PETROLEUM GEOLOGY OF NEPAL

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ABSTRACT

Magnetic, gravity and seismic surveys, extensive geological field mapping programs, structural and stratigraphic studies and petroleum geochemical investigations have been carried out in the Terai plains and the adjacent Siwalik Fold Belt of southern Nepal since the late 1970s. This work, which has been recently incorporated into a comprehensive evaluation, suggests that the country has attractive petroleum possibilities. Rocks with significant source potential have been sampled from outcrops, and thermal modeling suggests that, in the prospective part of Nepal, these potential source rocks are in the oil and gas generation window. Effective reservoir rocks are expected to be found in the Lower Siwalik, Sarkhet and Gondwana sandstones and in the carbonates of the Lakharpata Vindhyan Group.

Exploration opportunities in the Terai include structures associated with blind thrusts, basement-controlled drape and fault structures, stratigraphic pinch-outs and subcrop traps. Major folds and thrusts in the Siwalik Fold Belt are likely to provide structural traps. Drilling depths to objectives are from 3500 to 5000 metres in the Terai and from 2500 to 4000 metres in the Siwalik Fold Belt.

1.0 INTRODUCTION

This paper is based on the recently completed Nepal Source and Seal Study conducted by Alconsult International Ltd. (AIL) and the Nepal Petroleum Exploration Promotion Project/Department of Mines and Geology (PEPP/DMG) HMG of Nepal (Slind, 1993). Geochemical sample collecting, laboratory analysis, interpretation and modelling was conducted by the Geochemistry Section of the Institute of Sedimentary and Petroleum Geology (ISPG) of the Geological Survey of Canada. The study operated under the overall direction of Petro-Canada International Management Services (PCIMS) for the Canadian International Development Agency.

2.0 OBJECTIVE STUDY

The main objective of the study was to better understand the petroleum geology of Nepal and to define its oil and gas potential by combining existing data with new information acquired during the course of the study.

3.0 PROCEDURE

The project was a team effort consisting of Alconsult professionals in the fields of geology, geophysics (seismic, gravity), sedimentology, petrography and photogeology along with petroleum geochemists from the Geological Survey of Canada and geologists from the Petroleum Exploration Promotion Project of Nepal. The work done by the team consisted of: a) reviewing all petroleum-related information on Nepal and environs; b) collecting and analyzing oil and gas seep samples; c) conducting field traverses throughout southern Nepal to collect samples for geochemical and petrographic analyses; d) field mapping (structure) in selected critical areas; e) studying the sedimentology of potential reservoir rocks; and f) reviewing and interpreting all the existing Nepal geophysical data.

4.0 DATA BASE

The data base included all previous work in which the PEPP/DMG was involved. This data included: a) more than 10 years of geological field mapping (Schroeder, 1981; Shrestha and Shrestha, 1983); b) a regional aeromagnetic survey (CGG, 1980); c) a photogeological study (Hunting Geology and Geophysics Ltd., 1984); d) results of several geochemical investigations (Kayastha, 1989); e) information from the Shell Biratnagar 1 well; and f) basic field data and interpretations from four geophysical surveys: 1983-1984 World Bank/CGG 1250 km reflection seismic program (Harris, 1984), 1987-1988 PCIAC/Airborne 1651 km reflection seismic and gravity program (Friedenreich and Slind, 1989), 1988-1989 Shell Nepal 1940 km (615 km used in this interpretation) reflection seismic program, 1991-1993 French Government/CGG 422 km reflection seismic program.

5.0 GEOGRAPHICAL/GEOLoGICAL SETTING

The Kingdom of Nepal, an independent country lying between India to the south and China to the north (Figure 1), is 800 km long from east to west and ranges in width from

1Presented at the CSEG/CSPG Joint Convention, Calgary, Alberta, May 11, 1994. Manuscript received by the Editor October 17, 1994; revised manuscript received January 23, 1995.
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Thanks are given to Petro-Canada International Management Services, project managers for Canadian International Development Agency, and to the Petroleum Exploration Promotion Project of the Department of Mines and Geology of His Majesty's Government of Nepal for their assistance in preparing this paper.
130 to 230 km. The country is naturally separated into four major geographical/geological zones that parallel its long dimension (Frank and Fuchs, 1970; Mitchell, 1979; Stöcklin, 1980; Windley, 1983). Each zone has its own characteristic stratigraphy and structure and these zones are, from south to north, described below (Figures 2, 3).

5.1 Terai

The Terai is the Nepal portion of the Indo-Gangetic Plain that extends from the Indian Shield in the south to the Siwalik Fold Belt to the north. The Plain is a few hundred metres above sea level and is underlain by a thick, relatively flat-lying sequence of Mid to Late Tertiary molasse (Siwalik Group) which unconformably overlies subbasins of early Tertiary to Proterozoic sediments (Surkhet, Gondwana and Vindhyan Groups) and igneous and metamorphic rocks of the Indian Shield (Agrawal, 1977; Acharyya and Ray, 1982; Raiverman et al., 1983). The only deep well in Nepal (Shell Nepal B.V. Biratnagar 1, TD 3530 m in 1989) was drilled in the far eastern part of the Terai.

5.2 Siwalik Fold Belt

The Siwalik Fold Belt is from 5 to 45 km wide and rises abruptly from the Terai along the main frontal thrust (MFT). It consists of a series of ridges and valleys composed of thick beds of folded and fault-repeated Tertiary molasse (Siwalik Group) thrust to the south (Parkash et al., 1980; Herail et al., 1986). Gravity measurements and detailed field mapping indicate that the cores of at least some of these structures contain pre-Siwalik rocks that are considered to be hydrocarbon exploration objectives (Friedenreich and Slind, 1989; Ebner, 1989).

The Siwalik Fold Belt and the Terai are a part of the foreland of the Himalayas (Parkash et al., 1980). They have some similarities with the foothills and western plains of Alberta and British Columbia and are the main areas of petroleum interest in Nepal.

5.3 Lesser Himal

The Lesser Himal is a wide, stratigraphically and structurally complex zone that lies immediately north of the Siwalik Fold Belt and is separated from it by the south-verging main boundary fault (MBT). The majority of the Lesser Himal is composed of thrust sheets and nappes of metasediments and igneous rock of the Midland Super Group. The Group is of little hydrocarbon exploration interest, although the oil and gas seeps of the Dailekh area occur within the Midland Group (CPIT, 1973). These seeps are interpreted to have been generated in sediments below the nappes (Figure 2).

5.4 Higher Himal

The Higher Himal, which contains the spectacular peaks of the Great Himalayan Range, Everest, Annapurna, etc., is
thrust southward over the Lesser Himal by the main central thrust (MCT; Figures 1, 2). The zone is composed of a basal slab of metamorphic Proterozoic rocks overlain by a conformable sequence of Cambrian to Eocene Tethyan sediments (Bordet et al., 1981). Gas seeps occur in the upper Tethyan of northern central Nepal near the village of Muktinath (Figures 1, 2).

6.0 STRATIGRAPHY

The following discussion concentrates only on those rock units that have a direct bearing on hydrocarbon exploration (Figure 3).

**Vindhyan Super Group** — Vindhyan sediments, equivalent to those of the great Vindhyan Basin of Northern India, are interpreted to extend beneath the Terai and Siwalik Fold Belt. The Vindhyan is reported to have a maximum thickness of 5250 m (Agrawal, 1977; Srivastava et al., 1983) although at least 12 000 m of pre-Tertiary seismic reflections have been observed under the Terai. The Vindhyan, which is considered to be a major hydrocarbon exploration objective, consists of an unmetamorphosed sequence of stromatolitic limestone, shale and sandstone. Although dating is difficult, the Vindhyan is considered to be equivalent to at least a part of the Lakharpata Group of the Lesser Himal.

**Midland Super Group** — The Midland Super Group, which encompasses most of the rocks of the Lesser Himal, is not adequately dated, but is interpreted to be older than Carboniferous and to range well into the Precambrian (Frank and Fuchs, 1970; Stöcklin, 1980).

**Dailekh Group** — The Dailekh Group, the lower part of the Midland Super Group, is made up of phyllites, garnetiferous schists, feldspathic greywacke, volcanics and stromatolitic dolomites (Figures 2, 7). These rocks have been raised to the low green schist facies in the centre of the Midlands and the metamorphic grade increases in successive thrust sheets to the north (Mitchell, 1979; Bordet et al., 1981). The rocks of the Dailekh Group are not considered to be exploration objectives.

**Lakharpata Group** — The Lakharpata Group occupies the upper part of the Midland Super Group and, although not firmly dated, is interpreted to be of Late Precambrian to Late Paleozoic ages (Stöcklin, 1980; Shrestha and Shrestha, 1983). It is unconformably overlain by frequently organic dark shales and sandstones of the Gondwana and Surkhet Groups. This Group and its Vindhyan equivalent are an important exploration objective.

The Group contains the following formations and members:

- **Sangram Fm**: Greenish grey to black splintery shale, containing zones of relatively rich organic intervals (up to 9% TOC); some shales being burned for fuel; major potential source rock;

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**Fig. 2. Schematic cross-section through central Nepal.**
Fig. 3. Stratigraphic zonations of central-southern Nepal.

Ramkot Fm. Pink to grey sandstone and purple to grey shale 850 m thick;

Gawar Fm. Limestone and dolomite with abundant stromatolites and algal mats and becomes more shaly and sandy upwards; reaches a maximum thickness of 1700 m and is considered an exploration objective;

Khara Fm. Dark grey, microcrystalline limestone and shale;

Katwa Fm. Dark grey to black shales with minor stromatolitic dolomite; a potential source rock;

Aru Fm. Dense dolomite with lesser amounts of sandstone and shale; restricted to south-central part of Nepal; a potential subcrop reservoir.

Gondwana Group (Late Carboniferous to Early Cretaceous) — The Gondwana is a group of rocks occurring in basins on the Indian Craton (unconformably below the base of the Siwalik Group of the Terai) and in the southern thrust sheets of the Lesser Himal. The thickness of the Group in eastern and central Nepal, which is quite variable, is approximately 1000 m in the ridges immediately above the MBT in central Nepal and is interpreted from seismic analysis to be at least that thick in the basins of the Terai (Bashyal, 1980; Sakai, 1985; Dutta et al., 1983). The Group is separated into two formations. The Sisne Formation unconformably overlies the Lakharpata Group and is composed of diamictite and shale and contains late Paleozoic marine fauna. The formation has a few intervals that contain up to 10% TOC and is considered an important potential source rock. The Taltung Formation disconformably overlies this Sisne and is comprised of conglomerate sandstone shale.

Gondwana sediments are considered an exploration objective in Nepal. They probably occur in small pockets beneath the base Siwaliks (Figures 8, 9) in the eastern Nepal Terai, possibly in the Gandak depression in the Birganj and Lumbini areas and could be caught up in smaller thrust slabs beneath the Siwalik Fold Belt and main boundary thrusts. Good reservoir rocks were not seen in outcrop but several organically rich intervals have been mapped. The lower coal-bearing Gondwana could be both a source and reservoir for gas and the marine Upper Gondwana may be a potential oil source rock.

Surkhet Group (Late Cretaceous to Early Miocene) — The Surkhet Group occurs in the southern, central and western part of the Lesser Himal where it unconformably overlies Lakharpata or Gondwana rocks. The Group attains a maximum thickness of 1200 m and is separated into the Melpani, Swat and Sunar Formations (Sakai, 1983). The Group is correlated with the oil and gas producing formations of the Assam and Potwar basins (Rangarao, 1983) and with the “Unnamed Formation” of Northern India (Schroeder, 1981) sediments.

The Swat Formation is composed mainly of shale that contains intervals with greater than 2% TOC and some of the
Melpani organic shales have 20% TOC. In the Dang Valley, the porosity of a distinct Melpani sandstone is filled with solid hydrocarbon (Slind, 1993).

Siwalik Group (Late Miocene to Pliocene) — The Siwalik Group is a thick section of fresh-water molasse, exposed in a series of fault slices that make up the Siwalik Fold Belt and lie beneath the alluvial deposits of the Terai (Delcaillau, 1986). The Group is up to 4500 m thick and is separated into three formations: Lower Siwalik (LS), Middle Siwalik (MS1 and MS2) and Upper Siwalik (US). The lower part of the Group is composed of fine-grained sandstones containing shale intervals (LS and MS1) and becomes coarser grained upwards (MS2 and US). Petroleum objectives are expected to be restricted to the lower part of the Group where there is an effective combination of potential sandstone reservoirs and shale seals.

7.0 GEOPHYSICS

Geophysical exploration methods, reflection seismic, gravity and magnetics, combined with surface mapping and basin analysis, have established the subsurface framework of southern Nepal. Seismic control in eastern Nepal is quite dense (approximately 2 km x 4 km). This area is characterized by many basement-controlled structures offsetting sediment-filled subbasins and grabens beneath the Siwalik molasse. The grid (10 km x 15 km) of reconnaissance seismic lines covering the balance of the Terai has identified several geological settings which have the potential for hydrocarbon prospects. These include structural traps related to normal faulting involving pre-Siwalik formations and thrusting involving the Siwaliks (Figure 4); subcrop traps involving pre-Siwalik sequences (Figure 5); and structural traps associated with blind folds in front of the Siwalik Fold Belt (Figures 6, 7). The locations of seismic lines shown in Figures 4, 5 and 6 are shown on Figure 8.

The base Siwalik seismic marker (Figures 4, 5, 6) is an important reflection in the Terai region. It represents an unconformity that separates the Siwaliks (mid-Miocene and younger) from older strata (Lower Miocene to Precambrian). Figures 8 and 9 represent structural maps of this marker in
the eastern and western Terai, respectively. The unconformity lies between 3500 and 4600 m below the Terai plain which is approximately 100 m above sea level (asl.). There is no dominant east-west gradient to the base Siwalik marker; however, the dipping of the marker toward the Siwalik Fold Belt is very apparent.

Nine seismic and gravity traverses cross the Siwalik Fold Belt and identify major folds and thrust faults that may contain substantial thicknesses of potentially prospective pre-Siwalik rocks. Line 89 (Figures 9, 10) crosses a large Siwalik fold and demonstrates good reflections on the flanks of the structure but there is no coherent data in the core. Gravity measurements along this line show a substantial 25 mgal anomaly above regional for the traverse. Model studies show (using densities derived by methods described by Gardner et al., 1974) that the anomaly is caused by higher density rocks being involved in the core of the structure. These model densities are comparable with those of the prospective pre-Siwalik (Lakharpata) dolomite (Figures 11, 12).

From the above, it is apparent that the gravity method may be very beneficial and cost-effective in concert with seismic surveys in delineating hydrocarbon prospects in the southern part of Nepal.

8.0 GEOCHEMISTRY

A considerable amount of geochemical work has now been completed on rocks from Nepal. The oil from the Dailekh seeps is interpreted to come from a conventional source rock beneath the nappes and rocks with source potential have been sampled from the Lakharpata, Gondwana and Surkhet Groups. Thermal modelling suggests that potential source rocks in the prospective part of Nepal are in the marginally mature-for-oil to late-in-the-gas generation window.

9.0 RESERVOIR

Studies of outcrop samples and analyses of Shell Biratnagar I indicate that effective reservoirs and seals are likely to be found in the Lower Siwalik, Surkhet and Gondwana sandstones and shales. Outcrop studies have not identified large areas of carbonate reservoir development in the Lakhpata/Vindhyan Group, although it is expected that the unconformity at the base of the Siwalik molasse will provide a large number of attractive carbonate as well as clastic exploration objectives.

10.0 DRILLING

Nepal is virtually unexplored. The country's only well was drilled on a seismically defined, basement-controlled anomaly in the far eastern part of the country near Biratnagar. The well was abandoned at 3530 m after penetrating 3143 m of typical Siwalik molasse and 387 m of arkose and shale that was interpreted to be of Eocene or younger age. No hydrocarbons were recovered, although
small amounts of background (mud) gas were encountered in the lower part of the Middle Siwalik.

1.0 OPPORTUNITIES

Exploration opportunities in the Terai consist of structures associated with blind thrusts, basement-controlled structures, stratigraphic pinch-outs and subcrop traps. Major folds and thrusts in the Siwalik Fold Belt are likely to provide structurally controlled traps containing Lakharpata to Siwalik reservoirs. Drilling depths to objectives are from 3500 to 5000 metres in the Terai and from 2500 to 4000 metres in the Siwalik Fold Belt.

REFERENCES


Fig. 6. Eastern Terai, structure map of base Siwalik unconformity and location of Lines 31, 52 and 59.
Fig. 9. Western Terai, structure map of Base Siwalik unconformity and location of Line 89 (Siwalik Fold Belt traverse).


REFERENCES FOR GENERAL READING

Department of Mines and Geology Nepal (DMG), 1985, Nepal: exploration opportunities: Brochure.


Fig. 11. Structure cross-section along Line 89.

Fig. 12. Model study for Line 89 (Siwalik Fold Belt traverse).