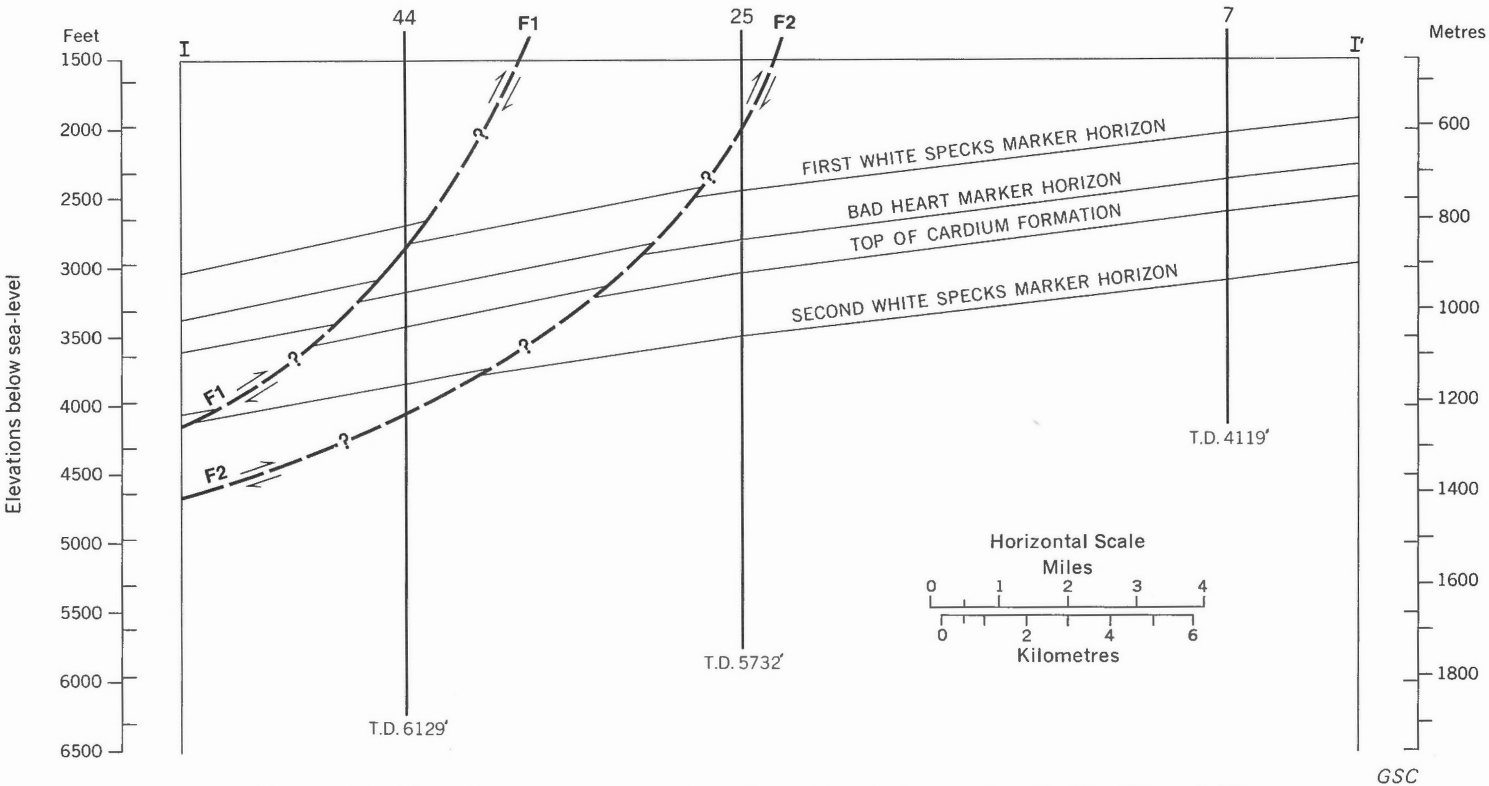


Figure 14. Structure cross-section along line I-I' showing faults F1 and F2; Edson area, Alberta

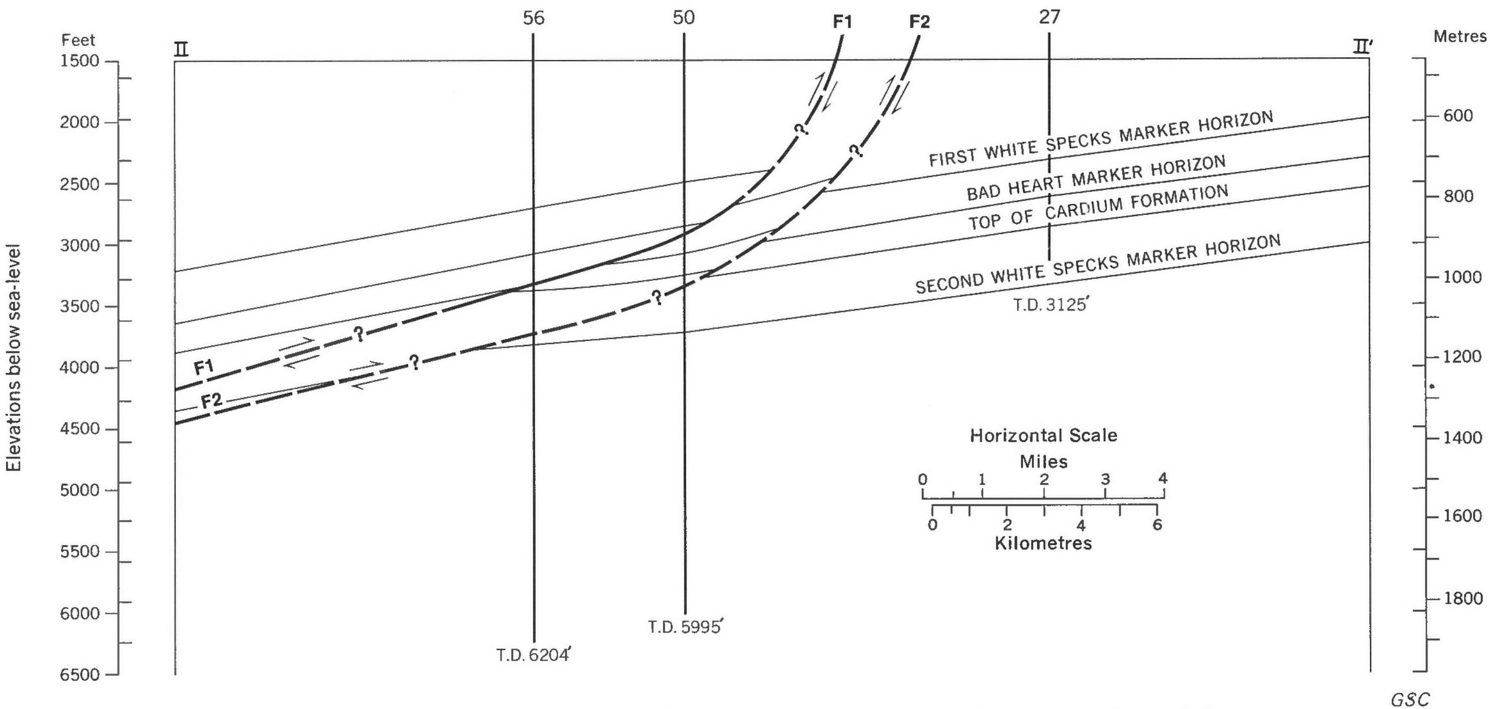


Figure 15. Structure cross-section along line II-II' showing faults F1 and F2; Edson area, Alberta

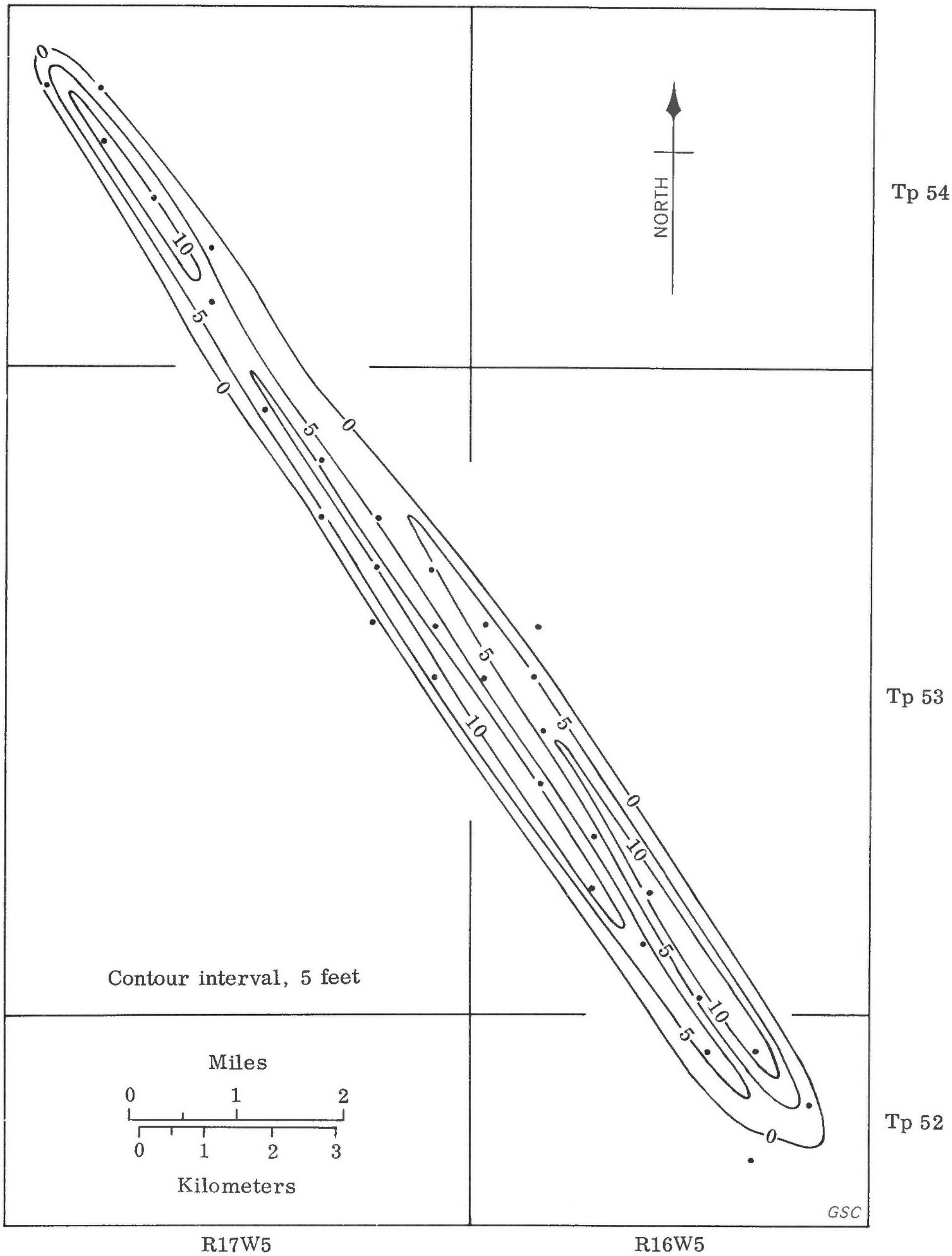


Figure 16. Sandstone thickness map of Cardium 'B' sandstone body; Edson area, Alberta (after Skiber, 1967)

APPENDIX I

Well Sections

Well 9. HB Edson 4-8-54-18

Location: lsd. 4, sec. 8, tp. 54, rge. 18W5
Elevation: 3,228 K.B.
Total depth: 6,435 feet
Completed: 1/8/62
Status: Abandoned
Summary log by R.N. Sinha of core and samples from 6,214 to 6,435 feet depth, stored at Oil and Gas Conservation Board, Calgary.

Sample Depth (feet)	Lithology	Thickness (feet)
	CARDIUM FORMATION	
6,214-6,285	Silty shale with traces of sand	71
6,285-6,290	Shale, dark grey, hard, pyritic, silty	5
6,290-6,312	Shale, dark grey, silty to sandy, pyritic, carbonaceous; a few pebbles of limestone and chert; lenticular laminations of grey, hard, silty sandstone; scour and fill structures; worm burrows	22
6,312-6,314	Conglomerate with shale matrix. Pebbles of chert are well rounded, average 2.5 cms; reverse graded bedding; diagenetic siderite	2
6,314-6,330	Sandstone, medium- to fine-grained, grey, cross-stratified, containing laminations of fissile, pyritic, dark grey, silty shale; scour and fill structures; worm burrows; siderite	16
6,330-6,340	Shale, dark grey, silty, carbonaceous, pyritic; lenticular laminations of grey, silty sandstone; pyritized rootlets, plant remains, nodules; worm burrows; scour and fill structures	10
6,340-6,392	Siltstone, dark grey, argillaceous; thin laminae of dark grey, silty shale and fine-grained sandstone; scour and fill structures; worm burrows	52
6,392-6,399	Sandstone, medium- to coarse-grained, conglomeratic, grey; granule conglomerate with laminations of dark grey silty shale; siderite, numerous worm burrows	7

Sample Depth (feet)	Lithology	Thickness (feet)
6,399-6,405	Shale, dark grey, silt, pyritic; thin beds of argillaceous siltstone and lenticular laminations of grey, fine-grained, silty sandstone; scour and fill structures common; small nodules of pyrite; plant fragments	6
6,405-6,435	Siltstone, argillaceous alternating with dark grey, pyritic, silty to sandy shale and argillaceous sandstone; worm burrows	30

Well 30. Champlin et al. Edson 12-19-53-16

Location. lsd. 12, sec. 19, tp. 53, rge. 16W5
Elevation: 2,937 K.B.
Total depth: 6,020 feet
Completed: 1/8/63
Status: Oil well
Summary log by R.N. Sinha of core and samples from 5,752 to 6,020 feet depth, stored at Oil and Gas Conservation Board, Calgary.

Sample Depth (feet)	Lithology	Thickness (feet)
	CARDIUM FORMATION	
5,752-5,815	Shale, silty	
5,815-5,823	Shale, silty, with some sand	8
5,823-5,842	Shale, dark grey, pyritic, alternating with grey, fine-grained, argillaceous, silty sandstone; pyritized rootlets; worm burrows	19
5,842-5,843	Conglomerate with dark grey, silty, pyritic, shaly matrix; well-rounded chert pebbles average 1.5 cm	1
5,843-5,860	Sandstone (arenite), light grey, medium- to fine-grained, well sorted, cross-stratified; interbedded dark grey, silty to sandy, pyritic shale and argillaceous siltstone; some chert pebbles; scour and fill structures very common; worm burrows; some contorted bedding	17
5,860-5,905	Shale, dark grey, silty, pyritic; few beds of grey, fine-grained sandstone; lenticular laminations; scour and fill structures; siderite; worm burrows	45
5,905-5,930	Silty shale	25
5,930-5,950	Shale, dark grey, silty; lenticles and laminae of sandstone, grey, fine-grained, silty, argillaceous, cross-laminated; pyritic nodules and plant fragments; siderite; worm burrows; contact with underlying beds is sharp	20
5,950-5,958	Conglomeratic sandstone and granule conglomerate; chert granules are well sorted and well rounded; plant fragments; grades into underlying beds	8
5,958-6,020	Shale, dark grey, pyritic, silty; stringers and laminations of siltstone; worm burrows at top; arenaceous fraction decreases with depth	62

Well 49. Champlin Wolf River 4-5-53-15

Location: lsd. 4, sec. 5, tp. 53, rge. 15W5
Elevation: 2,976 K.B.
Total depth: 8,147 feet
Completed: 21/7/66
Status: Abandoned
Summary log by R.N. Sinha of core and samples from 5,655 to 5,921 feet depth, stored at Oil and Gas Conservation Board, Calgary

Sample Depth (feet)	Lithology	Thickness (feet)
	CARDIUM FORMATION	
5,655-5,712	Shale, silty	57
5,712-5,750	Shale, silty, with laminae of fine sandstone	38
5,750-5,751	Shale, dark grey, silty; stringers of siltstone	1
5,751-5,752	Conglomerate with shale matrix; chert pebbles are well rounded and average 8 mm; shaly matrix is dark grey, hard, and pyritic	1
5,752-5,798	Shale, dark grey, hard, pyritic, silty; sandstone, grey, fine-grained, well-sorted, cross-stratified; siltstone, grey, argillaceous, scour and fill structures; nodules of pyrite; few chert granules; siderite; worm burrows	46
5,798-5,830	Shale, dark grey, silty, pyritic; laminae of very fine silt; plant fragments; rare worm burrows	32
5,830-5,921	Shale, dark grey, silty, pyritic; laminae of siltstone and sandstone, grey, argillaceous, very fine-grained; siderite; arenaceous fraction decreases with depth	91

APPENDIX II

Fossil Collections

The following microfossils in thin sections were identified by T.P. Chamney.
GSC loc. C-414. Cardium Formation, HB Edson 4-8-54-13 W5 at 6,297 feet.

Haplophragmoides sp.
Gaudryina sp.
Reophax sp.
?encrusting algal filaments
megaspores

Environment: restricted marine

GSC loc. C-415. Cardium Formation, HB Edson 4-8-54-13 W5 at 6,298 feet.

Reophax sp.
Miliammina sp.
?*Verneuilinoides* sp.
Bathysiphon sp.
Haplophragmoides cf. *H. crickmayi* Stelck and Wall
sponge spicules
megaspores and plant remains

Environment: restricted marine in close proximity to open marine.

GSC loc. C-416. Cardium Formation, HB Edson 4-8-54-13 W5 at 6,398 feet.

Globigerina sp.
Inoceramus sp. scattered prisms
gastropod fragments
ostracod fragments
megaspores and plant remains

Environment: marine with access to open water

GSC loc. C-417. Cardium Formation, HB Edson 10-3-54-17 W5 at 6,026 feet.

?*Verneuilinoides* sp.
megaspores and plant remains

Environment: non-marine to questionable restricted marine

GSC loc. C-418. Cardium Formation, HB Edson 10-3-54-17 W5 at 6,027 feet.

Trochammina sp.
sponge spicules
megaspores

Environment: restricted marine

GSC loc. 419. Cardium Formation, HB Edson 10-3-54-17 W5 at 6,036 feet.

Bathysiphon sp.
Reophax sp.
Bone fragments ?fish
plant remains

Environment: restricted marine

GSC loc. C-420. Cardium Formation, HB Edson 10-3-54-17 W5 at 6,039 feet.

Reophax sp.
holothuroidean sclerite
plant remains and magaspores
Environment: very restricted marine

GSC loc. C-421. Cardium Formation, HB Edson 10-3-54-17 W5 at 6,041 feet.

?Saccammina sp.
ostracods
algal encrustations
bone ?fish remains
plant remains
Environment: very restricted marine to brackish

GSC loc. C-422. Cardium Formation, HB Edson 10-3-54-17 W5 at 6,046 feet.

Ostracods
Environments: brackish to fresh water

GSC loc. C-423. Cardium Formation, Champlin et al. Edson 10-26-53-17 W5 at 6,110 feet.

Altered pelecypod shell fragments

GSC loc. C-424A. Cardium Formation, Champlin et al. Edson 10-26-53-17 W5 at 5,761 feet

Haplophragmoides sp.
sponge ?axon
sponge spicules
algal encrustations
megaspores (?Triletes sp.)
Environment: restricted marine, very quiet waters

The following invertebrate fossils were identified by J.A. Jeletzky.

GSC loc. 82033. Cardium Formation, HB Edson 4-8-54-18 W5 at 6,285 feet

Actinocamax n. sp.
Scaphites ex gr. S. impendicostatus-preventricosus Cobban
Inoceramus cf. I. deformis Meek
Age: Referable to some part of the Scaphites preventricosus and Inoceramus deformis zone, believed to be of latest Turonian age.

GSC loc. 82228. Cardium Formation, HB Triad Edson 6-21-52-17 W5 at 6,416 feet.

Indeterminate true belemnite
Age: Jurassic or Cretaceous

GSC loc. 82229. Cardium Formation, HB Triad Edson 6-21-52-17 W5 at 6,359 feet.

Inoceramus sp. indet
Age: Jurassic or Cretaceous

GSC loc. 82230. Cardium Formation, HB Triad Edson 6-21-52-17 W5 at 6,404 feet.

Inoceramus cf. *labiatus* var. *latus* Mantell
Age: Presumably represents either *Ostrea lugubris* or *Scaphites preventricosus* and *Inoceramus deformis* zone of Upper Turonian age but cannot be dated definitively because of poor preservation.

GSC loc. 82231. Cardium Formation, HB Triad Edson 6-21-52-17 W5 at 6,359 feet.

Inoceramus sp. indet.
Modiolus (s. lato) sp. indet.
Age: Jurassic or Cretaceous

PLATES I - VIII

PLATE I

Sedimentary Structures

1. Worm burrows in light grey arenite. The dark grey bed at bottom is silty shale. Champlin _et al_. Edson 12-8-53-16 (well 40), at 5,925 feet.

2. Worm burrows and the extent to which they have obscured bedding. Champlin _et al_. Edson 12-8-53-16 (well 40), at 5,925 feet.

3. Worm burrow in dark grey, silty shale. Champlin _et al_. Edson 12-8-53-16 (well 40), at 5,948 feet.

4. Reverse graded bedding in conglomerate with shale matrix. Note imbrication in pebbles. Champlin _et al_. Edson R 12-10-54-17 (well 10), at 5,888 feet.

5. Reverse graded bedding in conglomerate with shale matrix. HB Edson 4-8-54-18 (well 9), at 6,313 feet.

6. Reverse graded bedding in conglomerate with sand matrix. The dark grey masses in the second and third (from top) core pieces are of secondary siderite. Champlin _et al_. Edson R 12-10-54-17 (well 10), 5,939 feet.

7. Reverse graded bedding and secondary siderite in conglomerate with sand matrix. Champlin _et al_. Edson 12-8-53-16 (well 37), at 5,982 feet.

8. Reverse graded bedding in conglomerate with sand matrix. HB Edson 4-8-54-18 (well 9), at 6,392.5 feet.

9. Reverse graded bedding in conglomerate with sand matrix. Champlin _et al_. Edson 12-8-53-16 (well 37), at 5,984 feet.

10. Laminated arenite occurring between shale with pebbles. The contact between arenite and overlying shale is erosional. Champlin _et al_. Edson 12-19-53-16 (well 30), at 5,855 feet.

11. Conglomerate with shale matrix, showing reverse graded bedding. The contact between the conglomerate and arenite is erosional. Fina Edson 2-25-53-17 (well 22), at 5,879 feet.

12. Alternating shale - arenite sequence with worm burrows. The shale has an erosional contact with the arenite. Fina Edson 4-25-53-17 (well 21), at 5,937 feet.

13. Shale with a few thin arenite bands. The contact of shale and arenite appears erosional. HB Edson 4-8-54-18 (well 9), at 6,324 feet.

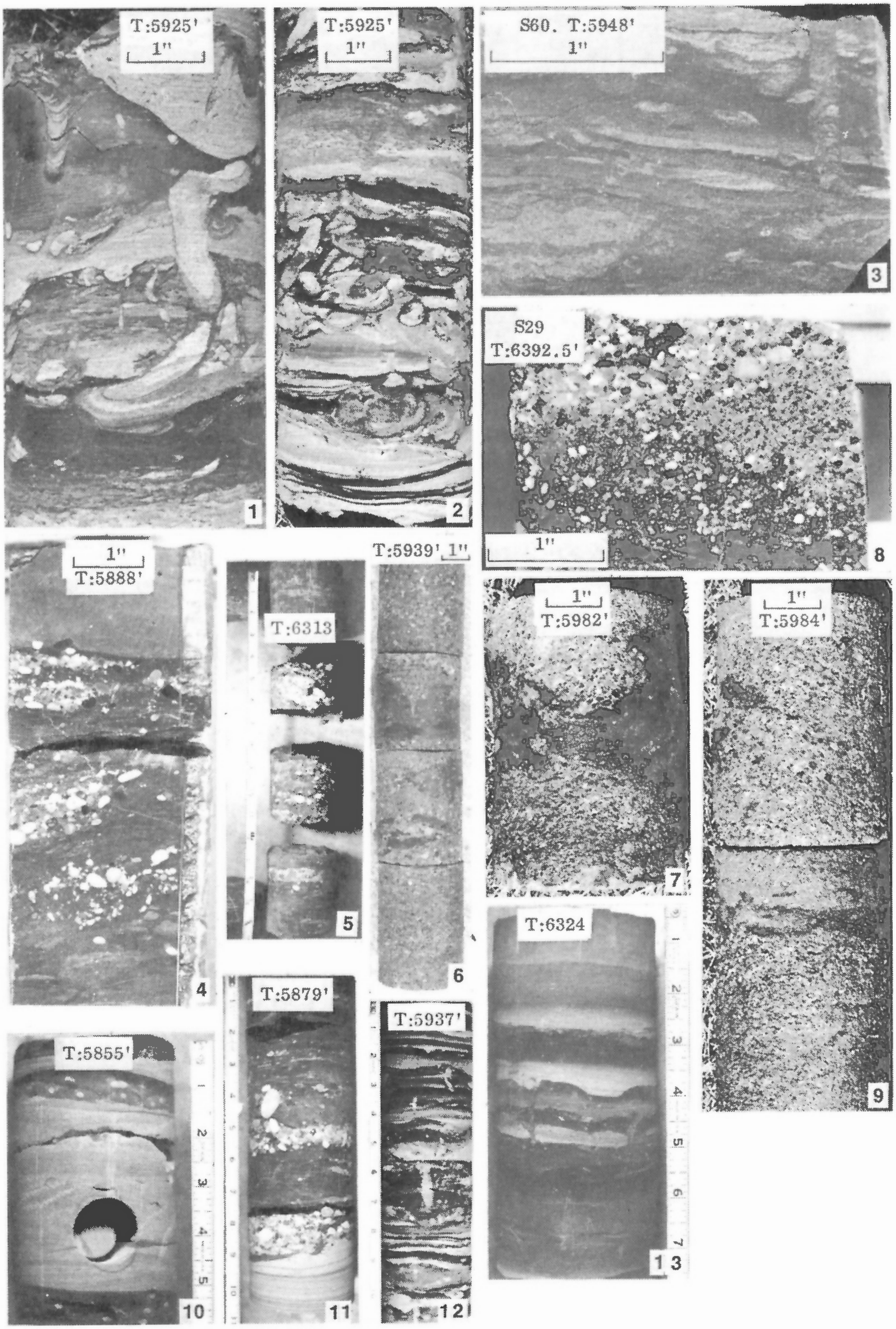

T:5925' 1"
1
T:5925' 1"
2
S60. T:5948' 1"
3
1" T:5888'
4
T:6313
5
T:5939' 1"
6
1" T:5982'
7
S29 T:6392.5'
1"
8
1" T:5984'
9
T:5855'
10
T:5879'
11
T:5937'
12
T:6324
13

PLATE II

Sedimentary Structures

1. Dark grey hard and pyritic shale containing pyritized sea weeds ? or roots ? HB Edson 6-21-52-17 (well 58), at 6,400 feet.

2. Cross-stratified arenite grading to silty shale. Fina Edson 4-25-53-17 (well 21), at 5,958 feet.

3. Cross-stratified arenite containing thin, hard shale. HB Edson 4-8-54-18 (well 9), at 6,318 feet.

4. Dark grey hard pyritic shale containing lustrous slickensided surfaces. HB Edson 6-21-52-17 (well 58), at 6,363 feet.

5. Alternating shale and arenite with lenticular laminations. Arenite dykes cut across the shale. Fina Edson 2-25-53-17 (well 22), at 5,865 feet.

6. Shale containing lenticular laminations of light coloured arenite. Champlin Wolf Creek R 4-5-53-15 (well 49), at 5,755 feet.

7. Composite set of cross-stratified arenites in silty shale. Burrows have obscured bedding at top and bottom. Arenites display disturbed bedding. HB Edson 4-8-54-18 (well 9), at 6,412.5 feet.

8. Local steep cross-beds in arenite. Shell Horner 7-30-53-15 (well 23), at 5,773.5 feet.

9. Dark grey pyritic shale showing vertical fractures possibly due to compression during compaction. Shell Wolf Creek A 7-12-53-15 (well 43), at 5,686 feet.

10. Thin-bedded and micaceous arenite showing scour and fill structure. Champlin Wolf Creek R 4-5-53-15 (well 49), at 5,763.5 feet.

11. Arenite squeezed into shale by compaction. Champlin _et al_. Edson 12-19-53-16 (well 30), at 5,857 feet.

12. Contorted beds of arenite and silty shale. Champlin _et al_. Edson 12-8-53-16 (well 40), at 5,935 feet.

PLATE II

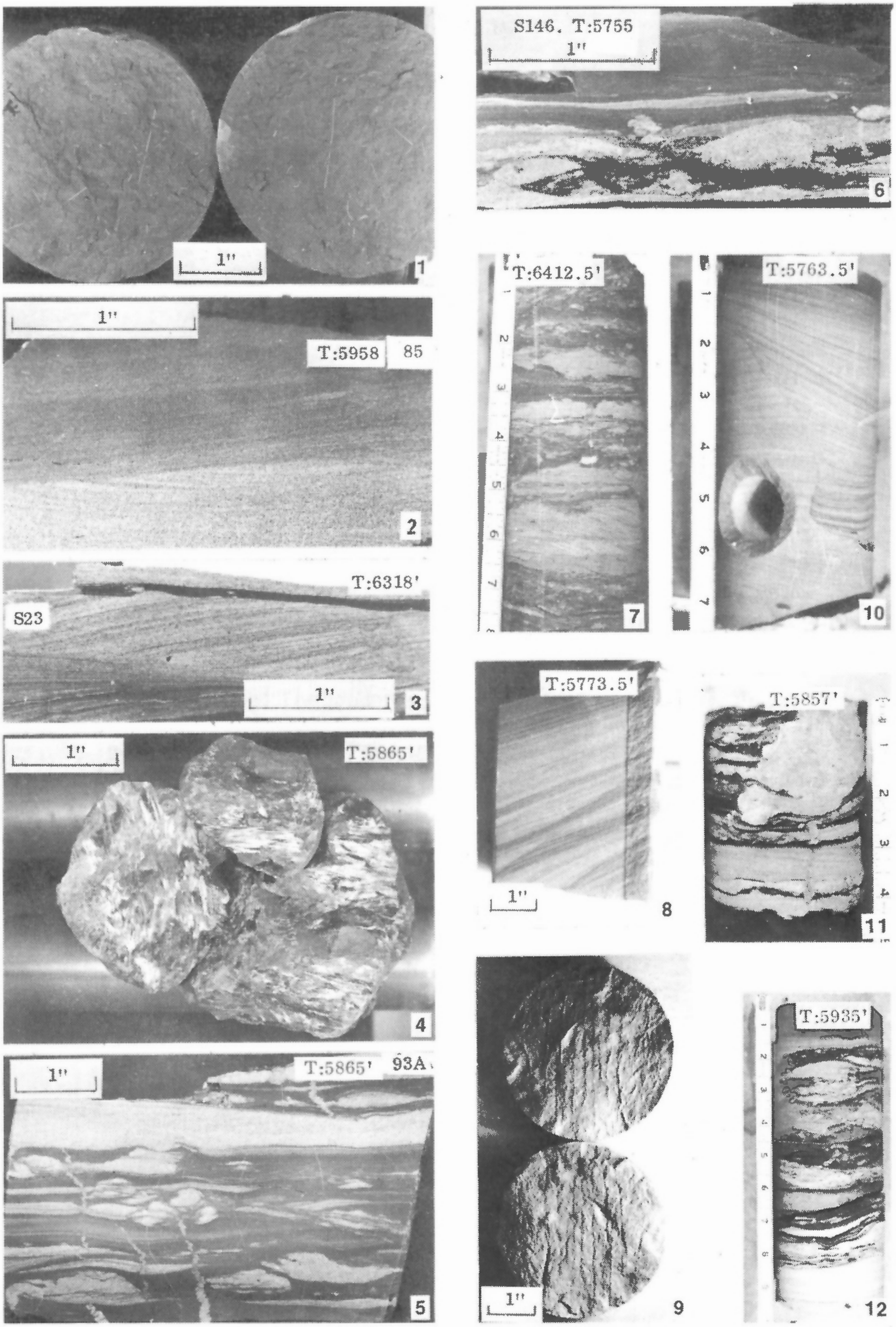

1"
1
1"
T:5958
85
2
T:6318'
S23
1"
3
1"
T:5865'
4
1"
T:5865'
93A
5
S146. T:5755
1"
6
T:6412.5'
7
T:5763.5'
10
T:5773.5'
1"
8
T:5857'
11
1"
9
T:5935'
12

PLATE III

Sedimentary Features

1. Granule conglomerate. Champlin et al. Edson R 12-10-54-17 (well 10), at 5,938 feet.

2. Dark grey irregular patches of siderite. Note the incorporation of granules in the siderite mass in the lower middle portion. Champlin et al. Edson R 12-10-54-17 (well 10), at 5,938 feet.

3. Sideritic replacement of granule conglomerate. Champlin et al. Edson R 12-10-54-17 (well 10), at 5,938 feet.

4. Secondary siderite criss-crossed by secondary calcite along major cracks. Hamilton Edson 10-29-52-18 (well 55), at 6,880 feet.

5. Pyrite nodule in dark grey, argillaceous siltstone. Note the preservation of original sedimentary features within the nodule. Champlin et al. Edson 12-19-53-16 (well 30), at 5,940 feet.

6. Modiolus (s. lato) sp. indet. HB Triad Edson 6-21-52-17 (well 58), at 6,359 feet.

7. Inoceramus sp. indet. HB Triad Edson 6-21-52-17 (well 58), at 6,359 feet.

8. Inoceramus cf. I. labiatus var. latus Mantell. HB Triad Edson 6-21-52-17 (well 58), at 6,404 feet

9. Indeterminate true Belemnite (poor fragment). HB Triad Edson 6-21-52-17 (well 58), at 6,414 feet.

10. Actinocamax n. sp. HB Edson 4-8-54-18 (well 9), at 6,285 feet.

PLATE III

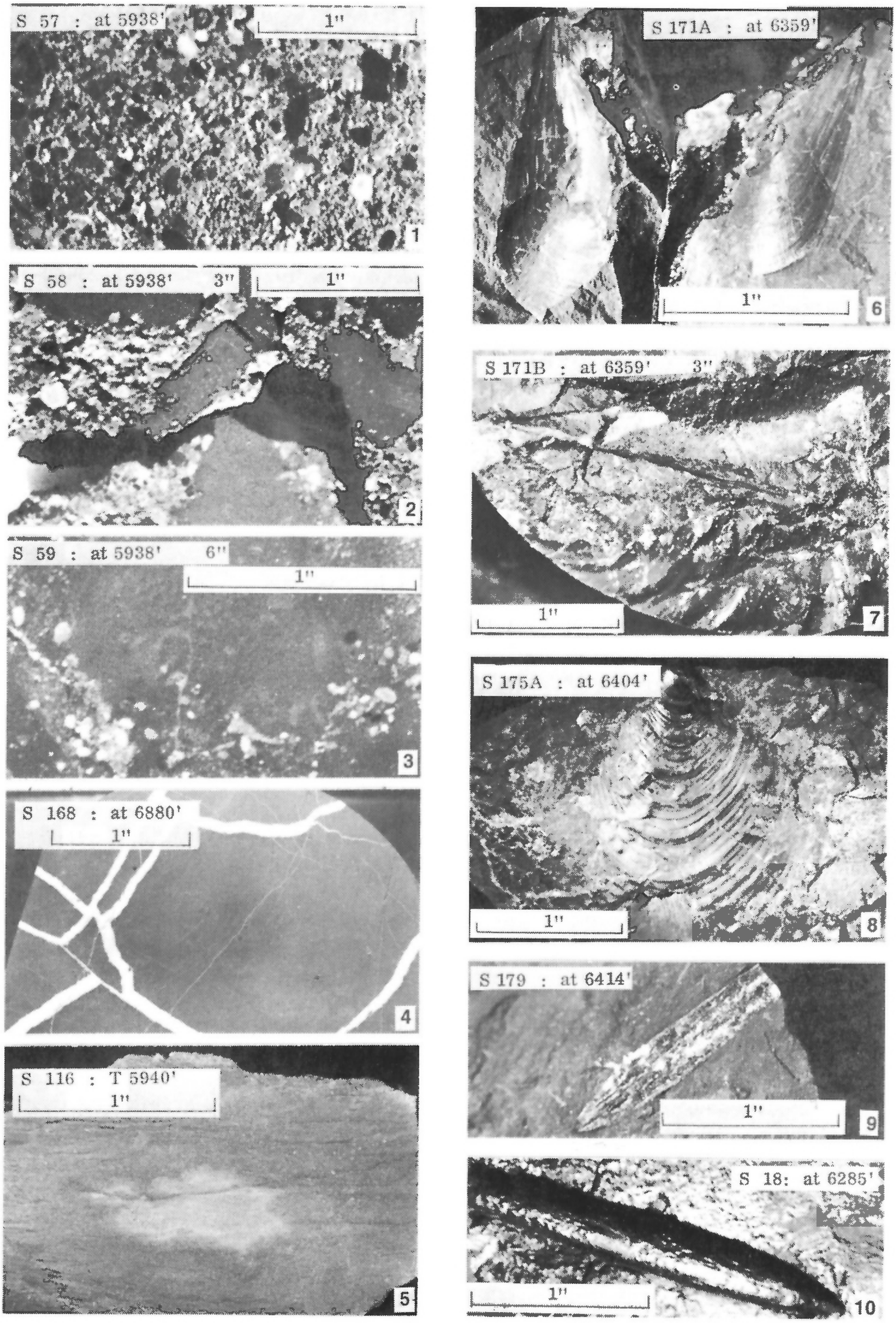

S 57 : at 5938'
1"
1
S 58 : at 5938' 3"
1"
2
S 59 : at 5938' 6"
1"
3
S 168 : at 6880'
1"
4
S 116 : T 5940'
1"
5
S 171A : at 6359'
1"
6
S 171B : at 6359' 3"
1"
7
S 175A : at 6404'
1"
8
S 179 : at 6414'
1"
9
S 18: at 6285'
1"
10

PLATE IV

Photomicrographs

1. Pyrite nodule in dark grey silty shale. Primary sedimentary structures are preserved within the nodule. A worm burrow replaced by pyrite may be seen on right. HB Edson 4-8-54-18 (well 9), at 6,387 feet.

2. Erosional contact between conglomerate and arenite. Fina Edson 2-25-53-17 (well 22), at 5,848 feet.

3. Pyrite nodule in dark grey silty shale. Primary sedimentary structures may be seen in and outside the nodule. Champlin et al. Edson 12-19-53-16 (well 30), at 5,940 feet.

4. Dark grey shale showing alignment of diagenetic micaceous clay minerals. Traces of silt may be seen. Crossed nicols. Champlin et al. Edson 10-26-53-17 (well 19), at 6,100 feet.

5. Dark grey shale containing broken shell of Inoceramus. Arrows mark the diagenetic pyrite replacing the shell material. Crossed nicols. HB Edson 6-21-52-17 (well 58), at 6,416 feet.

6. Dark grey silty shale with diagenetic pyrite. Crossed nicols. HB Edson 6-21-52-17 (well 58), at 6,434 feet.

7. Dark grey shale containing a foraminifer (Trochammina sp.). Crossed nicols. HB Edson 10-3-54-17 (well 13), at 6,027 feet.

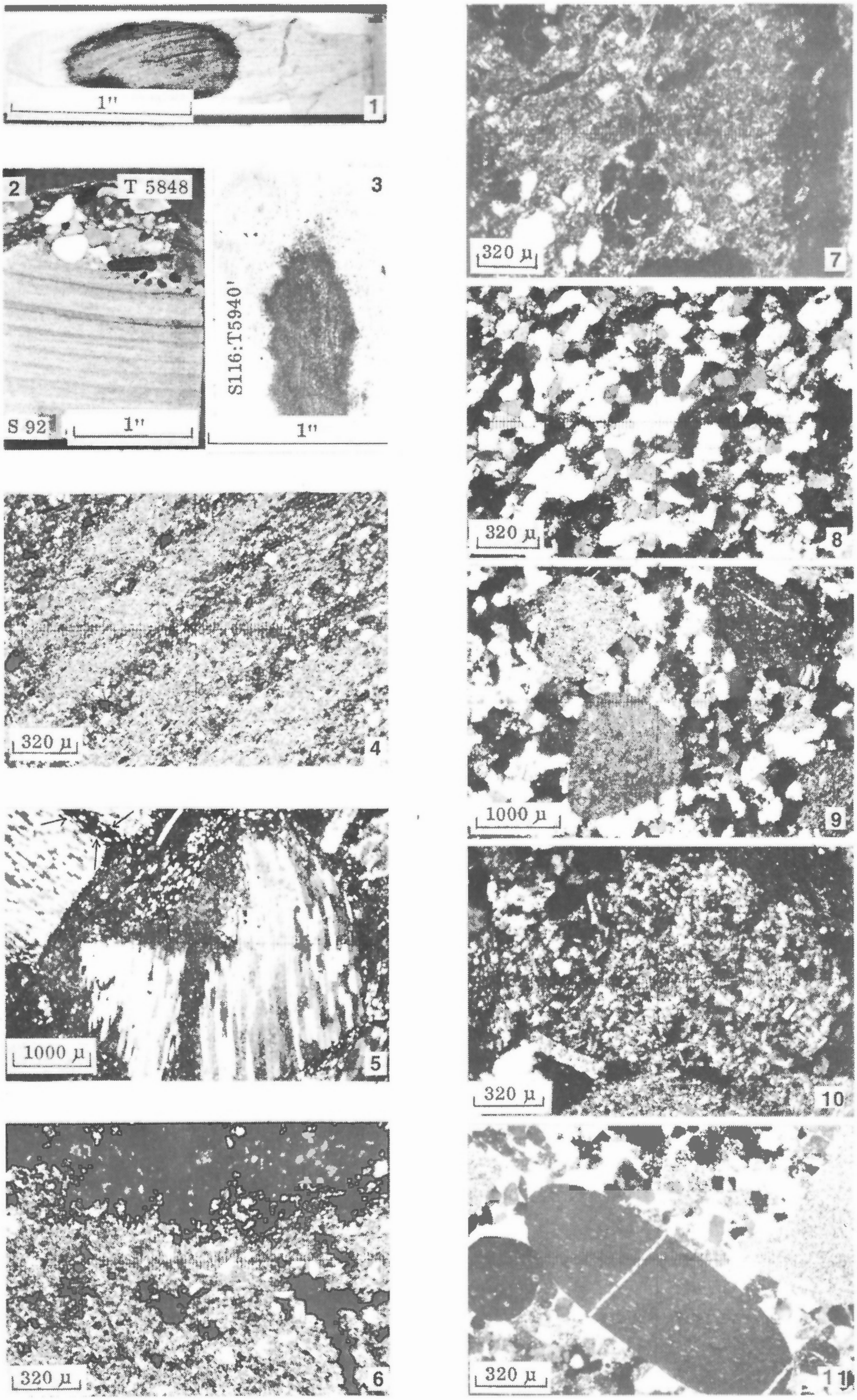
8. Fine-grained arenite. Most of the contacts are concavo-convex. Crossed nicols. Champlin Wolf Creek R 4-5-53-15 (well 49) at 5,768 feet.

9. Bimodal arenite containing pebbles of chert. Note the difference in roundness of chert pebbles and detrital grains. Crossed nicols. HB Edson 10-3-54-17 (well 13), at 6,046.5 feet.

10. Silicified organic remains in one of the chert pebbles. Crossed nicols. HB Edson 10-3-54-17 (well 13), at 6,046.5 feet.

11. Argillite pebble (containing two siliceous veins) in bimodal arenite. Crossed nicols. HB Edson 4-8-54-18 (well 9), at 6,392 feet.

PLATE IV



1"
1
2
T 5848
S 92
1"
3
S116:T5940'
1"
320 µ
4
1000 µ
5
320 µ
6
320 µ
7
320 µ
8
1000 µ
9
320 µ
10
320 µ
11

PLATE V

Photomicrographs

1. Foram (Haplophragmoides sp.), in fine-grained, silty arenite, filled in by diagenetic pyrite. Polarized light. HB Edson 10-3-54-17 (well 13), at 6,026 feet.

2. Conglomerate with shale matrix. The pebbles are of chert and display point and floating contacts. The pebble in the lower right corner is of ferruginous chert. Crossed nicols. Champlin et al. Edson 2-18-53-16 (well 38), 6,010 feet.

3. Microstylolitic contact between an orthoquartzite and chert pebbles in conglomerate with shale matrix. The contact contains ferruginous clay (marked by arrows). Polarized light. Hamilton Edson 10-29-52-18 (well 55), at 6,884 feet.

4. Conglomerate with shale matrix. Cementation of pebbles is by thin films (marked by arrows) of clay minerals. Crossed nicols. Home Mobil Malloch 10-34-52-15 (well 54), at 5,761 feet.

5. Conglomerate with shale matrix. The pebbles display floating contacts and the micaceous clay minerals of the matrix are aligned in accordance with their detrital outline as shown by arrows. Crossed nicols. Home Mobil Malloch 10-34-52-15 (well 54), at 5,761 feet.

6. Faulted veins of secondary silica in a ferruginous chert pebble. Home Mobil Malloch 10-34-52-15 (well 54), at 5,761 feet.

7. Silicified organic remains in a chert pebble. Crossed nicols. Champlin et al. Edson 12-24-53-17 (well 27), at 6,020 feet.

8. Agate pebble in conglomerate. Matrix is silty. Crossed nicols. Champlin Wolf Creek R 4-5-53-15 (well 49), at 5,752 feet.

9. Granule conglomerate with chert (CH) pebbles and some sand matrix. Quartz grains show authigenic growths (arrows). Note the intergranular void space (v). Polarized light. Champlin et al. Edson 12-25-53-17 (well 20), at 6,024 feet.

10. Granule conglomerate showing replacement of chert pebbles (CH) at periphery and along cracks (arrows) by siderite (s). Crossed nicols. HB Edson 4-8-54-18 (well 9), at 6,396 feet.

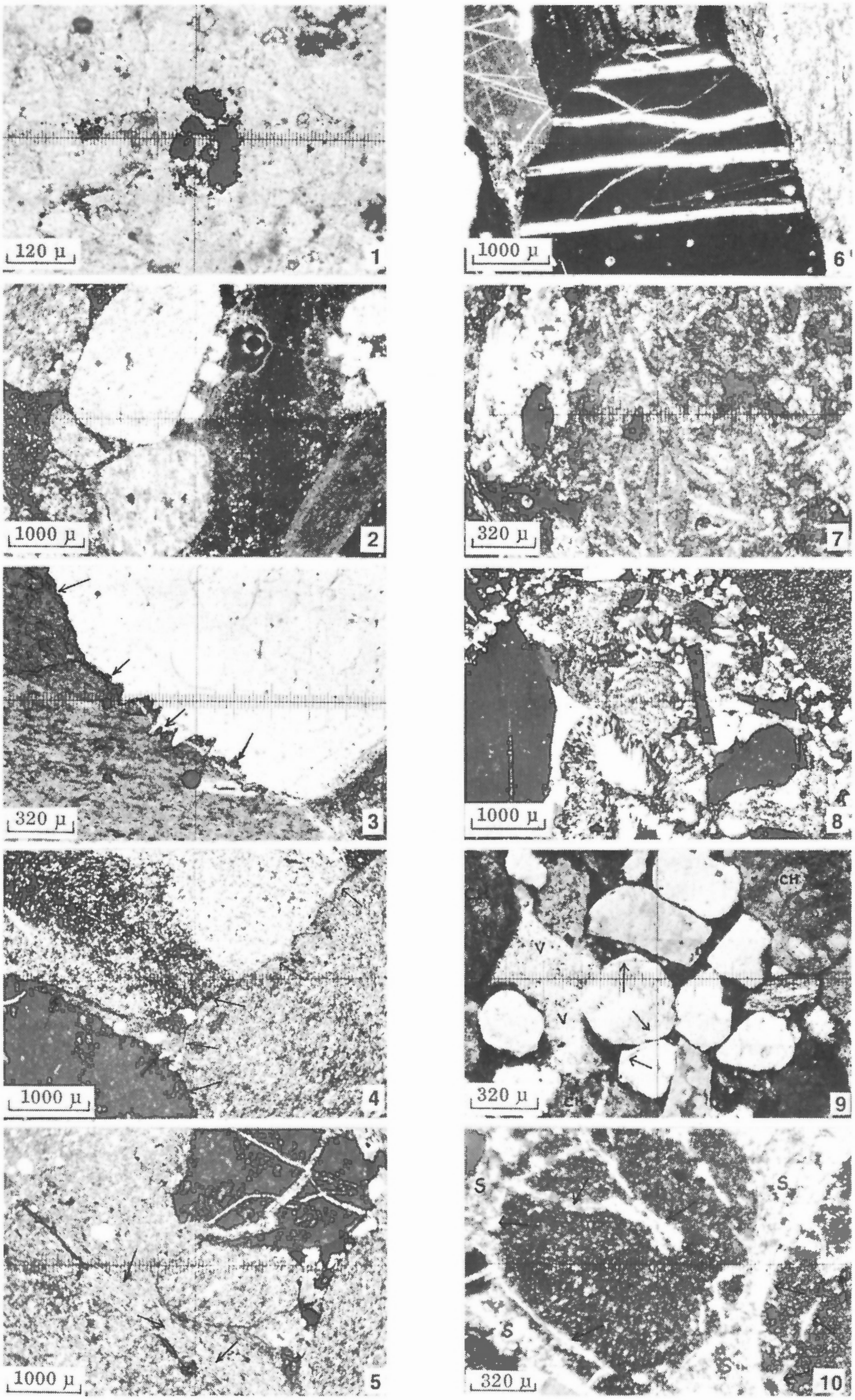

120 μ
1
1000 μ
2
320 μ
3
1000 μ
4
1000 μ
5
1000 μ
6
320 μ
7
1000 μ
8
CH
V
V
320 μ
9
S
S
S
S
320 μ
10

PLATE VI

Photomicrographs

1. Peripheral replacement of a chert granule (CH) by siderite (s). The replacement is not complete. Crossed nicols. Champlin et al. Edson R 12-10-54-17 (well 10), at 5,938 feet.

2. Replacement of a chert granule (CH) by siderite (s). The replacement is almost complete. Siderite fills in the intergranular spaces and acts as cement. Crossed nicols. HB Edson 10-3-54-17 (well 13), at 6,043 feet.

3. Granule conglomerate showing a chert pebble completely replaced by siderite. The fringes are darker due to decrease in crystallinity of siderite. Crossed nicols. Champlin et al. Edson 10-5-53-16 (well 47), at 6,110 feet.

4. Plant fragment completely replaced by siderite in a granule conglomerate. The original structure is preserved. Crossed nicols. Champlin et al. Edson R 12-10-54-17 (well 10), at 5,938 feet.

5. Plant fragment in a granule conglomerate, first replaced by siderite which in turn is partly replaced by pyrite (black patches). Crossed nicols. HB Edson 10-3-54-17 (well 13), at 6,041 feet.

6. Replacement of a chert granule containing silicified organic remains. The organic remains retain most of their original structure though replaced by siderite. Crossed nicols. HB Edson 10-3-54-17 (well 13), at 6,043 feet.

7. Development of siderite rims (arrows) around granules and other detrital grains. Some of the granules are wholly replaced by siderite (s) which also fills the intergranular spaces and acts as cement. Crossed nicols. HB Edson 10-3-54-17 (well 13), at 6,041 feet.

8. Arenite dyke cutting across shale mass. Polarized light. Fina Edson 2-25-53-17 (well 22), at 5,865 feet.

9. Arenite containing quartz grains with authigenic growths. Dust rings (marked by arrows) are incomplete and show floating contacts. Crossed nicols. HB Edson 4-17-54-18 (well 3), at 6,354 feet.

10. Arenite containing a quartz grain showing authigenic growths. The dust ring is almost complete and indicates the original roundness of the quartz grain. Crossed nicols. HB Edson 10-3-54-17 (well 13), at 6,046 feet.

PLATE VI

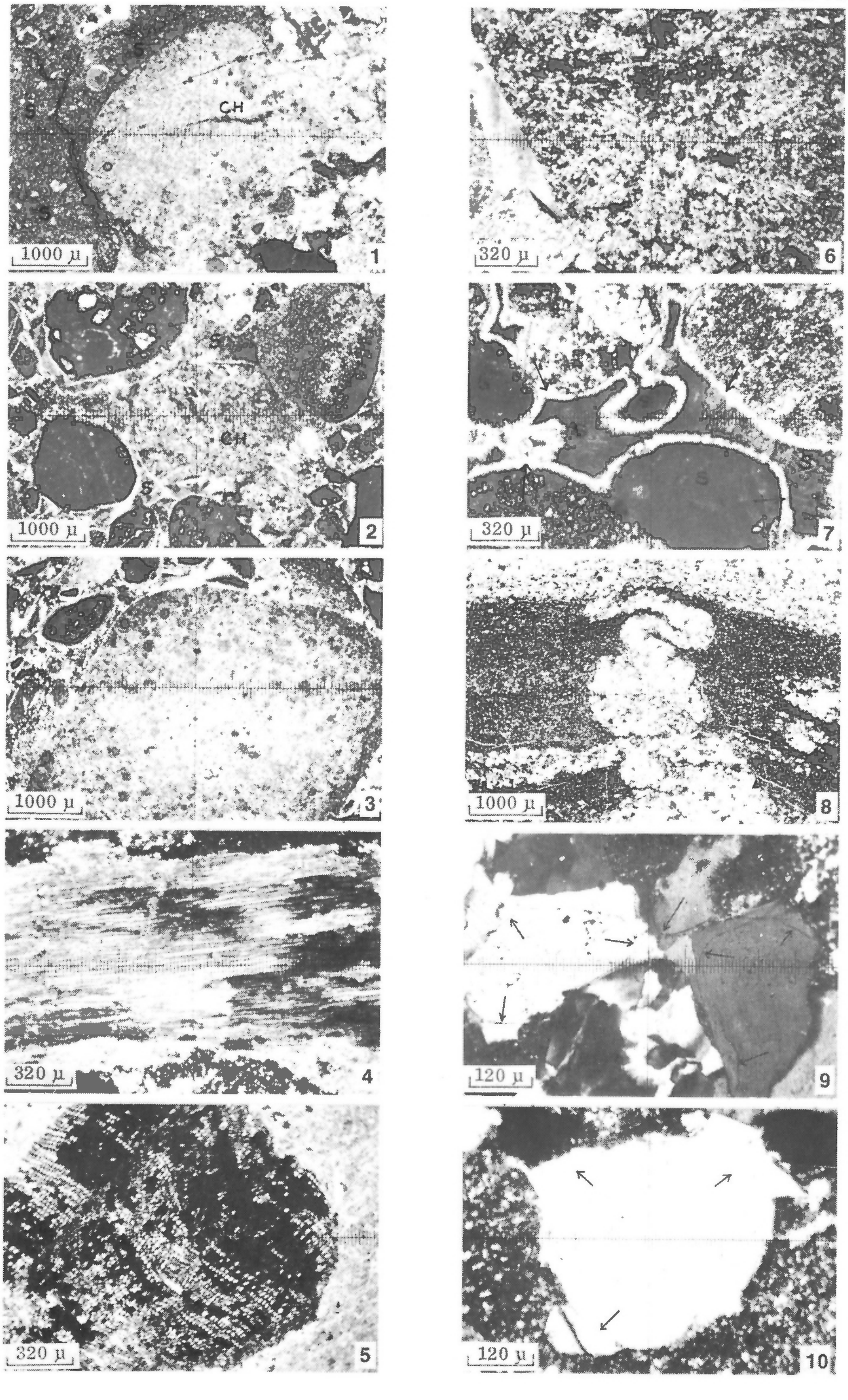

S
CH
1000 μ
1
320 μ
6
S
CH
1000 μ
2
S
320 μ
7
1000 μ
3
1000 μ
8
320 μ
4
120 μ
9
320 μ
5
120 μ
10

PLATE VII

Photomicrographs

1. Conglomerate with shale matrix (M). Chert pebble (CH) penetrated by smaller chert and quartz grains as shown by arrows. The contact between them is defined by a film of clay minerals. Crossed nicols. Home Mobil Malloch 10-34-52-15 (well 54), at 5,761 feet.

2. Grain of strained quartz penetrated by smaller quartz grains as indicated by arrows. Crossed nicols. HB Edson 10-3-54-17 (well 13), at 6,046 feet.

3. Biomodal arenite containing poikilitic carbonate. Note the floating contacts and angularity of grains. Crossed nicols. HB Edson 4-8-54-18 (well 9), at 6,392 feet.

4. Granule conglomerate containing poikilitic carbonate (c). Crossed nicols. HB Edson 4-8-54-18 (well 9), at 6,392.5 feet.

5. Fine-grained arenite displaying poikilitic carbonate. The entire carbonate mass occurring between grains has the same optical orientation. Crossed nicols. Fina Edson 2-25-53-17 (well 22), at 5,848 feet.

6. Fine-grained arenite containing poikilitic carbonate. Note reaction rims marked by arrows. Crossed nicols. Fina Edson 2-25-53-17 (well 22), at 5,848 feet.

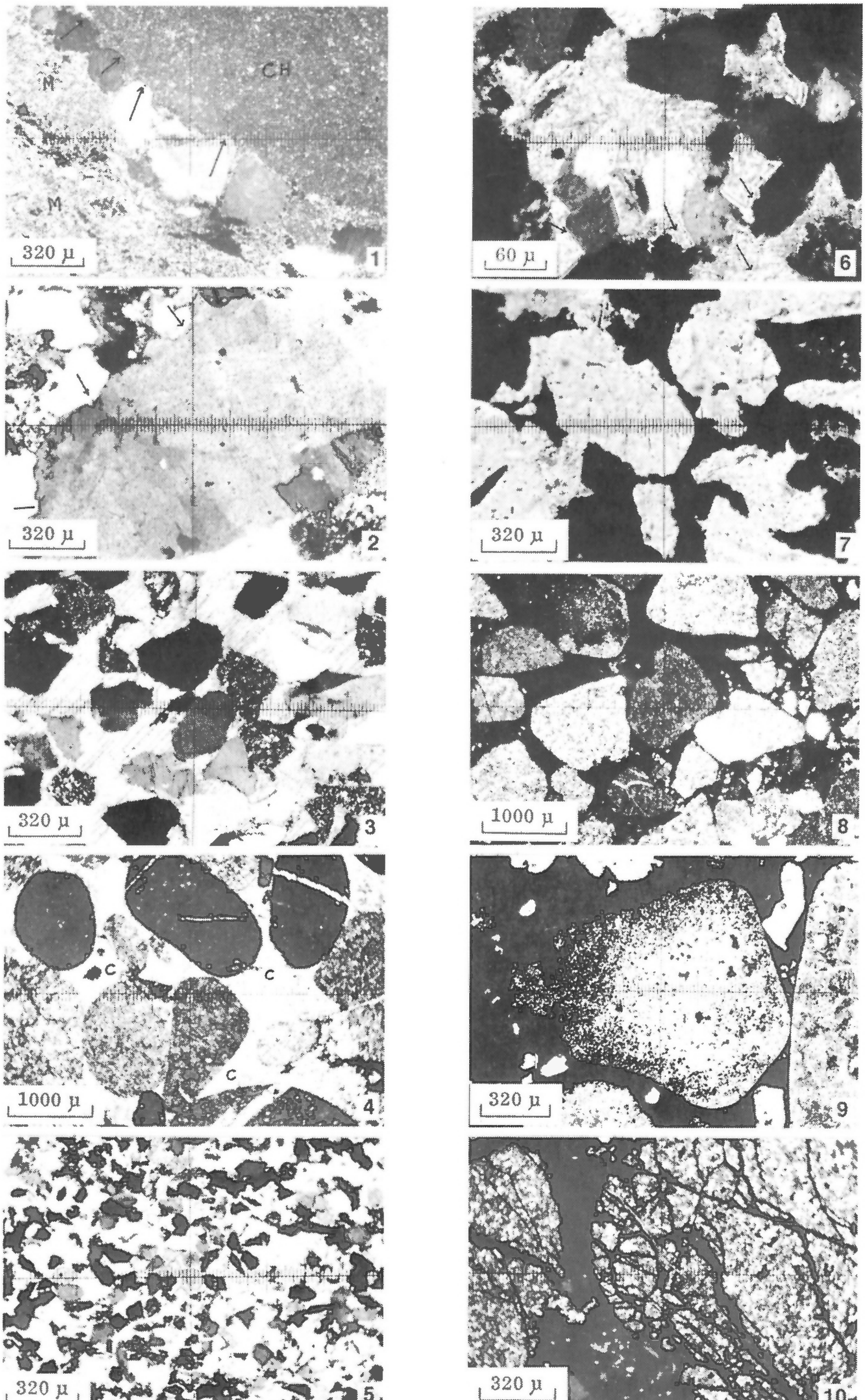
7. Pyrite cement in coarse-grained arenite. Note the angularity of grains owing to dissolution and replacement by pyrite. Polarized light. HB Edson 4-17-54-18 (well 3), at 6,375 feet.

8. Pyrite cement in granule-conglomerate. A few granules show replacement by pyrite. Polarized light. HB Edson 4-17-54-18 (well 3), at 6,353 feet

9. Replacement of a chert granule by pyrite in granule-conglomerate. The replacement is partial and peripheral. Polarized light. HB Edson 4-17-54-18 (well 3) at 6,353 feet.

10. Replacement of a chert granule along cracks and fractures. Crossed nicols. Champlin _et al_. 12-25-53-17 (well 20), at, 6,024 feet.

PLATE VII



M
CH
M
320 μ
1
60 μ
6
320 μ
2
320 μ
7
320 μ
3
1000 μ
8
C
C
C
1000 μ
4
320 μ
9
320 μ
5
320 μ
10

PLATE VIII

Photomicrographs

1. Spherulitic siderite, with typical 'iron cross' extinction, occurring at fringes of a chert granule in granule-conglomerate. Crossed nicols. Champlin et al. Edson R 12-10-54-17 (well 10), at 5,938 feet.

2. An oolite of siderite in granule conglomerate. Crossed nicols. HB Edson 10-3-54-17 (well 13), at 6,039.5 feet.

3. Floating contacts among chert and quartzite granules occurring in siderite. Crossed nicols. HB Edson 4-8-54-18 (well 9), at 6,396 feet.

4. Partial replacement of a chert granule by siderite. Most grains seem to have been completely replaced. Crossed nicols. HB Edson 4-8-54-18 (well 9), at 6,398 feet.

5. Broken Inoceramus shell in siderite. Pyrite (shown by arrows) replaces the shell. Crossed nicols. HB Edson 6-21-52-17 (well 58), at 6,405 feet.

6. A calcite vein in siderite. Note the transverse orientation of calcite crystals at the edges of the vein. Crossed nicols. Hamilton Edson 10-29-52-18 (well 55).

65

PLATE VIII